Title: Flow-ecology relationships and environmental flows assessment for the Ozark-Ouachita Interior Highlands and the West Gulf Coastal Plains

Project Summary: Providing adequate water quantity and quality in streams and rivers is a pressing issue worldwide. Determining appropriate environmental flows in streams is critical for defining and designing landscapes capable of sustaining natural resources at desired levels. This proposal develops the second phase in a multi-year study, involving many partners and a series of steps towards the goal of producing the scientific basis for environmental flow standards within the Ozark-Ouachita Interior Highlands and the West Gulf Coastal Plains. Important products of this work will be regional flow-ecology relationships that will form the scientific framework for setting environmental flow standards and understanding impacts of land use and climate change. These flow-ecology relationships will help determine environmental flow needs in the Ozark-Ouachita Interior Highlands and the West Gulf Coastal Plains and will provide the basis for conservation of numerous aquatic species of greatest conservation need, including yellowcheek darter, Arkansas darter, least darter, Strawberry River darter, swamp darter, Ozark shiner, longnose darter, silver redhorse, paleback darter, goldstripe darter, current darter, Ozark chub, Oklahoma salamander, Ouachita streambed salamander, Ozark hellbender, spotted dusky salamander, Ouachita dusky salamander, Red River mudpuppy, gapped ringed crayfish, coldwater crayfish, Neosho midget crayfish, Mammoth Spring crayfish, Meek's crayfish, ringed crayfish, William's crayfish, and numerous species of aquatic insects. This work will positively impact many species and ecosystems region-wide, those of greatest conservation need and otherwise.

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Total SWG Funding Requested: $190,181

Amount and Source of Matching Funds or In-kind Services: $142,055
- $50,110 graduate student tuition, University of Arkansas
- $89,385 unrecovered indirect cost, University of Arkansas
- $2,560 in-kind services, Arkansas Game and Fish Commission

Total Project Cost: $332,236

Funding priority actions addressed:

- Determine environmental flow needs for aquatic communities
- Project will provide information for many SGCN species, including 12 fish, 6 amphibians, 7 crayfish and many insects (see Project Summary)

Ecobasins targeted: All basins within Ozark-Ouachita Interior Highlands and the West Gulf Coastal Plains

Need

Providing adequate water quantity and quality (i.e., environmental flow) in streams and rivers is vital for maintenance of adequate human and wildlife water supply and for maintaining function across ecosystems as lotic waters interface with terrestrial and marine ecosystems. Environmental flows are viewed as a top environmental priority by many global organizations, yet determining adequate levels is often difficult because they can be impacted by many anthropogenic and natural factors, such as resource development (e.g. natural gas extraction), impoundment, irrigation and drought. Water use worldwide has increased steadily in the past 50 years (Holland 2007). Flows of water in streams and rivers affect freshwater organisms and ecosystems, but the relationship between them is often little studied and poorly known because it requires significant measurement of flow characteristics and biota at appropriate temporal and spatial scales. Knowledge of the flow magnitude, frequency, timing, duration, and rate of change needed to maintain particular organisms or ecosystem structure and function (environmental flows) would allow managers and conservation biologists to conserve high quality freshwater resources. Additionally, climate models predict temperatures and extreme precipitation events will increase in the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plain regions (Diffenbaugh et al. 2005), so determining environmental flows would allow researchers and managers to assess potential impacts of climate change on stream organisms or ecosystem structure and function (Xenopoulos et al. 2005).

Several recent approaches for environmental flow determination exist. One of these approaches, Ecological Limits of Hydrologic Alteration (ELOHA) appears to have promise in determining flows needed to maintain particular organisms or ecosystem structure and function (Poff et al. 2010). Key aspects of the approach include using existing hydrological and biological databases, stakeholder involvement in setting goals and risk tolerance, and an adaptive management process. The large volume of region-wide biological data available from numerous sources provides a data-rich starting point to initiate ELOHA for the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plain regions.

