PROPAGATION OF ENDANGERED FRESHWATER MUSSELS IN NORTH AMERICA

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Abstract *The extremely diverse molluscan fauna in North America has experienced a significant decline in recent decades, particularly in the United States. Of the nearly 300 taxa of freshwater mussels (Unionoidea), 70 (23%) are listed as endangered or threatened, and another 40 species (14%) are candidates for possible listing. Only in the last decade has the status of our 660 species of gastropods been evaluated, unfortunately with disheartening results. Although only 15 species are federally protected, at least 42 species have become extinct in the 20th century, and dozens of species are in precipitous decline in the southeastern United States. Canada's freshwater molluscs have faired better; of roughly 180 species of bivalves and gastropods, only 4 of the 51 mussel species and 2 of the 90 snail species are nationally protected.*

To address this urgent need to maintain and restore populations of these protected mussels and snails in North America, a raft of recovery activities was initiated in the last decade to prevent further extinctions through habitat protection and propagation. Propagation efforts were initiated in the upper Tennessee River system, home to 34 endangered mussel species, and have subsequently spread to other rivers with aggregations of rare molluscs. Freshwater mussel propagation work is underway at facilities in Virginia, Tennessee, Georgia, Missouri, Arkansas, Wisconsin, and Minnesota in efforts to augment populations in reproductive decline and to expand the ranges of extant populations. Similar work is underway at the University of Guelph in Ontario, focused on restoring nationally protected and other species occurring only in the Sydenham River, Canada.

As of 2001, nearly 330,000 juveniles of 16 endangered species were released into U.S. rivers in 7 states. Most of these were produced at the Freshwater Mollusc Conservation Center at Virginia Tech, Virginia and released into tributaries of the upper Tennessee River. Research continues at these facilities to identify host fishes for other endangered mussels and to improve culture techniques, particularly the rearing of juvenile mussels during the first 6 months of life. Development of a suitable diet is now critical for facilitating the transition from the pedal-feeding to filter-feeding stage. With the high level of research underway, a manual for mussel propagation is planned, to assist with species conservation at an international scale.

Keywords *Propagation, Freshwater, Mussels, Mollusca, North America.*

INTRODUCTION

The recovery and restoration of freshwater mussel species and populations in the United States was promulgated by two national initiatives. The Endangered Species Act (1973) and subsequent amendments provided the first substantial means to recognize, protect, and recover rare freshwater molluscs in the United States. Recovery plans for each mollusc on the USFWS (United States Fish & Wildlife Service) List of Threatened and Endangered Species specify the need not only to maintain existing populations and their requisite habitats, but to seek means to expand the ranges of those populations, both within resident rivers and into historic rivers. Most freshwater malacologists agree that without the expansion of known ranges for protected freshwater molluscs, there is almost no prospect of removing these species from federal protection.

In addition to this species-level approach to restoration and recovery of rare mussels and their ecosystems, the National Native Mussel Conservation Committee (1998) prepared a national strategy to conserve all native freshwater mussels in the United States. A draft of the plan, prepared by Biggins *et al.* (1996), was adopted by the national committee, composed of representatives from federal agencies, state fish and wildlife departments, and the commercial shell industry. The overall goal of this conservation

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plan was to conserve our nation's native mussel fauna and ensure that the ecological, economic, and biological values of this fauna to ecosystems and human society are maintained at a sustainable level. This umbrella document identified research, management, and conservation needs for the fauna; increased government and public awareness of their plight and habitat protection needs; and promoted cooperative partnerships at all governmental levels, non-governmental organizations, and local municipalities to protect and restore both mussels and environmental quality to river systems.

CONSERVATION IN NORTH AMERICA

In 1996, the wildlife management agencies of the United States, Canada, and Mexico entered into a Memorandum of Understanding (MOU) to establish the Canada/Mexico/United States Trilateral Committee for Wildlife and Ecosystem Conservation and Management. This cooperative agreement brought all three nations together for the first time to focus on continental needs for the conservation and management of wildlife resources and their management across national borders. The Trilateral Committee promotes and facilitates cooperation among the national agencies in virtual, mutually beneficial projects and programs to conserve wildlife, plants, biological diversity and ecosystems. Annual meetings are convened with delegations from each country, to address topics ranging from ongoing research projects and improvements in law enforcement, to species distributions and data base management. There are presently seven working groups that report to the three directors of the wildlife agencies; shared species, law enforcement, biodiversity information, sustainable use, migratory birds and wetlands, wildlife without borders, and the executive committee. Beyond the bilateral treaty framework of previous decades, this MOU now provides a mechanism for the three North American countries to discuss all wildlife-related issues, including molluscs.

