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Editorial

Ecology of Aquatic Invertebrates in Springs and Headwater Streams: Imperiled Habitats in a Changing World

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Headwater streams and springs and their resident biotas are vulnerable to a broad range of anthropogenic stressors. Especially notable among those stressors are urbanization, eutrophication, excessive groundwater withdrawals, mining, hydraulic fracturing ("fracking") associated with petroleum development, the introduction of non-native taxa, and the insidious impacts of climate change. Because of such impacts, headwater streams, springs and their contributing aquifers are imperiled systems at substantial risk of environmental damage or destruction, including the extirpation and extinction of their resident biological diversity and the alteration of their faunal assemblage composition. Although knowledge about these systems has markedly increased in recent decades, there remains much to be learned in order to improve conservation efforts aiming to maintain their ecological integrity. Benthic macroinvertebrates (BMIs) are an important tool for understanding and detecting changes in ecosystem integrity, and BMI community composition can be used to reflect cumulative impacts that cannot otherwise be detected through traditional water quality monitoring. However, our understanding of the diversity and ecology of BMIs occurring in springs and headwater streams is often limited compared to our knowledge of larger and more cosmopolitan surface water dominated systems.

This Special Issue provides a series of papers that advance our understanding of BMIs in headwater streams and springs, which will aid in elucidating ecological relationships, fine-tuning impact assessments, and promoting the conservation of these animals and their habitats. In this Special Issue, there are three papers related to spring ecosystems [1–3] and four papers related to small-discharge and headwater streams [4–7]. All of these papers deliver new and compelling findings, as well as useful tools and analyses that will aid future studies. This collection of papers represents a broad geographic range of stream habitats and conditions: four are centered on the Ozarks Physiographic region, one on the Piedmont streams of North Carolina, and another on Central Mexico.

Heth and Bowles [1] studied the effects of coldwater springs on BMIs along the length of the spring-dominated Missouri River. They found that large spring inflows had a profound effect on BMI communities. Specifically, BMI diversity and stream conditions associated with the inflows of surface-fed tributaries were more heterogeneous, as compared to more homogeneous diversity and conditions when the inflows emanated from large springs. Downstream of each large-magnitude spring, taxa richness sharply decreased, while taxa richness increased downstream of tributaries. Beta diversity usually declined downstream of the confluences with springs but increased downstream of the tributaries. The general findings showed that the Current River did not follow predictions from the long-standing River Continuum Concept [8], with large spring inflows disrupting the predicted patterns in the diversity and composition of BMI communities.

The study conducted by Cheri and Finn [2] was initiated because the authors noted that odonates (order Odonata, dragonflies and damselflies) are seldom used for stream

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bioassessment in North America as compared to other insects, particularly when monitoring the ecological impacts of organic pollution. They studied odonates from multiple microhabitats and all macroinvertebrates from riffle habitats in a dozen Ozark Highlands (USA) spring streams along a gradient of riparian physical conditions. Their primary finding was that odonates were strongly associated with riparian-specifific variables, although other riffle BMI taxa were associated with riparian variables to a lesser degree. Additional environmental variables, such as water chemistry, were much less useful for explaining variations in BMI composition. Their findings indicate that odonates themselves are a potentially useful indicator group that may aid in biomonitoring associated with the riparian structure around Ozark spring streams. Given that odonates have a global distribution that spans just about every type of aquatic habitat, the findings of Cheri and Finn [2] may have broad applicability to a diversity of other aquatic systems.

Worsham et al. [3] used data on an extant endemic parasitic nematode worm occurring in central Texas Springs to test predictions regarding how the extant distribution of this species was derived. This nematode occurs in some springs but not others, although they all appear to be suitable habitats, which presents a puzzling distributional pattern. This unexpected pattern offers a cohesive and widely accepted explanation for the aforementioned biogeographical pattern. The authors found that multiple severe droughts that have occurred since the Wisconsin glaciations are likely responsible for the present-day distribution of central Texas crenobionts. They further suggest that the data on contemporary species with obligate coevolution can help to fill data gaps in the paleo-record, because the extant distribution of some species indicates that their hosts have cohabitated without interruption since the arrival of the parasite. The findings of this study will be of great interest to researchers who study patterns in the occurrence and distribution of crenobiontic taxa, particularly in light of the management considerations for these sensitive and threatened habitats.