Additionally, the principal investigator recently completed a SWG-funded study examining flow-ecology relationships in a single flow regime within the Ozark Highlands (Leasure et al. 2014). Key findings of this study were: 1) Flow-ecology relationships varied temporally, 2) Water quality, geomorphology and habitat were often as, or more, important than hydrology, 3) Substantial variation among taxonomic groups in flow alteration-ecology relationships, and 4) Relatively high levels of uncertainty in flow-ecology relationships (even for significant relationships). Important remaining questions that need to be addressed are whether flow-ecology relationships vary spatially or by flow class? It is also important to improve our understanding of temporal variation in flow-ecology relationships given the substantial variation in flow-ecology relationships that we observed in just two years. Finally, we feel that it is important to broaden the taxonomic basis for flow-ecology assessments so we plan to incorporate amphibians, along with fish, crayfish and macroinvertebrates.

The ultimate goal of our proposed research is to develop region-wide environmental flow standards. This proposal develops the second phase in a multi-year study, involving many partners and a series of steps towards the goal of producing the scientific basis for environmental flow standards within the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plain regions. These steps include identifying and collating region-wide hydrological and biological databases, a hydrologic classification of rivers, and conducting aquatic community sampling at key sites in order to develop flow-ecology relationships within the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plain regions. A hydrologic classification of the region has been completed as part of a SWG-funded study (Leasure et al. 2015), but additional work is needed to complete the rest of the process.

The relationships developed in these two objectives can then form the basis for setting regional environmental flow standards and understanding impacts of land use and climate change. Specifically, we will establish flow-ecology relationships for the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plain regions. This will positively impact many species and ecosystems region-wide, those of greatest conservation need and otherwise. It will also be useful for addressing water use issues, such as those stemming from natural gas development.

Objectives

1. Develop flow-ecology relationships for fish and macroinvertebrates for the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plain regions using data from existing sources (e.g. USGS, EPA)
2. Develop regional-level flow-ecology relationships for fish, amphibians, crayfish and macroinvertebrates within multiple flow regimes of the Ozark-Ouachita Interior Highlands using a field sampling approach

Approach

Objective 1: Database analysis to develop fish and macroinvertebrate flow-ecology relationships

A recently completed companion SWG-funded study had three main objectives: 1) To classify streams into natural flow regimes, 2) To calculate a hydrologic disturbance index at specific gauged and ungauged sites (Leasure et al. 2015, Figure 1), and 3) To determine flow-ecology relationships in a single flow regime within the Ozark Highlands (Leasure et al. 2014). Additionally, as part of a current SWG-funded study we have estimated flow alteration at gauged sites and we are developing models to predict flow alteration at ungauged sites within the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plain regions. The present proposal intends to build on this work and will further develop flow-ecology relationships. First, we propose to identify and collate hydrological (mainly USGS) and biological (e.g. USGS, EPA, USFS, TNC, state agencies) databases to develop a spatial relation between existing flow and biological inventory data within each flow regime in the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plains. We hypothesize that flow alteration and hydrologic disturbance affects fish and macroinvertebrate population and community structure and dynamics. We will examine relationships between ecological response variables (e.g. species richness, diversity, density, traits) and flow alteration, hydrologic disturbance, geomorphic, land use, and climate variables to address this overarching hypothesis.

Hydrology data will be collected from the USGS National Water Inventory System. Ecologically relevant hydrological variables will be estimated from these data (Leasure et al. 2015, Fig. 2). Fish and macroinvertebrate biological databases for the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plains will be collected from all potential sources for initial screening. For both databases, an initial set of sites will be screened and a subset of sites will be selected based on data quality, temporal sequence, timing, drainage area, missing data, and other measures of data acceptability. We will examine all natural flow regimes within the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plains with adequate hydrology and biology data for further analysis.

Limitations of using existing hydrology and biology databases to examine flow-ecology relationships are spatial and temporal gaps in data, poor data quality and lack of standardization, and mismatches between hydrological and biological data. Further, studies of this type are typically restricted to gauged sites, constraining the potential sample size. We will use flow alteration and hydrologic disturbance data estimated at un-gauged stream sites based on our current and previous research. This will allow us to greatly expand our use of existing biological data and alleviate two of the problems mentioned above.

