Modeling Fish Assemblages in Stream Networks

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Introduction

We are developing a model to simulate how fish assemblages change in response to in-stream habitat patterns at watershed to basin scales. The poster describes a prototype model and "mock-up" application for the Marys River watershed, Oregon, to solicit feedback on the modeling approach.

Many models exist that predict how individual fish populations respond to habitat change. Less attention has been paid to projecting changes in the entire fish assemblage, even though species interactions can be an important factor determining the success of individual populations. Given the complexity of processes affecting fish assemblages, precise predictions may be impossible. At the very least, however, the process of building such a model, and playing "what-if" games to explore model sensitivity to various assumptions, can help us organize our understanding and better identify major knowledge gaps.

Criteria for Success

- Model incorporates critical processes in as simple a structure as possible.
- Model can be parameterized using available data and expert knowledge.
- Predictions reasonably mimic observed assemblage patterns and trends at watershed to regional scales. [Reach-scale predictions are not likely to be reliable.]

Representation of Stream Network

We believe that fish movement within the stream network plays an important role in structuring fish assemblages, requiring a model that operates at the whole-network scale.

The stream network is represented as a series of linked segments (or reaches). The model can generate a synthetic network with a specified topology or import GIS data for actual stream networks. The Marys River example uses the 1:100,000-scale stream coverage to define 234 linked segments within the watershed.

Each segment has a suite of ***habitat attributes***. Habitat attributes can be imported from existing habitat surveys or simulated. In the Marys River example we simulated 8 habitat attributes likely to influence fish assemblages: maximum summer temperature (7-day average of the daily maximum, 7dADM), peak winter velocity (m/s), % gravel and cobble, % sand and fines, % riffles, % glides, % pools, and maximum pool depth (cm). Habitat data from the Marys River Watershed Council, ODFW, ODEQ, and EMAP were used to relate habitat measurements to GIS-derived variables (slope, elevation, stream order, watershed area, distance to divide, geology). These relationships and associated random error were applied to estimate habitat attributes for each segment (Figure 1). Time-varying habitat attributes can be simulated by changing the variance of the random error (annual variability), imposing some hypothesized trend, or incorporating results from other models that simulate habitat changes over time.

Fish Species Attributes

Fish population models frequently use a Leslie matrix to estimate changes in population abundance over time based on life history parameters such as fecundity and survival rates at each life stage. Unfortunately such detailed life history data are not available for most fish species. Thus, we opted for a simpler, aggregated approach in the prototype model. Four basic attributes are defined for each species: habitat suitability index, species interactions matrix, mobility, and population growth potential.

The ***habitat suitability index*** (HSI) is conceptually similar to HSIs developed in the 1980s by the U.S. Fish and Wildlife Service. Suitability curves (or metrics) are defined for each habitat feature expected to influence the capacity of the segment to support the species. Metric scores range from 0 (unsuitable) to 1 (optimal). For the Marys River example, we used four metrics: (1) maximum summer temperature, (2) peak winter velocity, (3) habitat type, and (4) substrate type (e.g., Figure 2). The habitat and substrate metrics include subcomponents based on % pools, % riffles, % glides, maximum pool depth, % gravel-cobble, and % sand-fines, emphasizing different components for each species. In this example, metric curves were estimated from general information on species' preferences in the literature.

The suitability metrics are combined into an overall HSI. The model currently includes three options for calculating HSI: arithmetic mean, geometric mean, and modified minimum. The latter method, used in the Marys River example, multiplies the minimum metric value times the geometric mean of the remaining three metrics.

The ***species' interaction matrix*** (Table 1) expresses the degree to which the presence of one species is likely to influence the survival and growth of other species in the segment. Each species pair is assigned a value between -1 and +1. Most values are negative, reflecting the negative effects of competition and predation. Positive values express the beneficial effects of prey on predators.

The relative ***mobility*** and population ***growth potential*** are also rated on a scale of 0 to 1 for each species.

Modeling Fish Response

The current model uses an annual time step. At each time step and for each segment, the model predicts the presence/absence and relative density of each species, expressed as 0 (absent) or in the range of 1.0 to 1.5 (rare to abundant).

In every time step except the initial one, the first process is ***migration*** of species from segments they currently occupy to nearby ones. The distance that each species moves from a segment is a function of the global maximum movement distance, the species' mobility attribute, the relative density of the species in that segment, and a stochastic term.

After migration has taken place, each species is tested to determine whether it is eligible to stay in each segment. Values from the interaction matrix for every other species, weighted by that species' density and multiplied by the global interactions parameter, are either subtracted or added to the HSI to estimate the probability of occurrence (PO). A normally distributed error is added to simulate local stochasticity in occupancy.

The probability of occurrence is then compared to a global threshold. If more than one species in a segment is below the threshold, the species with the lowest probability is eliminated and probabilities of occurrence recalculated for all remaining species. This process repeats iteratively until all species in the segment have a probability of occurrence above the global threshold.

After species have been determined to occupy a segment, their ***relative density*** is calculated. Their initial density upon arrival, after migration, is set to 1.0 (rare). At each time step, species may increase or decrease in density, as a function of their growth potential attribute, their interactions-modified habitat suitability, a global maximum growth parameter, and a stochastic term. If the new relative density is below 1.0, the species is eliminated from the segment.

Example Model Outputs

We ran the prototype model for 14 fish species known to occur in the Marys River watershed: 10 natives and 4 exotics. The model includes several functions to summarize model inputs (e.g., Figures 1 and 2) and outputs, as maps, plots, and tables. Example outputs include the HSI (Figure 3), estimated species distributions and relative densities (Figure 4), species richness (Figure 5), and diagnostics identifying the limiting habitat metric (Figure 6).

