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Freshwater mussel conservation in Texas: a joint venture between the Dallas Aquarium and Texas Tech University

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Abstract

The goal of this study was to use a university and public aquarium partnership to begin a freshwater mussel conservation program in Texas. Several propagation and captive culture systems have been designed, constructed, and continue to be tested and improved upon as part of this project. Partnerships with other governmental and university entities have been cultivated to ensure the long-term success of this mission. While long-term funding is still an important and unresolved component that is necessary for the continuation of an effective conservation program, this project has provided the initial thrust towards a long-term program that has the potential to provide the state of Texas with an additional conservation tool for protecting remaining freshwater mussel populations and for performing much needed laboratory research on mussel-fish host relationships, early life history, feeding ecology, and juvenile mussel behavior.

Introduction

North America east of the Rocky Mountains is a biodiversity hotspot for freshwater invertebrate life, containing many of the world's Decapod, Gastropod, and Unionid species, among others. Texas may seem depauperate when compared to mussel-rich states like Alabama in sheer number of species per area, but in reality the Lone Star State is home to a very unique Unionid fauna with a high level of endemism. Geographic isolation of species due to long-term separation of drainages and a general pattern of freshwater drainages that flow independently to the Gulf of Mexico act as a barrier to dispersal and gene flow (Conner and Suttkus, 1986). In addition, the precipitation gradient from east to west Texas is extreme. Semi-arid west Texas is the location of several stream headwaters, while the gulf coast approaches tropical status when considering annual precipitation.

High rates of endemism coupled with cycles of severe drought and anthropogenic disturbances affecting water quality, quantity, and habitat have put many Unionid species at risk of extirpation and extinction. Over 50 species of freshwater mussel are native to Texas, with 15 listed by the Texas Parks and Wildlife Department as threatened or endangered since 2010 (Texas Register 35, 2010). Eleven species of freshwater mussels in Texas are under consideration by the U.S. Fish and Wildlife Department for listing under the protection of the Federal Endangered Species Act (Federal Register 71, 2006; Federal Register 74, 2009; Federal Register 75, 2010; Federal Register 76, 2011).

While the taxonomic placement, distribution, and habitat associations of the Texas-endemic species are under current investigation, most biologists familiar with Unionids in the state and nationwide agree that many populations of Texas mussels are at great risk of disappearing soon or suffering continued decline to the point of eventual elimination. In light of this problem, more research effort has been invested to determine the status of

the populations and habitats that remain viable and the basic biology and ecology of the otherwise understudied mussel species. Meanwhile, efforts to provide adequate flow in rivers where mussels exist and legal restrictions to reduce take due to habitat disturbance and water quality issues are increasing. At the same time, conservation plans for individual species are lacking and a statewide strategy for the recovery and protection of these animals has not yet been established. Competition for funding is increasing which may hamstring cooperation among experts, but at the moment efforts are largely united for the sake of this resource.

Propagation, culture, and release are strategies used widely for conservation of rare species and for supporting recreational take. In 2012, Texas Parks and Wildlife's Inland Fisheries Division released 12,346,519 fish of 17 different species in 280 water bodies to achieve recreation, management, and conservation goals (Smith and Saul, 2013). The federal government, universities, tribes, and many states agencies tasked with conserving Unionid faunas in decline have begun programs to propagate and release mussel species of concern in order to restore extirpated populations, or to boost population numbers to a condition deemed robust to foreseeable catastrophe. These programs all suffer varying degrees of growing pains, and measures of success are not always clearly defined (Strayer et al., 2004). Thus, proper planning and scientific justification for propagation, culture, and release is warranted to make best use of resources while maximizing the benefit of these actions. However, habitat conservation and reliable survey data are first necessary in order to direct propagation and release efforts to the most important species and locations.

Objective

The objective of this work was to determine habitat associations of freshwater mussels of concern in the upper Trinity and Brazos river watersheds and develop captive husbandry techniques for the eventual propagation and potential translocation of Texas endemic and rare freshwater mussels.

Task 1:

Collate previous survey data from a variety of source (TPWD, DCAFP) for the Trinity and Brazos River basins, and conduct additional surveys to identify appropriate mussel beds for monitoring.
Begin culturing algae for mussel feeding.

Task 2:

Carry out detailed habitat and species surveys of identified mussel beds within the Trinity and Brazos River basin. Begin monitoring selected mussel beds.

Task 3:

Develop preliminary husbandry techniques: maintaining freshwater mussels in captivity, monitoring feeding and growth.

Task 4:

Document husbandry of rare species.

Location

The Dallas Children's Aquarium at Fair Park (DCAFP) is located in an historic building located within Fair Park of Dallas and has operated as an aquarium since 1936. The aquarium is home to hundreds of aquatic species, including several pupfish species that are extinct in the wild, and has a broad conservation mission in addition to outreach and education. Texas Tech University is a large, state institution of higher education, located approximately 325 miles to the west in Lubbock, Texas. These two entities formed a partner conservation program with a focus at the onset on the upper Trinity River and the middle Brazos River because of their proximity to the DCAFP and documented mussel populations of state-threatened mussel species (e.g., Texas pigtoe, Texas heelsplitter, Texas fawnsfoot).

Methods

Haphazard, qualitative surveys were conducted along reservoir shorelines and at river access sites with wadeable depths throughout the summer months of 2012-2013 to locate potential broodstock for propagation activities and in search of healthy populations to monitor and use for suitable habitat assessment (Figures 1 and 2).

Figure 1. Survey site on the Brazos River at State Highway 67. Inset: a subfossil *T. macrodon* shell found at the site.

Figure 2. Survey site on the west fork of the Trinity River containing refuse and many recently deceased mussels. Inset: *M.nervosa* and an *A.confragosus* found stranded nearby.

