Saving the Higgins' Eye Pearlymussel (*Lampsilis higginsii*) from Extinction: 2002 Status Report on the Accomplishments of the Mussel Coordination Team

Mussel Coordination Team
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In cooperation with the

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April 2003

Abstract

Zebra mussels (*Dreissena polymorpha*) are an exotic species and a significant threat to native freshwater mussels of the Upper Mississippi River (UMR). At high densities, they compete for food, prevent opening/closing of shells, degrade habitat conditions, and prevent successful reproduction and recruitment.

Zebra mussels attach to nearly all underwater objects, including large boats and barges using the Federal navigation system of locks and dams on the UMR. In April 2000, the U.S. Fish and Wildlife Service (Service) determined that continued operation and maintenance of the Federal 9-Foot Channel Project would jeopardize the continued existence of the federally endangered Higgins' eye pearlymussel (*Lampsilis higginsii*). To avoid jeopardy, the Service recommended the U.S. Army Corps of Engineers (Corps) establish populations of Higgins' eye in areas with no/few zebra mussels, and implement a zebra mussel control program. Since April 2000, a variety of conservation measures have been implemented, including genetics studies, propagation of mussels at the Genoa National Fish Hatchery, propagation in cages in the UMR and tributaries, stocking juveniles, relocating adults, stocking glochidia-inoculated fish, cleaning and stockpiling adults, and survey/monitoring activities.

Background

The historic range of the Higgins' eye pearlymussel (*Lampsilis higginsii*) includes the UMR and major tributaries (Figure 1). The Higgins' eye pearlymussel was listed as a federally endangered species in 1976 under the Endangered Species Act. A recovery plan completed in 1982 might have been successful if the exotic zebra mussel (*Dreissena polymorpha*) had stayed away. Zebra mussels are an exotic species from Europe that entered the Great Lakes from ballast water of ocean ships. During the 1980's, they entered the Illinois/Mississippi River System by a connection with Lake Michigan at Chicago, Illinois. Today, they have infested nearly the entire navigable portion of the UMR (Figure 2).

Zebra mussels attach to nearly all underwater objects. They encrust hard objects and can form a thick "carpet" on the bottom of the river. Unfortunately, they seem to prefer attaching to native freshwater mussels (Figure 2). At high densities, they harm individual mussels and entire beds by competing for food, preventing opening/closing of shells, degrading habitat conditions, and preventing successful reproduction and recruitment.

An Ecological Disaster at the Prairie du Chien Essential Habitat Area

The 1982 Higgins' Eye Pearlymussel Recovery Plan described seven Essential Habitat Areas (EHA's) in the UMR that are critical to the survival and recovery of the species (U.S. Fish and Wildlife Service 1982); three additional areas were proposed in 2002 (Figure 1). The most important EHA was located in Pool 10 of the UMR at Prairie du Chien, Wisconsin. The Prairie du Chien EHA historically contained one of the most abundant and diverse mussel communities on the UMR; over 30 mussel species have been collected there including an abundance of Higgins' eye. Recovery of Higgins' eye under the Endangered Species Act required a viable mussel community at the Prairie du Chien EHA (U.S. Fish and Wildlife Service 1982).

The Prairie du Chien EHA is routinely sampled by the Corps. Between 1996 and 1999, they found a significant decline in abundance and recruitment of native mussels with a corresponding increase in abundance of zebra mussels (Table 1). Welke et al. 2000 describes the consequences to native mussels:

> *"With equal sampling effort in 1996, 1998, and 1999, only 27, 20, and 7 species of native mussels were collected here, respectively. No Higgins' eye pearlymussels and no recruitment of any native mussel species were detected in the 1999 sampling, however, a carpet of zebra mussels several inches thick covered the mussel bed. Higgins' eye pearlymussel populations in the Mississippi River are at imminent danger of extirpation by zebra mussels. Should that occur, the gene pool would be fragmented and survival of the Higgins' eye pearlymussel would depend on two small, less-than-robust populations; one in the St. Croix River and the other in the Wisconsin River."*

River Biologists Take Action to Save Higgins' Eye from Extinction

After the decline in mussels at the Prairie du Chien EHA, State and Federal river biologists took action to save the Higgins' eye from extinction. In particular, they evaluated mussel propagation and relocation techniques. A mussel culture facility was quickly constructed at the Genoa National Fish Hatchery (NFH) in Wisconsin (Figure 3). In the spring of 2000, the biologists obtained five gravid female Higgins' eye from the St. Croix River and inoculated host fish (592 largemouth bass and 752 walleye yearlings) with glochidia. Their efforts were successful in producing approximately 92,000 juvenile Higgins' eye; 4,800 were subsequently released into the lower Wisconsin River in 2000 (Steingraeber 2002). They also installed two propagation cages in Pool 4 of the UMR which produced three juvenile Higgins' eye (Davis 2001).

More Help on the Way

Between 1998 and 2000, the Corps and the Service were involved in formal consultation under Section 7 of the Endangered Species Act. The consultation focused on the Higgins' eye pearlymussel and impacts from operation and maintenance of the existing 9-Foot Channel Project for another 50 years. Zebra mussels were a primary issue because they harm native mussels and are transported by towboats and other large craft to upstream areas on the UMR using the Federal navigation system (Figure 2). In its April 2000 Biological Opinion, the Service determined that operation and maintenance of the navigation project for an additional 50 years would jeopardize the continued existence of the Higgins' eye pearlymussel because it provides for a steady upstream transport of zebra mussels on the UMR. In order to avoid jeopardy, the Service recommended the Corps establish populations of Higgins' eye in areas with no/few zebra mussels and implement a zebra mussel control program (U.S. Fish and Wildlife Service 2000). The Corps accepted the Service's recommendations and established an interagency Mussel Coordination Team (MCT) to assist in implementing the Biological Opinion requirements.

Higgins' Eye Pearlymussel Relocation Plan

MCT members include the Wisconsin, Minnesota, and Iowa Departments of Natural Resources, U.S. Geological Survey, U.S. Coast Guard, National Park Service, Science Museum of Minnesota, Corps and Service (Figure 4); assistance is also provided by Iowa State University and the University of Minnesota. An important accomplishment of the MCT is the Higgins' Eye Pearlymussel Relocation Plan. The interim goal of the plan (next 10 years) is to maintain/establish viable populations of Higgins' eye pearlymussels; a critical task is the establishment of five new and viable populations in areas of the UMR that have no/few zebra mussels. The long-term goal of the plan is to restore Higgins' eye populations to year 2000 levels with at least four geographically separate EHA's.

In July 2002, the Corps released the Definite Project Report and Environmental Assessment for the Relocation Plan for the Endangered Higgins' Eye Pearlymussel (*Lampsilis higginsii*) (U.S. Army Corps of Engineers 2002). The plan recommends spending $2,542,000 through 2010 on a variety of relocation activities. The plan uses a combination of five relocation methods at 10 sites to reach the interim goal of five new populations over the next 10 years:

Relocation Method	Number of Sites
Adult relocation	Adults relocated at two sites
Glochidia relocation	Inoculated hatchery and wild fish released at two sites
Juvenile relocation	Cage or hatchery production released at two sites
Subadult relocation	Cage or hatchery production released at two sites
Multiple techniques	Juveniles, subadults and adults at one site
	Glochidia-inoculated fish, juveniles and adults at one site

Summary of Activities

Mussel Propagation at the Genoa National Fish Hatchery

Mussel conservation activities in 2000 developed a protocol for collecting gravid females and glochidia, inoculating host fish, and producing juvenile mussels at the Genoa NFH and in cages (Steingraeber 2002). In 2001, the Corps conducted a literature search of previous mussel culture activities on the UMR to assist in refining mussel propagation activities (Pritchard 2001). Methods, procedures, and results at the Genoa NFH are described in Steingraeber (2002) and Welke et al. (2000).

Like many freshwater mussels, the Higgins' eye requires a host fish to complete its life cycle (Figure 5). Eggs are fertilized and stored in the female's gills. Here they transform into a parasitic form called glochidia. When gravid, adult females display a unique lure on their mantle tissue that resembles a small fish (Figure 5). The lure attracts predatory fish like largemouth bass, smallmouth bass, and walleye. When a fish strikes the lure, it ruptures the gill chambers of the mussel. Glochidia are expelled into the mouth of the fish and attach to the gills. If the fish is a suitable host, glochidia encyst, transform into juvenile mussels, detach from the gills, and fall to the sediment. Juveniles surviving to adulthood complete the life cycle.

In nature, the female mussel brings (lures) a host fish to her glochidia. In the hatchery, we bring the glochidia to the fish. Gravid female Higgins' eye are collected in the field by divers and transported to the hatchery. Females used for propagation are measured and marked. Glochidia are flushed from the gills of the female with a syringe and water into a glass container (Figure 6). Glochidia are tested for viability with a microscope and table salt; viable glochidia quickly "snap shut" their shells when contacting salt placed in their water. A quantity of viable glochidia (2 to 10 milliliters) is added to a bucket containing host fish, water, and an airstone. Contents are mixed for a period of time (2 to 5 minutes) and a sample fish is examined under a microscope to estimate the number of attached glochidia. If the gills appear adequately inoculated with glochidia (50 to 100), fish are placed in a holding tank. If not, the sample fish is returned to the bucket, the contents stirred, and the process continued until inoculation occurs.