PROPAGATION POLICY

In September 2000, the U.S. Fish and Wildlife Service and the National Marine Fisheries Service published a new policy regarding the controlled propagation of species protected under the Endangered Species Act (Federal Register 65(183):56916-56922). The policy provides the following guidelines in the application of controlled propagation: prevent the extinction of listed taxa, develop propagation methods and technology, maintain genetic diversity, sustain refugia populations, provide progeny for establishing new populations, and supplement extant populations to facilitate recovery of the listed species. Because the intent of this Act is to provide a means to conserve the ecosystems inhabited by listed species, the first priority is to recover populations in their natural habitats without resorting to controlled propagation. If such propagation becomes necessary, it must be conducted in a manner to preserve genetic and ecological integrity of the species and minimize risks to extant populations. The policy goes on to promote adherence to various aspects of propagation activities, in keeping with standard protocols employed by the American Zoo and Aquarium Association (AZA) for animals, Center for Plant Conservation (CPC) for plants, and other federal agency guidelines in animal husbandry. Although the controlled propagation of mussels falls under this policy, there are aspects of molluscan reproduction and rearing that do not fit the standard vertebrate model in the previously mentioned protocols. Therefore some leniency and independence has been allowed to accommodate the quirks of this taxon, relative to genetic and risk management plans.

GENETIC CONSIDERATIONS

The relevancy of conservation genetics has been scrutinized in at least three contexts: assessing population viability, identifying biological units and inferring phylogenetic relationships (Goldstein *et al.* 1999). To anticipate the need for maintaining the genetic integrity of mussel populations, a group of mussel biologists and conservation geneticists was queried by the U. S. Fish and Wildlife Service, in order to draft guidelines to reduce the prospect of unnecessary and potentially deleterious mixing of genetically distinct populations. For population augmentation, defined as enhancing recruitment within an existing population, juveniles should be propagated from brood stock obtained from the recipient population. If the recipient population is inadequate in size to provide gravid females, then the following hierarchy of brood stock selection based on geographic distance is to be followed: another population in the same river system; a population in an adjacent river system; a population in a distant river system; or the only population of sufficient size to provide brood stock for propagation of juveniles.

Brooding females are selected from the most proximate populations to retain the distribution of characteristics that distinguish remnant populations. Presently, augmentation of populations falls into all four categories. The extreme scenario conserns efforts to propagate the endangered tan riffleshell (*Epioblasma florentina walkeri*), now restricted presumably to a single reproducing population of 2,000 adults within a 1 km reach of Indian Creek, Tazewell County, Virginia (Rogers *et al.* in press).

Reintroduction, the return of individuals to historic habitat, should follow the same guidelines when selecting the donor population. In addition, a reintroduction or augmentation plan should consider re-establishment near the centre of historic range. With current evidence tending to support global climate change (Graham & Grim 1990), such a strategy should optimize the prospect of success and persistence of the population.

Supportive propagation can result in a genetic tradeoff, where a gain in total production of juvenile mussels is offset by a simultaneous reduction in effective population size and enhanced loss of genetic variability (Ryman & Lakrie 1990). Promoting unequal contributions by resident females and males to subsequent generations is minimized by selecting different females each year for production of progeny. By not retaining gravid females (and males) as brood stock for repeated reproduction, we minimize the detrimental genetic effects recorded in captive populations such as inbreeding, genetic defects, founder effect, or domestication selection. Depletion of genetic variability is particularly problematic when absolute population size is small.

The maintenance of several isolated populations can actually increase overall genetic diversity because significant allelic differences due to local adaptations can be preserved. Also the random effects of genetic drift will tend to fix different alleles in different populations, so that overall diversity may be preserved among populations (Chesser 1983). For many mussel species, genetic isolates are a given rather than an option, elevating adequate population size as the primary criterion for survival.

WHAT SHOULD WE PROTECT?

