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Biological Feasibility of Freshwater Mussel and Pearl Culture In Gulf Coast States

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Production of freshwater pearls from mussels has been shown to be a viable enterprise in Tennessee, and the freshwater environments and mussel species in Gulf Coast states provide ample resources for this fledgling industry to expand. Mussel species such as the washboard (*Megalonaias nervosa*), threeridge (*Amblema plicata*), and others in rivers and reservoirs are capable of producing quality pearls once the implantation technique for pearl formation becomes more widely known. Methods for the propagation of freshwater mussels with recirculating aquaculture systems have been developed recently to allow culture of rare or commercial species. Wild-caught mussels could be replaced by cultured juveniles, such that regulated harvest in state waters would have no adverse effect on native populations. The production of quality pearls of various shapes and colors provides the economic impetus to establish a pilot pearl project on the Gulf Coast.

The freshwater mussel fauna in the southeastern United States is very diverse because of the wide variety of lotic and lentic environments. Most tributaries and main stem rivers in the Interior Basin and along the Gulf and South Atlantic coasts are rich in mussel species. Distinct faunal assemblages are the result of historical and regional differences in physiography, water chemistry, and other lotic factors that interact to create distinct assemblages and a high degree of endemism in these river basins (Heard, 1970). However, a plethora of natural and anthropogenic factors have affected species richness in these rivers, causing significant declines and extirpations. The Endangered Species Act of 1973 and subsequent amendments provide legal protection for those species considered to be endangered or threatened throughout all or a significant portion of their range. A total of 69 of the nearly 300 species and subspecies of freshwater mussels in the United States are federally listed as endangered or threatened, and most of these occur in the Southeast. Between 34% and 71% of all species are considered to be imperiled, defined to include species that are endangered, threatened, or of special concern (Williams et al., 1993). The decline of mussel species is evident in coastal rivers as well as Interior Basin watersheds (Neves et al., 1997).

The impetus to help recover these imperiled species is federal laws that have specified individual recovery plans, which has led to the development of propagation techniques for these endangered species but that are also applicable to all freshwater mussel species. The "Gulf Pearls Project" of the Mississippi–Alabama Sea Grant Consortium has been established to examine the conservation biology, fisheries ecology, and sustainable economic use of freshwater mussels and marine mollusks for pearl production along the Gulf Coast. Thus, the propagation and culture of commercial species of freshwater mussels, suitable for use in pearl culture, are important aspects of this project. In this paper, I provide a brief history of freshwater mussel harvest and propagation efforts and summarize recent advancements in culturing technology.

HISTORY OF MUSSEL HARVEST

The exploitation of freshwater mussel shells in the United States for the purpose of making pearl buttons dates back to at least 1800 (Coker, 1919). However, an industry for button making did not develop until John Boepple set up a small business along the Mississippi River in 1891 (Claassen, 1994). At about that time, the American garment industry began commercial production of clothing, and a need arose for domestically produced white buttons to replace expensive pearl buttons taken from the ocean. From humble beginnings in Muscatine, IA, in 1891, the pearl button industry became a booming enterprise, with automated factories established along the entire Mississippi River and its major tributaries. Because of the requirements of availability, white nacre, and shell quality, only a select group of mussel species was harvested by a variety of collection techniques such as clam tongs, pitchforks, rakes, and dredges. Both shallow and deep water areas of lakes and rivers were exploited for the target species to such an extent that a "shell rush" swept through the Mississippi Riv-

er Valley at the turn of the century (Claassen, 1994).

Harvested mussels were taken to shell camps and steamed open in large vats, and the shells were taken to factories to be cut, drilled, polished, and packaged for shipment to garment factories in the eastern United States. After the cookout stage, musselers sifted through the cooking vats and pressed through the meats in search of natural pearls. The presence of natural pearls in freshwater mussels was known to both Native Americans and early European explorers (Kunz and Stevenson, 1908), but the quest for quality pearls intensified as a result of the commercial harvest of shells and the recovery of pearls in "cooked out" mussels (Kunz, 1898). The button business and pearl hunting boomed until the early 1940s, when the discovery of plastics put an end to the need for mussel shells.