Table 2 shows propagation results from the Genoa NFH in 2002 (number of fish inoculated, glochidia attachment and transformation rates; Gordon 2002). To date, approximately 8,600 host fish (largemouth bass, smallmouth bass, walleye) have been inoculated with Higgins' eye glochidia at the Genoa NFH (Figure 7). These fish are used in cage propagation activities, released into the wild, or kept as transforming juveniles in the hatchery. It takes approximately 2 to 4 weeks for transformation from glochidia to juvenile mussel (Figure 8).

Studies on Higgins' eye found a high level of genetic variation compared to other federally endangered species (Bowen 2003). Higgins' eye does not contain genetically distinct populations in study areas of the St. Croix River and the UMR. However, to preserve this high level of genetic variation, we will use glochidia from as many different female Higgins' eye as possible from the same collection site. We currently have three sites for collecting gravid females and glochidia: lower St. Croix River at Hudson, Wisconsin; Pool 11 at Cassville, Wisconsin; and Pool 14 at Cordova, Illinois. Fish released into cages in the upper reaches of the

UMR are inoculated with glochidia from the St. Croix River; likewise, fish released into cages or the wild in lower reaches receive glochidia from Pool 11 or 14, depending on which is closer to the release site. Tissue samples are taken from each female used to inoculate fish. In the future, we hope to use genetic testing (micro satellites) to determine if mussels collected from monitoring came from our relocation efforts.

Propagation of Higgins' Eye Pearlymussels in Cages

In the early 1900's, fat muckets (*Lampsilis siliquoidea*) were successfully propagated in large wooden "corrals." Corrals were surrounded with wire mesh to exclude predators and confine mussels (Figure 9). In June 2000, two propagation cages (wooden and metal frames) were installed in Lake Pepin (Figure 10). The wooden cage contained fish inoculated with glochidia from black sandshell mussels (*Ligumia recta*); one subadult black sandshell was recovered in June 2001. The metal cage contained fish inoculated with glochidia from Higgins' eye pearlymussels; three subadult Higgins' eye were recovered in June 2001 (Davis 2001; Figure 10). Numerous zebra mussels attached to the inside of the wooden cage; both cages were also heavy and difficult to sample. We modified cages and currently use two types: open cages in areas of high flow, and closed cages in areas of low flow. Open cages are constructed of aluminum frame and ½-inch wire mesh screen (12 by 24 by 36 inches; Figure 11). Wire screen is secured to the frame with pop rivets. The top of the cage can be opened to insert host fish and secured with plastic ties. Glochidia transformed from the gills of host fish pass through the bottom of the cage directly to the river bottom. These cages are slanted in front to provide stability in currents, and they have a 3/8-inch plywood board attached to the front to give host fish a refuge from currents.

Closed cages are a little larger and have a 3/8-inch plywood bottom to collect juvenile mussels (18 by 24 by 36 inches; Figure 11). In closed cages, a 3- to 6-inch layer of sediment is placed on the bottom of the cage as habitat for transformed juveniles. For ease of collection and replacement, both types of cages can be separated from their aluminum bases, which can remain on the river bottom.

Cage propagation techniques are described in Davis 2001 and 2002. In a typical placement, glochidia-inoculated fish and cages are transported by boat to the relocation site. Depending on their size, approximately 30 to 50 fish are placed in each cage. Divers are used to transport and secure the cage to the river bottom. Cage locations are marked with Global Positioning System (GPS) coordinates, lines/buoys, and shoreline references. After approximately 3 to 4 weeks, glochidia transform and fall off the gills of the host fish into the substrate of the river in open cages. Divers return at this time and release host fish to the river; the divers usually return in approximately 4 months to inventory contents of closed cages (Figure 12). Cages may be extremely heavy if a lot of sediment has deposited inside. Normally, two divers and two deckhands are needed to inventory cage contents. Cages are brought to the surface either by divers or by a winch and placed in the boat or on shore. Water from buckets or a pump is used to carefully wash contents from each cage. In 2002, we used a benthic sampling trough with ¼-inch mesh screens; mud and sand sediments were carefully washed through the screens and into the tray with water from a bilge pump. For cages full of sediment, we used a 4-inch suction pump designed for gold mining; sediment and mussels from inside the submerged cage were pumped to the sampling trough and screens on the boat (Figure 13).

To date, 84 cages with 3,365 host fish have been placed in Pools 1, 2, 3, and 24 of the UMR, lower St. Croix River and lower Wisconsin River. This represents approximately 238,700 potential juveniles.

Monitoring. Cage monitoring activities are described in Davis 2001 and 2002. With one exception, we have not monitored open cages; monitoring will begin in 2003 when mussels are large enough to collect. Because open cages are used in high velocity areas, it may be difficult to find juveniles/subadults as glochidia may be transported a considerable distance downstream. On June 15, 2001, 15 Higgins' eye were found under an open cage at the Hudson Site; they were 19 to 27 millimeters long and 12 months old. In comparison to other locations, current velocities at the Hudson Site are fairly low, which may explain our good fortune in finding these mussels.

In closed cages, juveniles fall to the sediment in the cage for collection. However, if water velocity is high, it is likely that a few/many are swept through the sides of the cage and settle somewhere downstream. On the basis of observations at the Genoa NFH, juvenile Higgins' eye are mobile and may also crawl out of the cages. We started monitoring closed cages in 2001 (Figure 14). To date, cages have produced 1,465 mussels representing 15 species (Table 3). Seventy-five percent (1,097) were Higgins' eye pearlymussels. We were surprised to find a variety of other species in the cages considering that all host fish were raised in isolated hatchery ponds at the Genoa NFH and were not subject to inoculation by other riverine mussels. One explanation is that cages act as fish attractors. Glochidia transforming from fish outside the cage may flow into the cage with river currents and settle to the bottom. As a test, we installed six empty closed cages in the summer of 2002 and will monitor them in 2003. Another explanation is that there may be a natural drift of glochidia in the river; glochidia passing into the cage may inoculate our host fish in the cage, transform, and settle to the bottom. If so, there should be no juvenile mussels in the six empty cages since they contain no host fish.

Production of juvenile Higgins' eye varied among cages at the same site (Table 4). For example, production of juvenile mussels in eleven cages placed in Lake Pepin ranged from 6 to 153 per cage. This is interesting because each cage received the same number of host fish (50 walleye each) that had been inoculated with standard methods at the Genoa NFH and randomly collected from the holding tank.

Likewise, production of juvenile Higgins' eye in cages varied among sites (Table 4). We can explain some of this variation; most of the 11 cages placed in Pool 1 were filled with sediment from summer floods and consequently produced only eight juveniles. However, we also experienced low production at the Pool 3 Site on the UMR; four cages produced only nine juveniles. For comparison, 222 juveniles were produced from two cages at the Prescott Site on the St. Croix River that were also placed on the same day and located only a mile or so upstream. The difference may be better habitat conditions in the St. Croix River at the Prescott Site.

Higgins' eye produced in cages were grouped into three age classes to evaluate growth and survival:

Age 1 Juveniles (4 months old). Age 1 juveniles are from cages placed in June and sampled in

September of the same year; they have completed one growing season. Growth over this time period ranged from 8 to 22 millimeters at the Hudson Site, 5 to 10 millimeters at the Prescott Site, 9 to 22 millimeters at the Lake Pepin Site, and 15 to 26 millimeters at the Pool 1 Site.

Age 2 Subadults (16 months old). Age 2 subadults have completed two growing seasons. It appears that survival in cages is excellent. For example, in June 2002, 15 Age 1 juveniles 19 to 27 millimeters long were collected from a cage in the St. Croix River at the Hudson Site and relocated to a cage at the Lake Pepin Site. The cage was monitored in September 2002 and all mussels were alive; total shell length ranged from 25 to 35 millimeters (Figure 14). Growth was approximately 7 millimeters over these 3 months.

Age 3 Subadults (28 months old). Age 3 subadults have completed three growing seasons. In June 2000, a closed cage was placed at the Lake Pepin Site. The cage was monitored 1 year later and three juveniles 7 to 10 millimeters long were collected. They were relocated to a cage at the Pool 3 Site in June 2001 and recaptured in June 2002; lengths were 15 to 21 millimeters. They were subsequently relocated to a cage at the Prescott Site and recaptured in September 2002; they were 35 to 45 millimeters long and grew approximately 10 millimeters over the 3-month period. Growth and survival of these three individuals appear to be excellent (Figure 14).

Overall, Total Shell Length of Higgins' eye at Age 1, 2, and 3 is approximately 10 to 20 millimeters, 20 to 40 millimeters, and 40 to 50 millimeters, respectively. In comparison, we have been unable to produce similar results in hatchery conditions at the Genoa NFH (Gordon 2002). Juveniles at 3 months of age in the hatchery are less than 1 millimeter long, versus 8 to 22 millimeters long in cages in the St. Croix River. Survival to 60 days has also been poor in the hatchery; in contrast, survival in cages appears to be excellent for Age 1 and older individuals, perhaps due to protection from larger predators.