Genetic research in better-studied freshwater faunal groups such as fishes indicates that differences between population genomes may challenge the biological species concept and muddy the waters to define units of protection. Proponents of the phylogenetic species concept attempt to recognize minimal units that can be recognized phylogenetically within a nested hierarchy (Davis & Nixon 1992). Regardless of which classification vector is pursued, freshwater mussels fit the metapopulation paradigm fairly well, with host fish usually providing the mechanism for genetic interchange between river and tributary, and among tributaries. The construction of dams, habitat destruction, and water pollution has effectively blocked gene flow among units of the metapopulations in many river systems, essentially creating isolated populations with uncertain viabilities. For management agencies reproductively isolated populations can be treated as management units, recognized by significant divergence of allele frequencies at nuclear or mitochondria loci (Moritz 1994). Conservation and monitoring of these discrete, closed populations is tractable. More difficult to define is the evolutionarily significant unit (ESU), describing a population with a genome of novel evolutionary potential because of isolation or divergence in genotypic or phenotypic traits. Waples (1991) defined an ESU as a population essentially isolated reproductively from other conspecific populations, and which represents an important component in the evolutionary legacy of the species. As noted by Bowen (1998), the first aspect of the definition can be explained and defended by the concept of allopatric speciation, whereas the second aspect is difficult to define. The former aspect can be readily explained by genetic models that involve genetic drift, natural selection, mutation and other factors influencing isolated populations. In small populations, simulation modeling has shown that genetic drift is the dominant factor regulating the loss of genetic variation (Lacy 1987). Conversely, the latter evolutionary legacy aspect has no corresponding model to anticipate traits of evolutionary units. Bowen (1998) presents the biological uncertainty very succinctly when he states:

> *"in applying the principles of ESUs, conservationists probe one of the darkest chasms in evolutionary biology, embodied by the question – how do new organisms arise?"*

There is a perceived need to protect locally adapted gene pools, but how much character change is evolutionarily significant? Goldstein *et al.* (1999) stated that evolutionary significance is essentially a subjective anticipation of an unknowable future and is too vaguely articulated to be applicable in specific conservation programs or as a proximate criterion for recovery objectives. Application of the concept of evolutionary potential (prospect for change) is a conundrum, as populations undergo varying degrees of change. If based on allele frequencies, themselves used to identify populations in need of protection, then this leads to a shell game of baseline data where the justification for diagnostic criteria requires that the criteria themselves change (Goldstein *et al.* 1999).

Without consensus on how such factors as isolation, selection, genetic draft, and others cooperate to produce organismal evolution or speciation, then how can we defend ESUs to resource managers? Because processes that contribute to speciation are more theoretical than factual, an alternative approach, different from phylogenetic distinction or novelty, is more acceptable in the conservation plans of resource agencies. There is also a potentially significant danger in promoting ESUs as a currency for defining protection of populations, from a biological and managerial perspective. Differences in allele frequency can occur so quickly, even as a result of anthropogenic environmental change (Dillon 1988), that the credibility of protection for evolution's sake is lost. Some authors seemingly de-emphasize the phylogenetic species concept for conservation purposes because it requires too much and unreasonable levels of protection (Avise 1989; Moritz 1994). If scientists are unable to establish objective and reasonable criteria for ESUs, then administrators and managers will proceed with quantifiable objectives in their time frame of years and decades, rather than the centuries and millennia for fulfillment of the vague species concept.

RECOVERY IN THE TENNESSEE RIVER

Our propagation work occurs within a cornucopia of species richness which, in spite of Tennessee Valley Authority dams, has sustained high diversity upstream of the chain of impoundments on the river and its major tributaries. To describe the extent of our restoration goal, 91 species are recorded historically in the Tennessee River system; of those, roughly 50 species occupy our work area in southwestern Virginia and northeastern Tennessee. To complicate matters, several taxonomic questions remain to be answered on possible species complexes, intra-specific differences in morphology among populations, and the degree of genetic mixing within wide-ranging species. One day we may know enough about the reproductive modes, population biology, and demographic traits of self-sustaining populations to be able to apply population viability analysis (PVA) models to provide a rough estimate of how many mussels and how much habitat is needed to insure a healthy population over a projected time frame (Thomas 1990). Malacologists operate in a model-sufficient but data-deficient science, awaiting definitive studies to provide keystone data sets to substitute for numeric assumptions in modeling efforts. Our rudimentary concept of a life table for mussels is synonymous with a list of longevities for various species, not age-specific survival and fecundity rates as in vertebrate populations. There is no magical population size or mean density that guarantees the persistence of mussel populations, because stochastic events, natural catastrophes and the unusual life cycle provide unpredictable elements to long-term viability. Therefore, we limp along as empiricists, using personal knowledge, shared experiences and complementary research sciences to guide our conservation programs.

To implement the objectives specified in recovery plans and the national strategy document, we implemented a 10-year propagation program at Virginia Tech to test and refine previous but mostly anecdotal studies of propagation attempts in the early 1900's (Lefevre & Curtis 1910; Isely 1911; Lefevre & Curtis 1912; Howard 1914; Corwin 1920; Coker *et al.* 1921; Howard 1922). Beginning in the 1980's, a cadre of graduate students launched into studies on the life history (Zale & Neves 1982; Neves & Widlak 1988; Bruenderman & Neves 1993; Yeager *et al.* 1994; Hove & Neves 1994; Michaelson & Neves 1995) and population biology (Neves & Widlak 1987, 1988; Neves & Moyer 1988) of various species principally in the upper Tennessee River system. With a sufficient understanding of mussel biology and reproduction of a suite of species, a new directive began; namely, to develop the techniques and technology to produce, culture, and release juvenile mussels.