We explored how varying the relative importance of habitat versus species interactions affects the estimated species distributions and richness (Figure 7). Mean richness declines as the global interactions parameter is increased, reflecting the segregation of species' habitat use in response to competitive and predatory interactions.

Increasing year-to-year variations in habitat attributes also reduced species richness, with less mobile species (e.g., sculpin) and species with dispersed patches of suitable habitat (e.g., northern pikeminnow) affected more severely (Figure 8).

Finally, we modified stream temperatures to approximate historical conditions and projected future increases due to global climate change. Figure 9 illustrates the results for cutthroat trout. Mean species richness decreased with increasing temperature, from 4.24 under historical conditions, 4.09 present-day, to 2.93 with a projected increase of 4^{o}C in the future.

Future Directions

We are still actively refining the model and model parameters. Major next steps include (a) separate HSIs for spawning and (b) a biannual time step, for winter and summer. We are particularly interested in whether adding more detail to the model significantly improves our confidence in model outputs. If you know of datasets or watersheds that would be good opportunities for model evaluation or interesting applications, please let us know.

Source

Poster presented at 41st Annual Meeting of the American Fisheries Society, Oregon Chapter, February 16-18, 2005, Corvallis, OR.

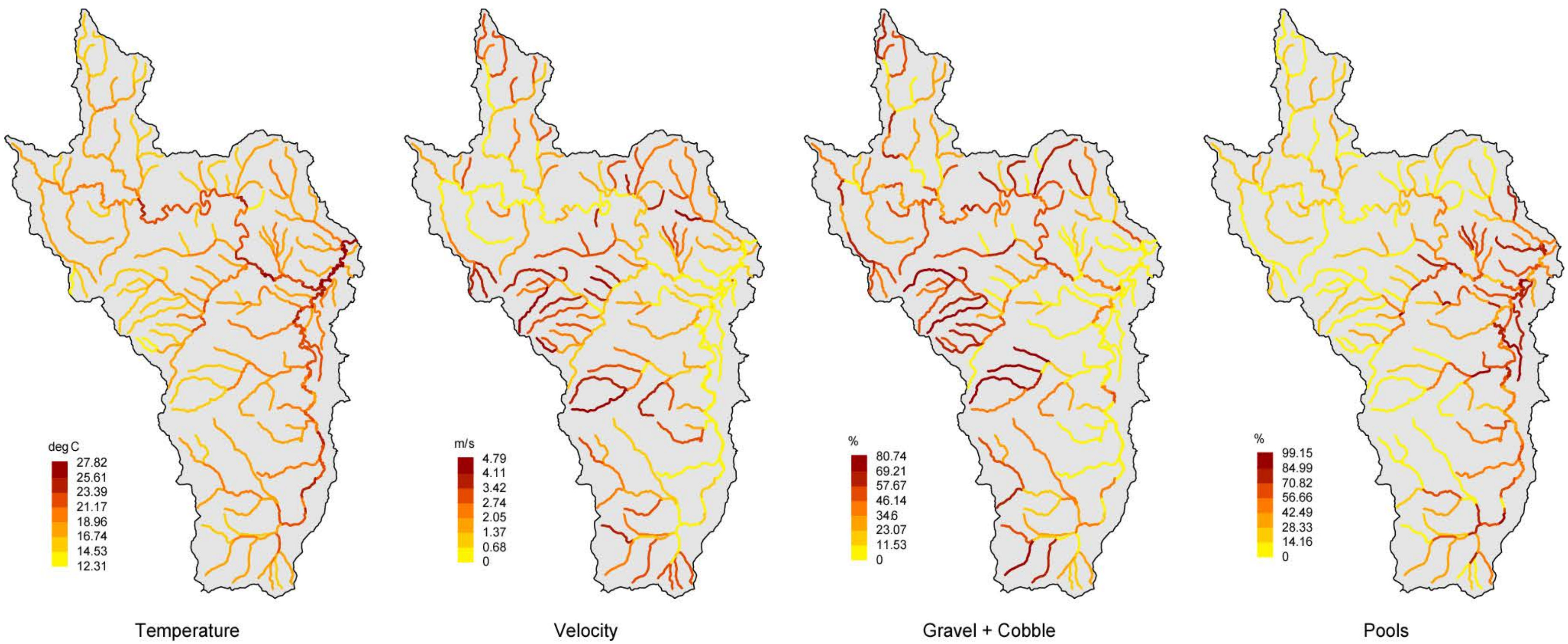


Figure 1. Simulated habitat for Marys River watershed

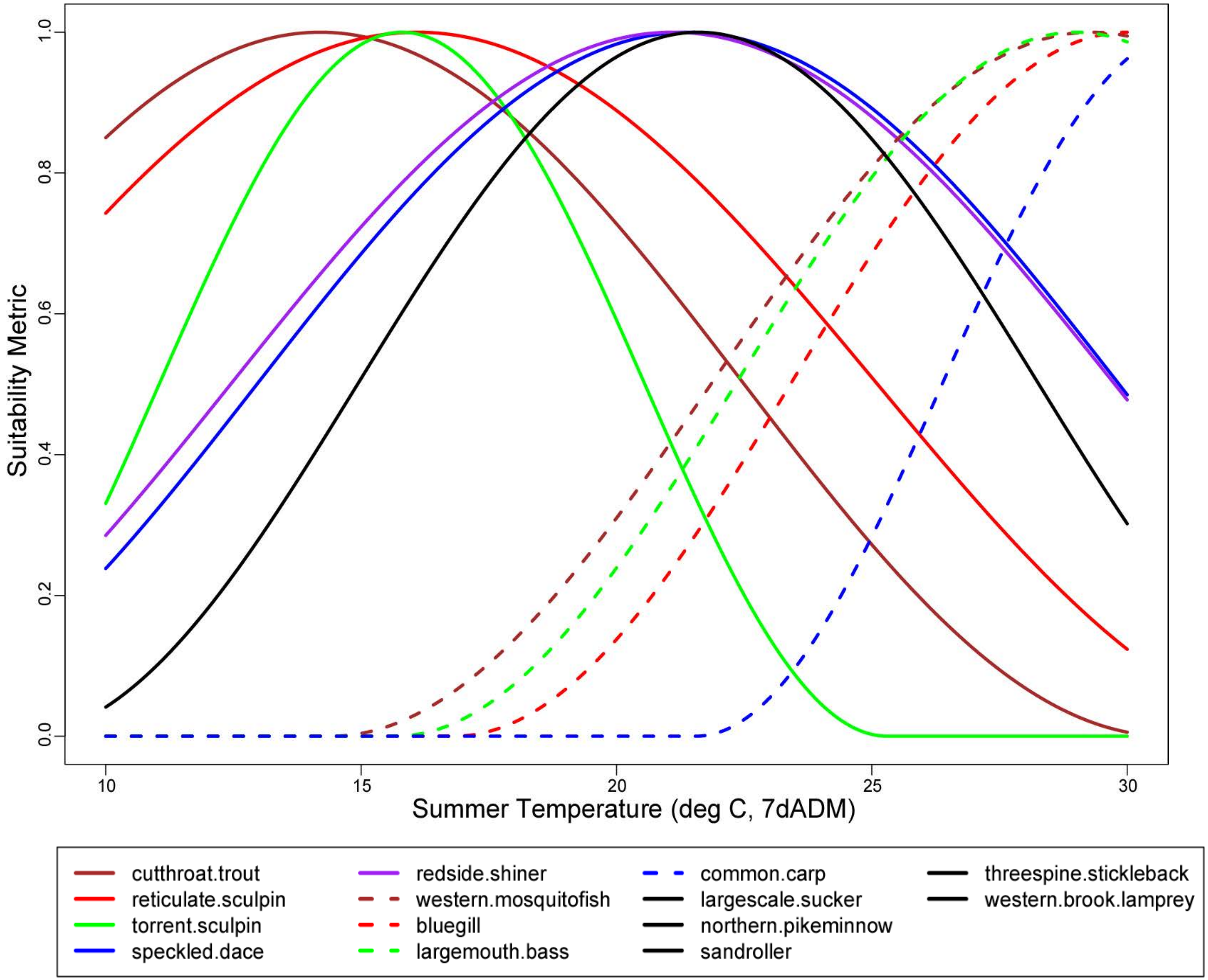


Figure 2a. Suitability curves for temperature

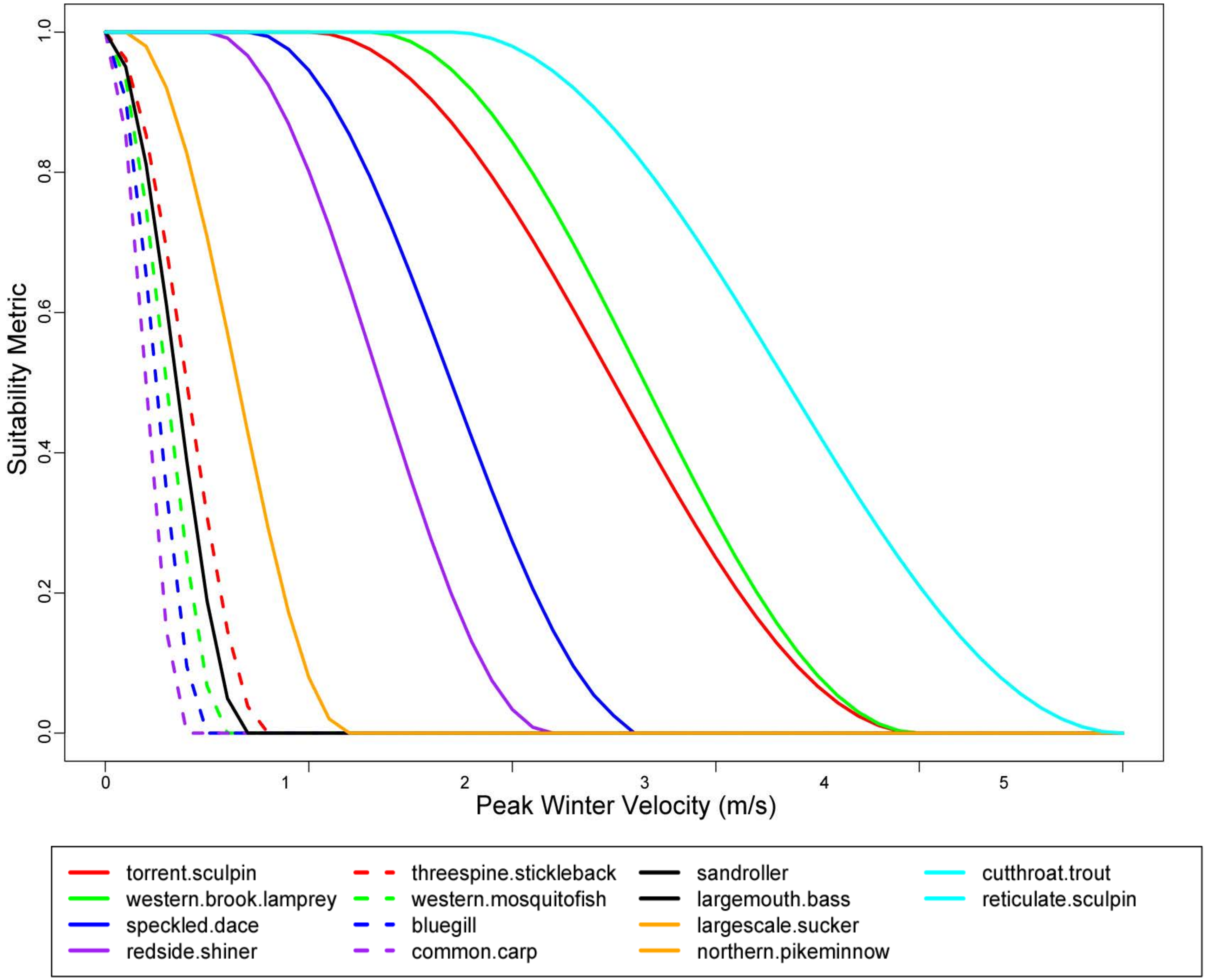


Figure 2b. Suitability curves for velocity

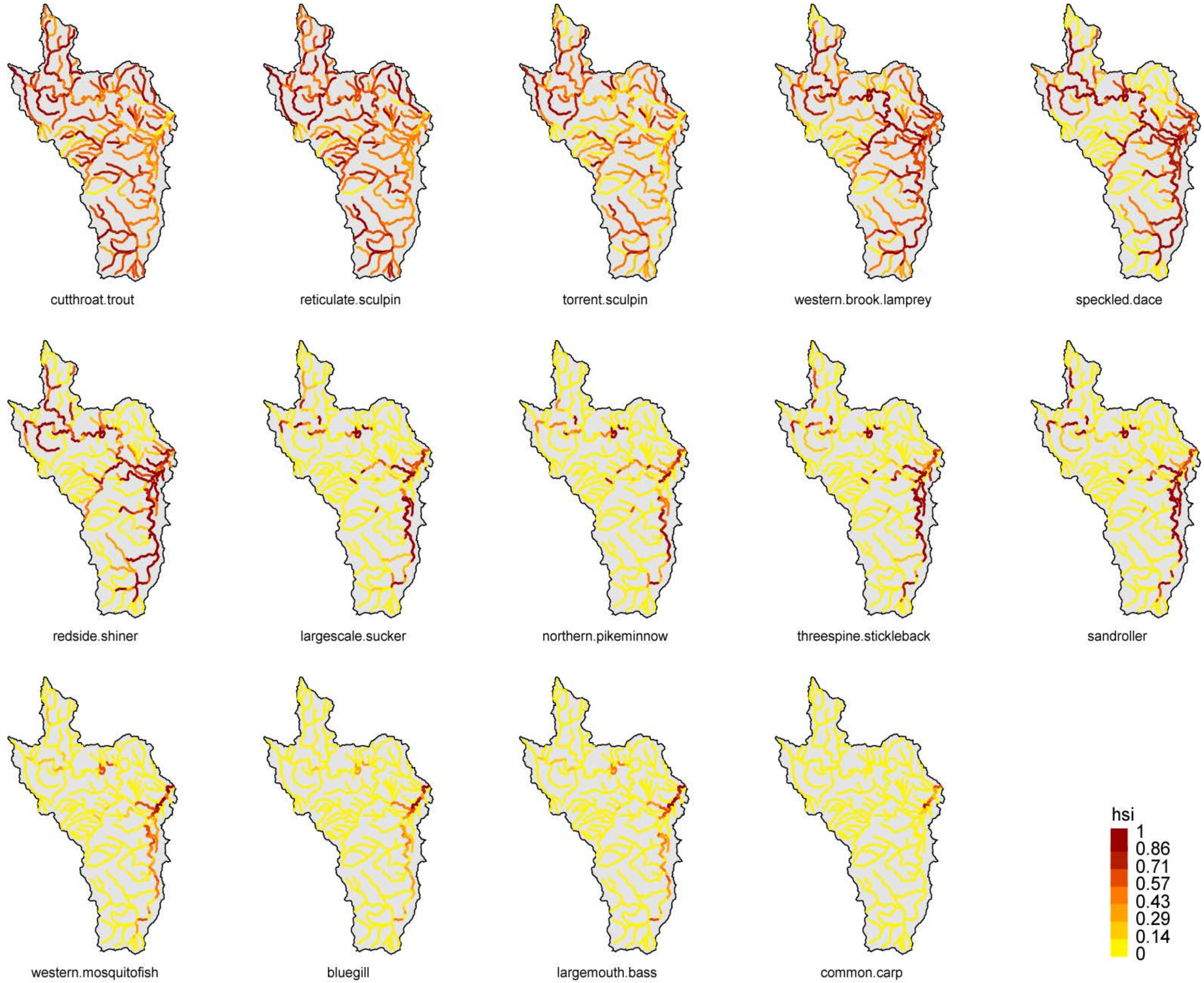


Figure 3. Estimated HSI given current habitat conditions

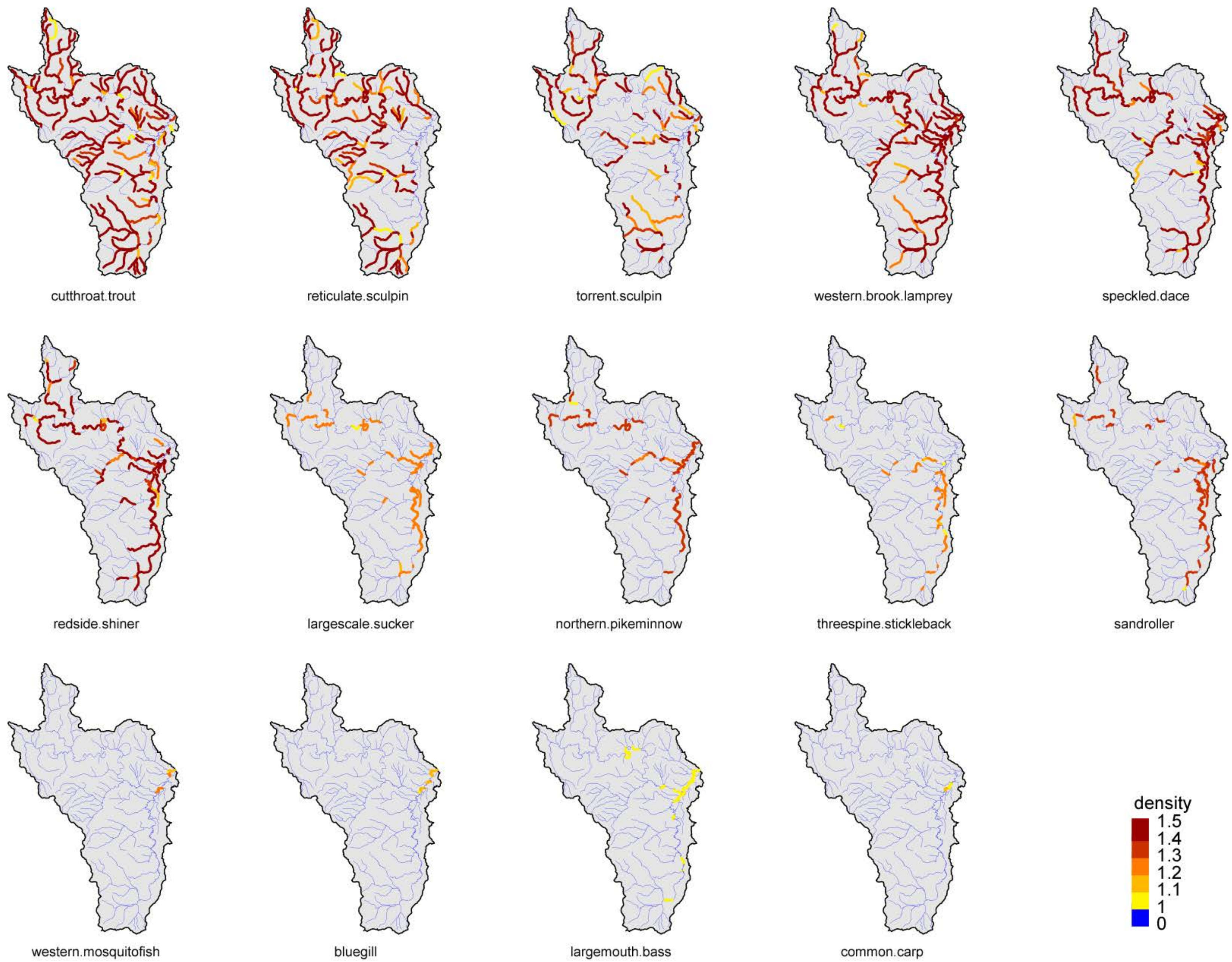
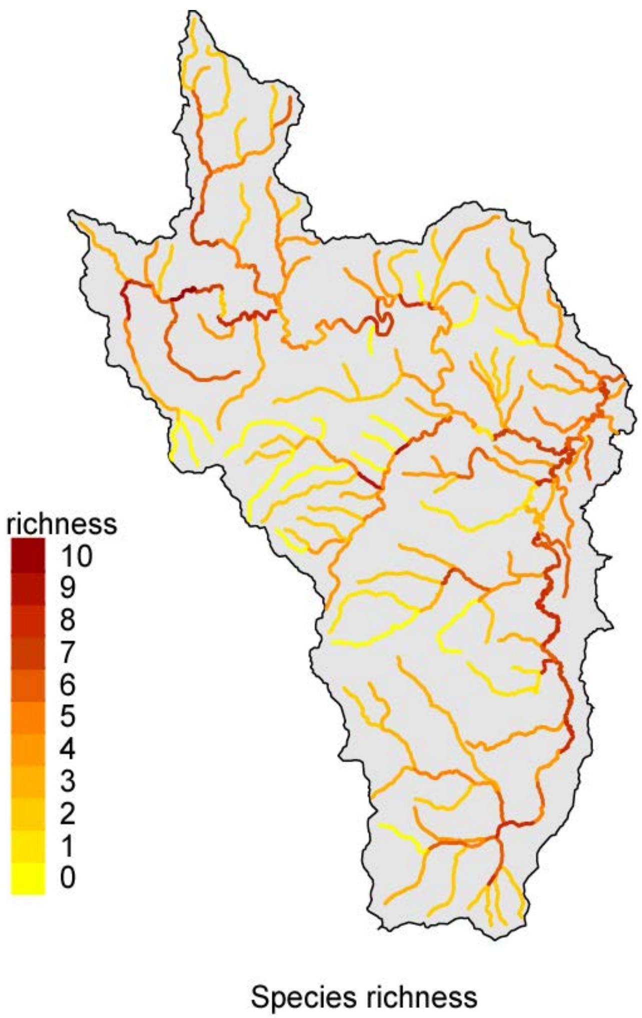