Subadults Ready for Stocking. On the basis of monitoring data in September 2002, we have approximately 1,097 Higgins' eye mussels being held in propagation cages in the UMR and the St. Croix River (Table 5); 547 Age 1, 547 Age 2, and 3 Age 3 mussels. We also have nine cages at the Lake Pepin Site that have not been monitored. We estimate that these cages may contain an additional 400 Age 1 mussels. In total, we hope to have approximately 1,500 subadult Higgins' eye for stocking in the UMR and tributaries this summer. Kelner and Heath (2003) describe methods we will use for placement and subsequent monitoring of subadults.

Since 2000, zebra mussel abundance has increased in the lower St. Croix River. While zebra mussel densities in the lower St. Croix River are still low, they appear to be self-sustaining now and a source population for the UMR. In 2002, zebra mussels were found attached to subadult Higgins' eye inside propagation cages in the lower St. Croix River and in the UMR in Pools 3 and 4. They were also attached to the inside of cages but usually not on the outside. Propagation cages placed in Lake Pepin in 2000 had large numbers of zebra mussels inside cages but very few on the outside (Figure 10). Propagation cages may protect zebra mussels from fish predation. Magoulick and Lewis (2002) found that freshwater drum and other species significantly reduced densities of larger (>5 millimeters) zebra mussels that were attached to the surface of clay tiles in Lake Dardanelle, Arkansas. In June 2002, six empty cages were placed at two sites in Lake Pepin; three were completely enclosed in 1/4-inch screen, which may provide a refuge for zebra mussels. The remaining three cages had one side left open so fish could get inside and presumably eat zebra mussels. Cages will be monitored in 2003.

Stocking Juveniles

Stocking juvenile Higgins' eye is a relocation method we are trying in several UMR tributaries. In July and August 2000, juveniles were taken from the Genoa NFH and placed by a diver into wooden-framed, screen covered trays that were anchored to the bottom of the lower Wisconsin River, Wisconsin (Figure 15). On July 20, 2001, the contents of six hatchery trays (substrate and juvenile Higgins' eye) were placed by a diver in the lower Black River, Wisconsin (Heath 2002). The contents of all trays were placed on the substrate within 2 meters of each other in an area previously identified as a mussel bed.

To date, approximately 8,300 juveniles from the Genoa NFH have been released into the lower Wisconsin and lower Black Rivers in Wisconsin (Table 6). Monitoring will begin in 2003 when mussels are large enough to collect using methods described by Kelner and Heath (2003).

A major challenge at the Genoa NFH has been high mortality and slow growth of transformed juveniles (Gordon 2001). In 2001, high mortality was caused by predacious Hydra and flatworms; only 7.6 percent of juveniles in one hatchery treatment survived over 60 days. Average size of juveniles after 60 days in the hatchery was less than 1 millimeter, compared to 8 to 22 millimeters for juvenile mussels of similar age from propagation cages in the St. Croix River. Until we can improve survival and growth in the hatchery, juveniles are stocked as soon as possible after transformation. This may not help reduce mortality, though. In 2001, we placed juveniles from the Genoa NFH in two small screen cages in the St. Croix River to try to minimize predation. Only one juvenile Higgins' eye was later recovered from the cages, indicating poor survival.

Stocking Glochidia-inoculated Fish

Another relocation technique is stocking host fish that have been inoculated with glochidia. To illustrate this technique, on October 10 and 11, 2001, 1,800 host fish of six species were inoculated with Higgins' eye glochidia (Gritters 2001). Glochidia came from female mussels collected in the UMR, Pool 14, at Cordova, Illinois. Host fish included largemouth bass, smallmouth bass, spotted bass (*Micropterus punctulatus*), walleye, white bass (*Morone chrysops*) and freshwater drum (*Aplodinotus grunniens*). Hatchery fish (1,050) came from the Genoa NFH and the Rathbun State Fish Hatchery. The remaining wild fish (750) were collected by electrofishing in the Iowa River in the vicinity of the release site. Host fish were inoculated in the field and released into the Iowa River (Figure 16). Attachment rates for glochidia ranged from 27 to 65 per fish; an estimated 101,227 glochidia were attached to released fish. Assuming a transformation rate of 65 percent, approximately 65,765 juveniles may have settled to the bottom of the Iowa River. In another release, 450 glochidia-inoculated smallmouth bass were released into the lower Wisconsin River (Heath 2001). These fish were inoculated at the Genoa NFH with glochidia from females collected from the lower St. Croix River; estimated total attachment was 25,020 glochidia and potential for 16,263 juvenile Higgins' eye.

To date, approximately 7,000 glochidia-inoculated fish have been released into the Wapsipinicon, Cedar, and Iowa Rivers in Iowa and the lower Wisconsin River in Wisconsin (Table 7). Host fish released were inoculated and held at the Genoa NFH, or captured from the receiving water and inoculated in the field (Figure 16). Although this technique is simple to conduct, monitoring will be difficult because we do not know where fish travel over the 3- to 4-week period when transformation occurs. In 2004, we will radio tag some host fish so we have an idea where they travel over this time period to assist in monitoring.

Cleaning and Stockpiling Adults

One way to increase survival of native mussels in waters infested with zebra mussels is to periodically clean them of zebra mussels and return them to their habitat (Hallac and Marsden 2001). Often, Higgins' eye and other mussels are completely covered with zebra mussels (Figure 2). We currently have three clean and stockpile sites (Pool 11, 14 and lower Wisconsin River) totaling 547 adult mussels (Figure 17). Anderson (2002) described methods used to clean and stockpile 197 adult Higgins' eye at the Pool 11 Site. In general, mussels are collected at a site infested with zebra mussels, cleaned of zebra mussels by scrubbing with a stiff brush, measured, sexed, individually marked and photographed. They are returned to the river and hand-placed on the bottom by divers at a known location marked by GPS coordinates, rope/buoys, or shoreline references. A year later, they are monitored and recleaned, if necessary. Another benefit of the stockpile sites is that females can easily be collected for fish inoculation.

Cleaning and Relocating Adults

At locations where zebra mussels pose a significant threat to native mussels, adults are cleaned of zebra mussels and relocated to areas of the UMR within the species' historic range having no/few zebra mussels (i.e., we move them out of harm's way). We have two adult relocation sites: one in Pool 2 above the confluence of the Minnesota River in the Twin Cities, Minnesota, and another in Pool 3 near Hastings, Minnesota. These two sites were chosen because recent mussel surveys found good populations with few zebra mussels (Kelner and Davis 2000, 2002).

For unknown reasons, zebra mussels have not infested the UMR upstream of Lock and Dam 3 as they have in downstream areas below Lake Pepin in Pool 4. Adult zebra mussels are transported upstream of Lock and Dam 3 by towboats and barges and are present at Upper St. Anthony Falls, the most upstream navigation lock and dam on the UMR (Yager 1993). We also know they successfully reproduce above Lock and Dam 3; veligers have been collected below Lock and Dam 2 in previous studies. The Minnesota River enters the UMR approximately 2 miles downstream of Lock and Dam 1. It provides a significant amount of fine sediment from Minnesota's farming country. Perhaps the fine sediments interfere with survival, growth, and/or attachment of veligers in Pools 2, 3, and upper 4. Or, perhaps flow velocities and growth rates do not allow for settlement of veligers until they reach lower Pool 4. What we know at this time is that the reach of the UMR from the Coon Rapids Dam in the Twin Cities metropolitan area to upper Pool 4 in Lake Pepin has a diverse mussel community that does not appear to be adversely affected by zebra mussels (Kelner and Davis 2000, 2002).

To date, 471 adult Higgins' eye and approximately 2,100 State-listed species have been relocated from Pool 11 at Cassville, Wisconsin (2000), and Pool 14 at Cordova, Illinois (2001). We relocated 370 adult Higgins' eye to the Pool 2 Site and 101 to the Pool 3 Site. The Cordova relocation project is described in Anderson et al. 2002; this relocation was accomplished as part of a mussel workshop conducted by the Illinois Chapter of the American Fisheries Society. Cleaning and processing methods are the same as previously described; mussels are then placed in burlap sacks suspended in water in a hatchery truck and transported to the relocation site (Figure 18). They are transported by boat and hand-placed in the river bottom by divers. The location of the site is noted by GPS coordinates, rope/buoys, and shoreline references.

Survival of relocated adults is good; of 63 Higgins' eye recovered at the two relocation sites in 2002, only one was found dead (Davis 2002). Also, gravid females were collected at both relocation sites in September 2002, suggesting that relocated adults may already be creating new/enhancing existing populations (Figure 18). We observed unusual growth (exaggerated growth arrest lines and inturning) along the ventral margin of shells from several individuals at the Pool 2 Site (Figure 18). Otherwise, they appeared to be in good health and grew an average of 3.3 millimeters from July 2001 to September 2002 (14 months). Starting next year, we will be using methods described by Kelner and Heath (2003) to monitor relocated adults.

Long-Term Monitoring of Mussels at Essential Habitat Areas

Native and zebra mussels have been monitored at several EHA's and other important sites since 2000 (Tables 8 and 9). Of particular interest are results from the Prairie du Chien EHA where density of Higgins' eye and other native mussels remains low in comparison to high abundance of zebra mussels (Farr and Miller 2003; Figure 19). Unfortunately, this trend is evident for native mussels at other EHA's (Figure 20).

One of the most interesting discoveries is the abundance of adult Higgins' eye found in shallow water areas of the UMR during the past two summers. Previous studies have shown that Higgins' eye is usually associated with deeper water. This summer we collected 371 adult Higgins' eye from the Cordova EHA; most came from shallow water by wading (polywogging). We also collected and stockpiled 197 adults this summer from the Cassville Site; again, nearly all were collected by wading in shallow water versus diving in deeper water.

