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An introduction to directions in freshwater mollusk conservation: molecules to ecosystems

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The goal of conservation biology is to protect Earth's biological diversity. Biodiversity includes genetic diversity (the number and frequency of genes within species), species diversity (i.e., plants, animals, and microorganisms on Earth), and assemblage/ecosystem diversity (McNeely et al. 1990). Thus, biodiversity can be studied from a multitude of disciplinary perspectives, ranging from molecular genetics to evolutionary biology, and from autecology (e.g., life history) through population, community, and ecosystem ecology. Moreover, studies of biodiversity often address biotic and abiotic factors that influence biodiversity at spatial scales that range from microhabitat to global. The more that is known about biodiversity, the more likely it is that scientists and conservationists will be able to protect biodiversity. Thus, scientific knowledge about organisms drives conservation efforts. However, we know far more about some groups of organisms than we do about others. For example, Strayer (2006) reported that the best-studied freshwater invertebrate groups have roughly the same number of described species as do freshwater fishes, but the number of published papers about those freshwater invertebrates is 1/10th the number of published papers about freshwater fishes.

Freshwater mollusks belong to one of the more intensively studied invertebrate groups. Freshwater mollusks are among the most imperiled taxonomic groups in the world, and they constitute 708 of the ~7000 species included in the 2002 International Union for the Conservation of Nature and Natural Resources (IUCN) Red List of Threatened Species (Lydeard et al. 2004). Furthermore, 42% of the 693 recorded animal species extinctions are mollusks, and 99% of the mollusks that have become extinct were nonmarine taxa. Freshwater bivalves of the superfamily Unionoidea are distributed worldwide, but they are most diverse in North America. Between 850 and 900 freshwater bivalve species are recognized, 200 of these species are on the IUCN Red List, and 189 of the listed species are located in the USA (Lydeard et al. 2004). Thirty-seven of the 297 known North American taxa are presumed extinct, and another 165 are considered possibly extinct, critically imperiled, imperiled, or vulnerable (Master et al. 2000). The scorecard is even more dismal for freshwater gastropods in the USA. Approximately 60 freshwater gastropod species in the USA are presumed extinct, 20 are on the US federal endangered or threatened species list, and another 290 species are of conservation concern (Johnson 2003). In other words, 9% of all freshwater gastropod species in the USA are extinct, and 48% are conservation targets. This rate of imperilment exceeds that of every other major animal group in North America (Perez and Minton 2008).

Because of the growing concern about the conservation of freshwater mussels in North America, stakeholders met in 1995 to discuss freshwater mussel declines and to gather information on trends, research needs, and recovery activities, and they drafted a National Strategy for the Conservation of Native Freshwater Mussels. The 2007 Symposium of the Freshwater Mollusk Conservation Society (FMCS; http://ellipse.inhs.uiuc.edu/FMCS/) was held in Little Rock, Arkansas, from 13 to 15 March 2007. The theme of the symposium was *Directions in Freshwater Mollusk Conservation: Molecules to Ecosystems*. The plenary session of the symposium was structured to provide information to support revision of the

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society's primary guidance document, "The National Strategy for the Conservation of Native Freshwater Mussels" (National Native Mussel Conservation Committee 1998), to include all North American freshwater mollusks. The 10 papers that resulted from this plenary session provide a molecules-to-ecosystems review of current knowledge and identify future directions in research for the conservation and management of this imperiled group; they are briefly introduced here.

Bogan and Roe (2008) discuss the status of and future research directions for freshwater bivalve diversity, systematics, and evolution by providing a concise historical review of freshwater mussel taxonomists and their systematic treatments of the group. This genealogy is followed by an overview of the worldwide distribution of freshwater bivalve families, and the paper closes with a discussion of phylogenetic studies, development of molecular tools and new data sets, and directions for advancement of understanding of freshwater mussel evolution and relationships.

Barnhart et al. (2008) provide a comprehensive and fascinating review of freshwater mussel adaptations for host infection and larval parasitism. They provide descriptions of the adaptations, hypotheses for the evolution of larval parasitism, descriptions of glochidial morphology (including adaptations for attaching to gills vs skin), host-infection strategies (including evolutionary relationships within mussels), and host specificity.

Relatively few studies have attempted to use theory from population biology and conservation genetics to gain insight into strategies for effective conservation. Berg et al. (2008) describe a stage-based conceptual model that integrates demographic and genetic changes associated with declines in freshwater mussel populations throughout different life stages. They use population viability analysis (PVA) as a framework to explicitly consider both demographic and genetic stochasticity. They suggest that use of the PVA conceptual model in freshwater mussel conservation will allow evaluation of relative risks from demographic stochasticity, loss of genetic variation, environmental degradation, and catastrophic events.

