BIG BIOLOGY Meets Microclimatology: Defining Thermal Niches of Trout and Other Stream Species for Spatial Conservation Planning Using Massive Interagency Databases

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Introduction

Temperature profoundly affects the ecology of ectotherms like trout and other stream species and is an environmental characteristic subject to change from global warming and habitat alteration. Spatial information about the realized thermal niches of species and where temperatures are most suitable or constraining would be useful for conservation planning and strategic investing this century. Here, we developed a large species occurrence database (>23,000 surveys at >13,000 sites) by compiling existing electrofishing datasets from state and federal agencies and linked the information to accurate NorWeST stream microclimate scenarios that exist for all rivers and streams in the American West (Fig. 1; Table 1; Isaak et al. 2016). The goal was to develop a taxonomically generalizable, spatially explicit way of describing and mapping thermal niches.

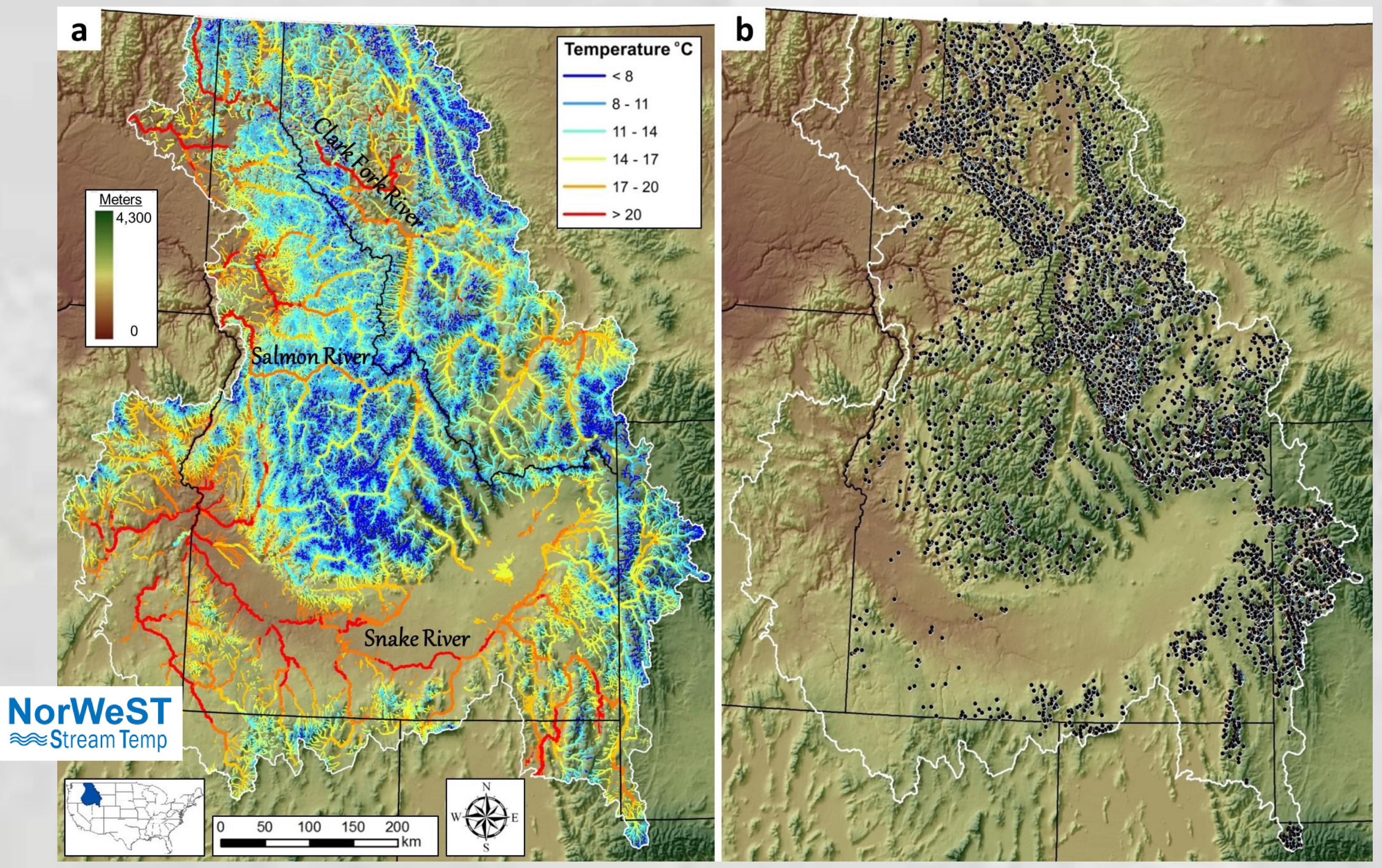


FIG. 1. Subset of NorWeST stream temperature scenarios that shows mean August stream temperature for 1993–2011 in the 149,000-km study area network (panel a). Scenarios for this area were developed from 20,072 summers of monitoring data at 7,691 unique stream sites. Species occurrence data from 23,021 electrofishing surveys at 13,769 unique stream sites (panel b, black dots) were linked to the temperature scenario to describe thermal niches.

Electrofishing data providers:

Stream temperature data providers:

Table 1. Species and number of occurrences in a dataset used to describe thermal niches in Rocky Mountain streams.

Common Name	Species	Occurrences
Longnose dace	*Rhinichthys cataractae*	169
Speckled dace	*Rhinichthys osculus*	52
Redside shiner*	*Richardsonius balteatus*	129
Longnose sucker	*Catostomus catostomus*	235
Mountain whitefish	*Prosopium williamsoni*	2,026
Cutthroat trout	*Oncorhynchus clarkii*	11,543