Various methods and laboratory conditions to maintain and rear juvenile mussels in captivity were tested to include aspects of water quality, substratum, food, flow, light and other environmental factors thought to be important in the early life history of juvenile mussels (Gatenby *et al.* 1996, 1997; O'Beirn *et al.* 1998; Gatenby 2000; Henley *et al.* 2001). Much of the research has been empirical and sequential, based on repetitive trials with various species. The rainbow mussel (*Villosa iris*) and wavyrayed lampmussel (*Lampsilis fasciola*), which are sympatric with numerous endangered species, have served as our surrogates for endangered species, so that our likelihood of success with rare species is enhanced.

Although the publications provide adequate descriptions and results of experiments with test species, there are also completed experiments that were not publishable because of excessive mortality, unexpected events, predation, algae blooms, and a suite of unexpected events. These experiments did not meet the rigours of peer review, but they have provided a wealth of learning and experience in progressing toward the goal of juvenile mussel propagation for any target species. The unpublished literature on freshwater mussels, bound in theses, dissertations and final reports gathering dust on the shelves of prestigious institutions, is a treasure trove of experiences, but unknown to newcomers interested in increasing their chances for success within a reasonable time frame. As with fish culture, there is no substitute for an experienced hatchery manager; someone with academic training and a wealth of empirical knowledge to know when environmental conditions and animals 'look' good and when they don't. That also needs to be the goal of mussel hatchery managers; to learn the essentials of mussel biology and culture and then closely monitor culture trials to gain that level of experience and skill to complement what is provided through scientific literature.

MAKING MUSSELS

The technology and techniques required to propagate mussels are sufficiently developed now so that interested biologists working at academic institutions, research laboratories, fish hatcheries, and aquatic field stations can delve into the culture of resident species. Briefly, the production of juvenile mussels begins by collecting gravid female mussels from the wild or a holding facility, and host fishes suitable for that species. In the laboratory, glochidia in the female are flushed out by marsupial puncture along the ventral margin using a hypodermic needle and syringe filled with water. This non-lethal method allows the return of spent females unharmed. These glochidia are then introduced into a tank holding the host fish, with aeration to keep the water agitated and promote attachment of glochidia to the gills or fins of the fish. After 0.5-1 hour of exposure, the infested fish are moved to large aquaria where glochidia begin the transformation process. Once these newly metamorphosed juveniles drop from the fish host, usually 2-3 weeks depending on water temperature, they are siphoned from aquaria and placed in sediment trays for culture in recirculating artificial stream systems (Henley *et al.* 2001). We have recorded significant differences in survival and mortality among species, due principally to substrate composition. Some juveniles do well in fine sediment, whereas juveniles of other species (typically riffle swelling) do poorly. Thus, there is no single culture system that can be used for all species. Juveniles are fed algae cultured in large Kalwall tubes, and obtain some nutrition from the microflora within the sediment layer. Juveniles are fed periodically such that an algal cell density of roughly 30,000 cells/ml is sustained in the water column. Settled algae become the principle diet component of pedal-feeding juvenile mussels (Yeager *et al.* 1994), and planktonic algae sustain the juveniles that become proficient as filter-feeders after about 60 days. Food quantity and quality are critical for good survival and growth of the juveniles, and we have found that *Scenedesmus*, *Nanochloropsis*, and *Neochloris* are genera with species suitable for the diet of juvenile mussels. From a pragmatic perspective, we recommend that locally dominant species of algae should be tested for nutritional quality, to perhaps avoid the labour and expense of monocultures or rigorous conditions to maintain uncontaminated cultures. Another option is to employ the culture methods used in China; namely, to direct the flow of fertilized pond water through channels into holding units containing sediment and juvenile mussels. This latter system works well for the environmentally tolerant, fast-growing species used for pearl culture such as *Hyriopsis cummingi* and *Cristaria plicata* but may be less suitable for sensitive species (Dan *et al.* 2001). The geographic location, water resources, and available facilities should be considered in the development of a propagation plan tailored to meet the needs of target species.

JUVENILE PRODUCTION

Our first release of endangered, juvenile mussels in the United States occurred in fall 1997 in the Hiawassee River, Tennessee. A batch of endangered tan riffleshells

TABLE 1
Endangered juvenile mussels released in Tennessee and Virginia in 1998-2001.