Outreach

From local news articles and public radio shows to Fox News and Associated Press articles, MCT mussel conservation activities have been widely publicized. Of particular interest to the media are activities associated with propagation in cages and at the Genoa NFH, and news about zebra mussels (Figure 21). In 2003, we hope to release an updated version of the booklet "Freshwater Mussels of the Upper Mississippi River"(Wisconsin Department of Natural Resources 1985). This booklet was originally published in 1985 by the Wisconsin Department of Natural Resources and used extensively in public outreach efforts. In addition, we hope to have up and running an Internet web site on mussels of the UMR.

Zebra Mussel Control Plan

The second requirement of the Biological Opinion is development of a reconnaissance study by the Corps to determine the necessary measures, projected costs, and likelihood of success in controlling zebra mussels in the UMR (U.S. Fish and Wildlife Service 2000). In March 2002, the Corps produced a "Draft Reconnaissance Study, Measures for Managing Zebra Mussels in the Upper Mississippi River Navigation System - Federal Interest Assessment." Although the document has not been finalized, zebra mussel activities have been initiated.

In 1991, the first zebra mussel was collected on the UMR in Pool 8 near La Crosse, Wisconsin. Although densities have declined in lower reaches of the UMR and the Illinois River since then, zebra mussels are still abundant in most navigation pools upstream of the Illinois River. In 1992, the Corps began monitoring zebra mussels at the navigation locks and dams from Upper St. Anthony Falls to Pool 10. In 1993, densities in the lockworks ranged from zero at Lower St. Anthony Falls and Lock and Dam 1 to 6.5 per square meter at Lock and Dam 7 (Yager 1993); in general, densities increased in a downstream direction. In 1998, the Wisconsin and Iowa Departments of Natural Resources began collecting zebra mussel veligers below locks and dams on the UMR. In 2001, the Corps expanded veliger studies to include the UMR downstream of Locks and Dams 2 through 19 (Stoeckel 2002; Figure 22). They also sampled veligers from major tributaries in hopes of finding potential relocation areas for Higgins' eye that had no/few zebra mussels. Unfortunately, veligers were collected at nearly all sites; at this time, only the Chippewa River and the UMR above Upper St. Anthony Falls Lock and Dam are free of zebra mussels (Table 10). Veliger sampling continued in 2002 and included additional tributaries; results will be available in 2003.

Zebra mussels appear to be expanding their range on the UMR and tributaries within the historic range of Higgins' eye, which may result in fewer places for possible relocation. Figure 23 shows an abundance of native and zebra mussels in 2002 at several important mussel habitats on the UMR. Although zebra mussels are increasing their densities in some areas, there appears to be a significant reduction in abundance of zebra mussels on the Illinois River and the UMR in Pool 24. Consequently, we are reevaluating the potential for relocation of Higgins' eye into these former habitats. In 2001, we also saw a "die-off" of zebra mussels in several UMR pools in the upper reaches including Adult Clean and Stockpile Sites in Pools 11 (Cassville) and 14 (Cordova). Unfortunately, this phenomenon did not last, and zebra mussels returned in 2002. However, the potential exists that zebra mussel abundance may decline significantly in portions of the historic habitat of Higgins' eye, offering the potential for relocation and establishment of new/enhancement of existing populations.

One concern on the horizon is the exotic quagga mussel (*Dreissena bugensis*), which is similar in appearance to zebra mussels and a potential threat to native mussels. Approximately 9 years ago, zebra mussels outnumbered quaggas by 100 to one in Lake Erie. Today, this trend is reversed and quaggas, which apparently outcompete zebra mussels, now outnumber zebra mussels by 10 to one (Mississippi Interstate Cooperative Resource Association 2002). Unfortunately, quagga mussels also survive in deeper water and spawn in colder water than zebra mussels, which may allow them to become established in more northern reaches of the UMR and tributaries.

Future Activities

We will continue with our relocation activities in 2003 and beyond. New items include:

Monitoring open cage sites
Monitoring sites where glochidia-inoculated fish have been released into the wild
Stocking subadult mussels
Installing two wooden "corrals" in Lake Pepin (Pool 4)
Installing three floating cages in UMR Pools 9 and 11
Installing closed bottom cages in UMR Pools 12 and 13
Monitoring clean and stockpile sites and recleaning, if necessary
Surveying mussels at seven locations including UMR Pools 17, 19, and 20
Conducting a shallow water survey of mussels at Harpers Slough EHA, UMR Pool 10
Producing an updated booklet "Freshwater Mussels of the Upper Mississippi River"
Producing an Internet web site on "Freshwater Mussels of the Upper Mississippi River"

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Table 1. Summary data on evidence of recent recruitment (percent individuals and species less than 30 mm total shell length) and unionid and zebra mussel density in the East Channel, Upper Mississippi River, Prairie du Chien, Wisconsin. Information from U.S. Fish and Wildlife Service (2000) based on unpublished 1999 data from the U.S. Army Corps of Engineers.

Year	Number of Quadrants	Unionid Recruitment		Mean Density Individuals /sq m	
		% Ind. <30mm	% Species <30mm	Unionids	Zebra Mussels
1984	20	10.7	45.8	113.6	
1985	30	15.2	66.7	149.1	
1987	30	34.4	75.0	68.5	
1988	30	24.5	52.0	79.5	
1989	10	16.3	44.4	83.6	
1990	30	14.8	42.1	80.0	
1992	30	17.6	36.8	44.7	
1993	30	41.5	44.4	28.3	2.0
1994	40	20.7	52.0	63.4	36.5
1996	60	32.4	66.7	59.2	10,853.0
1998	60	25.8	45.0	10.1	1,762.0
1999	60	0.0	0.0	1.7	56,507.0

Table 2. Number of host fish inoculated with Higgins' eye glochidia and subsequent attachment and transformation rates, Genoa National Fish Hatchery, Wisconsin, Spring 2002 (Gordon 2002).

Rate	Walleye	Smallmouth Bass	Largemouth Bass
No. fish inoculated	1,700	1,780	1,750
No. glochidia encysted /fish	149 - 170	146 - 166	165 - 283
% survival to juvenile	38.0	41.0	47.0
No. juveniles/fish	57 - 65	60 - 68	78 - 133
Est. juveniles produced	100,400	106,540	176,600

Table 3. Species collected from mussel propagation cages in the Upper Mississippi and St. Croix Rivers.

Common Name	Scientific Name	Number (per cage)	Percent total
Higgins' eye pearlymussel	*Lampsilis higginsii*	1,097 (1 - 200)	74.9
Asiatic clam	*Corbicula sp.*	162 (1 - 120)	11.0
Paper pondshell	*Utterbackia imbecillis*	129 (1 - 56)	8.8
Fragile papershell	*Leptodea fragilis*	33 (1 - 15)	2.2
Threeridge	*Amblema plicata*	15 (2 - 5)	1.0
Lilliput	*Toxolasma parvus*	10 (1 - 3)	0.7
Pink healsplitter	*Potamilus alatus*	6 (1 - 3)	0.4
Pink papershell	*Potamilus ohiensis*	6 (1 - 2)	0.4
Black sandshell	*Ligumia recta*	1	0.1
Rock pocketbook	*Arcidens confragosus*	1	0.1
Giant floater	*Pyganodon grandis*	1	0.1
Plain pocketbook	*Lampsilis cardium*	1	0.1
Threehorn wartyback	*Obliquaria reflexa*	1	0.1
Spike	*Elliptio dilatata*	1	0.1
Ohio River pigtoe	*Pleurobema sintoxia*	1	0.1
	Total	1,465	

Table 4. Propagation of Higgins' eye pearlymussels in cages in the Upper Mississippi and St. Croix Rivers.

Date	Location	Name	No. Cages	Host-No.	L.h. Female Location	Date Monitored	No. L. hig. No.(range)	TSL (mm)	Age (mo)
6-5-01	SCR0.2	PRESCOTT	2-CR	SMB-75	ST.CROIX	9-26-02	222(37-185)	20-42	16
6-5-01	SCR16.5	HUDSON	4-CR	SMB-75	ST.CROIX	6-20-02	196(0-96)	17-31	12
5-30-02	UMR848.2	POOL 1	16-CR	LMB-30	ST.CROIX	9-30-02	8(0-6)	15-26	4
6-5-01	UMR810.6	POOL 3	4-CR	SMB-75	ST.CROIX	6-20-02	9(0-5)	15-33	12
5-25-00	UMR779.4	L. PEPIN	2-CR	LMB-75	ST.CROIX	5-31-01	3(0-3)	9-13	12
5-29-02	UMR779.4	L. PEPIN	11-CR	WAE-25	ST.CROIX	9-24-02	547(6-153)	9-22	4

CR = closed bottom rectangular cage.
TSL = total shell length
WAE = walleye
LMB = largemouth bass
SMB = smallmouth bass
SCR = St. Croix River
UMR = Upper Mississippi River

Table 5. Contents of mussel propagation cages on the Upper Mississippi River and tributaries. Data from most recent monitoring.