Construction of host-fish study chambers and mussel propagation equipment preceded propagation and host fish studies. Captive culture systems for post- transformation juveniles, two to 10 millimeter long juveniles, and sub-adult mussels were constructed based upon existing designs in use at other mussel culture facilities, and available materials at hand. Mussel growth, survival, and system reliability were assessed and system adjustment and modifications were made as necessary to improve results and optimize operation.

Fish experimentation chambers were constructed using AHAB™ tanks and manifolds and homemade gutters with shelving units already available. Water was plumbed for flow-through operation initially, but the high calcium content of the well water necessitated conversion to a recirculating system to avoid clogging of filters, valves, etc. The tanks were designed with a baffle so that water flows across the bottom of the tank and carries waste and juvenile mussels to the outflow which eliminates the need to siphon the tank bottom. The tanks are also very space efficient and durable for ease of use.

A recirculating micro-raceway was constructed using a five gallon bucket and a small pump as used in the "mucket buckets" designed by Barnhart (2006). This micro-raceway allows for sediment to be used for culture of mussels greater than 1mm in length and is relatively self-cleaning (Figure 3). Algal diet and fresh water are dripped into the system continuously, providing consistent turnover and food for juvenile mussels.

Figure 3. A self-contained micro-raceway for rearing juveniles in sediment.

Mussels were collected at sites where death was imminent due to lack of water during several surveys. They were relocated to converted raceways (Figure 4) at the Lewisville Aquatic Ecosystem Research Facility (LAERF), a former Texas Parks and Wildlife Department (TPWD) fish hatchery, now operated by the United States Army Corps of Engineers (USACE) for aquatic plant restoration and research. These animals were monitored for survival, growth, and reproductive activity while serving as a barometer for system functionality and to gauge individual species tolerances for captive life before propagated mussels were available. The raceway was modified to include a settling chamber at the raceway head for silt to fall out of suspension, and stair-step baffles behind sediment trays to encourage water to flow evenly over mussels while reducing silt accumulation in the sediment trays containing sand and gravel. Water was supplied from Lake Lewisville and from the facility outflow stream. The stream provided increased algal concentrations, while the reservoir water maintained a more consistent temperature and each source served as a backup for the other.

Figure 4. Outdoor raceways at LAERF modified to hold mussels in an artificial riffle.

Mussels that were collected gravid in the field or that became gravid after a period of residence in the LAERF raceway were relocated to the DCAFP where a refrigerated chamber was constructed after designs common in other propagation facilities (Figure 5). Maintaining brooding female mussels around 10°C in individual tanks within a recirculating system allows for constant monitoring of broodstock and extension of the brooding period so that host fishes can be acquired or multiple tests can be conducted through time with

glochidia from a single brooding mussel (Bosman, personal observations). This also reduces stress and metabolic rates for the brooding female, which improves water quality within the system and glochidia quality.

Figure 5. Refrigerated broodstock chamber with recirculating water filtration system.

Fishes were collected for propagation from existing research facility populations and from the wild in conjunction with other research projects targeting fishes using seines, minnow traps, and electrofishing under permits from TPWD. Wild collected fishes were held in aquaria, raceways, or ponds depending on size, species, and need for specialized care until needed for propagation. Fishes held in outdoor facilities (raceways and ponds) were provided aeration and weekly supplemental feeding, with constant water flow from a nearby reservoir (Lake Lewisville). Fishes held indoors received aeration, daily inspection and feeding, and constant flow of well water, or weekly water changes, and medication as needed for health. Fishes were euthanized or added to the DCAFP display collection at the end of experimentation. All fish-related activities were approved by Texas Tech IACUC and described in protocol #12072-09.

Inoculation of host fishes followed standardized protocols (Jones and Neves, 2002) using a glochidia bath, or placement of glochidia solution directly onto fish gills (Figure 6). Fish were placed into individual or single species tanks and siphoned every 2-3 days until three successive siphon collections yielded zero glochidia or juveniles. Fishes were held at approximately 18-26°C, with water temperature depending on seasonality and varying <1°C per day.

Figure 6. A novel method for inoculating gar species with glochidia. Tubing fitted was inserted into the mouth of the fish which introduced water containing a light dose of anesthetic into the buccal cavity and flowed past the gills. A Y-coupling allowed a glochidial suspension to also be introduced into the water stream, facilitating inoculation through the mouth of the fish rather than from behind the opercles.

Public outreach involved an information placard and display tank at the DCAFP wherein several adult mussels of different species were maintained for approximately two months at a time (Figure 8).These mussels were fed commercial and in-house cultured algal diets at night and allowed to clear the water for the next day's visitors viewing. The tank habitat was modified so that the rear contained stacked cobble substrate while the front of the tank held a sand and gravel mixture that encouraged the mussels to burrow themselves where observation was easiest for the public.

Figure 8. Freshwater mussels on display at DCAFP filtering algae and demonstrating cryptic poses.

Phytoplankton of several species collected from local ponds and commercial sources were cultured for mussel diets over the course of the project but were not tested specifically as dietary supplements due to low numbers of cultured juvenile mussels. All species were tested with *Daphnia sp*. as a general test for toxicity. Algal culture was conducted under artificial "super-actinic" lighting in 2 L plastic bottles and 4 L glass jugs with filtered atmospheric air forced in to supply agitation and CO_2. A 90-10 deionized and well water blend was used with Guilliard's F2 fertilizer added at recommended rates for culture media. A 25-mL sample of algae harvested from the previous batch was inoculated into a 2 L bottle of fresh media and allowed to multiply for 3-4 days or until a dark green color was reached. This 2 L batch was then moved into a 4 L jug with an additional 2 L of new media and allowed to reach a maximum density again. At this point, while algae were still in the logarithmic growth stage and maximally nutritious, they were harvested to be fed and 25mL were retained to start the process again (Figure 9).