Cultured Pearls

While the button industry was booming in the United States, Mikimoto and associates in Japan were perfecting techniques to produce spherical, cultured pearls with implants of bead nuclei milled from the shells of freshwater mussels. That technique was perfected in the 1940s, and by the early 1950s, the United States became the exclusive supplier of freshwater mussel shell to produce beads for Japan's cultured saltwater pearl industry. That industry has now expanded into other Asian countries and the South Pacific, maintaining a demand for mussel shells to provide nuclei for pearl farms that use a variety of oyster species. Between 1992 and 1997, annual exports of shell from the United States have ranged from 665 to 3,132 metric tons (Neves, 1999). Once beads are produced and implanted, pearl formation by accretion is analogous to the mechanism of shell formation and repair in bivalves (Panha and Phansuwan, 1996). However, much of the descriptive science and techniques for pearl culture are guarded as proprietary secrets. Today, the cultured pearl industry provides 230,000 jobs and generates retail sales approaching $3 billion worldwide (Hubbs and Jones, 1996). Shells gathered in U.S. rivers and reservoirs provide the bulk of nuclei for this international enterprise.

Lesser known, but more affordable, freshwater pearls of various shapes have also become available on the world market. Early freshwater pearls came from Lake Biwa, Japan, but water pollution essentially eliminated production from this lake. Most of the small, rice-shaped pearls are produced in China with two species of freshwater mussels, *Hyriopsis cumingi* and *Cristaria plicata*. These large mussel species grow rapidly, exhibit lustrous nacre, and have been used for centuries as a source of pearls and mother-of-pearl. In the last two decades, a profusion of pearl farms and modern techniques in China have begun to saturate the market with these smaller pearls. By the mid-1990s, techniques to produce large semiround and round pearls had been developed, resulting in improved quality and a quantity suitable for the international market. Chinese freshwater pearls are nonnucleated, unlike cultured marine pearls. The pearls are produced by implanting pieces of mantle tissue from a donor mussel into the mantle or between mantle and shell of a recipient mussel, resulting in the formation of natural pearls. Freshwater pearls are becoming more widely accepted, and, because of their affordability and beauty, the once discrete freshwater and saltwater pearl markets have begun to merge.

The pioneering work of American Pearl Company (APC) in Tennessee has set the standard for an expanded pearl industry in the United States. In 1963, APC began experiments to nucleate various species of mussels with appropriate shell qualities to produce quality pearls. Founder and chief executive officer John Latendresse adapted Japanese techniques for pearl culture to a few mussel species in Tennessee. After both implants of shell nuclei and a mantle tissue nucleating process were tested, a protocol was gradually developed to produce "baroque" (odd-shaped) pearls. Pearls shaped as bars, wings, domes, navettes, and other oddities provide a wealth of options for the jewelry trade (Heideger, 1993). Beginning with its first successful commercial harvest in 1983, the company has perfected techniques to produce pearls in 3–5 years and to hold mortality at less than 20% in implanted mussels. From empirical experimentation and persistence, APC has become an internationally successful competitor in the freshwater pearl market. The two mussel species in the Southeast that provide the best white pearls are the washboard (*Megalonaias nervosa*) and threeridge (*Amblema plicata*). However, other white-nacred species in the genera *Quadrula*, *Fusconaia*, and *Pleurobema* may be suitable for pearl production in Gulf Coast states. A variety of other mussel species with colored nacres could be evaluated for pearl-production potential (Table 1). Vast freshwater resources for the establishment of pearl farms occur along the Gulf Coast, and a need exists to test the suit-

TABLE 1. Examples of mussel species with colored nacres in the Southeast.

Species	Nacre color
Purple wartyback (*Cyclonaias tuberculata*)	Purple
Elephantear (*Elliptio crassidens*)	Salmon/purple
Spike (*Elliptio dilatata*)	Salmon/purple
Fragile papershell (*Leptodea fragilis*)	Pink
Black sandshell (*Ligumia recta*)	White/pink
Bankclimber (*Plectomerus dombeyanus*)	Purple
Pyramid pigtoe (*Pleurobema rubrum*)	Pink
Pink heelsplitter (*Potamilus alatus*)	Purple
Pink papershell (*Potamilus ohiensis*)	Pink/purple
Bleufer (*Potamilus purpuratus*)	Purple

ability of various water body types for the culture of mussel species identified as potential candidates for pearl culture (Ward, 1985). John Latendresse predicted that the Southeast would become a major pearl-culturing area (Heideger, 1993). Although that potential has not been realized, proven implant techniques for native mussel species and appropriate environmental conditions certainly exist for an expansion of pearl culture into neighboring states along the Gulf Coast.