Rainbow trout*	*Oncorhynchus mykiss*	3,977
Chinook salmon	*Oncorhynchus tshawytscha*	1,728
Brown trout†	*Salmo trutta*	1,228
Bull trout	*Salvelinus confluentus*	2,809
Brook trout†	*Salvelinus fontinalis*	7,036
Slimy sculpin	*Cottus cognatus*	759
Rocky Mountain tailed frog	*Ascaphus montanus*	957
Columbia spotted frog	*Rana luteiventris*	214

*Non-native to some streams within the study area.
†Non-native to all streams within study area.

Methods

Hierarchical logistic regression models were used to describe species occurrence probabilities across a wide range of mean August temperatures (4–21 °C). The models enabled multivariate assessments, so we also included reach slope from the NHDPlus dataset (McKay et al. 2012) and mean summer flow from the Western U.S. Stream Flow Metrics dataset (Wenger et al. 2010) in the regressions to control for the effects of these environmental gradients that sometimes mediate thermal relationships.

Results

Statistically significant temperature effects were ubiquitous among species (all 14 models had a significant linear effect; 9 of 14 models also had a significant quadratic effect) while flow significantly affected 8 species, and slope affected 10 species (Table 2). Response curves depicting thermal niches showed that species occurrence probabilities peaked across a wide range of temperatures and all species had distinct warm- or cold-edge distribution boundaries (Fig. 2). Bull trout, cutthroat trout, brook trout, and tailed frogs had especially cold thermal niches and showed warm-edge boundaries; whereas rainbow trout and brown trout had warmer niches with cold-edge boundaries that indicated temperatures were unsuitably cold in many streams. Remaining species (longnose dace, speckled dace, redside shiner, longnose sucker, mountain whitefish, Chinook salmon, slimy sculpin, and Columbia spotted frog) also had warm niches showing cold temperature constraints.

Table 2. Parameter estimates and standard errors (in parentheses) for the multivariate models predicting occurrence of 14 aquatic species in Rocky Mountain streams.