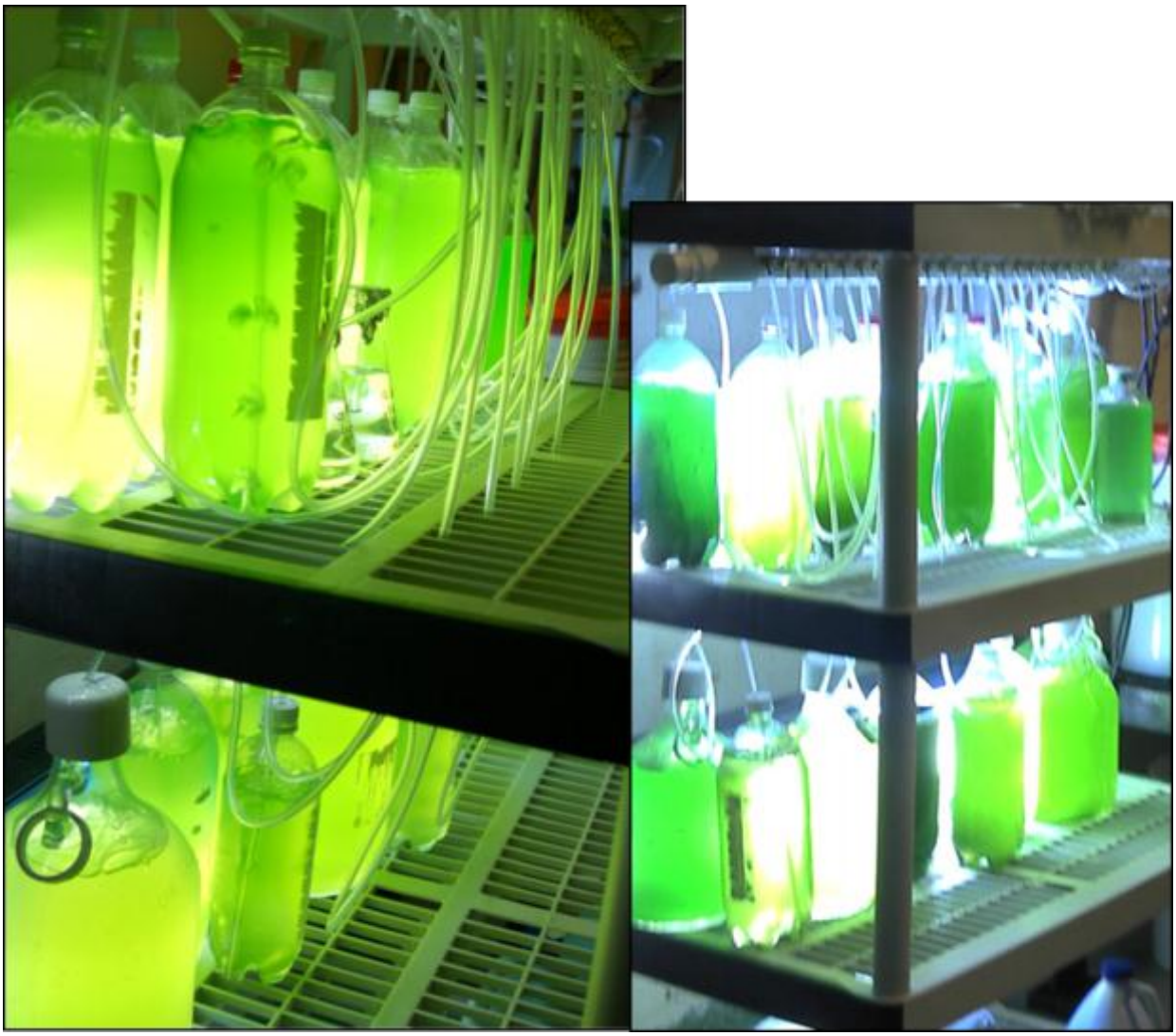

Figure 9. Algae cultures at DCAFP used for supplementary feed in captive mussel culture

Results

Surveys at 55 sites including reservoirs and rivers in the upper Trinity and middle Brazos watersheds yielded mixed results (Tables 1 and 2), with few live individuals of common species found at reservoir sites. The upper Trinity survey sites contained several beds and urban mussel populations, although those on the West Fork of the Trinity between Lake Bridgeport and Eagle Mountain Lake have been dewatered since initial observations, resulting in near total loss of those populations. Reservoir shoreline surveys on Lakes Grapevine, Lewisville, and Lavon yielded many freshly dead and stranded mussels searching for deeper water during reservoir level reductions in the summers of 2012-2013. While not testing explicitly for habitat associations in the scope of this study, several trends emerged for presence of species in certain habitats and species co-

occurrences that have been documented previously, such as *Q. apiculata* frequently occurring in impounded waters, while *Q. mortoni* and *T. verrucosa* were found only in flowing streams (Howells et al., 1996).

Table 1. Mussel sampling sites in the Brazos and Trinity basins.