Figure 4. Projected fish density given current habitat conditions



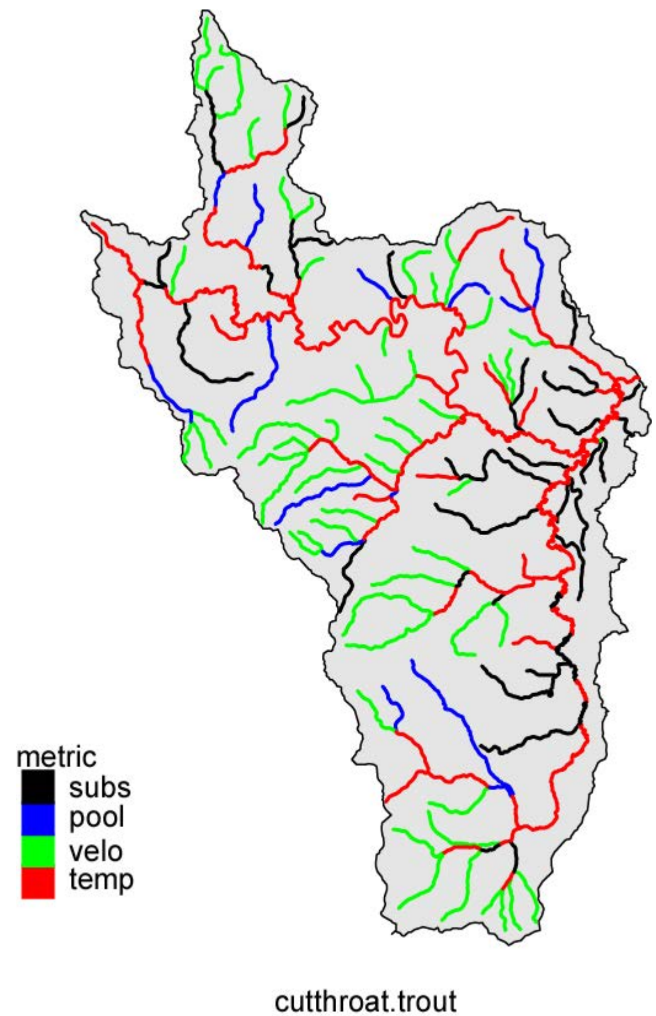


Figure 5. Projected species richness given current conditions

Figure 6. Limiting suitability metric for cutthroat trout given current conditions