FRESHWATER MUSSEL PROPAGATION

The reproductive biology of freshwater mussels is unique among mollusks. The larvae (glochidia) are obligate parasites on the gills or fins of fish and exhibit various degrees of host fish specificity. Females are fertilized internally by siphoning in the sperm released by males, and eggs are fertilized in the suprabranchial cavity. Fertilized eggs are retained in the water tubes of the gills and develop to the glochidial stage. Females can contain between 50,000 and 5 million glochidia, depending on the species and size of female (Yeager and Neves, 1986). When glochidia are mature, they are released as free-floating individuals or in packets called conglutinates. These glochidia must come in contact with or be ingested by a suitable host fish for attachment and metamorphosis to the juvenile stage. Mussel species vary in host fish specificity, but most are restricted to a limited number of suitable hosts (Neves et al., 1985). After metamorphosis, juveniles drop from the host fish and begin their benthic life, maturing in usually 4–8 years.

The culture of freshwater mussels in the United States has a brief history, beginning in 1894 (Jones, 1950). At that time, the U.S. Bureau of Fisheries became actively involved in mussel research for fear that intensive harvest for button shells would deplete mussel stocks in the Mississippi River. A research station was established at Fairport, IA, to investigate the biology, life history, and propagation potential of species being harvested by the pearl button industry. The production and monitoring of juvenile mussels was one aspect of that research effort, but much of the data was anecdotal, with limited monitoring of juvenile survival and growth during the culture period (Lefevre and Curtis, 1912; Coker at al., 1921; Howard, 1922). The main laboratory building was destroyed by a fire in 1917, resulting in the loss of most records and materials. The laboratory shifted its emphasis from shellfish to finfish in the 1930s, and the era of mussel investigation essentially ended.

Renewed interest in freshwater mussel propagation resumed in the 1980s as a result of the federal listing of 23 endangered mussel species in 1976–77. Recovery plans for each of these species identified propagation as a means to augment existing populations, expand the range of extant populations, and reintroduce the species into historic habitat. However, a review of the earlier literature provided few insights on how to proceed with a propagation effort. Therefore, work began in the early 1980s at Virginia Tech to study the reproductive biology and identify host fishes and environmental requirements of adult and juvenile mussels (Zale and Neves, 1982; Neves and Moyer, 1988; Neves and Widlak, 1988). With these studies as a foundation, production and culture of juvenile mussels for federally endangered species using host fish infestations began in the early 1990s (Bruenderman and Neves, 1993; Hove and Neves, 1994; Michaelson and Neves, 1995). Efforts to metamorphose glochidia to juveniles with artificial media, rather than host fish, met with some success (Isom and Hudson, 1982; Keller and Zam, 1990). However, until the survival and fitness of these

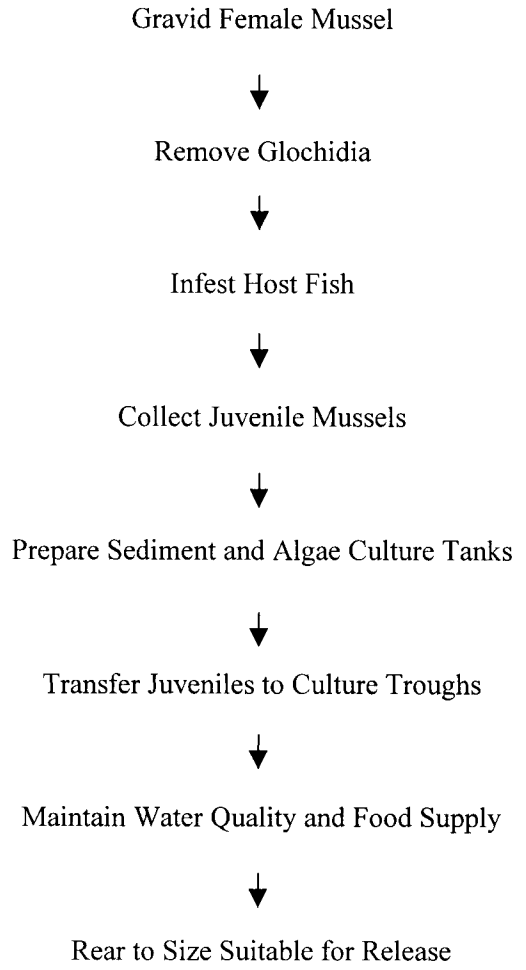

Fig. 1. Sequence of steps to produce juvenile mussels from recirculating culture systems.

artificially produced juveniles have been tested, there is cautious optimism in the applicability of this technique to large-scale production.

