Supplementary Materials: Putting Flow-Ecology Relationships into Practice: a Decision Support System to Assess Fish Community Response to Water-Management Scenarios

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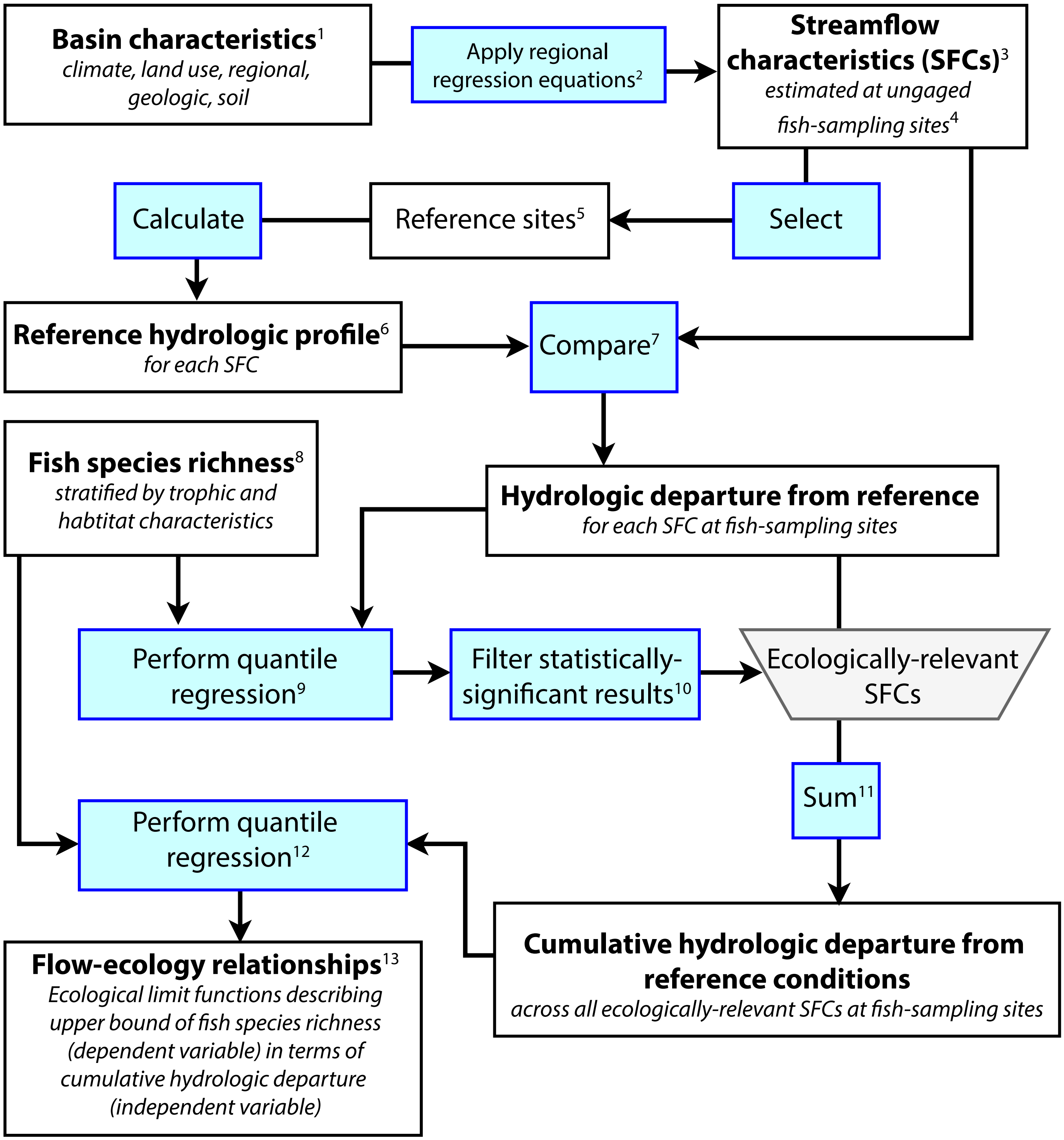

Figure S1. Annotated workflow for development of flow-ecology relationships used in the case study. All methods referred to in this workflow are described in detail in [1,4]. All data used in development of these flow-ecology relationships are available at: DOI: 10.5066/F7JH3J83.