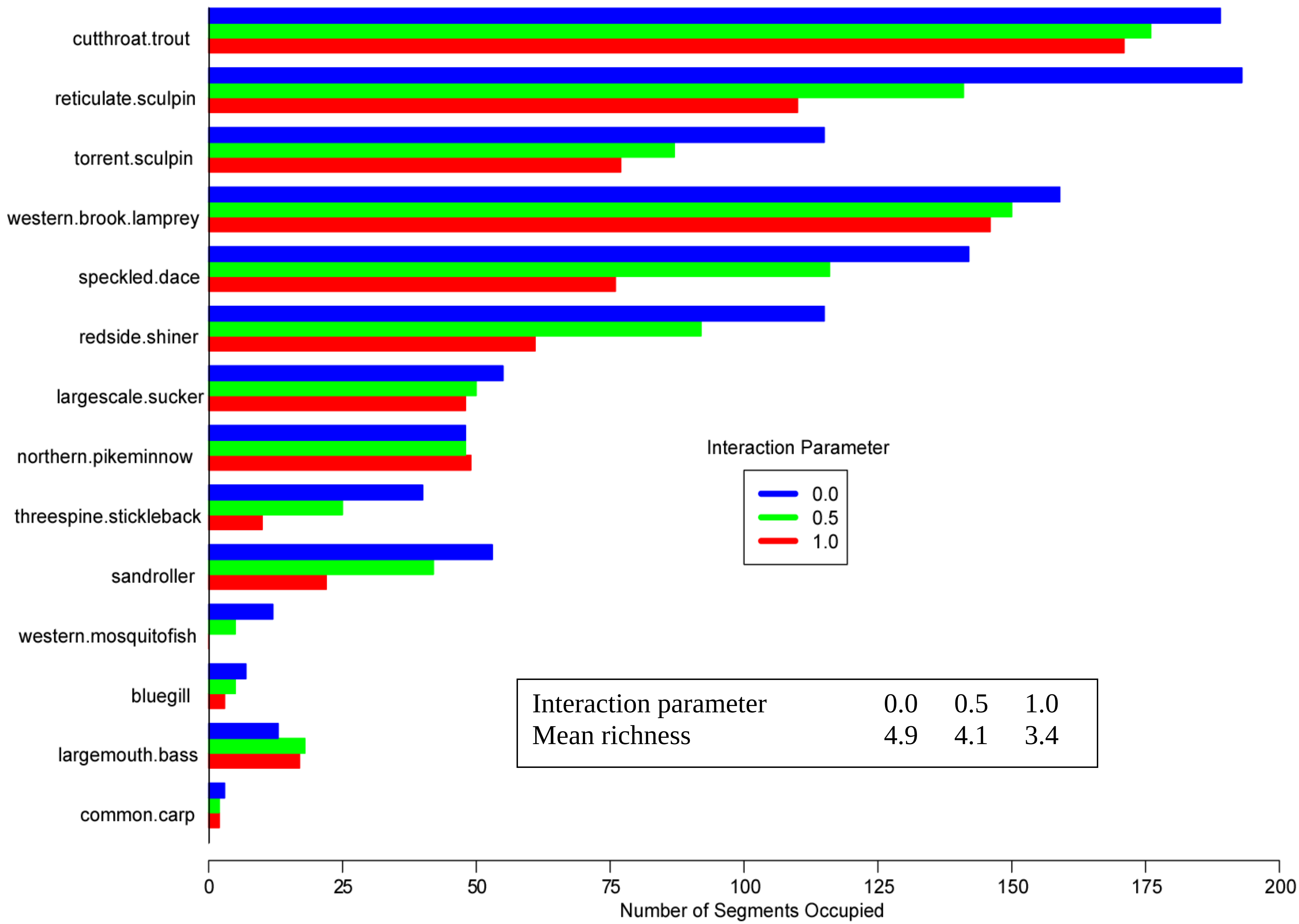


Figure 7. Number of segments occupied by each species given three scenarios of increasing competition / predation

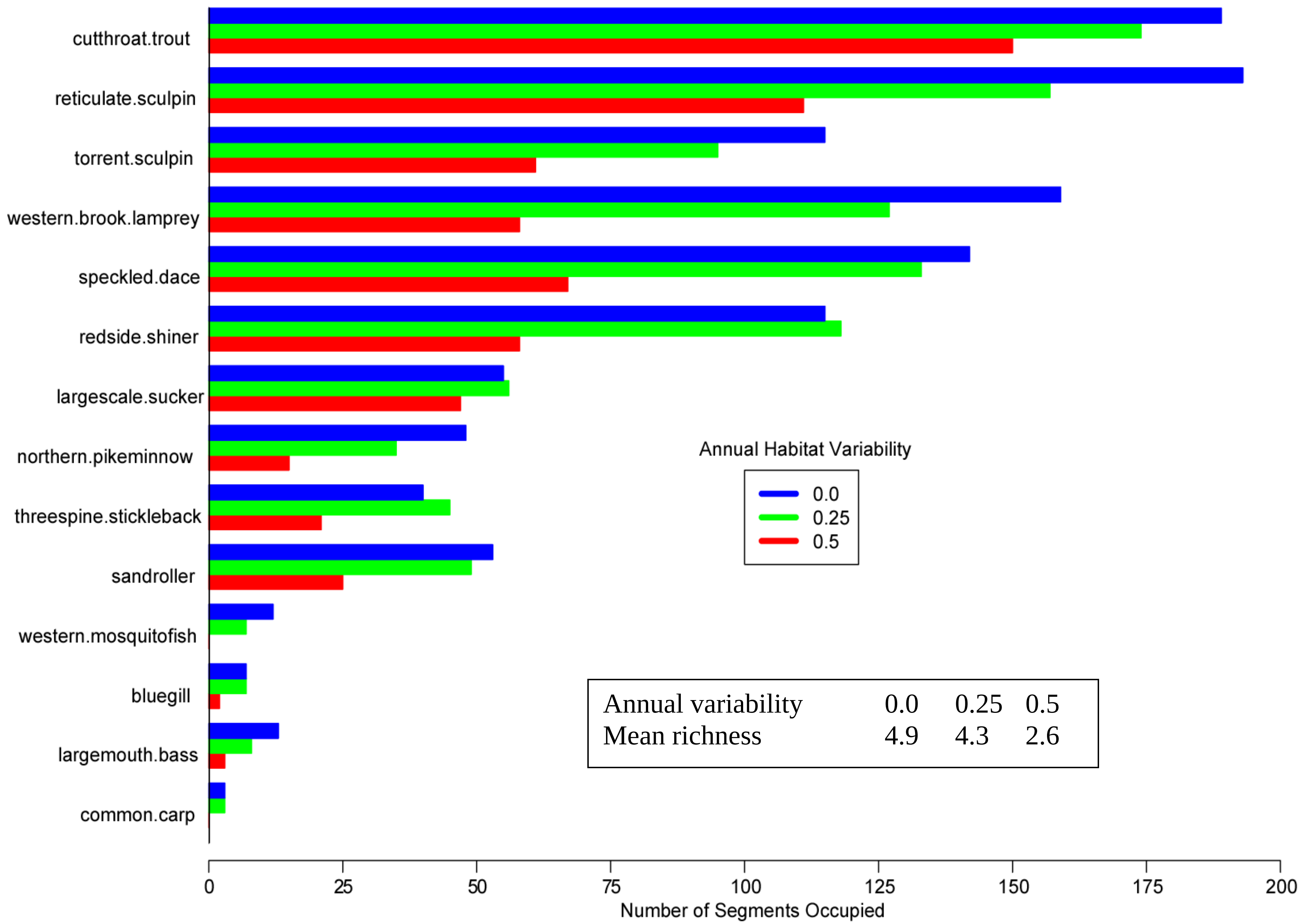


Figure 8. Number of segments occupied by each species given different scenarios of annual habitat variability