Date	Location	Name	Cage ID #	Type	Host-No. Sp	L.h. Female Location	Date Monitored	No. L. hig.	TSL (mm)	Age (mo) June 2003
6-5-01	SCR0.2	PRESCOTT	99	CR	SMB-75	St.CROIX	9-26-02	159	20-42	24
6-5-01	SCR0.2	PRESCOTT	100	CR	SMB-75	St.CROIX	9-26-02	158	20-42	24
						St.CROIX	9-26-02	3	35-45	36
6-5-01	SCR16.5	HUDSON		CR	SMB-75	St.CROIX	6-20-02	215	17-31	24
5-29-02	UMR779.4	L. PEPIN	1	CR	WAE-25	St.CROIX	9-24-02	272	9-22	12
						St.CROIX	9-24-02	15	25-35	24
5-29-02	UMR779.4	L. PEPIN	2	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	3	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	11	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	13	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	14	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	15	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	16	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	17	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	19	CR	WAE-25	St.CROIX				
5-29-02	UMR779.4	L. PEPIN	20	CR	WAE-25	St.CROIX	9-24-02	275	9-22	12
						Totals	**Age (mo)**	**Number**	**TSL (mm)**	
							12	**547**	**9-22**	
							24	**547**	**20-42**	
							36	**3**	**35-45**	
							Total	**1097**		

9 Cages at UMR779.4 not monitored yet = may have approx. 400 L. higginsi 24 months old in June, 2003 = total mussels available for relocation = 1,500.

CR = closed bottom rectangular cage.
TSL = total shell length
WAE = walleye
LMB = largemouth bass
SMB = smallmouth bass
SCR = St. Croix River
UMR = Upper Mississippi River

Female Batch Number = female Higgins' eye used in inoculation of host fish
- Batch 1 = Female Nos. 502,506,510,514,515
- Batch 2 = Female Nos. 725,727,730,731,732,733,734,735,738,739,740,741,742,749,752,753,755,1310
- Batch 3 = Female Nos. 762,763,764,766,767,780,781,785,788,795,894

Table 6. Juvenile Higgins' eye pearlymussels produced at the Genoa National Fish Hatchery, Wisconsin and relocated to tributaries of the Upper Mississippi River. WIR = Wisconsin River, Wisconsin. BLR = Black River, Wisconsin. WAE = walleye, LMB = largemouth bass, SMB = smallmouth bass.

Date	Location	No. Juveniles	Host Species	Female
7-10-00	WIR-RM6.5	3750	WAE, LMB	ST.CROIX
8-1-00	WIR-ORION	1100	WAE, LMB	ST.CROIX
7-20-01	BLR-RM60.62	1914	SMB, LMB	ST.CROIX
6-20-02	BLR-RM60.62	1200	WAE, LMB	ST.CROIX

Table 7. Number of glochidia inoculated host fish released into the Upper Mississippi River and tributaries. W = wild fish; GFH = Genoa National Fish Hatchery; RFH = Rathbun State Fish Hatchery. WAP = Wapsipinicon River, Iowa. IAR = Iowa River, Iowa. CDR = Cedar River, Iowa. WIR = Wisconsin River, Wisconsin.

Date	Location	# Fish Female Lh.	Smallmouth Bass	Largemouth Bass	Walleye	Other
10-10-01	IAR- Iowa City	1800 CORDOVA	1.	500 GFH 500 RFH 76 W	37 W 50 RFH	1.
6-4-02	IAR - Iowa City	615 CASSVILLE	615 GFH			
6-4-02	WAP - Central Cty	1100 CASSVILLE			1100 GFH	
6-4-02	WAP - Anamosa	900 CORDOVA		900 GFH		
6-8-01	CDR - Palisades	1198 ST.CROIX	793		405	
6-4-02	CDR - Palisades	615 ST.CROIX	615 GFH			
6-13-01	WIR-RM89.16	450 ST.CROIX	450 GFH			
5-29-02	WIR - RM 89.16	275 ST.CROIX	275 GFH			

1. 60 wild freshwater drum, 577 wild white bass, unknown number of wild spotted and smallmouth bass.

Table 8. Monitoring sites for native and zebra mussels on the Upper Mississippi River and tributaries. EHA = Essential Habitat Area; WIR = Wisconsin River; SCR = St. Croix River; UMR = Upper Mississippi River.

Site	Location	2000	2001	2002
Orion EHA	WIR			X
Interstate EHA	SCR	X		
Hudson EHA	SCR	X		
Prescott EHA	SCR	X		
Winters Landing	UMR Pool 7	X	X	
Whiskey Rock EHA	UMR Pool 9	X	X	X
Harpers Slough EHA	UMR Pool 10	X	X	
East Channel EHA	UMR Pool 10	X	X	X
McMillan Island EHA	UMR Pool 10	X	X	
Cassville	UMR Pool 11		X	X
Bellevue	UMR Pool 13	X		X
Cordova EHA	UMR Pool 14	X	X	
Sylvan Slough EHA	UMR Pool 15	X		X
Muscatine	UMR Pool 17	X		X
Pool 24 Relocation Site	UMR Pool 24			X

Table 9. Most recent monitoring results from ten Essential Habitat Areas on the Upper Mississippi River and tributaries. Lower Wisconsin River = Orion (ORI); Lower St. Croix River = Interstate (INT), Hudson (HUD), Prescott (PRS); Upper Mississippi River = Whiskey Rock (WKR), Harpers Ferry Slough (HFS), Prairie du Chien (PDC), McMillan Island (MMI), Cordova (CDV), and Sylvan Slough (SSL). Percent individuals <30 mm total shell length is used as an indicator of recent recruitment. Density is expressed as individuals per square meter. Data from Farr and Miller 2002, 2003 (1/4-square meter samples) and Wisconsin Department of Natural Resources (1-square meter samples*).

Variable	ORI	INT	HUD	PRS	WKR	HFS	PDC	MMI	CDV	SSL
Samples	99*	150*	152*	40	50	40	40	50	40	40
Species	21	27	27	10	10	4	16	6	3	7
Individuals	612	2950	999	52	43	10	36	24	6	59
Density (#/m2)	1.4	19.7	6.6	5.2	3.4	1.0	3.6	1.9	0.6	5.9
%Ind.<30mm					9	0	11	17	0	14
No. *L. higginsii*	0	2	12	0	0	0	0	0	0	1

Table 10. Density of zebra mussel veligers (number/liter) in the Upper Mississippi River and tributaries, 2001.

River	July	August	September
UMR at Coon Rapids, MN	0	0	0
St. Croix at Kinnickinnic Narrows., WI	0.08	0.66	0.44
St. Croix. at Prescott, WI	1.10	2.41	2.11
Chippewa, WI	0	0	0
Black, WI	0	0.02	0
Yellow, IA	37.10	26.90	18.40
Wisconsin, WI		0.38	0.02
Turkey, IA	39.60	3.60	
Maquoketa, IA	0	1.10	6.84
Wapsipinicon, IA	10.35	3.91	0.20
Rock, IL	0	0.03	0.65
Cedar, IA	0	0	0.80
Iowa, IA	0.13	0.42	0.23
Skunk, IA	5.40	0.60	0
Des Moines, IA	16.50	0.20	0.85

