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SYMPOSIUM PAPER

Introducing freshwater mollusk diversity in a biodiversity hotspot

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Mollusks are an incredibly diverse group of animals second only to insects in described species. Freshwater mollusks are distributed globally, occurring on all continents except Antarctica (Graf and Cummings 2021, Strong *et al.* 2008). Mollusks provide valuable ecosystem services by improving water quality, enhancing nutrient cycling, and playing critical roles in aquatic food webs (Atkinson *et al.* 2023). Globally, freshwater ecosystems host a disproportionately large amount of biodiversity relative to their size (Dudgeon *et al.* 2006, Reid *et al.* 2023). However, biodiversity is declining at a greater rate in freshwater systems globally than in terrestrial and marine systems (Reid *et al.* 2019), and mollusks represent one of the most diverse aquatic groups with more than 6,000 species (Böhm *et al.* 2021).

The freshwater mollusk fauna of the Mobile Basin in the southeastern U.S.A. is potentially the most diverse in the world, but one-third of this incredible fauna is now extinct due to flow regulation and habitat alteration (Strayer *et al.* 2004, Williams *et al.* 2008). Similarly, mollusk populations globally have been severely reduced or extirpated in many freshwater systems due to anthropogenic stressors including habitat modification (*e.g.*, dams and urbanization) and degraded water quality (Böhm *et al.* 2021). Globally, 40% of freshwater bivalves are considered threatened, which is probably an underestimate given the lack of data for many regions, and the situation for gastropods is thought to be even worse (Lopes-Lima *et al.* 2018, Böhm *et al.* 2021). Therefore, it is critical to understand freshwater mollusk patterns of diversity, their role in the functioning of ecosystems, and ways to move forward with conservation efforts.

The American Malacological Society met in Tuscaloosa, Alabama for its 89th annual meeting from August 1–5, 2023. As the society met at the freshwater diversity hotspot for this group, it was an easy decision to center the President's Symposium around the theme of "Freshwater Mollusk Diversity in a Biodiversity Hotspot." The overarching goal of this symposium was to bring together malacologists whose research spans comparative phylogenetics, population genetics, ecosystem ecology, and conservation of freshwater mollusks. Characterizing species richness and diversity is critical for identifying the processes that drive speciation and evolution. Furthermore, understanding the role of species as drivers of ecosystem processes is imperative to preserve, utilize, and sustain ecosystems globally. Anthropogenic activities result in the loss of biodiversity and enhance the ability of exotic species to invade and persist in novel habitats (Reid *et al.* 2019, Albert *et al.* 2021). As these activities are expected to increase through time, advances in understanding the consequences of species loss on ecosystems are needed to guide appropriate management and conservation decisions.

Collectively this symposium focused on patterns of biodiversity and ways to push freshwater mollusk research further. The body of work presented examined experimental and theoretical work from studies of the importance of museum collections, the addition of species and the loss of species from freshwater ecosystems to the cultural significance of mollusks. Themes arising from this symposium and included in this issue include the:

- Critical importance of high-quality long-term data on mollusk populations
- Enhancement of data accessibility and standardization of data formatting
- Significance of museum records and collections and the utility of digitizing these data
- Need for a better understanding and documentation of global distributions and diversity of mollusks
- Role of mollusks in ecosystem services including cultural services

Summary of the Presentations and Papers in this Issue

Arthur Bogan's manuscript (2024) provides a captivating overview of his five-decade-long journey in studying freshwater mussels. The paper is organized into four distinct periods of his career: graduate school at the University of Tennessee, Knoxville; the Academy of Natural Sciences of Philadelphia; a consulting period from 1992 to 1996; and his current position at the North Carolina Museum of Natural Sciences.

Bogan reflects on the evolving landscape of freshwater bivalve research, emphasizing the transition from shell-focused studies to a more integrative approach incorporating comparative anatomy, host-fish interactions, behavior, and molecular data. Bogan discusses the challenges in taxonomy faced during his early career, noting the instability of freshwater mussel taxonomy and discrepancies in classification among different experts. The impact of the Endangered Species Act of 1973 is highlighted, marking a turning point in freshwater mussel conservation. Bogan summarizes highlights of his academic career to date, including collaborations with many renowned malacologists and his role as a curator at the Academy of Natural Sciences of Philadelphia. The section on his consulting years discusses survey work and its important role in enhancing understanding of extant bivalve populations. Bogan also discusses his tenure at the North Carolina Museum of Natural Sciences, emphasizing collaborative projects, recent advancements in molecular techniques such as anchored hybrid enrichment and their contribution to a more nuanced understanding of unionid evolution and phylogeny. Bogan concludes by connecting his work to broader global perspectives on freshwater bivalves, discussing their taxonomy, zoogeography, and the urgent need for conservation efforts.