Site No.	County	Drainage	Description
1	Palo Pinto	Brazos	Brazos River at US Hwy 180 crossing nr Mineral Wells,Tx
2	Bosque/ Johnson	Brazos	Brazos River at FM1175/1118 crossing nr Cleburne,Tx
3	Young	Brazos	Brazos River at State hwy 67 crossing nr South Bend,Tx
4	Johnson	Brazos	Nolan River at Co Rd 4 nr Cleburne,Tx
5	Johnson	Brazos	Nolan River at US 67 and Lake Pat Cleburne
6	Somervell	Brazos	Paluxy River at US hwy 67 nr Glen Rose,Tx
7	Somervell	Brazos	Paluxy River at State hwy 144 nr Glen Rose,Tx
8	Bosque/ Hill	Brazos	Lake Whitney (Brazos) Chisolm Trail Park Hwy174
9	Young	Brazos	Brazos River at US hwy 380 crossing nr Graham
10	Baylor	Brazos	Brazos at US hwy 277/183 crossing nr Seymour
11	Somervell	Brazos	Brazos River at Hwy US 67 crossing nr Glen Rose
12	Denton	Trinity	Lake Lewisville arm E of Marina
13	Denton	Trinity	Lake Lewisville Spillway Arm
14	Denton	Trinity	McWhorter's Creek at Fish Hatchery Rd nr Lewisville,Tx
15	Denton	Trinity	Elm Fork Trinity at FM 428 Greenbelt access
16	Wise	Trinity	Walnut Creek at FM 2257 nr Reno, Tx
17	Denton	Trinity	Elm Fork Trinity at FM 455 Greenbelt acccess
18	Wise	Trinity	West Fork Trinity at FM3390 nr Paradise, Tx
19	Wise	Trinity	West Fork Trinity at FM4757 nr Boyd, Tx
20	Wise	Trinity	West Fork Trinity at State hwy 114 nr Boyd,Tx
21	Wise	Trinity	West Fork Trinity at FM4668 nr Boydx Tx
22	Denton	Trinity	Elm Fork Trinity Below Lake Lewisville Dam (LLELA)
23	Denton	Trinity	Lake Grapevine North shore at High Rd
24	Parker	Trinity	Clear Fork Trinity at Kelly Rd Nr Aledo, TX
25	Dallas	Trinity	Elm Fork Trinity at E Belt Line Rd nr Carrolton,Tx
26	Dallas	Trinity	Denton Creek at MacAruther Blvd Nr Coppell, Tx
27	Dallas	Trinity	Denton Creek Natches Trace Nr Coppell, Tx
28	Denton	Trinity	Clear Creek at Hartlee Field Rd nr Denton, Tx
29	Denton	Trinity	Timber Creek at S. Edmonds Ln nr Lewisville, Tx
30	Denton	Trinity	Timber Creek at FM1171 nr Flower Mound,Tx
31	Collin	Trinity	Lake Lavon at 3286 crossing nr Lucas,TX

Table 2. Mussels collected at each study site location.

Site No.	Mussels Present	Latitude	Longitude
1	no live mussels or shell found	32.797315	98.186355
2	no live mussels or shell found	32.204041	97.605928
3	no live mussels or shell found	33.024394	98.645042
4	no flowing water, no live mussels or shell found	32.376705	97.471728
5	*P.grandis* shell only	32.325322	97.447489
6	dewatered	32.230281	97.776027
7	dewatered	32.233775	97.754405
8	*Q.apiculata, T.texasensis P.purpuratus* shell only	32.143611	97.480369
9	no flowing water, no live mussels or shell found	33.176072	98.755881
10	very shallow water, no live mussels or shell found	33.580771	99.267561
11	one subfossil *T.macrodon* shell only	32.270495	97.663116
12	Juvenile *P.grandis, U.imbecillis, T.parvum, Q. apiculata, P.pururatus*	33.078596	96.909581
13	Juvenile *P.grandis, U.imbecillis, T.parvum, Q. apiculata, P.amphichaenus*	33.071943	96.924172
14	*L.teres, T. parvum*	33.052573	96.937577
15	*L.teres, T. parvum, P.amphichaenus, P.purpuratus, L.fragilis, P.grandis, Q.mortoni*	33.307731	97.041722
16	*U.imbecillis* shell only	32.965641	97.611844
17	*T.truncata, Q.mortoni, T.verrucosa, A.plicata** (*shell only)	33.326529	97.029031
18	*L.teres ,T.verrucosa, T.truncata, L.fragilis, P.purpuratus, Q.apiculata*	33.138439	97.652953
19	*L.teres, T.verrucosa, T.truncata, L.fragilis, P.purpuratus, Q.apiculata, M.nervosa, A.confragosus*	33.034741	97.534172
20	*L.teres, T.verrucosa, T.truncata, L.fragilis, P.purpuratus, Q.apiculata, Q.mortoni*	33.074041	97.538876
21	*T.verrucosa, L.teres*	33.051625	97.557609
22	*L.teres, O.reflexa, T.parvum, Q.apiculata, Q.mortoni, P.purpuratus, L.fragilis, T.verrucosa,*	33.061046	96.969705
23	*L.fragilis, P.amphichaenus, L.hydiana, P.grandis, U.imbecillis*	33.020431	97.151654
24	*U.tetralasmus* shell only	32.652751	97585822
25	*P.purpuratus, Q.mortoni* shell only	32.950473	96.939205
26	*P.grandis, P.purpuratus, L.teres, Q.apiculata, O.reflexa, A.confragosus*	32.989072	96.965921
27	*L.teres, P.grandis, O.reflexa*	32.983968	96.982228
28	*T.parvum, Uniomerus sp.** (*shell only)	33.262348	97.054275
29	no live mussels or shell found	33.015367	97.003658
30	*U.tetralasmus* shell only	33.040841	97.048374
31	*Q.apiculata, T.parvum, P.purpuratus, L. teres, P.grandis* shell only	33.096713	96.534278

Algae were collected from ponds and outdoor research facility tanks (wild strain) and cultured to isolate "natural" diet algae in addition to algae cultured from commercially available strains used frequently in aquaculture. At the time of this report, five strains of algae continue to be cultured from initial propagules brought into the lab and are fed to broodstock in refrigerated systems, juveniles, and mussels on display at

DCAFP in a diet that also contains commercially produced algal concentrates. The cultured algae are also used to "seed" outdoor culture systems at LAERF (Figure 10). A student intern used these strains to develop species-specific volumetric cell density curves using a spectrophotometer over the course of summer 2014 which will be used for more precise measurement of dietary preparations.