Objective 2: Field study developing multi-taxa flow-ecology relationships for Ozark-Ouachita Interior Highlands.

A recently completed companion SWG-funded study determined flow-ecology relationships in a single flow regime within the Ozark Highlands (Leasure et al. 2014). We will use a similar field approach to circumvent the spatial and temporal gaps and data comparability issues with using existing hydrology and biology data as proposed in Objective 1. This field approach will be completed at a smaller spatial scale than Objective 1 due to time and personnel constraints.

Aquatic community sampling will be conducted over a range of flow alteration and hydrologic disturbance levels (e.g., dams, water withdrawals) in the Ozark-Ouachita Interior Highlands. We will sample 20 sites in each of two natural flow regimes in each of two ecoregions in each project year (160 sampling events). Sampling will be confined to two flow regimes, likely a groundwater flow class and a perennial runoff flow class (Leasure et al. 2015, Figure 1), so that comparisons can be made between the effects of flow alteration and hydrologic disturbance on different flow regime classes. Reaches will be stratified by habitat, with three each of riffles, runs, and pools sampled at each site.

Fish and crayfish will be sampled via three-pass backpack electroshocking (Dauwalter et al. 2003, USEPA 2009, Rabeni et al. 1997) after placement of 1.6 cm^2 mesh block-nets at the upstream and downstream ends of each unit to prevent organisms from escaping or biasing sampling data by moving from one unit to another. Fish from each pass will be kept in buckets until all passes are completed and processed separately. All fish will be identified to species level and to size class and released onsite. Benthic macroinvertebrates will be sampled using two methods, a quantitative richest-targeted habitat (RTH) method and a qualitative multi-habitat (QMH) method devised for the National Water Quality Assessment (NAWQA) program by Moulton et al. (2002). In the RTH method, a quantitative sample of invertebrates is taken from the habitat type determined to support the richest invertebrate community in the reach. The QMH method is a qualitative sampling technique used to document the invertebrate taxa that are present in all habitat types throughout a sampling reach (Moulton et al. 2002). Discrete QMH collections are taken from each of the different instream habitats present in the reach and combined into a single composite sample. Benthic macroinvertebrates will be identified to the lowest practical taxonomic level, usually genus. Stream-dwelling amphibians will be sampled using time and area constrained searches stratified by habitat (Heyer et al. 1994). Within each stream reach, we will sample three 10-m transects. Within each transect, a single observer will spend 10 mins turning natural cover objects along the stream edge for adult semi-aquatic salamanders and 10 mins dipnetting and turning instream cover objects for larvae and adults of fully aquatic species. Amphibian surveys will focus particularly on two common stream-breeding salamander genera, *Eurycea* (Oklahoma/many-ribbed, cave, and longtail salamanders) and *Desmognathus* (dusky salamanders), that vary in degree of terrestriality and have proven to be informative bioindicators in prior studies (Willson and Dorcas 2003, Crawford and Semlitsch 2007, Price et al. 2011). These common and widely-distributed species will serve as indicators of habitat quality that may be applied to rare or range-restricted species such as Hellbenders.

Habitat data collected will include depth, substrate size, current velocity, percent canopy openness, and area of each unit. Geomorphology measurements such as bankfull width, bankfull depth and low bank height will be taken, and a rapid habitat assessment score will be given to each site. Physical-chemical data, including temperature, pH, DO, conductivity and salinity will be collected. Water samples will be taken for nutrient analyses (total and dissolved nitrogen and phosphorus). Temperature loggers placed at each site will record temperature fluctuations for study duration. Hydrologic, land use/land cover, geology, soils and climate data will be obtained from GIS work associated with Objective 1. Biological data will be used to calculate species densities along with biological response variables including measures of community richness, diversity, and evenness, and trait-based community metrics derived from an Index of Biotic Integrity specifically developed for the Ozark Highlands (Dauwalter et al. 2003) and Ouachita Mountains.