Research along multiple resource axes and the interactions among these axes will be needed to determine the resource requirements of mussels and to understand how mussel communities influence each other and the rest of the food web. Vaughn et al. (2008) describe exciting research developments in the freshwater mussel community and foodweb ecology. Their review of mussel feeding behavior and diet includes modes of feeding, the structure and function of cilia, and recent understanding of food resource use through a variety of analyses, including stable-isotope and fatty-acid analysis. They describe the effects of mussel communities on ecosystem services and food webs in a discussion that illustrates recent gains in our understanding of the functional role of freshwater mussels as habitat, substrate stabilizers, bioturbators, and nutrient recyclers. They discuss the context-dependent roles and potential influence of freshwater mussels on other organisms in the aquatic community.

Landscape ecology has the potential to help define the best spatial scales for scientific studies and management activities. Newton et al. (2008) review 3 areas in which landscape ecology has been used to understand and manage freshwater mussels: 1) use of hydraulic data when delimiting patches of mussel habitat, 2) the importance of connectivity of habitat patches to understanding and conserving freshwater mussels, and 3) links between watershed events and the quality, extent, location, and connections among patches of mussel habitat.

Ecological stoichiometry, the study of the balance of multiple elements in ecological interactions and processes, provides a broad conceptual framework for understanding and generating hypotheses about the ecological interactions and processes that might be essential to mollusk conservation and restoration efforts. Christian et al. (2008) discuss nutrient release via biodeposition and excretion and the ecological stoichiometry of the food resources, body composition, and nutrient release of freshwater mussels. They focus on 3 themes: 1) C, N, and P biodeposition and excretion, 2) body C, N, P, C:N, C:P, and N:P composition, and 3) relative homeostasis of stream macroinvertebrate and freshwater mussel stoichiometry.

Maintenance of abiotic conditions that support mollusk populations or remediation of conditions that currently will not support viable populations are fundamentally important to all efforts to conserve or restore freshwater mollusks. Cope et al. (2008) evaluate differential exposure pathways, exposure durations, and sensitivities of free glochidia, encysted glochidia, juveniles, and adult freshwater mussels to environmental contaminants. They identify common and unique characteristics of each life stage in relation to exposure to contaminants.

Lysne et al. (2008) review the challenges and opportunities in freshwater gastropod conservation and set the stage for 2 papers that address the status of freshwater gastropods. Their review focuses on 4 topics: 1) the need for a national freshwater gastropod conservation strategy, 2) a review of current knowledge and the need for basic research on gastropod taxonomy and systematics, 3) the need for basic ecological data, and 4) conservation challenges, including water quality and quantity, invasive species, and captive care and propagation. Their paper concludes with a discussion of opportunities for conservation success, such as establishment of local working groups that have the interest, expertise, and ability to collect, review, and disseminate information to those individuals or agencies that determine natural-resource policy.

Perez and Minton (2008) discuss practical applications for taxonomy and systematics in conservation of North American freshwater gastropods and include an excellent review of the role of systematics that transcends taxonomic groups. They address the need to define theoretical conservation management units, provide an example of lessons learned from practical application to freshwater gastropods, and explore how the evolutionary process complicates management unit designation. They conclude with a discussion of how to provide management unit information for those charged with conservation and the importance of providing this information in a consistent system of species description, redescription, and classification.

Brown et al. (2008) focus on the conservation ecology of North American pleurocerid and hydrobiid gastropods. They review what is known about the distribution, life history, and population ecology of these gastropods, their functional role in ecosystems, and the effects of invasive gastropods on both pleurocerid and hydrobiid gastropods.

The mollusk scientific community has made great strides in understanding the life history, distribution, and ecology of freshwater mollusks; however, only the groundwork has been laid. Each of these papers provides important information on our current knowledge of freshwater mollusks, points out important areas for future research, and highlights conservation needs. Product delivery is a crucial part of advancing mollusk conservation from theory to application, from a collection of interesting facts and novelties to success stories involving conserved units and habitats.

This series of papers provides exciting examples and directions useful to the broader fields of evolutionary biology, biogeography, ecology, from organisms to ecosystems, and conservation. Gains in scientific knowledge and conservation efforts often are most effective when achieved through the combined and concerted efforts of nongovernmental organizations, agencies, and researchers. We hope that this special issue serves as a resource to mollusk researchers and conservationists and provides a synergy for efforts within the entire aquatic research and conservation community.

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