Figure 10. An outdoor culture tank with an extremely robust algal population.

Propagation systems were developed after the commercially available AHAB systems designed for zebrafish culture and experimentation due to ease of use and in order to use space efficiently. In addition to our custom AHAB system, we manufactured several flow-through tank systems for holding different sized host fishes by species or individually and have used them successfully (Figure 11). These systems were used for host fish trials of yellow sandshell, paper pondshell, and false spike. Yellow sandshell results were as expected, with longnose and spotted gar producing juveniles at the highest rates. Paper pondshell was found to use several host fishes (including bluegill, western mosquitofish, and bullhead minnow) at low success rates, and false spike trials were inconclusive due to very low glochidia viability and attachment at the time of inoculation. However, a single juvenile was collected from wild caught red shiners from the Guadalupe River, where false spike had been observed brooding nearby in early July of 2014. That juvenile awaits genetic identification.

Thirty adult freshwater drum, the sole host for several mussel species, were transported to LAERF on August 26, 2014 from Langston University in Oklahoma, and will be used to host glochidia from a gravid bluefer currently held in the broodstock chiller in the coming weeks. The drum may also potentially be used for Salina mucket, which are also brooding developing embryos in the broodstock chiller at this time and are expected to be mature after approximately two months. The acquisition of freshwater drum will also allow propagation of fragile papershell, deertoe, fawnsfoot, and test a hypothesis that it is the sole host of Texas fawnsfoot, Mexican fawnsfoot, Salina mucket, and Texas heelsplitter, which are congeners of freshwater drum host-specific mussels.

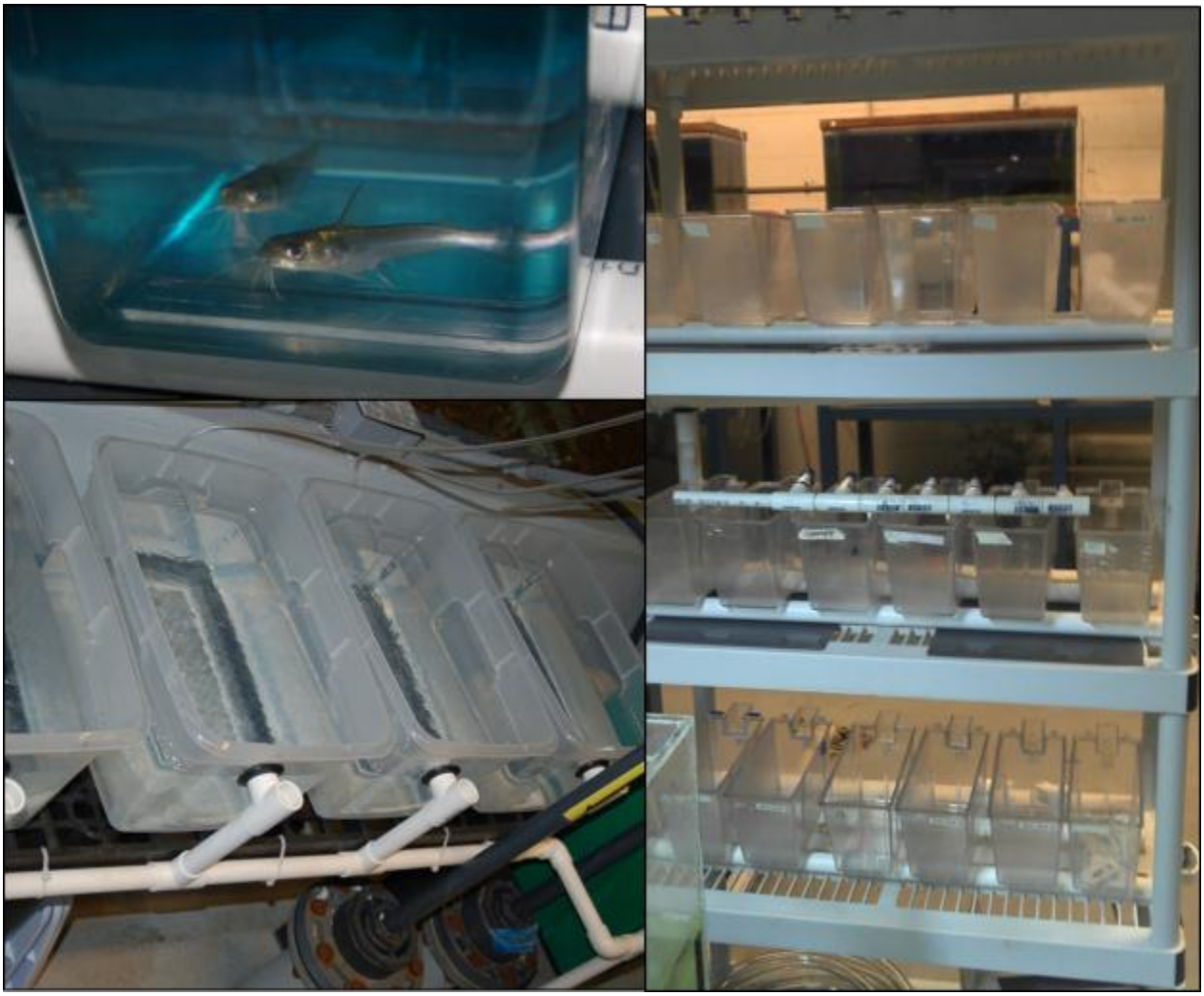

Figure 11. Clockwise from upper left: Juvenile channel catfish in 3L AHAB tank, AHAB system under construction, 10L plastic container tanks for larger individuals in host fish studies.