Regression analyses will be used to examine relationships between response variables (e.g. species richness and diversity of fish, crayfish, macroinvertebrates, and stream-dwelling amphibians; relative abundances; number of intolerant species; various trait-based community metrics) and predictor variables (e.g. flow alteration, HDI, geomorphology, land use, climate). A previous study found multiple relationships between ecological response variables (e.g. species richness and diversity of fish, crayfish, macroinvertebrates) and predictor variables of hydrology, geomorphology, habitat and water quality (Leasure et al. 2014, Figure 3 as an example). Linear regressions will be performed between these variables, but a generalized additive model (GAM) approach will also be used to examine these relationships so that threshold response or curvilinear relationships can be detected. Redundancy analysis (RDA) will also be used to examine simultaneous relationships between community data and habitat, geomorphologic, physical-chemical, water quality and hydrologic variables.

Expected Results and Benefits

Results from this work will provide the scientific foundation for ultimately producing environmental flow standards within the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plains. We will identify and collate region-wide hydrological and biological databases and develop flow-ecology relationships for multiple flow regimes within the Ozark-Ouachita Interior Highlands and West Gulf Coastal Plains. Objective 2 will employ a rigorous field sampling design at a smaller spatial scale that will provide comparable flow and ecology data that will be used to quantify environmental flows and flow-ecology relationships for the Ozark-

Ouachita Interior Highlands. Additionally, work completed within Objective 2 will provide methodologies to apply to other regions. The relationships developed in these two objectives can then form the basis for setting regional environmental flow standards and understanding impacts of land use and climate change. This work will positively impact many species and ecosystems region-wide (see Project Summary for list of SGCN affected). It will provide essential information and tools for dealing with water use issues, such as those resulting from natural gas development.

Principal investigators and students will share information from this project via publications and presentations at local to international meetings. As part of this project we will add data to the databases maintained by the Arkansas Game and Fish Commission and the Arkansas Wildlife Action Plan and the National Monitoring Partnership database. Finally, we will provide annual progress reports and a final report after the completion of the project.

Budget

Total SWG Funding Requested: $190,181
Total Project Match: $142,055
Total Project Cost: $332,236

Requested SWG Funds	**2016**	**2017**	**Total**
Salary/Benefits			
3 Graduate Students	$57,901	$57,901	$115,802
3 Research Technicians	$17,589	$18,117	$35,706
Operating Expenses			
Travel	$11,760	$12,113	$23,873
Materials & Supplies	$14,800		$14,800
Capital Expenses	$0		$0
Total	$102,050	$88,131	**$190,181**

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Project Leader

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<u>Previous SWG Grants</u>

Magoulick, D.D., R.J. DiStefano, B.K. Wagner and J.W. Fetzner, Jr. 2014-2016. Arkansas Game and Fish Commission. Invasive species effects, population status and population genetics of crayfish species of greatest conservation need (*Orconectes marchandi*, *Orconectes eupunctus*, and *Cambarus hubbsi*) in the Ozark Highlands of Arkansas and Missouri. $80,208.

Magoulick, D.D. and D.R. Leasure. 2014-2016. Arkansas Game and Fish Commission. Quantification of hydrologic alteration and relationships to biota in Arkansas streams: Development of tools and approaches for un-gaged streams. $53,000.

Magoulick, D.D., S. Longing, J.W. Quinn, J. Jackson, J. Duzan and J. Petersen. 2011-2014. Arkansas Game and Fish Commission. Classification of Arkansas flow regimes, regional ecological-flow response relationships and environmental flows assessment for the Ozark region. $172,000.

Entrekin (PI) Evans-White et al. Co-PI. 2010-2012. Arkansas Game and Fish Commission. Assessing physical, chemical, and biological effects before, after, and during gas well construction in headwater streams. $231,847.

Entrekin (PI) Evans-White et al. Co-PI. 2009-2010. Arkansas Game and Fish Commission. Assessing biological effects of natural gas drilling on headwater streams in the Fayetteville Shale region. $248,908.