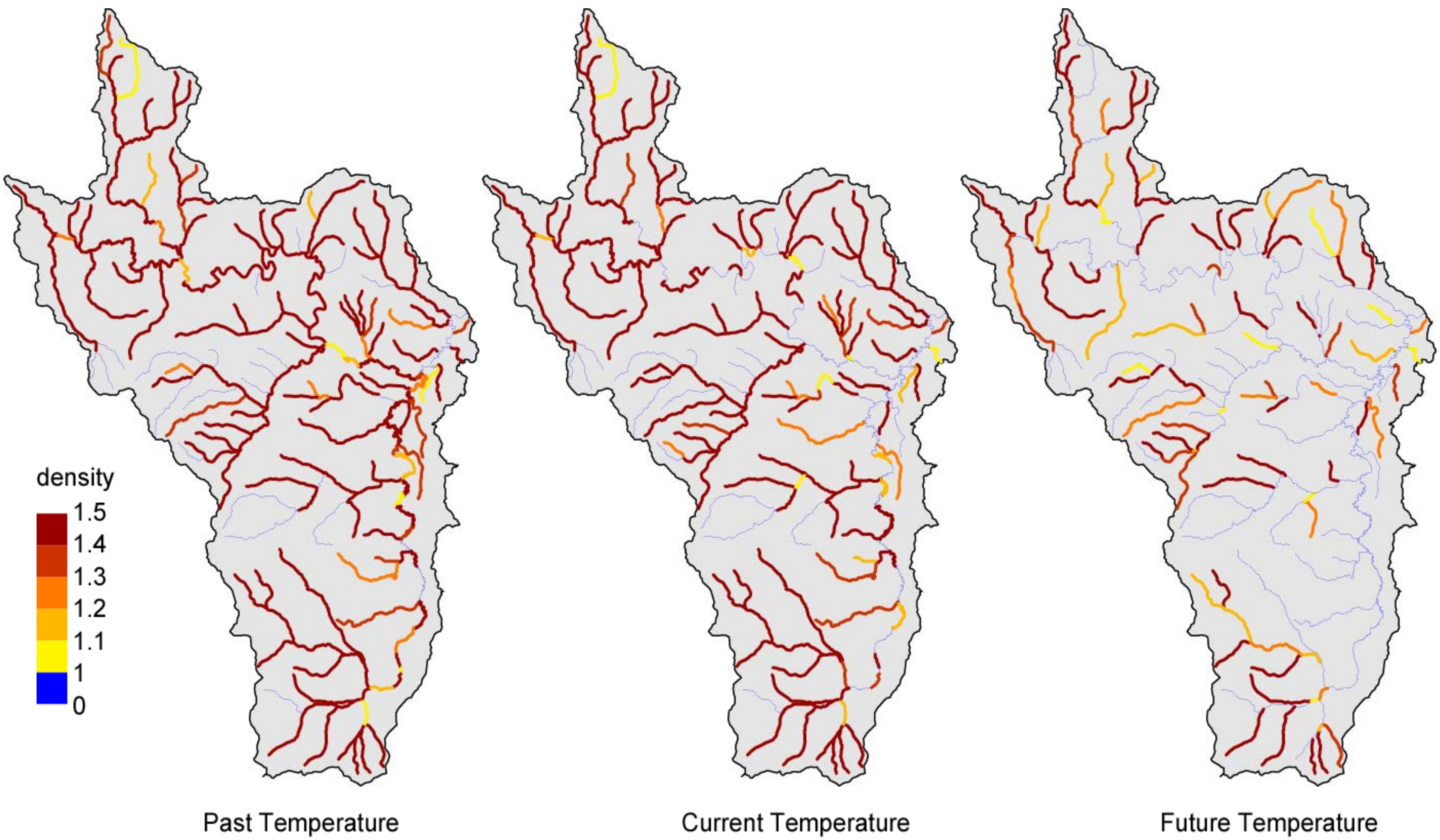


Figure 9. Projected cutthroat trout density given historical, current, and estimated future summer temperatures

Table 1. Species interactions matrix

Species Responding

Species Acting		CT	RS	TS	SD	RD	LS	NP	ST	S	BL	LB	CC	B	WM
cutthroat trout	CT	0.0	0.0	0.0	-0.1	-0.2	0.0	0.05	-0.1	0.0	0.0	0.05	0.0	0.0	-0.1
reticulate sculpin	RS	0.0	0.0	-0.1	0.0	0.0	0.0	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0
torrent sculpin	TS	0.0	-0.3	0.0	-0.1	0.0	0.0	0.05	0.0	-0.1	0.0	0.0	0.0	0.0	0.0
speckled dace	SD	0.05	0.0	0.0	0.0	0.0	0.0	0.05	0.0	-0.1	0.0	0.05	0.0	0.0	0.0
redside shiner	RD	-0.1	0.0	0.0	0.0	0.0	0.0	0.05	-0.1	0.0	0.0	0.05	0.0	-0.1	-0.1
largescale sucker	LS	0.0	-0.1	-0.1	0.0	0.0	0.0	0.05	0.0	0.0	0.0	0.05	-0.2	0.0	0.0
northern pikeminnow	NP	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	0.00	-0.2	-0.2	0.0	0.0	0.0	-0.1	-0.2
threespine stickleback	ST	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.0	-0.1	0.0	0.05	0.0	0.0	-0.1
sandroller	S	0.05	0.0	0.0	0.0	0.0	0.0	0.05	-0.1	0.0	0.0	0.05	0.0	0.0	0.0
western brook lamprey	BL	0.0	0.0	0.0	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.00	0.0	0.0	0.0
largemouth bass	LB	-0.1	0.0	0.0	-0.1	-0.2	-0.1	0.00	-0.2	-0.2	0.0	0.00	-0.1	-0.1	-0.3
common carp	CC	0.0	-0.1	-0.1	0.0	0.0	-0.2	0.00	0.0	-0.1	-0.1	0.05	0.0	0.0	0.0
bluegill	B	-0.1	0.0	0.0	0.0	-0.1	0.0	0.00	-0.1	0.0	0.0	0.05	0.0	0.0	-0.1
western mosquitofish	WM	0.05	0.0	0.0	0.0	-0.1	0.0	0.05	0.0	0.0	0.0	0.05	0.0	-0.1	0.0