Fish Community Response to Departures in Hydrologic Reference Conditions, Tennessee River Basin, Southeastern USA

H23C-1291

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Abstract

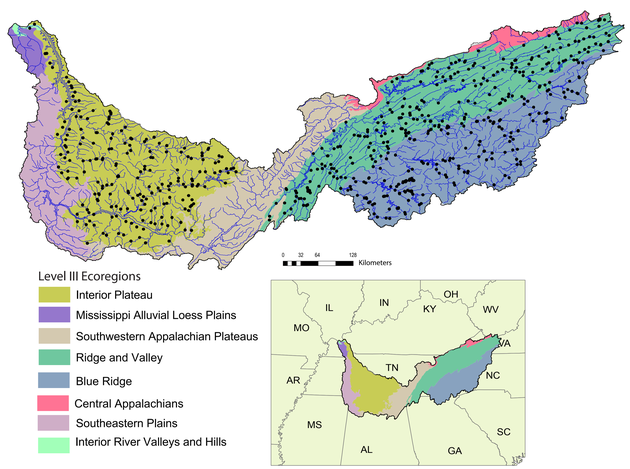
Quantitative relationships between streamflow alteration and aquatic ecosystem response remain elusive despite decades of research. Over the course of a multi-year study in the ecologically diverse Tennessee River basin, USA, we have (1) identified statistical relations between fish community and streamflow characteristics at 33 sites with observed fish and flow data, (2) developed a statistical model to estimate streamflow characteristics at an additional 662 fish sampling sites without observed flow data, (3) related the departures of estimated streamflow characteristics from reference ranges and observed fish species richness to identify the most influential streamflow characteristics by ecoregion and fish group (11 groups based on habitat, trophic level, and reproductive grouping), and (4) developed ecological limit functions that quantify the response of fish species richness to departures from hydrologic reference conditions.

Reference ranges for 19 streamflow characteristics were defined for three major ecoregions in the Tennessee River basin, based on the best obtainable observed streamflow conditions. Qualitative evaluation of these conditions indicates they generally correspond to maximum fish species richness. Quantile regression and multi-dimensional scaling were used to identify subsets of 1 to 4 characteristics for each ecoregion and fish group, useful in understanding potential ecological consequences of hydrologic modification. Across the 11 fish groups and 3 ecoregions, 21 ecological limit functions were identified relating departure of streamflow characteristics from reference and fish species richness. All relationships are negatively sloped, indicating fish species richness decreases with increased departure from hydrologic reference conditions. Though ecological limit functions describing the upper boundary of point distributions are commonly emphasized, we contend that interpretation of the interior point distributions is a necessary step towards improved insight into how fish communities respond to variations in flow regime and other environmental stressors.

Streamflow characteristic (SFC)

Abbreviations and simplified definitions

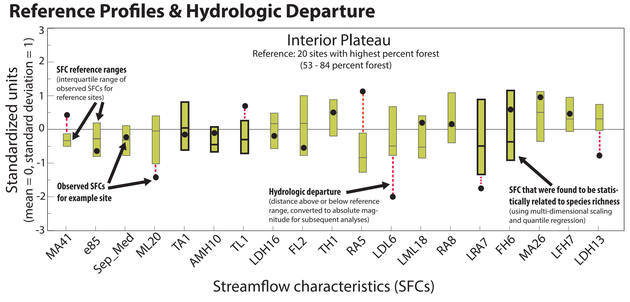
Magnitude	MA41 – Mean annual runoff
	AMH10 – Maximum October streamflow
	e85 – streamflow value exceeded 85-percent of time
	Sep_med – median September daily flow
	LRA7 – Rate of streamflow recession
Ratio	LDH13 – Average 30-day maximum
	ML20 – Base flow
	TA1 – Constancy
	RA5 – Number of day rises
Frequency	FH6 – Frequency of moderate flooding (three times median annual flow)
	LFH7 – Frequency of moderate flooding (seven times median annual flow)
Variability	MA26 – Variability of March streamflow
	LML18 – Variability in base flow
	LDL6 – Variability of annual minimum daily average streamflow
	LDH16 – Variability in high-pulse duration
	FL2 – Variability in low-pulse count
Date	TL1 – Annual minimum flow
	TH1 – Annual maximum flow
	RA8 – Flow direction reversals