Species	Intercept	Temperature	Temperature[2]	Flow†	Slope
Longnose dace	-6.25 (0.30)	0.717* (0.131)	-0.221* (0.104)	0.287* (0.094)	-26.2* (9.12)
Speckled dace	-9.84 (1.17)	2.14* (0.579)	-0.851* (0.325)	-0.332 (0.236)	-55.0* (23.8)
Redside shiner	-8.79 (0.69)	0.946* (0.256)	-0.300 (0.187)	-0.0332 (0.133)	-82.4* (20.8)
Longnose sucker	-6.17 (0.33)	0.438* (0.111)	-0.178 (0.104)	0.160 (0.103)	-57.1* (11.0)
Mountain whitefish	-4.13 (0.18)	0.196* (0.051)	-0.0577 (0.046)	0.810* (0.070)	-23.7* (5.70)
Cutthroat trout	0.67 (0.10)	-0.115* (0.021)	-0.108* (0.018)	0.0876* (0.030)	-3.28* (0.98)
Rainbow trout	-2.15 (0.13)	0.337* (0.035)	-0.136* (0.035)	0.532* (0.048)	-3.42 (2.42)
Chinook salmon	-1.10 (0.21)	0.265* (0.053)	-0.0807 (0.048)	0.0635 (0.076)	-44.5* (6.27)
Brown trout	-4.85 (0.20)	0.461* (0.058)	-0.221* (0.053)	0.438* (0.063)	-15.0* (3.85)
Bull trout	-2.39 (0.13)	-0.383* (0.032)	0.023 (0.035)	0.674* (0.054)	-9.26* (1.85)
Brook trout	-0.74 (0.11)	0.145* (0.023)	-0.247* (0.025)	-0.0242 (0.033)	-14.4* (1.28)
Slimy sculpin	-2.73 (0.13)	0.194* (0.048)	-0.152* (0.058)	0.127* (0.063)	-5.84 (3.14)
Rocky Mountain tailed frog	-3.32 (0.15)	-0.413* (0.046)	-0.208* (0.065)	0.154* (0.060)	3.28 (1.71)
Columbia spotted frog	-4.49 (0.15)	0.256* (0.071)	-0.277* (0.092)	0.0302 (0.088)	-2.28 (3.99)

[2]Quadratic effect.
†Based on natural-log-transformed values.
*Statistical probability ≤ 0.05.