Annotations for Figure S1

1. Defined in Table II in [1].
2. Listed in Table III in [1]. Regional regressions were necessary to model SFCs at fish sampling sites due to insufficient spatial and temporal overlap between fish sampling sites and stream gauges [2].
3. Defined in Table I in [1]. SFCs are listed in Table S1.
4. N = 138 fish sampling sites on the Cumberland Plateau of Tennessee and Kentucky. Site locations are provided in [3].
5. The 20 most forested sites in the study area were selected as reference sites, following [4].
6. Defined as the interquartile range (25th to 75th percentiles) for each SFC, calculated across all reference sites [4]. Reference profiles for the case study are presented in Table S1.
7. For each SFC at each fish-sampling site, the numerical difference (Euclidean distance) outside the reference profile was used to quantify hydrologic departure outside the range of natural variability [1,4]. Hydrologic departure data are provided in [3].
8. At each fish sampling site, species presence/absence data were used to calculate species richness by fish category based on trophic and habitat characteristics; see Table I in [4] for fish category definitions. Fish community data used in this case study is provided in [3].
9. Application and statistical interpretation of quantile regression are explained in [5,6].
10. For each combination of fish category and SFC (expressed as a hydrologic departure value), quantile regression models at the 85th, 90th, and 95th quantiles were tested for statistical significance. SFCs with at least one significant ($p < 0.05$) quantile were retained and considered ecologically-relevant. Ecologically-relevant SFCs for each fish category are denoted by X in Table S2.
11. Values representing hydrologic departure from reference conditions were summed across all ecologically-relevant SFCs to produce cumulative hydrologic departure from reference for each SFC at fish-sampling sites.
12. For each fish category, quantile regression was performed with fish species richness as the dependent variable and cumulative hydrologic departure from reference as the independent variable. This produced a flow-ecology relationship (specifically, in this case study, an ecological-limit function) for each fish category.
13. Flow-ecology relationships for this case study are depicted in Figure S2. Parameters for ecological limit functions are presented in Table S2.

Table S1. Interquartile ranges defining hydrologic reference conditions for the Cumberland Plateau in northern Middle Tennessee and southeast Kentucky.

Streamflow characteristics[a]	Interquartile range (standardized values)[b]	
	25th	75th
Mean annual runoff (MA41)	-0.4378	0.4214
Lowest 15% of daily flow (E85)	-0.7534	-0.3982
Baseflow (ML20)	-1.0035	-0.6059
Constancy (TA1)	-0.6497	-0.2439
Maximum October flow (AMH10)	-0.6390	-0.1579
Timing of the annual lowest flow (TL1)	-0.6690	0.0440
Variability in high-pulse duration (LDH16)[c]	-1.0507	-0.5254
Variability of flow pulses less than the 25th percentile (FL2)[c]	-0.8015	-0.4791
Timing of the annual highest flow (TH1)[c]	-0.0140	0.4261
Number of day rises (RA5)[c]	-0.0055	0.3788
Annual minimum daily flow variability (LDL6)	0.4113	0.9080
Variability of baseflow (LML18)	0.2971	0.7334
Flow direction reversals (RA8)[c]	-0.0708	0.0974
Rate of recession (LRA7)	0.7039	1.1597
Frequency of moderate flood (FH6)[d]	0.1221	0.7247
Variability of March flow (MA26)	0.1483	0.7131
Frequency of moderate flood (LFH7)[e]	0.5543	0.8789
Ratio of annual 30-day maximum to median annual flow (LDH13)	0.3537	0.7679

[a] Identified in [1,2]

[b] Defined by 25th and 75th percentiles of the 20 most forested sites (87 to 98 percent forested) within the study area [3]

[c] Characteristics used to define the hydrologic reference profile but not used in subsequent analysis because of low prediction accuracy (r-squared < 0.4) [1]

[d] Represents flood events greater than 3 times the median annual flow.

[e] Represents flood events greater than 7 times the median annual flow.