Mussel Species	**Release Sites**	**Number Released**
oyster mussel	Clinch River	75,604
	Powell River	120,475
combshell	Clinch River	12,701
	Powell River	22,111
fanshell	Clinch River	8,014
tan riffleshell	Hiwassee River	7,312
	Indian Creek	2,113
purple bean	Clinch River	138
	Indian Creek	5,034
snuffbox	Clinch River	2,146
	Powell River	1,970
dromedary	Clinch River	851
birdwing pearlymussel	Clinch River	44
crackling pearlymussel	Clinch River	5
Total number released		**258,518**

(*Epioblasma florentina walkeri*), 2-3 months of age, were released as surviving progeny from culture experiments. Using our indoor recirculating culture systems beginning in 1998, we have produced, cultured, and released roughly 260,000 endangered juvenile mussels of 9 species into rivers of Tennessee and Virginia (Table 1). These juveniles were released principally at sites upstream of existing populations to expand species ranges and at sites to augment reproduction of resident populations. Site selections were based on recommendations provided by a team of federal and state biologists familiar with ambient water quality, fish populations, substrate conditions, and point and non-point source discharges in the targeted rivers. We projected that an evaluation of the juvenile releases conducted in 1998 and 1999 would occur in 2002, based on anticipated growth rates of the juveniles , vulnerability to quadrat sampling, and dispersal at sites of release. As judged by preliminary experiments with the release of young juveniles in a hatchery raceway fed directly by river water (Hanlon 2000), we feel confident that we will recover progeny from our laboratory-reared cohorts.

PROPAGATION EFFORTS IN NORTH AMERICA

In order to provide an overview of other endangered mollusc propagation work in North America, I contacted biologists known to be involved with propagation and queried other mussel biologists on the electronic bulletin board specializing in freshwater mussel conservation (UNIO list-server). There are seven other facilities in the U.S.

TABLE 2
Recovery work on endangered and rare molluscs at other locations in the United States and Canada

State/Province	Facility	Species	Recovery Work
Missouri	Southwest Missouri State University	Fat pocketbook Pink mucket	Host fish identifications Release of juveniles
Wisconsin	Genoa National Fish Hatchery	Higgins' eye	Release of juveniles Release of infested fish
Minnesota	University of Minnesota	Winged mapleleaf	Host fish identifications Release of juveniles
Arkansas	Arkansas State University	Fat pocketbook	Host fish identifications Release of juveniles
Tennessee	Tennessee Tech	Littlewing Pink mucket Cumberland bean	Culture of juveniles Host fish identifications
Georgia	Southeast Aquatic Research Institute	Finelined pocketbook Alabama moccasinshell Interrupted rocksnail Plicate rocksnail	Release of juveniles Snail culture
Ontario	University of Guelph	Rayed bean Wavyrayed lampmussel Northern riffleshell Salamander mussel	Host fish identifications Recovery plan preparation

and one in Canada currently developing or implementing propagation techniques for a suite of species protected in their locale (Table 2) but I know of no efforts underway in Mexico to propagate rare species in that country. A description of the propagation work and target species at each facility is summarized below, beginning with the single project in Canada.

Canada

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is responsible for determining the national status of wild species, subspecies, varieties, and nationally significant populations at risk in Canada. COSEWIC is composed of representatives from each provincial and territorial government wildlife agency, four federal agencies, three national non-governmental agencies, and the co-chairs of the species specialist groups. Thus, input on species protection is truly a national effort and concern. The list of molluscs protected in Canada includes the following freshwater mussel species: the extirpated dwarf wedgemussel (*Alasmidonta heterodon*) and the endangered rayed bean (*Villosa fabalis*), wavyrayed lampmussel (*Lampsilis fasciola*), northern riffleshell (*Epioblasma torulosa rangiana*), and salamander mussel (*Simpsonaias ambigua*).

The only significant work underway in Canada to propagate endangered mussels is being conducted by Dr. Gerry Mackie at the University of Guelph in Ontario. Primary objectives of his project are initially to identify resident hosts for the endangered species in the Sydenham River; *V. fabalis*, *L. fasciola*, *E. t. rangiana* and *S. ambigua*. The Sydenham River supports the most speciose and productive mussel communities historically known in Ontario. The rayed bean, northern riffleshell, and salamander mussel presently occur in the river, and the wavy rayed lampmussel was an historic resident. A laboratory at the University of Guelph has been set up to conduct this research and to serve as a unionid artificial culture system for rearing juveniles of species at risk. A Sydenham River Recovery Team is presently drafting a recovery plan, to include unionids and other aquatic fauna of significance to the river and to Canada.