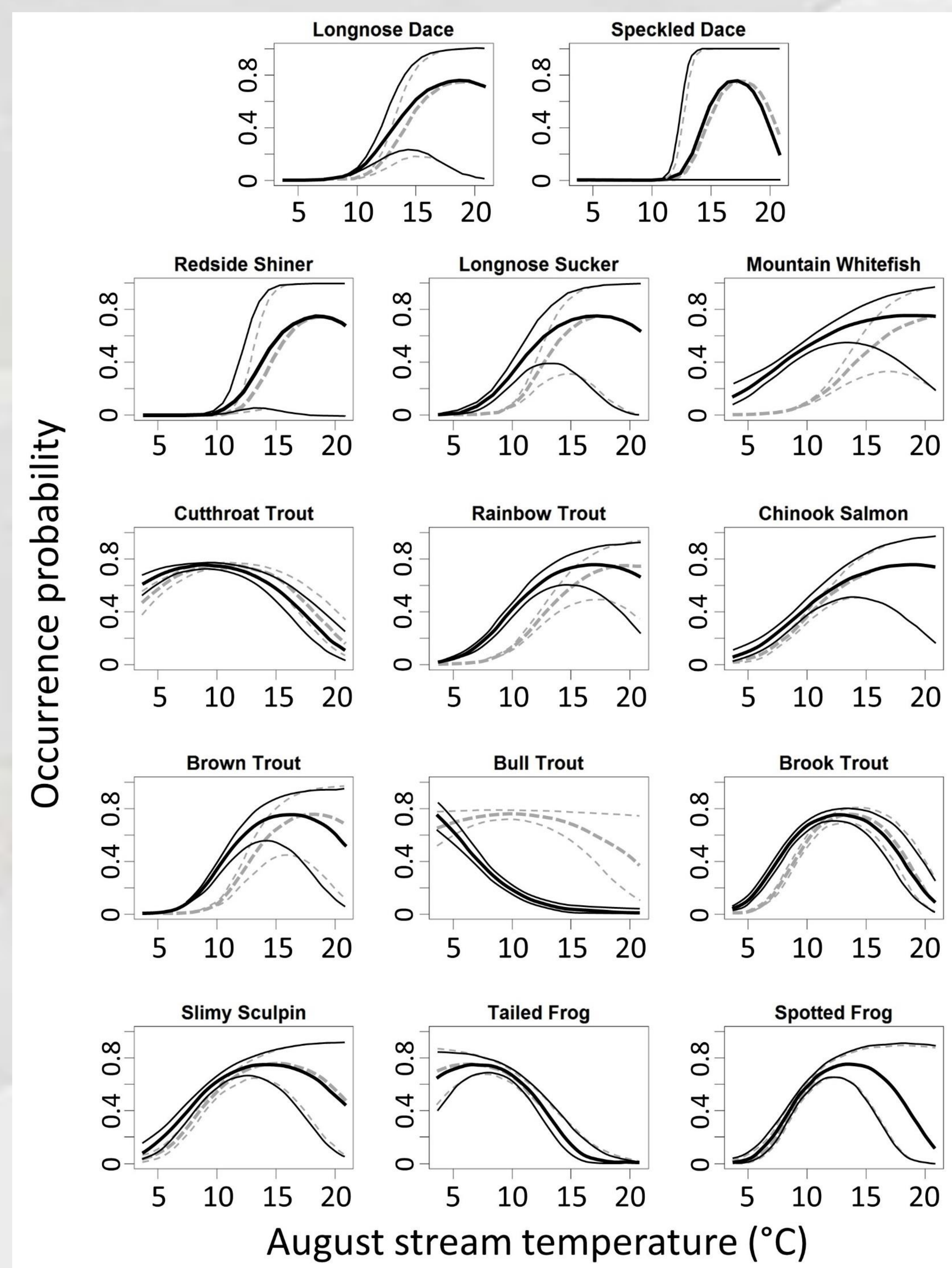


FIG. 2. Thermal response curves for 14 stream species based on temperature-only models (grey dashed lines) and multivariate models that included temperature, reach slope, and summer flow (black solid lines; thin lines indicate upper and lower 95% confidence intervals). The multivariate models provided large improvements over the temperature-only models (122 AIC point decrease on average), so thermal niche descriptions from the former were assumed to be more accurate.