Culture of juvenile mussels from post-transformation has been successful with the commonly reared fatmucket, but no other species at this point. Yellow sandshell and paper pondshell faced early mortality in the standard "mucket bucket" designed for juvenile culture (based on Barnhart, 2006), and no other species have been propagated since due to lack of appropriate host fishes or viable glochidia. Copepods have been a competitor and nuisance species in the mucket buckets and likely caused mass mortality of yellow sandshell and paper pondshell. Calcium scale is also an issue when using well water at DAFCP, which quickly clogs the fine (125micron) mesh screens used in the mucket buckets and requires extra maintenance.

Fish lures and host attraction behavior were documented for two species, with a notable difference from other accounts in the literature. Yellow sandshell and Louisiana fatmucket lure strategies were observed and photographed during the study. Yellow sandshell lures observed during this study appear different from those documented by Rypel (2008), with the added features of distinct orange bands and knob-like protrusions as well as mantle tissue protrusion and undulation at the anterior. A single Louisiana fatmucket in captivity was observed with an eyespot on an otherwise poorly developed fish mimic mantle lure (Figure 12).

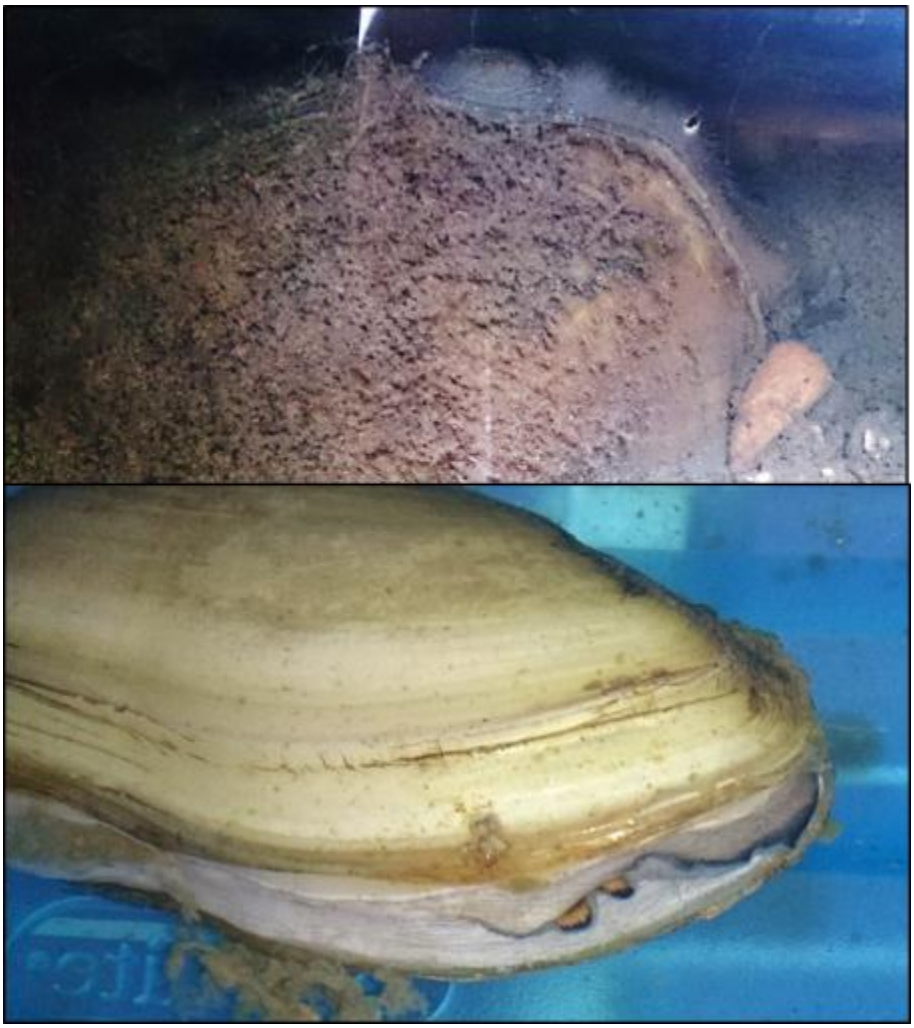

Figure 12. Top: Louisiana fatmucket with lure showing eyespot. Bottom: yellow sandshell with an undescribed mantle lure feature (orange and black caruncles).

Raceway design has improved significantly through several iterations and continues to be modified through time to improve water quality for mussels and reduce maintenance and disturbance of the mussels while facilitating monitoring. Growth and survival were monitored initially at monthly intervals, then at a reduced frequency to prevent the act of removing the mussels from their sediment trays for measurement from impacting their growth. Adult mussels held in the raceway system were less motile and appeared to be more sensitive to frequent disturbances than the active juveniles held in indoor culture systems. Survival was high in general, with interruptions in water flow and silt deposition from infrastructure maintenance likely causing small mortality events. An unusually harsh winter weather event also caused an outdoor culture system to ice over, which resulted in a small proportion of mussels expiring from that system. Since many of the mussels used to test outdoor culture systems were rescued from drying pools and receding reservoir waterlines, a degree of stress was assumed to carry over and result in delayed growth or early onset mortality.