Magoulick, D.D. 2005-2007. Arkansas Game and Fish Commission. Effect of the introduced crayfish, *Orconectes neglectus*, on native crayfish in the Spring River drainage. $68,390.

Figures

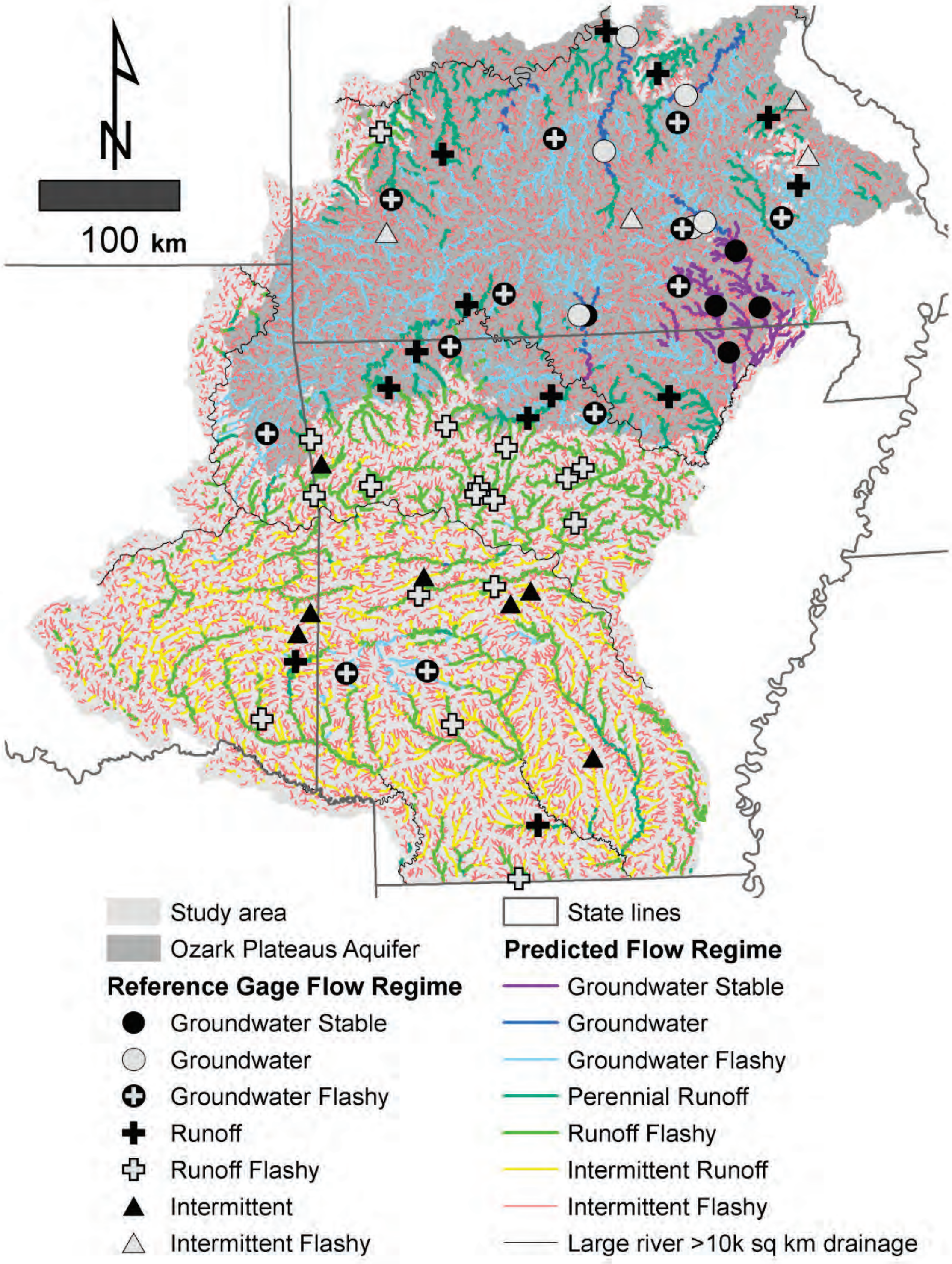

Figure 1. Natural flow regimes of 64 reference gages were identified using mixture- model cluster analysis based on 10 flow metrics. Natural flow regimes of all stream segments were predicted based on climate and catchment characteristics using a random forest model.