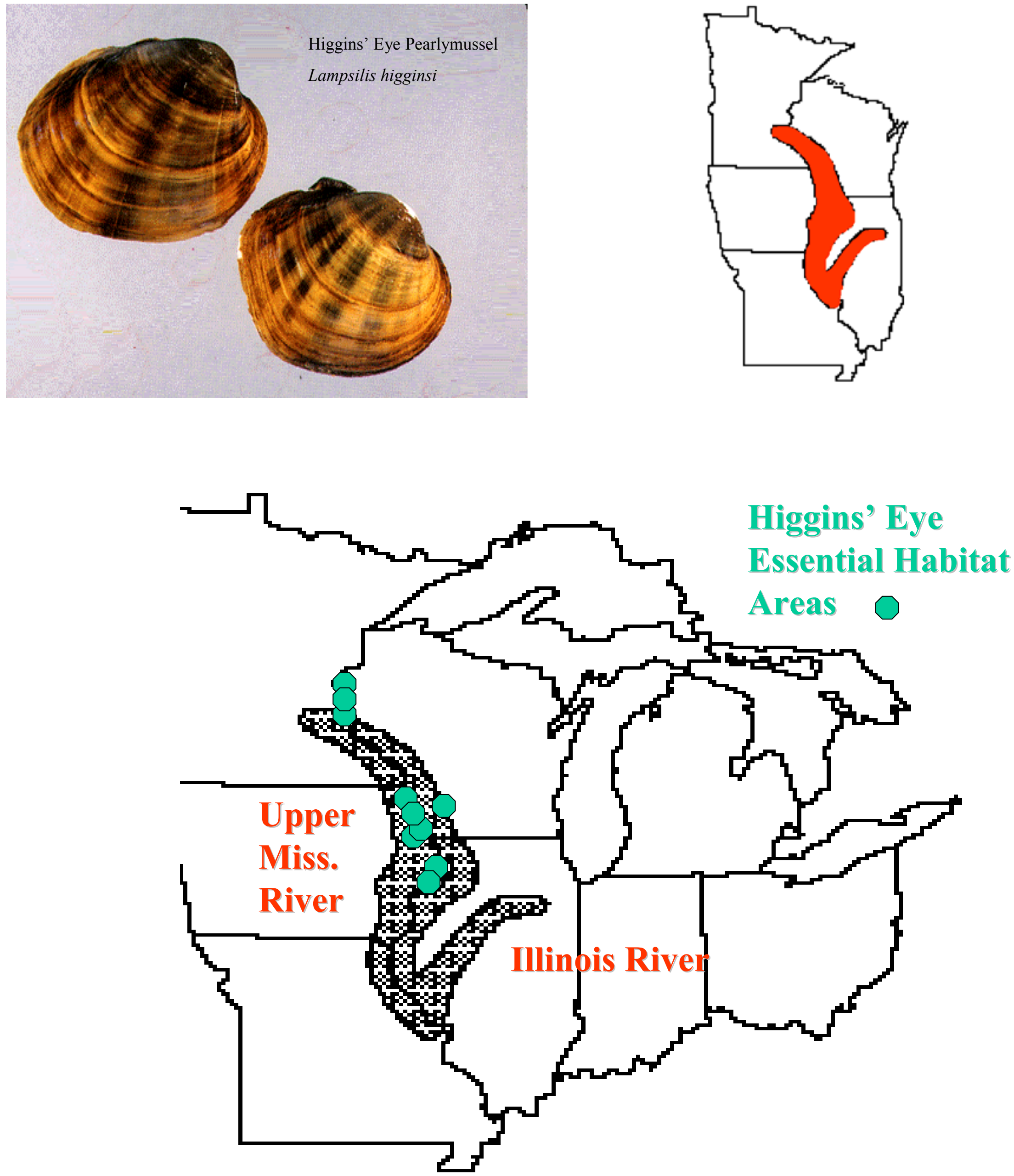

Figure 1. The federally endangered Higgins' eye pearlymussel (*Lampsilis higginsii*); male on left, female on right. The historic range of the Higgins' eye pearly mussel is shown in red. Ten Essential Habitat Areas (green dots) were identified in the 1982 and draft revised recovery plan.

Figure 2. Top photos show the distribution of zebra mussels between 1988 and 2000. (photos courtesy of the U.S. Geological Survey). The middle photos show zebra mussels attached to a barge in the Twin Cities, Minnesota, and a houseboat in La Crosse, Wisconsin. (photos courtesy of the Minnesota Department of Natural Resources). The bottom photos show zebra mussels scooped from the bottom of Lake Pepin by a diver; they formed a “carpet” on the bottom. They also covered individual mussels; this fat mucket (*Lampsilis siliquoidea*) was removed from the bottom sediment by divers. All exposed areas were covered by zebra mussels. (photos courtesy of the Minnesota Department of Natural Resources).

Figure 3. Mussel propagation facilities at Genoa National Fish Hatchery located in Pool 9 of the Upper Mississippi River near Genoa, Wisconsin. (photos courtesy of U.S. Fish and Wildlife Service)

MUSSEL COORDINATION TEAM

Upper Mississippi River and Tributaries

PARTNERING AGREEMENT

We, the partners involved in the management of native unionid mussel fauna on the Upper Mississippi River and tributaries, are committed to working together as a trusting, cooperative team to coordinate planned mussel studies and projects and share information on the management of native mussel resources and the control of invasive non-indigenous mussel species.

GOALS

I. We will actively work to foster confidence and mutual trust by discussing issues openly and respecting differences if they arise.

II. Consistent with our own programs, authorities, and funding limitations, we will work jointly towards our objectives of conserving native mussels and controlling non-indigenous mussels.

III. We will encourage interagency and public communications about our ongoing studies and plans to maximize public awareness of and involvement in our mussel conservation and control activities.

IV. We will coordinate our activities to avoid duplication of efforts and administrative delays.

V. We will share information on mussel conservation and non-indigenous mussel control activities.

MEMBERS

U.S. Army Corps of Engineers - St. Paul District

U.S. Army Corps of Engineers - Rock Island District

U.S. Fish and Wildlife Service - Region 3

U.S. Geological Survey - UMESC

National Park Service - Regional Office

U.S. Coast Guard

Iowa Department of Natural Resources

SCWRS Director

Science Museum of Minnesota - SCWRS

Illinois Department of Natural Resources

Minnesota Department of Natural Resources

Wisconsin Department of Natural Resources

Figure 4. Partnering Agreement establishing the Mussel Coordination Team (MCT).

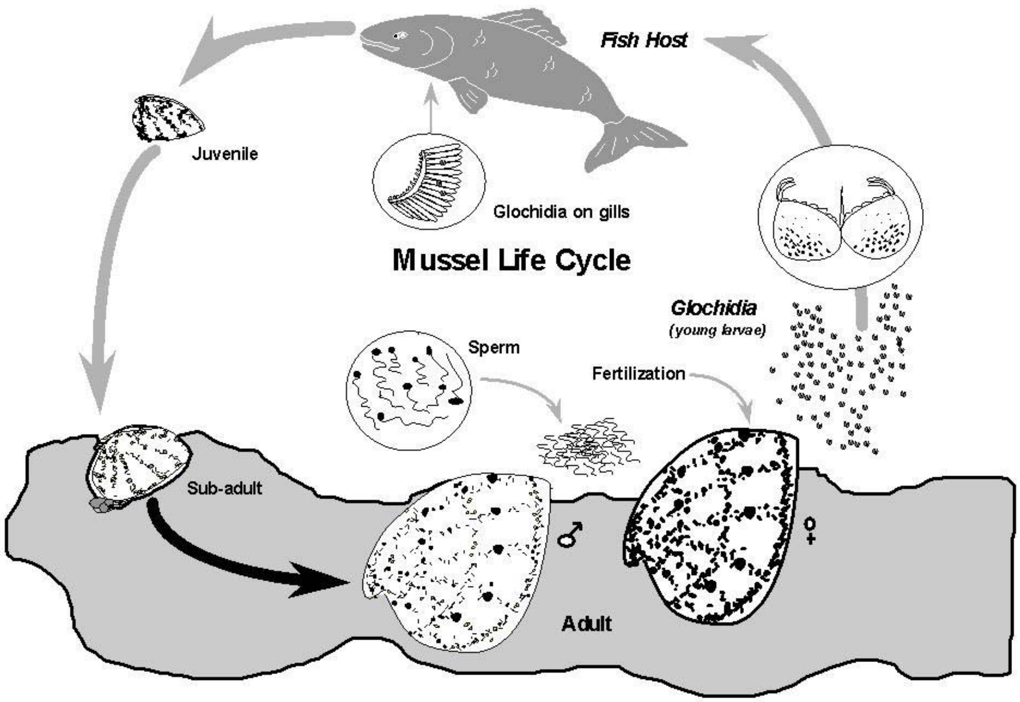

Figure 5. Life history of freshwater mussels. The bottom photo shows the fish "lure" displayed by a gravid female mussel to attract a host fish (*Lampsilis reeveiana*; photo courtesy of Chris Barnhart, Southwestern Missouri State College, Missouri). The lure of the female Higgins' eye pearlymussel is similar.

Figure 6. Collection of glochidia from a gravid female Higgins' eye pearlymussel at the Genoa National Fish Hatchery, Wisconsin. Glochidia are collected by injecting water into the gills with a syringe. Glochidia (middle left) are flushed into a collecting dish, tested for viability with salt, and a measured quantity placed in a bucket containing host fish. Contents of the bucket are mixed for a period of time. The gills of an individual host fish is examined under a microscope to estimate the number of attached glochidia. When a suitable number of glochidia are attached, host fish are placed into a concrete holding tank. (photos courtesy of U.S. Fish and Wildlife Service)

Figure 7. Host fish produced at Genoa National Fish Hatchery for glochidia inoculation include largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieui*), and walleye (*Stizostedion vitreum vitreum*). Bottom right photo shows host fish (largemouth bass) in a bucket ready for addition of Higgin's eye glochidia. (photos courtesy of U.S. Fish and Wildlife Service)