Missouri

The propagation of endangered mussels in Missouri is being conducted at Southwest Missouri State University under the supervision of Dr. Chris Barnhart. Fish hosts were identified for the fat pocketbook (*Potamilus capax*) and pink mucket (*Lampsilis abrupta*) in 1998-1999. Gravid females of the candidate Neosho mucket (*Lampsilis rafinesqueana*) from the Fall River in Kansas were used to produce approximately 52,000 juveniles for release at sites in the Fall River Wildlife Refuge and the Verdigis River, Kansas. In 2001, roughly 1600 juveniles of the pink mucket were released into the Meramec River, Missouri.

Wisconsin

The Genoa National Fish Hatchery in LaCrosse modified a section of their hatchery building in 1999 for the purpose of producing and culturing juveniles of the endangered Higgins' eye mussel (*Lampsilis higginsii*). Infestations of glochidia on fish hosts were successful, and 3,750 juveniles were released into the Wisconsin River in 2000. In 2001, 3,900 glochidia-infested fish hosts were released at Mississippi River sites in Wisconsin, Minnesota, and Iowa. An estimated 150,000 glochidia on these fish were distributed equally among the three states. An additional 2,500 juveniles were released in Wisconsin waters and 2,500 juveniles are planned for release in Minnesota waters.

Minnesota

Host fish studies are underway at the University of Minnesota, supervised by Mark Hove, to identify suitable hosts for the endangered winged mapleleaf (*Quadrula fragosa*) now reduced to the upper Mississippi River drainage. Successful transformation resulted in 35 juvenile winged mapleleafs being released into the St. Croix River in 2001. Plans are being made to obtain funding for construction of a freshwater mussel propagation facility along the St. Croix River where two endangered species, winged mapleleaf and Higgins' eye mussel (*L. higginsii*) reside.

Arkansas

In spring 2001, 4,400 juveniles of the endangered fat pocketbook (*P. capax*) were released into Middle Ditch at Big Lake National Wildlife Refuge. The mussels were produced at Southwest Missouri State University and transported to the release site in the St. Francis River basin. Host fish identifications are being conducted by Dr. Jerry Farris at Arkansas State University for several endangered species, and the State of Arkansas is preparing a facility to attempt propagation of juveniles in 2002.

Tennessee

For roughly the last 10 years, conservation work by Dr. Jim Layzer at Tennessee Tech has focused on the identification of host fishes for a suite of endangered species in the state. Graduate student projects have also made use of raceways at state hatcheries to determine whether they could be seeded with young juveniles and reared for several years. Six common mussel species have been reared successfully in the raceways, and juveniles 2-4 years of age have been released into various rivers in eastern Tennessee. Although no endangered juveniles have yet been produced and reared for release, the Tennessee Cooperative Fishery Research Unit has propagation projects planned for the next few years.

Georgia

The field station of the Southeast Aquatic Research Institute under the direction of Dr. Paul Johnson, has projects on both mussels and snails in Georgia and Tennessee. In 2000, the facility released 475 *Lampsilis altilis* into the Conasauga River, Georgia, and 390 *L. altilis* into theTennessee portion of that river. In 2001, 50 *Medionidus acutissimus* were released into Holly Creek, Georgia. The field station is being expanded to allow greater production potential for mussels and for culturing various species of rare snails, such as *Leptoxis downiei* and *L. plicata*. This is the only propagation facility with a recovery program for rare freshwater snails, the most extinction-prone taxon in the Southeastern U.S.

Virginia

In addition to our work at Virginia Tech, the State of Virginia is developing a mussel propagation facility at its Buller State Fish Hatchery, supervised by Brian Watson. Water from the South Fork Holston River is being diverted through a pond, to raise water temperature, and then channeled through concrete raceways with substratum and captive mussels. Preliminary results to rear juvenile mussels in the raceways are promising (Hanlon 2000), and this portion of the hatchery is to be renovated for the long-term holding of endangered adult mussels and the rearing of juveniles to a size suitable for release into rivers of Southwest Virginia.

Other States

Fledgling efforts are being initiated in the states of North Carolina, New Hampshire, Ohio, West Virginia, Mississippi and Alabama to conduct life history studies on resident species and to explore the possibility of propagation at hatcheries, university laboratories, or other governmental facilities. In the last two years, there has been a groundswell of interest in reversing the downward trend in mussel populations through the Midwest and Eastern United States. Successful propagation is now viewed as a feasible and mandatory activity if further extirpations and extinctions are to be prevented. Mussel fever, manifested by symptoms of hopefulness, optimism and anticipation, is spreading through the community of freshwater biologists who feel a surge of positiveness for this beleaguered fauna.