David Stayer's paper (2024) focuses on two scientific problems central to future unionid freshwater mussel conservation: population monitoring and dynamic lags that affect mussel populations. Strayer highlights the monitoring mismatch that occurs among different river systems, agencies, and the lack of accessible mussel population data. These mismatches and lack of accessible data hinder conservation efforts and communication among researchers and managers. Furthermore, given the long lifespan of many freshwater mussels, drivers that affect mussel populations take decades to play out. Thus, mussel populations are often not in equilibrium with their current environments, leading to extinction debts and colonization credits. Collectively, Strayer's paper makes suggestions for improving monitoring, enhancing coordination of monitoring, and combining monitoring into model applications that include time lags to better integrate monitoring into broader programs of research and management that could improve conservation efforts in this highly imperiled group.

Vaughn and Atkinson's paper (2024) highlights the importance of long-term data in understanding freshwater mussel population dynamics. Our understanding and the causes of freshwater mussel declines are limited by the lack of long-term data monitoring species abundance, demographic parameters, and community composition. The authors leverage a three-decade long dataset of freshwater mussel surveys in the Kiamichi River, Oklahoma to highlight changes in abundance and composition and the roles these animals play in nutrient storage and cycling at four sites that were monitored over time. Their 30 years of data indicated that overall abundance of mussels in the river declined substantially. Further, species composition and the proportion of species with different functional traits has changed. They attribute changes in mussel abundance and composition to the combined impacts of decadal-long cyclical drought in the region and water management. Specifically, the proportion of drought-tolerant species in the mussel community generally increased during the drought periods, and then decreased in the last decade as more sensitive species rebounded during wetter conditions. While mussels in the region have evolved under these cyclical wet and dry conditions, water management is a new constraint. Sardis Reservoir, an impoundment of a major tributary to the river, is changing the flows and availability of water. Overall, these results provide valuable insights on the status of mussel communities in the river and their contributions to ecosystem function.

Whelan and colleagues (2024) investigate genetic diversity in members of the imperiled freshwater gastropod family Pleuroceridae. Despite the precarious status of most species within this family, crucial conservation data, particularly population genetics and genomics, have remained conspicuously absent. Focusing on two species that have experienced severe range contractions, the authors employ cutting-edge population genomic analyses. Contrary to expectations, following significant range contractions both species exhibit remarkable genetic diversity, and intriguingly, neither displays evidence of a bottleneck. The study introduces the "Rapid Localized Extirpation Hypothesis," a novel conceptual framework proposed in light of the new findings. Notably, this hypothesis explains why previous population genetic studies failed to detect bottlenecks in pleurocerids, even among range-restricted species. Beyond its explanatory power, the hypothesis sets the stage for future investigations into pleurocerid habitat requirements and offers anticipatory insights into their responses to habitat changes.

Finally, Maine and O'Brien's paper (2024) highlights the cultural importance of freshwater mussels to Native Americans and various conservation efforts in their paper "A long-term research program to restore freshwater mussels as a tribal First Food." Mussel populations are in decline globally but provide many important ecological services including cultural services. Freshwater mussels are a First Food, a traditional resource of cultural and ecological significance, to Native Americans like the Confederated Tribes of the Umatilla Indian Reservation (CTUIR) and other Columbia River Basin tribes. While the harvesting of mussels remains a right under Treaty of 1855, widespread harvest of mussels has not occurred for many decades, reducing the human-mussel connection. The CTUIR has worked for 20 years to restore ecological and cultural connections to mussels through risk assessment, monitoring, and restoration. Here they highlight

their results from the 'Master Plan: Freshwater Mussel Conservation, Supplementation, Aquaculture, Restoration, and Research' for restoring self-sustaining populations of freshwater mussels to CTUIR subbasins and the wider Columbia River Basin for the restoration of cultural and ecological services.

The loss of biodiversity is an urgent concern, one that threatens the integrity of ecosystems along with the essential services they provide (Dudgeon *et al*. 2006, Oliver *et al*. 2015, Atkinson *et al.* 2023). The next several decades will be a time of rapid change for mollusk populations, which will be threatened by novel pollutants, climate change, biological invasions, and land-use change. Furthermore, there are conservation mismatches between protected lands and where most of the imperiled taxa live (Jenkins *et al.* 2015). Biodiversity loss is disproportionately high in freshwaters, particularly for mollusks (Lopes-Lima *et al*. 2018, Reid *et al.* 2019). However, there are opportunities to enhance our knowledge of this group and better their protection. Given the high diversity of mollusks and their global distribution, it is critical that we better understand patterns of diversity and their role in the ecosystem. Collectively, the papers included in this issue highlight avenues for future research and documentation efforts, improvements in knowledge regarding these groups, and how we can use both past cultural and scientific information to inform pathways for restoration and community and engagement.

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