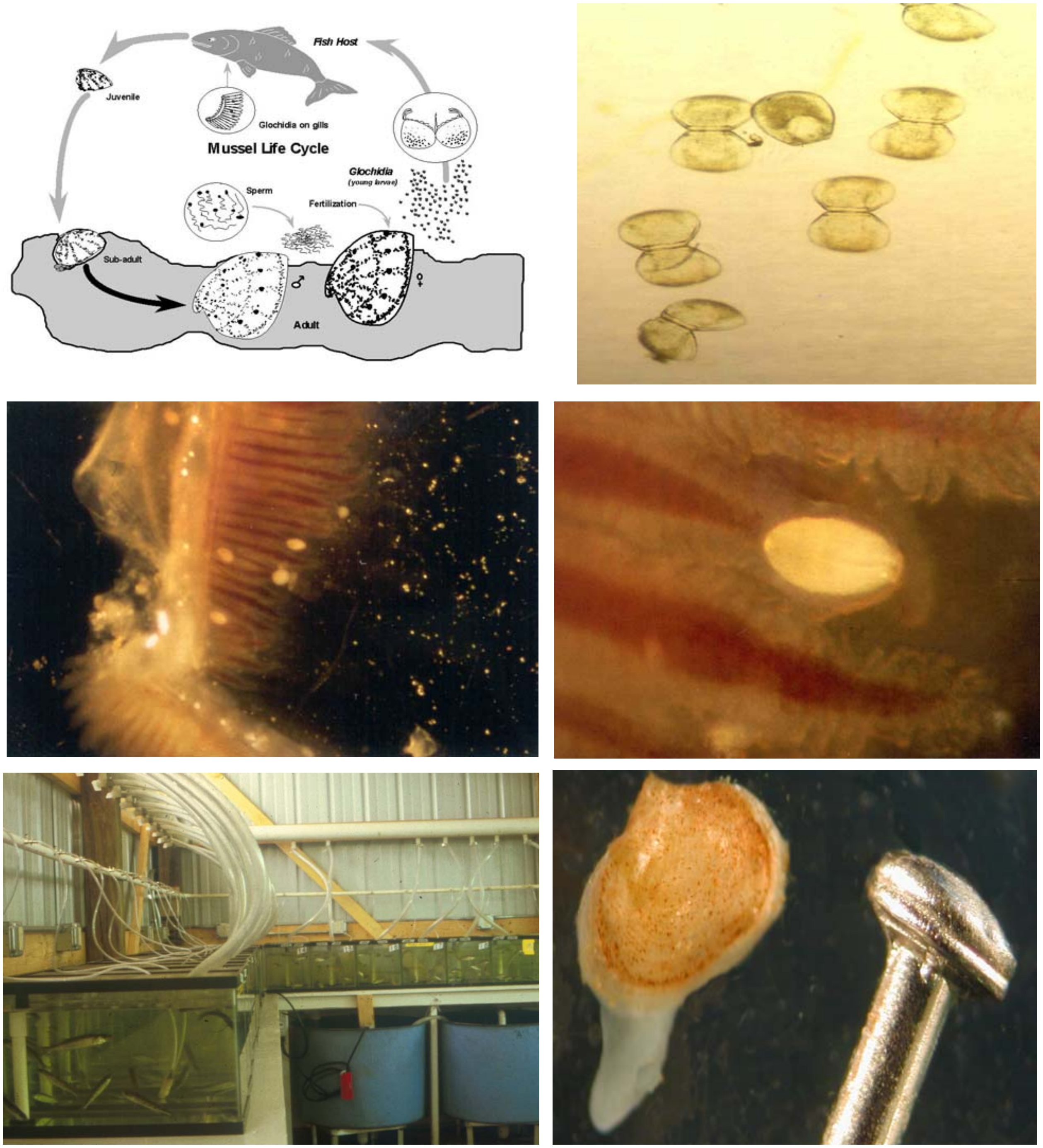

Figure 8. Transformation of glochidia from Higgins' eye pearlymussels at the Genoa National Fish Hatchery, Wisconsin. In mixing buckets, glochidia (top left) attach to the gills of host fish (middle left) and encyst (middle right). Host fish are placed in aquariums and glochidia transform, fall of the gills and settle to the bottom as juveniles. The juvenile shown in the lower right photo is approximately 0.75 millimeters long; it is shown next to the head of a pin for size comparison. (photos courtesy of the U.S. Fish and Wildlife Service)

Figure 9. Historic photos of mussel propagation in wooden "corrals" in Lake Pepin, Pool 4, near Lake City, Minnesota. Photos were taken by R. Corwin around 1916 and are courtesy of the Milwaukee Public Museum.

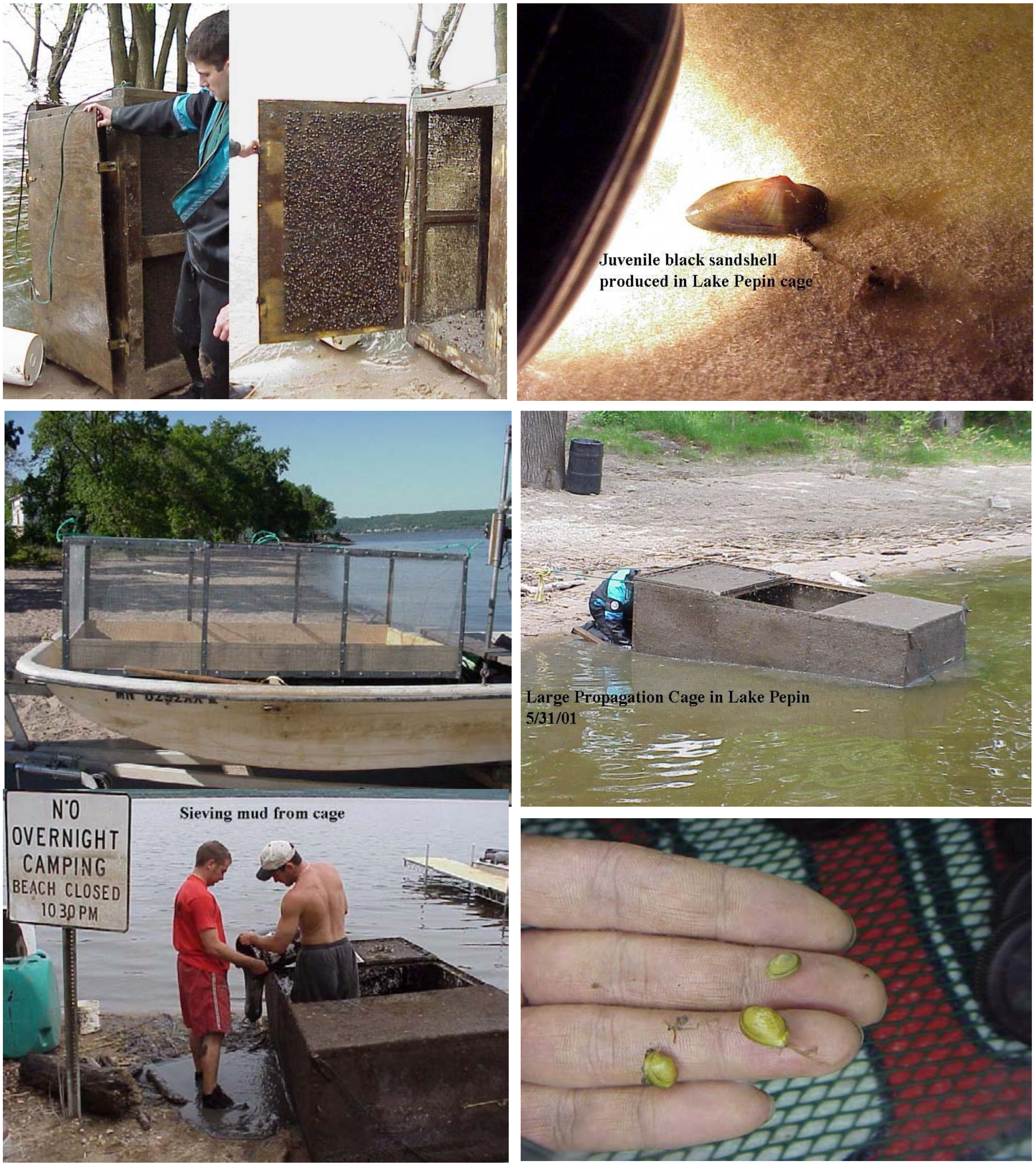

Figure 10. Two propagation cages placed in Lake Pepin (Pool 4) in June 2000. Zebra mussels are shown attached to the inside of the wooden cage in the top photos; one subadult black sandshell (*Ligumia recta*) was found in June, 2001. The middle and bottom photos show installation of a metal frame and subsequent monitoring. The cage filled with sediments and was difficult to monitor; three subadult Higgins' eye pearlymussels (*Lampsilis higginsii*) were collected in June 2001. (photos courtesy of the Minnesota Department of Natural Resources).

Figure 11. Cages used to propagate Higgins'eye pearlymussels on the Upper Mississippi River. Cages are constructed of aluminum sides, base and ½-inch screen. The top left photo shows two types of cages; the cage on the left is used in low current areas and the right one in higher velocity areas. These are open cages with no bottoms; closed cages have a 3/8-inch plywood bottom to collect transformed mussels (top right photo). The middle and bottom photos show the process of transporting cages (closed) to the relocation site, adding host fish (smallmouth bass) and placing cages on the river bottom. (photos courtesy of the Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service)

Figure 12. Monitoring cages in the Upper Mississippi and St. Croix Rivers. Cages are brought to the surface and placed in the boat or on shore. Water is used to wash contents; benthic sampling trays are used to screen sediment and small mussels. Larger mussels and sediment can be washed using the cage as a screen. (photos courtesy of the Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service)

Figure 13. Suction dredge used by the Minnesota Department of Natural Resources to sample mussels. Diver places suction nozzle inside cage or on river bottom; contents are pumped to screening trays where mussels are sorted. (photos courtesy of the U.S. Fish and Wildlife Service)