Two studies assessed the habitat preferences of rare Ozarkian aquatic insect species [4,5]. Annatarone et al. [4] modeled the distribution of an endemic winter stonefly (*Allocapnia mohri*) in the Ozarks and Ouachita mountains of Arkansas, where it occurs in headwater streams that are often intermittent. The known distribution of this species had not been evaluated previously with respect to land use patterns or climatic variables. Because stoneflies are especially sensitive to habitat disturbance, the habitat-specific models generated in this study will serve to better protect *A. mohri* as well as other sensitive and endemic species. Many Ozark headwater streams are being permanently damaged by activities associated with hydraulic fracking [9] and development. The results of this study will be useful for land managers who want to identify suitable habitats for *A. mohri* and better protect them. The models further suggest that *A. mohri* may already be experiencing habitat loss in some portions of its range in the Ouachita Mountains.

Longing and Magoulick [5] studied the flight capacity of two endemic water beetles (Dytiscidae: *Heterosternuta sulphuria* and *H. phoebeae*) in response to habitat drying. These dytiscid species occupy different habitat types, and their distributions apparently do not overlap. Stream habitat drying experiments indicated a weak capacity for flight and overland migration of *H. sulphuria*, with low probabilities of survivorship in microhabitats exposed to drying. In contrast, *H. phoebe* showed a greater capacity for flight. They found that weak flight capacity and apparent intolerance to habitat drying have important implications for the evolutionary history and conservation of *H. sulphuria* in small Ozark streams exposed to variable flow regimes and stream margins vulnerable to disturbances. As noted by Annatarone et al. [4], hydraulic fracking threatens the integrity of headwater streams, thus making *H. sulphuria* more vulnerable to extirpation compared to *H. phoebe*, which prefers downstream habitats in larger watersheds and may be less vulnerable to such disturbances. This study also highlights the importance of environmental filtering for community assembly [10] and how variation in traits (i.e., dispersal ability) in a community can lead to the persistence or loss of populations under different disturbance regimes (e.g., drying).

The enormous diversity of BMIs in Mexico remains largely undocumented. To help to address this matter, Luna-Luna et al. [6] studied aquatic beetle diversity among three study sites in the state of Tlaxcala. Among those sites, they identified twenty-three species, fifteen genera, and six families (Elmidae, Dryopidae, Dytiscidae, Gyrinidae, Haliplidae, and Hydrophilidae), although their diversity and abundance varied widely. Using species accumulation curves and β-diversity estimates, they found that the maximum estimated number of species has not been achieved at any of the three sites, indicating there is still substantial coleopteran diversity remaining to be documented. This study clearly shows that aquatic beetle diversity at the aforementioned sites in Tlaxcala, and probably all of Mexico, is likely substantial, which is also true for many other invertebrate groups in this region.

The final paper in this Special Issue studied the diversity of aquatic invertebrates across 30 streams on the watershed scale to assess the impacts of impervious cover [7]. Increasing impervious cover associated with urbanization has a negative impact on stream conditions and BMI diversity. The authors' data showed that both taxa richness and diversity declined at a greater rate than trait richness and diversity along an in-stream habitat diversity gradient. They also found that the taxa and traits were associated with specific microhabitats or combinations of microhabitats. By correlating taxa in urban streams with specific microhabitats, we can better evaluate the success of stream restoration in restoring stream function and in stimulating BMI community recovery. The results of this study will be particularly useful for gaging the overall impacts of urbanization on streams in the Piedmont region as well as elsewhere.

The seven papers in this Special Issue present compelling data and findings that will be of particular interest to resource professionals who are seeking to protect these habitats and understand the ecology of BMIs in spring-dominated and smaller headwater systems. Accordingly, these findings and research methodologies could also encourage additional research questions to be studied.

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