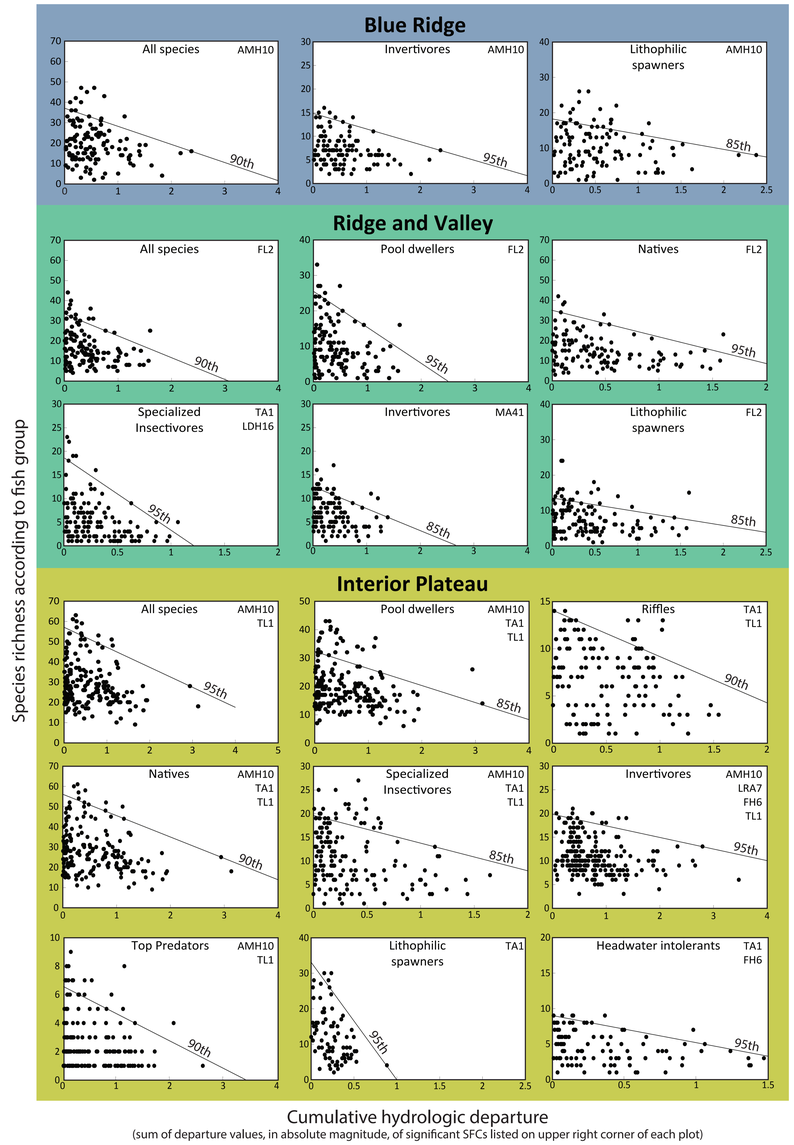
A previous study (Knight et al., 2008) identified these SFCs as ecologically relevant to fish-community data in the Tennessee River basin.

The Tennessee River basin drains approximately 106,000 square kilometers of the southeastern United States and is one of the most diverse temperate freshwater ecosystems in the world. The Interior Plateau, Ridge and Valley, and Blue Ridge ecoregions comprise the majority of the basin. At each of the 662 fish-sampling sites located in these ecoregions, species richness was determined for the fish community as a whole ("all species") and for 10 fish groups defined by characteristics such as habitat preference and environmental tolerance. Also, 19 SFCs (list in the table to the left) were estimated at each site using published regional regression models (Knight et al., 2012).

Reference Profiles & Hydrologic Departure



Three ecoregion-specific hydrologic reference profiles (Interior Plateau, Ridge and Valley, and Blue Ridge) were defined using SFCs found to be statistically related to the fish community in the Tennessee River basin (example on the left, Interior Plateau). For the purposes of our study, basins with the highest percent forest cover were assumed to represent the least disturbed landscape conditions. Reference ranges for each SFC were defined using the interquartile range of SFCs from the 20 most forested sites in each ecoregion. SFCs used for defining reference conditions were calculated using observed daily mean streamflow data.



Methods & Results

(1) Multivariate correlation (BEST procedure in PRIMER-E) was used to reduce the number of SFCs considered ecologically relevant in the Tennessee River basin from 19 to subsets (by ecoregion and fish group) containing 1 to 7 SFCs. In the Blue Ridge, no SFCs were statistically related to 4 of the 11 fish groups: pool dwellers, top predators, intolerants, and headwater intolerants. In the Interior Plateau, no SFCs were statistically related to omnivorous fish.