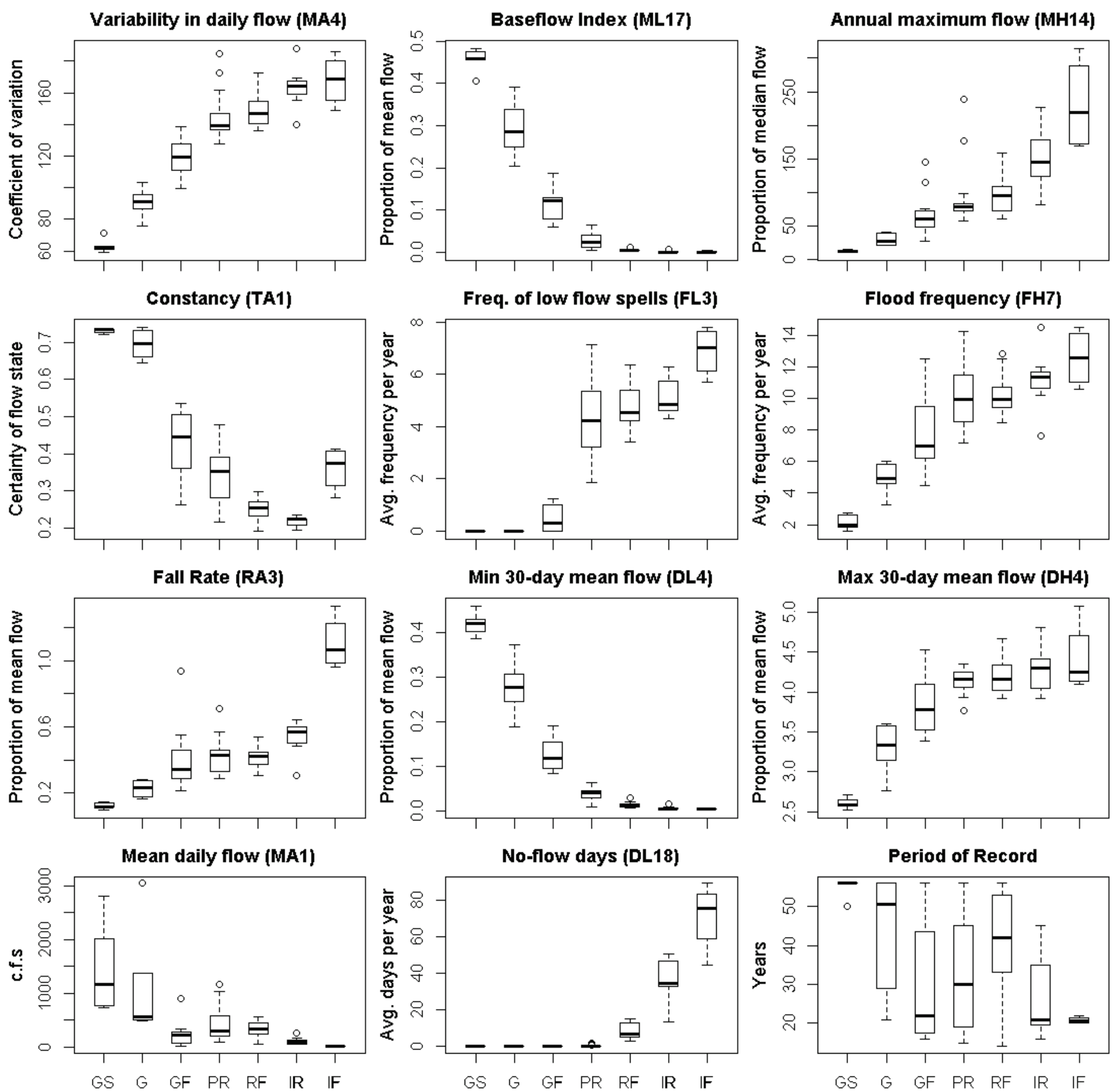

Figure 2. Flow metrics used in cluster analysis compared among natural flow regimes: Groundwater Stable (GS), Groundwater (G), Groundwater Flashy (GF), Perennial Runoff (PR), Runoff Flashy (RF), Intermittent Runoff (IR), and Intermittent Flashy (IF).