CONCLUSION

The first generation of mussel culturists is being trained now at a few academic institutions in the United States. While one battery of conservationists focuses on the improvement of habitat through legislation, governmental programs, and cooperative agreements with private landowners, another set will hone their skills on production technology and improving the methods for culture of endangered juveniles. For too long have we sat idly by, watching our world-class biodiversity decline and disappear for benign neglect. We are rapidly approaching the time when national aquatic propagation facilities, to replace narrowly focused fish hatcheries, will play a key role in the future existence of rare species and their sustainability in nature. Comparing these facilities and their utility with salmon hatcheries is like comparing apple snails to orange roughey. The mission of these aquatic conservation centres will be to establish self-sustaining, wild populations of rare vertebrates and invertebrates, such that no sustained augmentation will be needed. The tragedy of salmon restoration in the Pacific Northwest stems from their exploitation and economics having priority over conservation (Meffe 1992). Fortunately 99% of the biological diversity that biologists propose to conserve are not shot, netted, hooked or somehow exploited for economic or recreational gain. The balance of nature has reverted to becoming a placation within society; namely, to allow all species to survive somewhere in their defined range so that ecological processes and ecosystems can proceed unfettered by the myopic perceptions of the dominant human species.

The harvest is plenty but the workers are few. That biblical paradigm is apropos for our current inertia to reverse the trends of habitat degradation and losses of populations at all spatial scales. My hope is that international recognition of declining freshwater mollusc populations will initiate pro-active conservation efforts before another spasm of extinctions sweeps across river systems, as a stigma on this new century that touts ecological awareness and a strong conservation ethic.

REFERENCES

AVISE J.C. 1989 A role for molecular genetics in the recognition and conservation of endangered species *Trends in Ecology and Evolution* **4**: 279-281.

BIGGINS R. G., NEVES R. J. & DOHNER C. K. 1996 *National strategy for the conservation of native freshwater mussels* Draft report, U.S. Fish and Wildlife Service, Asheville, NC. 31 pp.

BOWEN B. W. 1998. What is wrong with ESUs?: the gap between evolutionary theory and conservation principles *Journal of Shellfish Research* **17**: 1355-1358.

BRUENDERMAN S. A. & NEVES R. J. 1993. Life history of the endangered fine-rayed pigtoe Fusconaia cuneolus (Bivalvia: Unionidae) in the Clinch River, Virginia *American Malacological Bulletin* **10**: 83-91.

CHESSER R. K. 1983 Isolation by distance: relationship to the management of genetic resources. In: Schonewald-Cox, C. M., Chambers, S. M., MacBryde, B., Thomas, W. L. (Eds.) *Genetics and Conservation: A Reference for Managing Wild Plant and Animal Populations* Benjamin/Cummins, NY. pp. 67-77.

COKER R. E., SHIRA A. F., CLARK H. W. & HOWARD A. D. 1921 Natural history and propagation of fresh-water mussels *Bulletin of the U.S. Bureau of Fisheries* **37**: 75-181.

CORWIN R. S. 1920 Raising freshwater mussels in enclosures *Transactions of the American Fisheries Society* **49**: 81-84.

COMMITTEE ON THE STATUS OF ENDANGERED WILDLIFE IN CANADA (COSEWIC). 2000 *Canadian species at risk* COSEWIC Secretariat, Environment Canada, Ottawa, ON.

DAN H., MAZID M. A. & HUSSAIN M. G. 2001 *Freshwater pearl culture: principles and techniques* Bangladesh Fisheries Research Institute, Mymensingh, Bangladesh

DAVIS J. I. & NIXON K. C. 1992 Populations, genetic variation, and the delimitation of phylogenetic species *Systematic Biology* **41**: 421-435.

DILLON R. T., JR. 1988 Minor human disturbance influences biochemical variation in a population of freshwater snails *Biological Conservation* **43**: 137-144.

GATENBY C. R., NEVES R. J. & PARKER B. C. 1996 Influence of sediment and algal food on cultured juvenile freshwater mussels *Journal of the North American Benthological Society* **15**: 597-609.

GATENBY C. R., PARKER B. C. & NEVES R. J. 1997 Growth and survival of juvenile rainbow mussels, *Villosa iris* (Bivalvia:Unionidae), reared on algal diets and sediment *American Malacological Bulletin* **14**: 57-66.

GATENBY C. R. 2000 *A study of holding conditions, feed ration, and algal foods for the captive care of freshwater mussels* Ph.D. dissertation, Virginia Tech, Blacksburg, VA. 238 pp.

GOLDSTEIN P. Z., DESALLE R. AMATO G. & VOGLER A. P. 2000 Conservation genetics at the species boundary *Conservation Biology* **14**: 120-131.