Six thousand liter mesocosms and mussel basket systems have shown to be an effective alternative to the raceway as a closed system that can allow water chemistry, nutrient and light levels to be manipulated for replicated mussel culture experiments while still facilitating phytoplankton densities similar to those found in more traditional pond culture systems. Aeration provides vertical water movement and encourages phytoplankton growth and division while also providing flowing water for mussels in suspended baskets (Figure 13). High volume-to-surface-area ratio decreases evaporation rates and stabilizes water temperature throughout diel cycles and short-term weather changes.

Figure 13. A floating mussel basket with air lift used in the 6000L mesocosm tanks.

Mucket buckets were initially tested with freshly transformed juvenile mussels from Missouri State University (Figure 14 and 15). The first batch of 1000 juveniles expired within two weeks of entry to the system due to high temperature shock. The second batch contained several dozen individuals at the end of the first year

from the initial 1000, growing to approximately 5 mm on average, and was moved into the micro-raceway. In this system, they grew for another year before half were transferred to an outdoor culture system for comparisons in growth. The micro-raceway growth rate declined and eventually all individuals held therein died, probably because the volume of water was not sufficient to sustain the level of food required by these quickly growing mussels. This effect has been observed in the mucket buckets and other indoor systems as well (Bosman, personal observation), where mussels require increasing volumes of water as they grow to larger sizes to meet their dietary, respiratory, mineral, and waste removal requirements. We have thus concluded that this system is sufficient as a transitional system from the mucket bucket to a larger scale outdoor system, but likely cannot provide enough food for the growing mussels without fouling as they reach a biomass per liter threshold that is yet to be determined.

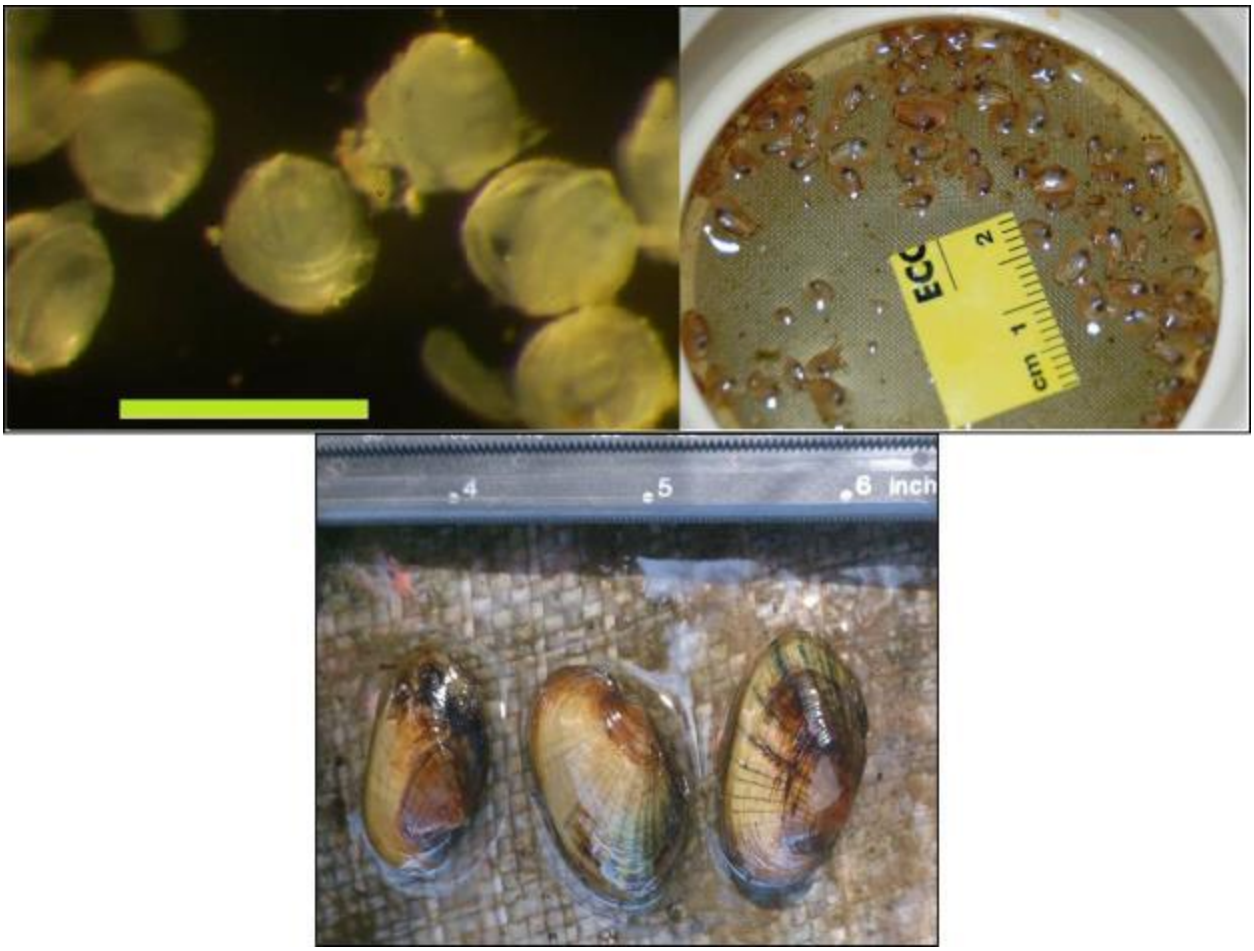

Figure 14. *Lampsilis siliquoidea* donated from Missouri State University for culture system testing.