Current Production Methods

Production of juvenile mussels begins with the collection of gravid females from wild populations (Fig. 1). On the basis of previous research, suitable host fish are collected, preferably from water bodies with few existing mussels to minimize acquired immunity to glochidia (Reuling, 1919; Arey, 1923). Glochidia are nonlethally flushed from gravid females with a water-filled hypodermic syringe and needle. Glochidia flushed through the water tubes of the gills are collected in a dish and placed in a small tank under vigorous aeration to keep them suspended. Host fish are placed in the tank and become infested with the glochidia. Infested fish then are placed in aquaria for the transformation period (1–3 wk).

Newly metamorphosed juvenile mussels are siphoned from the bottom of the aquaria and placed into small dishes with sediment that has been boiled or autoclaved to remove invertebrate predators and pathogens. Laboratory experiments have shown that sediment is essential for the survival and growth of juveniles (Gatenby et al., 1996). These dishes are placed in a recirculating system consisting of a reservoir tank, raceway trough, and small drive pump or airlift pump to circulate the water (O'Beirn et al., 1998). The raceways are 3 m long × 66 cm wide, with water flow regulated by an inline flow meter or by the amount of air delivered to the upwelling pipe. Water depth is maintained at 20 cm via the standpipe, resulting in a volume of 170 liters in the raceway. Water hardness is maintained at ca. 200 mg/liters $CaCO_3$.

Juvenile mussels are fed unicellular algae, cultured in 250-liter Kalwall tubes with appropriate nutrient media (Ukeles, 1971). A variety of species, such as *Neochloris oleoabundans, Scenedesmus* sp., *Chlorella* sp., and others, are fed at a concentration of 20,000 cells/ml, and algae are harvested at the late exponential growth phase (Gatenby et al., 1997).

Because the purpose of the juvenile mussel propagation facility at Virginia Tech is to propagate endangered mussel species, juveniles are not typically retained beyond 3 mo of age. Juveniles are transported to rivers with existing populations and released to augment natural reproduction or to expand the range of the resident population. To apply these techniques to commercial species, juvenile mussels could be transported to a grow-out facility to sustain a captive population or to augment natural reproduction in a population where adults are collected for pearl culture. Collection of adults from a source population, with replenishment by stocking of juveniles, is the most practical option for pearl production at this time.

As judged by harvest records from the Tennessee River system alone (Hubbs and Jones, 1996), adequate wild populations of washboard and threeridge mussels exist in those reservoirs to sustain numerous pearl farms in the Southeast. Because of die-offs of Akoya pearl oysters in Japan in recent years, the demand for shell nuclei has decreased drastically. Shell harvest in U.S. waters has been inconsequential over the last 3 yr, and size classes in exploited populations continue to increase un-

der minimal harvest pressure. Thus, sufficient mussels of adequate size are available for domestic pearl culture.

Conclusion

The success of APC provides positive evidence that economic success is possible for an effectively run pearl farm in the U.S. Southeast. However, a detailed economic analysis is needed to evaluate feasibility of an expanded pearl industry in Gulf Coast states. The Southeast has the greatest diversity of freshwater mussel species in the world, including an array of lotic species well suited for pearl production. Because nacre colors of many of these species include white, purple, pink, magenta, salmon, orange, and suffusions of iridescence, the opportunity exists to produce naturally colored pearls unlike any of those currently produced overseas. If or when the techniques of pearl culture in China, or those perfected by APC, become known or are worked out independently, the production of round or semiround pearls in U.S. mussel species would catapult a fledgling U.S. venture into the world market as a major player. With strands of 9-mm high-luster round pearls from China selling for up to $8,000 each (Torrey, 1999), the economic incentive is adequate to investigate freshwater pearl culture for areas that are economically depressed but rich in aquatic resources. The "Gulf Pearls Project" is a somewhat novel and intriguing venture, with potential to create new jobs and revenues in coastal states with the necessary mussel species, water bodies, and entrepreneurs. Once the implantation technique becomes more widely known, quality pearls of various shapes and colors could become economic by-products of our mussel fauna in southeastern rivers, further justifying the protection of water quality and biological resources of long-term sustainability.

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