(2) Quantile regression was used to further reduce the number of SFCs by relating the departures of individual SFCs to species richness and dropping SFCs that did not have a significant ($p < 0.05$) 85th, 90th, or 95th regression quantile. At least 1 SFC was dropped from most subsets, and 7 of the preliminary subsets identified by the BEST procedure were eliminated completely. Significant SFCs composing these final subsets, by ecoregion and fish group, are listed on upper right corner of plots to the left.

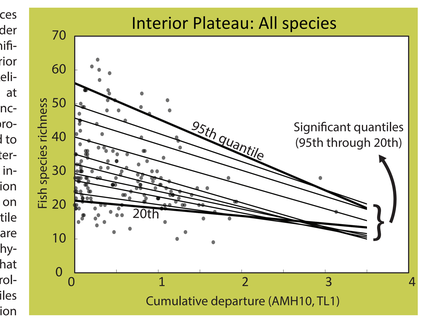
(3) Significant departures were summed to represent cumulative departure and related to species richness using quantile regression. Significant quantile regression lines ($p < 0.05$) are assumed to represent ecological limit functions, described by 85th, 90th, or 95th quantiles (plots to the left).

Ecological Limit Functions

The intercepts for "All species" in the Blue Ridge (37 species), Ridge and Valley (33 species) and Interior Plateau (57 species), highlight the difference in overall species richness between ecoregions. The Interior Plateau has greater species richness than either the Blue Ridge or Ridge and Valley; yet, the rate of potential species loss (slope of quantile regression line) is similar across ecoregions, ranging from ~9 to 11 potential species loss for each unit increase in cumulative departure. Potential species loss as a function of departure varies by both fish group and ecoregion. For example, lithophilic spawners are abundant in the Interior Plateau (intercept = 33 species) compared to the Blue Ridge (18 species) and Ridge and Valley (13 species), and potential species loss for lithophilic spawners is much greater in the Interior Plateau (~33 potential species loss per unit of departure) than the Blue Ridge (slope = 4) or Ridge and Valley (slope = 3.9). Several fish groups such as pool-dwellers (slope = 10), natives (slope = 13), and specialized insectivores (slope = 15) show a greater rate of potential species loss in the Ridge and Valley, compared to the Interior Plateau or the Blue Ridge.

Interior quantiles

Interpretation of the relationship between fish-speices richness and hydrologic departure may only consider the highest quantile with the most statistical significance. For example, as departure increases in an Interior Plateau stream, the upper bound shows that the likelihood of maintaining 57 species decreases (Figure at right). The exclusive use of the upper-bound limit function gives a "best possible" scenario, which may not provide resource managers with the information needed to make a decision about a proposed change in the watershed or stream. Determining statistically significant interior quantiles may provide additional information about the possible influence of hydrologic alteration on sites with sub-optimal fish-species richness. Quantile lines for all-species richness in the Interior Plateau are not parallel and generally converge with increasing hydrologic departure (Figure at right), suggesting that other environmental factors are interacting with hydrology to influence all-species richness. If interior quantiles were instead parallel this would suggest no interaction with other environmental factors though an additive effect is possible.



Conclusions

- **Hydrologic reference conditions can be defined using landscape attributes**, particularly when the attribute exhibits a variance such that reference sites are distinct from other sites.
- Statistically discernible **functions relating fish-species richness and hydrologic departure can be described using 1 to 4 streamflow characteristics** at the scale of Level III Ecoregions.
- In this study, **wedge-shaped distributions are not the result of internal structure**, indicating regional applicability of identified ecological limit functions.
- Ultimately, characterizing the unique role of hydrology in **the management of aquatic ecosystems will require an approach that accounts for multiple limiting influences and interactions** among hydrology, water quality, and physical basin attributes.

Related work

Knight et al., 2008. Relating streamflow characteristics to specialized insectivores in the Tennessee River Valley: a regional approach. Ecohydrology 1: 394–407.

Knight et al., 2012. Modeling ecological flow regime: an example from the Tennessee and Cumberland River basins. Ecohydrology 5: 613–627.

Murphy, J.C., Knight, R.R., Wolfe, W.J., and Gain, W.S., 2012, Predicting ecological flow regime at ungaged sites: A comparison of methods: River Research and Applications 29: 660-669.

Knight et al., 2013. In Press. Ecological limit functions relating fish community response to hydrologic departures of the ecological flow regime in the Tennessee River basin, USA. Ecohydrology, Accepted Article, available online.

http://tn.water.usgs.gov/projects/EcologicalFlows/

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