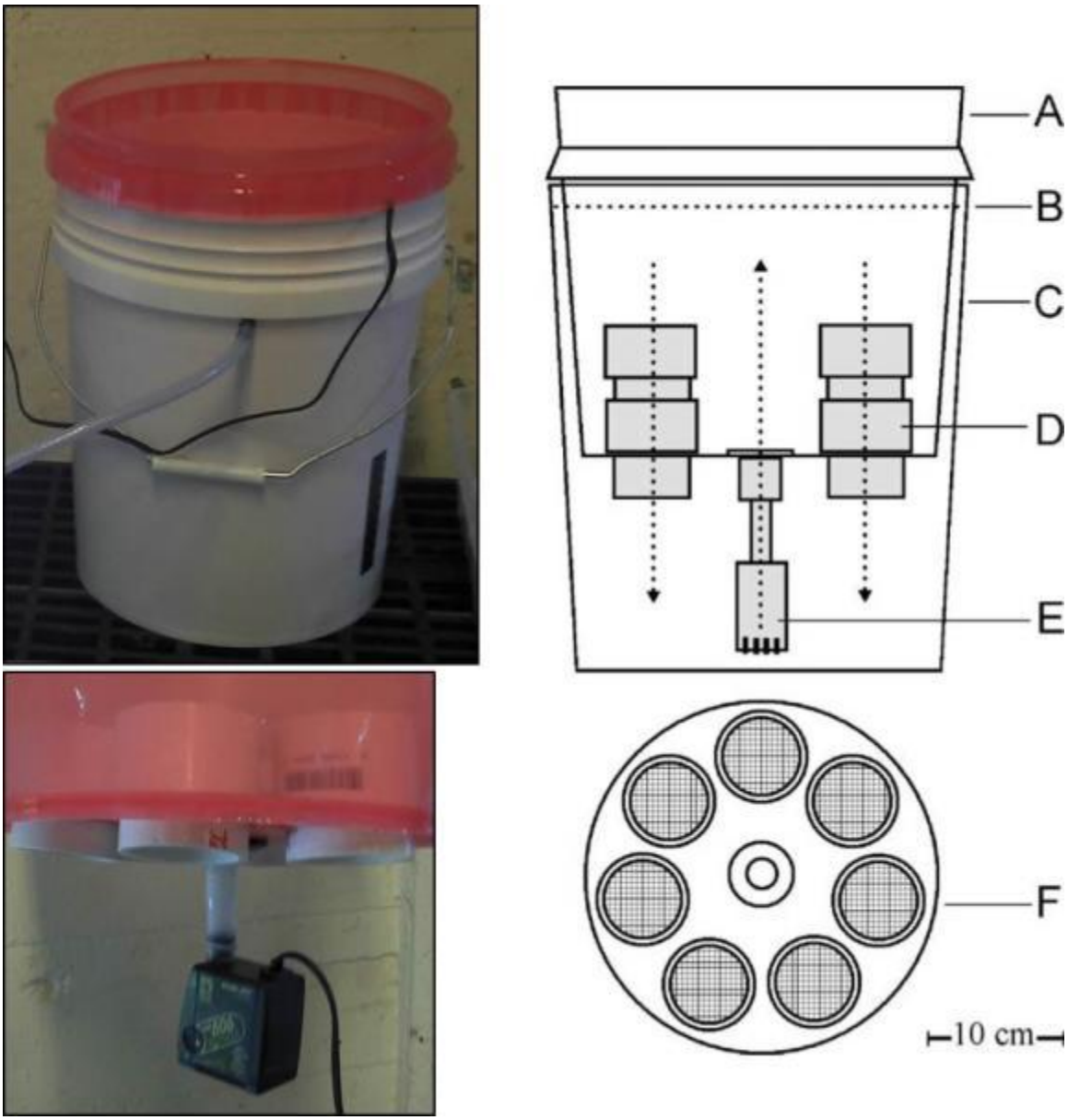

Figure 15. Left: "Mucket-bucket" fashioned after figure at right from Barnhart, 2006). A: top bucket, B: water line, C: bottom bucket, D: mussel chamber (nested filter cups), E: magnetic drive pump, F: top view of upper bucket.

Discussion

Surveys conducted for this project have validated a trend found in many Texas rivers and streams wherein mussels often occur in seemingly unsuitable habitat, yet are frequently not found where they are expected. While attempting to locate broodstock for this study, small urban streams were found to harbor pondhorn and Lilliput mussels. Larger urban streams (e.g., Denton Creek in Grapevine) contained several mussel species in what appeared to be unsuitable habitat. Even the Elm Fork of the Trinity, which was

considered toxic a few decades ago and requires that sampling be conducted using haz-mat equipment, has shown to contain state-threatened mussel species (A. Oliver, personal communications).

While the authors and study partners feel that significant and hard-earned success has resulted from this project, no rare mussel species have been propagated at this point. We have gained a considerable amount of experience through improvement of propagation and culture systems, and are seeking additional funding to continue our research and move from initial development and testing to scale up and provide systems that can be readily used by conservation practitioners. In the future we will also produce mussels for use in toxicology and other lab studies while protocols for determining population reintroduction and monitoring are developed.

While we make gains in propagation and culture efficiency and expand our success with additional species, the need still exists for a conservation strategy, state-wide and species-specific, which includes funding long-term conservation efforts such as propagation and monitoring of released propagules. There is a considerable degree of competition among consultants, universities, and agencies in the state for limited funding to accomplish necessary research for conservation of this resource, leading to overlap, inefficiency, and data collected that are not useful in comparisons among studies.

Through consultation with other mussel propagation experts, a trend that emerges is that for success in all the steps, from propagation to culture and eventual release size, progress is slow, mortality rates can be high, and partnerships are essential for the function of conservation programs. This project has suffered some of these setbacks, but the improvements in propagation we have developed, and the support of motivated partners, will help to ensure long-term success in mussel conservation.

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