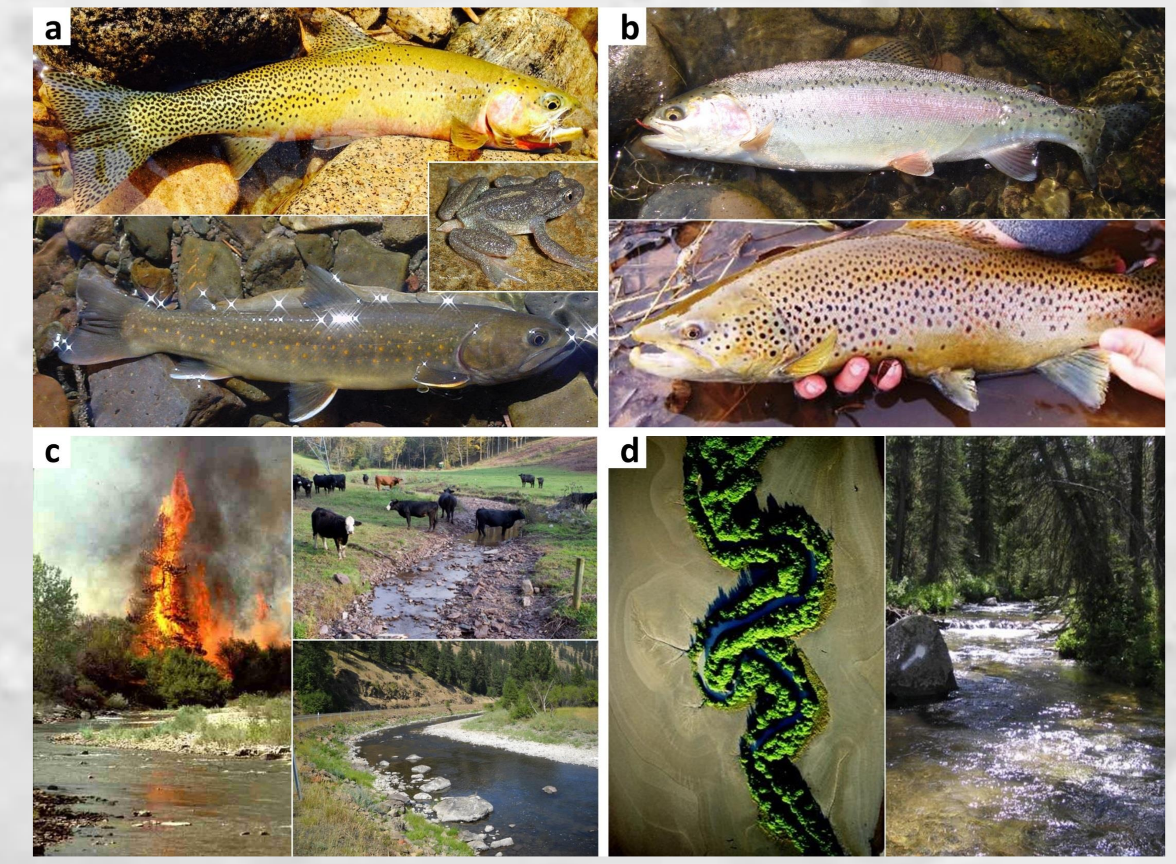
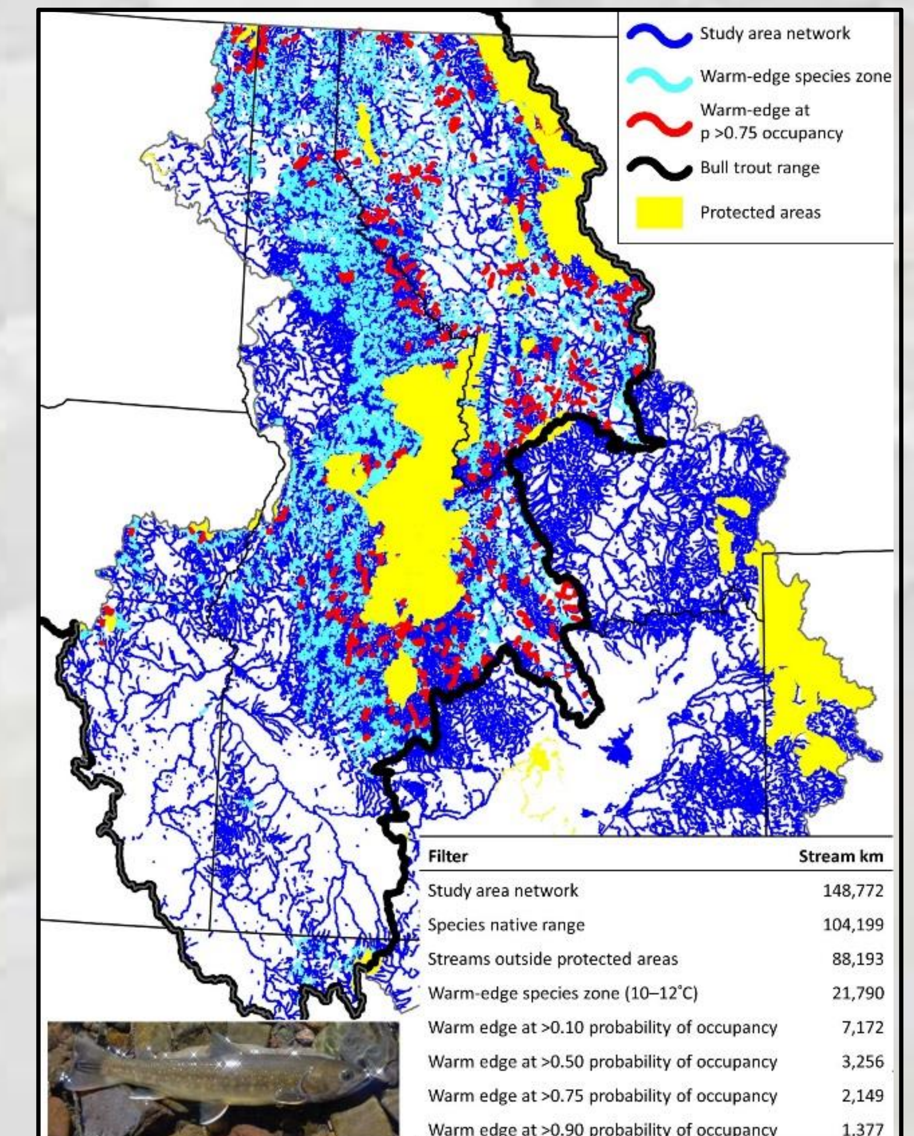