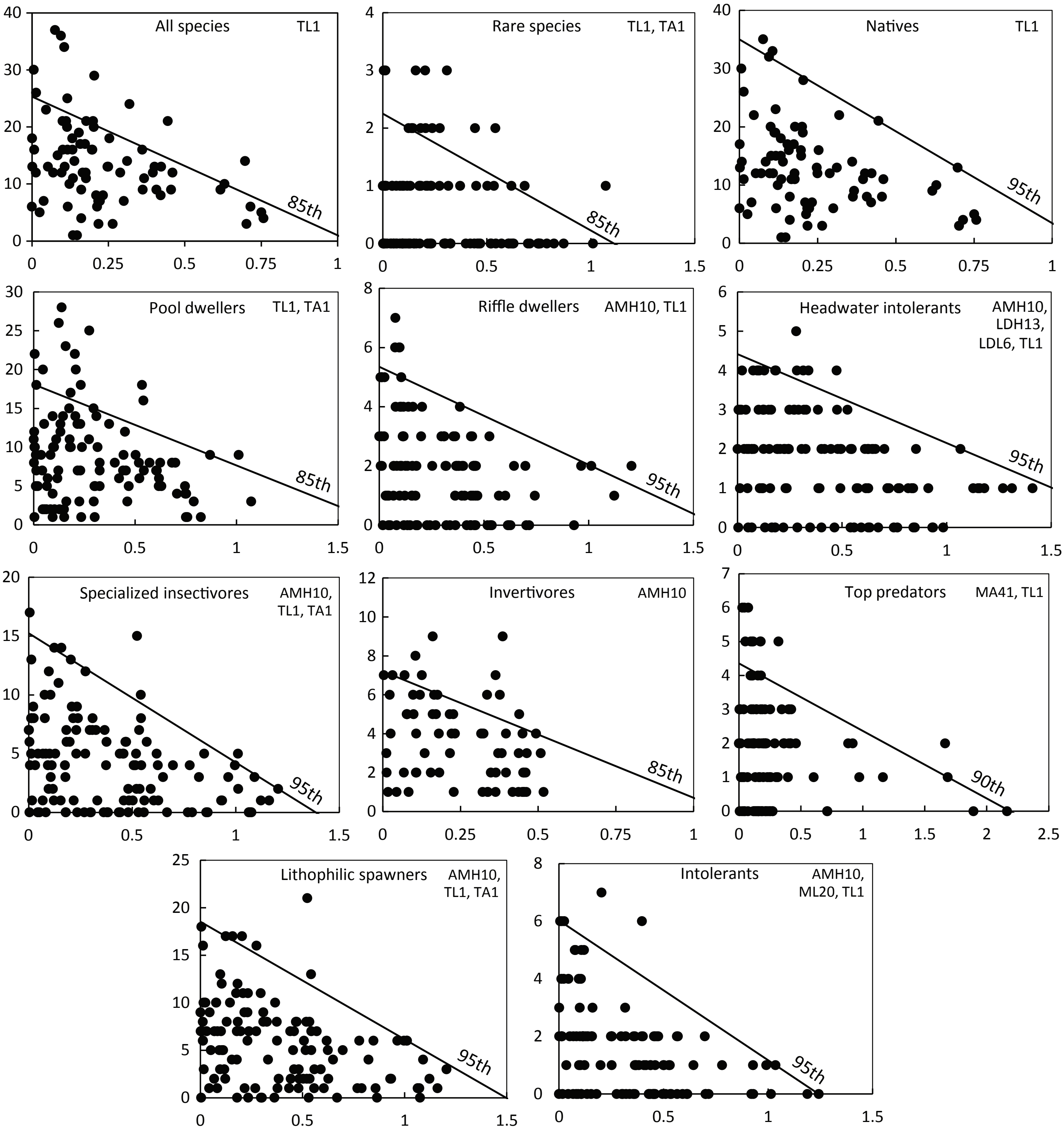

Figure S2. Flow-ecology relationships for 138 sites on the Cumberland Plateau of Tennessee and Kentucky, obtained by applying methods from [1,4] to fish datasets described in [3]. All horizontal axes represent cumulative hydrologic departure from reference conditions; see Table S1 for hydrologic reference profiles. All vertical axes represent numbers of species. Ecological limit functions are denoted by solid lines, with regression quantile noted on line. Streamflow characteristics used to calculate cumulative hydrologic departure from reference conditions are listed in the upper right corner of each plot. See Table S2 for slopes and intercepts of ecological limit functions.