GRAHAM R. W. & GRIM E. C. 1990 Effects of global climate change on the patterns of terrestrial biological communities *Trends in Ecology and Evolution* **5**: 269-322.

HANLON S. D. 2000 *Release of juvenile mussels into a fish hatchery raceway: a comparison of techniques* M.S. Thesis, Virginia Tech, Blacksburg, VA.

HENLEY W. F., ZIMMERMAN L. L., NEVES R. J. & KIDD M. R. 2001 Design and evaluation of recirculating water systems for maintenance and propagation of freshwater mussels *North American Journal of Aquaculture* **63**: 144-155.

HOVE M. C. & NEVES R. J. 1994 Life history of the endangered James spinymussel *Pleurobema collina* (Conrad, 1837) (Mollusca:Unionidae) *American Malacological Bulletin* **11**: 29-40.

HOWARD A. D. 1914 A new record in rearing fresh-water mussels. *Transactions of the American Fisheries Society* **44**: 45-47.

HOWARD A. D. 1922 Experiments in the culture of fresh-water mussels *Bulletin of the U.S. Bureau of Fisheries* 38: 63-89.

ISELY F. B. 1911 Preliminary note on the ecology of the early juvenile life of the Unionidae *Biological Bulletin* **20**: 77-80.

LACY R. C. 1987 Loss of genetic diversity from managed populations: interacting effects of drift, mutation, immigration, selection, and population subdivision *Conservation Biology* **1**: 143-158.

LEFEVRE G. & CURTIS W. C. 1910 Experiments in the artificial propagation of fresh-water mussels. *Bulletin of the U.S. Bureau of Fisheries* **28**: 615-626.

LEFEVRE G. & CURTIS W. C. 1912 Studies on the reproduction and artificial propagation of fresh-water mussels *Bulletin of the United States Bureau of Fisheries* **30**: 105-201.

MEFFE G. K. 1992 Techno-arrogance and halfway technologies: salmon hatcheries on the Pacific Coast of North America *Conservation Biology* **6**: 350-354.

MICHAELSON D. & NEVES R. J. 1995 Life history and habitat of the endangered dwarf wedgemussel *Alasmidonta heterodon* (Bivalvia:Unionidae) *Journal of the North American Benthological Society* **14**: 324-340.

MORITZ C. 1994 Defining evolutionarily significant units for conservation *Trends in Ecology and Evolution* **9**: 373-375.

NATIONAL NATIVE MUSSEL CONSERVATION COMMITTEE 1998 National strategy for the conservation of native freshwater mussels *Journal of Shellfish Research* **17**: 1419-1428.

NEVES R. J. & MOYER S. N. 1988 Evolution of techniques for age determination of freshwater mussels (Unionidae) *American Malacological Bulletin* **6**: 179-188.

NEVES R. J. & WIDLAK J. C. 1987 Habitat ecology of juvenile freshwater mussels (Bivalvia: Unionidae) in a headwater stream in Virginia *American Malacolgical Bulletin* **5**: 1-7.

NEVES R. J. & WIDLAK J. C. 1988. Occurrence of glochidia in stream drift and on fishes of the Upper North Fork Holston River, Virginia. *American Midland Naturalist* **119:** 111-120

O'BEIRN F. X., NEVES R. J. & STEG M. B. 1998 Survival and growth of juvenile freshwater mussels (Unionidae) in a recirculating aquaculture system *American Malacological Bulletin* **14**: 165-171.

ROGERS S. O., WATSON B. T. & NEVES R. J. In press. Life history and population biology of the endangered tan riffleshell (*Epioblasma florentina walkeri*) (Bivalvia:Unionidae) *Journal of the North American Benthological Society* **20**: 582-594.

RYMAN N. & LAIKRE L. 1991 Effects of supportive breeding on the genetically effective population size *Conservation Biology* **5**: 325-329.

THOMAS C. D. 1990 What do real population dynamics tell us about minimum viable population sizes? *Conservation Biology* **4**: 324-327.

WAPLES R. S. 1991 Pacific salmon *Oncorhynchus* spp., and the definition of "species" under the endangered species act *Marine Fisheries Review* **53** :11-22

YEAGER M. M., CHERRY D. S. & NEVES R. J. 1994 Feeding and burrowing behaviors of juvenile rainbow mussels *Villosa iris* (Bivalvia:Unionidae) *Journal of the North American Benthological Society* **13** :217-222.

ZALE A.V. & NEVES R. J. 1982 Fish hosts of four species of lampsiline mussels (Mollusca:Unionidae) in Big Moccasin Creek, Virginia *Canadian Journal of Zoology* **60**: 2535-2542.