FIG. 3. Species with cold thermal niches like native Rocky Mountain tailed frogs (inset a) cutthroat trout (top a), and bull trout (bottom a) are often replaced by species with warmer niches like rainbow trout (top b) and brown trout (bottom b) in downstream portions of stream networks. Anthropogenic and natural disturbances may increase stream temperatures (c) but restoration or maintenance of well-shaded stream courses helps ameliorate temperature gains (d) and could be done strategically to improve the resilience of local populations. Photo credits: panel a) Mike Young, Wayne Lynch, Bart Gamett; panel b) Brett Roper; panel c) Bill Wolfe, Boise National Forest, Dona Horan; panel d) Dan Isaak, Water Encyclopedia.

Discussion

Our results help explain a commonly observed pattern in Rocky Mountain trout communities wherein species with cold thermal niches occur in headwater streams and are replaced by species with warmer thermal niches in downstream areas and most large rivers (Fig. 3). Along this same continuum, thermally-mediated cold- and warm-edge boundaries occur for most species and represent locations where populations may be most sensitive to thermal changes associated with global warming or habitat alteration. Habitat protection or restoration could be targeted at those areas to protect local populations, or monitoring programs established to describe long-term species range contractions or expansions. Moreover, because our approach uses accurate, published geospatial datasets to represent stream environments, strategic assessments can be rapidly done across river basins, the range of a species, or for an entire state using a GIS to query, summarize, and highlight those areas where biological communities are sensitive to thermal changes (Box 1 provides an example for bull trout). Strategic information could then be combined with local information about site impairment to prioritize and rank conservation projects across large areas. Isaak et al. (2017) provide additional details about this research and the geospatial resources listed below can be used for implementation.



Filter	Stream km
Study area network	148,772
Species native range	104,199
Streams outside protected areas	88,193
Warm-edge species zone (10–12˚C)	21,790
Warm edge at >0.10 probability of occupancy	7,172
Warm edge at >0.50 probability of occupancy	3,256
Warm edge at >0.75 probability of occupancy	2,149
Warm edge at >0.90 probability of occupancy	1,377

Box 1. Using a temperature zone criterion of 10–12 °C, stream reaches at the warm-edge distribution boundary of bull trout within their native range were queried using a GIS. Those reaches were then filtered to identify reaches occurring outside of protected areas such as national parks and wilderness areas that had population occupancy probabilities >0.1, >0.5, >0.75, and >0.9 based on the Climate Shield model predictions (Isaak et al. 2015). This simple set of spatial queries reduced the 149,000 km study area network to <8,000 km where habitat protection or restoration to maintain cool temperatures would help bolster local bull trout populations.

Acknowledgements

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