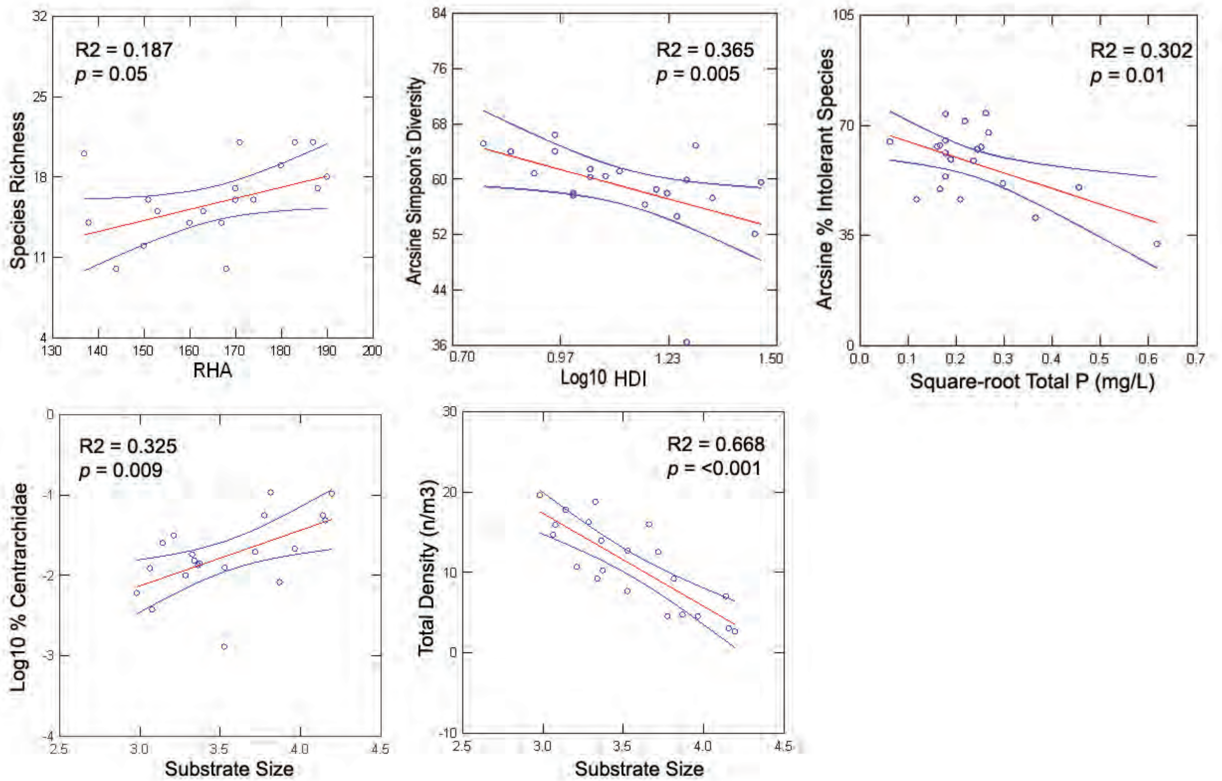

Figure 3. Important fish ecology-environment relationships in 2012. RHA is a qualitative index of stream geomorphology and habitat quality. Hydrologic disturbance index (HDI) is based on factors such as dam density, proximity to roads and canals, and water withdrawals (Falcone et al. 2010). Only significant relationships in the best models are shown. Blue lines indicate 95% confidence intervals.