Table S2. Streamflow characteristics, expressed as hydrologic departure from reference conditions, used in ecological limit functions for the Cumberland Plateau in northern Middle Tennessee and southeast Kentucky (upper table) and ecological limit function parameter estimates (lower table, all $p < 0.05$).

	Fish species category[b]										
Streamflow characteristic[a]	Natives	Headwater Intolerants	Intolerants	Invertivores	Lithophilic spawners	Pool dwellers	Riffle dwellers	Rare species	Specialized insectivores	All species	Top predators
Maximum October flow (AMH10)		X	X	X	X		X		X		
Average 30-day maximum flow (LDH13)		X									
Annual minimum daily average flow variability (LDL6)		X									
Timing of annual lowest flow (TL1)	X	X	X		X	X	X	X	X	X	X
Baseflow (ML20)			X								
Constancy (TA1)					X	X		X	X		
Mean annual runoff (MA41)											X
	Ecological Limit Functions										
Quantile	0.95	0.95	0.95	0.85	0.95	0.85	0.95	0.85	0.95	0.85	0.9
Intercept	35.0	4.4	6.0	7.2	18.5	18.1	5.3	2.3	15.2	25.3	4.4
Slope	-31.5	-2.3	-4.9	-6.5	-12.4	-10.4	- 3.3	-2.0	-11.0	-24.3	-2.0

[a] Defined in [2,1,4]
[b] Defined in [4]

Table S3. Streamflow characteristics (units in parentheses) describing modeled streamflow time-series for water-management scenarios at model location 1 (see Fig. 2C). [$m^3/s/km^2$, cubic meters per second per square kilometer of drainage area.]

Streamflow characteristics[a]	Water-management scenarios[b]				
	Baseline	Decreased IBT	Increased demand	New withdrawal	Minimum release
AMH10: maximum October flow ($m^3/s/km^2$)	0.027	0.013	0.024	0.027	0.029
LDH13: Ratio of annual 30-day maximum to median annual flow (dimensionless)	0.97	1.20	0.99	0.97	0.82
LDL6: Annual minimum daily flow variability (%)	0	0	0	0	0.51
TL1: Timing of annual lowest flow (Julian day)	273.98	275.41	274.02	273.98	263.97
ML20: Baseflow (dimensionless)	0.4	0.38	0.45	0.4	0.45
TA1: Constancy (dimensionless)	0.35	0.45	0.48	0.35	0.31
MA41: Mean annual runoff ($m^3/s/km^2$)	0.167	0.129	0.174	0.167	0.168

[a] See [1,2] for definitions of streamflow characteristics.
[b] See Table 1 in the main text for scenario definitions.

Table S4. Streamflow characteristics (units in parentheses) describing modeled streamflow time-series for water-management scenarios at model location 2 (see Fig. 2C). [$m^3/s/km^2$, cubic meters per second per square kilometer of drainage area.]

Streamflow characteristics[a]	Water-management scenarios[b]				
	Baseline	Decreased IBT	Increased demand	New withdrawal	Minimum release
AMH10: maximum October flow ($m^3/s/km^2$)	0.030	0.029	0.030	0.029	0.030
LDH13: Ratio of annual 30-day maximum to median annual flow (dimensionless)	0.98	0.99	0.98	1.01	0.97
LDL6: Annual minimum daily flow variability (%)	1.62	1.62	1.50	2.47	1.63
TL1: Timing of annual lowest flow (Julian day)	265.12	265.12	265.12	260.53	265.72
ML20: Baseflow (dimensionless)	0.33	0.33	0.33	0.32	0.33
TA1: Constancy (dimensionless)	0.35	0.35	0.37	0.26	0.35
MA41: Mean annual runoff ($m^3/s/km^2$)	0.156	0.154	0.156	0.153	0.156

[a] See [1,2] for definitions of streamflow characteristics.
[b] See Table 1 in the main text for scenario definitions.

References

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