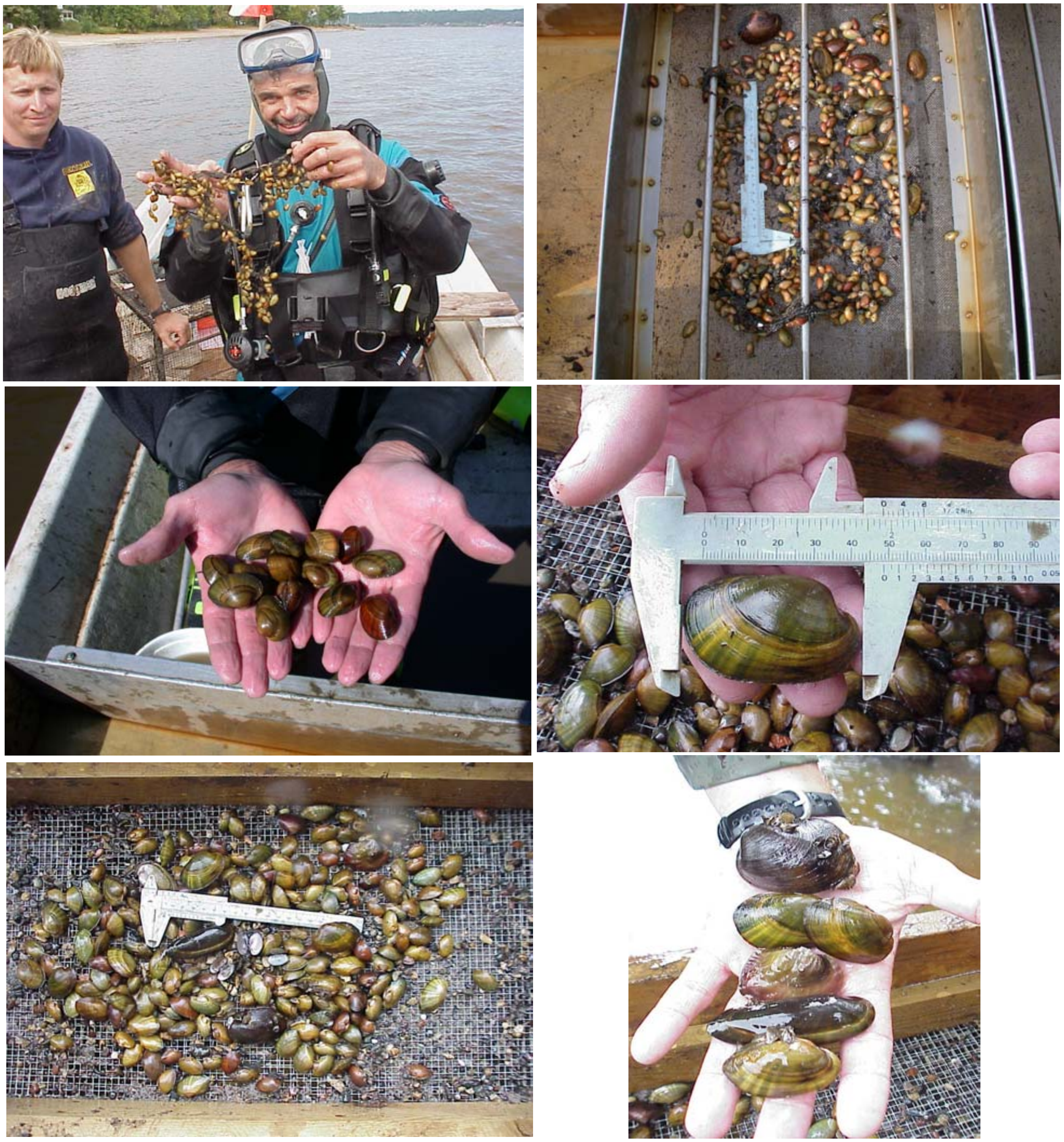

Figure 14. Higgins' eye pearlymussels produced in cages in the Upper Mississippi and St. Croix Rivers. The diver is holding 3-month old Higgins' eye mussels by their byssal threads. The top tray contains approximately 562 mussels (547 are 3 months old and 9 - 22 mm long). The middle left photo shows 15 individuals from this tray that are 15 months old and 25 - 35 mm long. The 28-month old individual in the middle right photo is approximately 48 mm long. The bottom photos show a mixture of age groups and species; the right photo shows 3 Higgins' eye and a rock pocketbook, monkeyface and black sandshell. (photos courtesy of the Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service)

Figure 15. Stocking juvenile Higgins' eye pearlymussels into the Lower Wisconsin River, Wisconsin. Juveniles were produced at the Genoa National Fish Hatchery, Wisconsin. The diver is submerging a wooden tray containing approximately 3,700 juveniles. The juvenile in the photo is less than one millimeter long and is shown next to the head of a pin for size comparison. The bottom photo shows a small cage placed in the Lower St. Croix River in 2001. (photos courtesy of the Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service)

Figure 16. Stocking glochidia inoculated fish into the Iowa River, Iowa. Host fish are obtained from a fish hatchery or collected in the wild from the Iowa River. Laboratory equipment is set up in the field and glochidia collected from female Higgins' eye pearlymussels. Glochidia are inserted into the gills of larger host fish with a pipette; smaller host fish are inoculated in a bucket containing glochidia. Host fish are released into the Iowa River and in approximately 2 - 4 weeks glochidia transform, fall off the gills of the host fish, and settle to the river bottom as juveniles. (photos courtesy of the U.S. Fish and Wildlife Service)

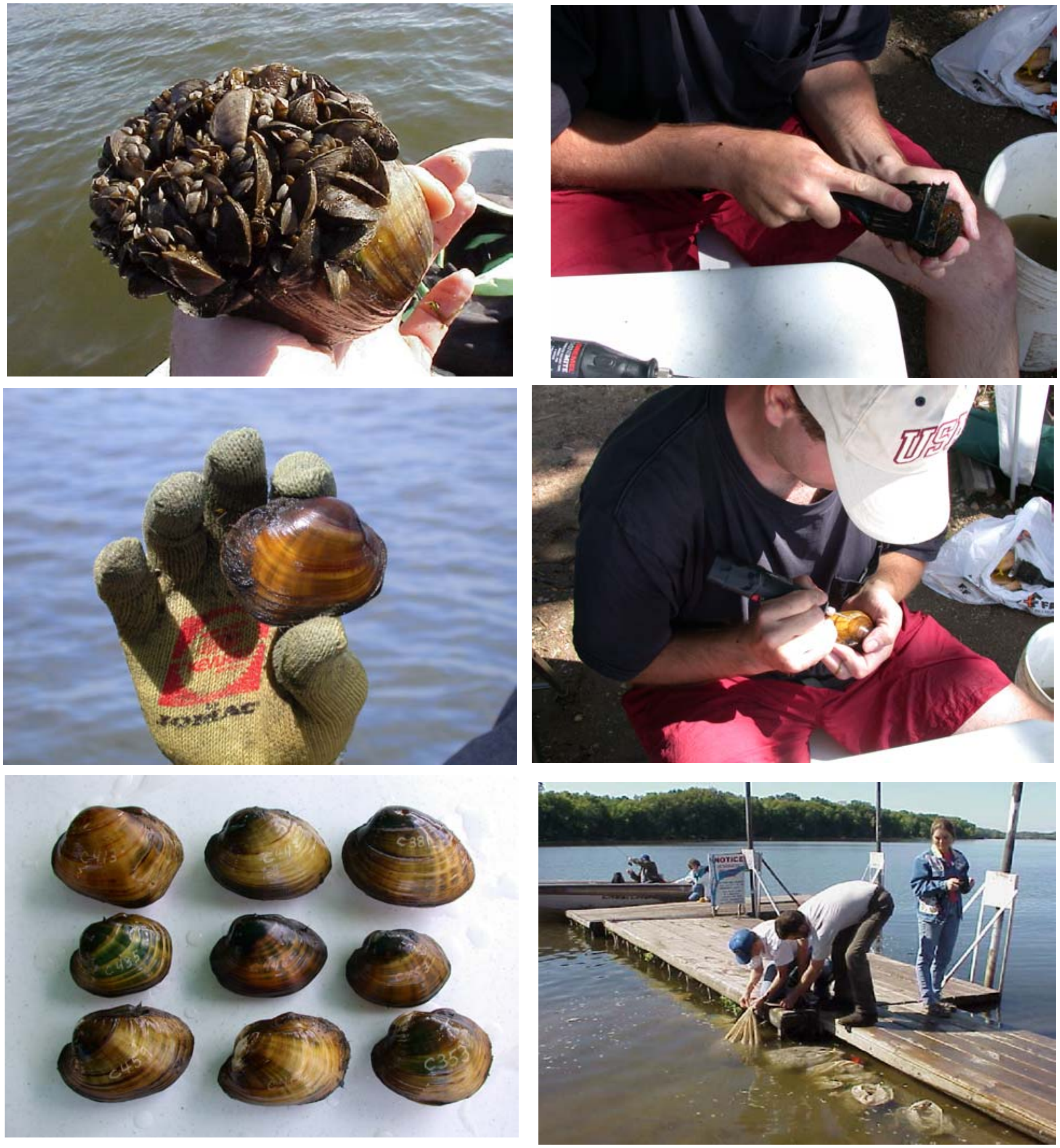

Figure 17. Cleaning and stockpiling adult Higgins' eye pearlymussels in the Upper Mississippi River. Adults were collected by diving and wading, brought to shore, and cleaned of zebra mussels with a brush. The lower left photo shows byssal threads from attached zebra mussels that are nearly impossible to remove. Mussels were measured, sexed, marked, photographed and hand placed by divers into the river bottom at a known location where they will be monitored and recleaned, if necessary. (photos courtesy of the Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service).

Figure 18. Adult Higgins' eye pearlymussels cleaned and relocated on the Upper Mississippi River. 370 adults were relocated to a site in Pool 2, and 101 relocated to a site in Pool 3. The bottom left photo shows a gravid female collected in September, 2002 at the Pool 3 Site. The bottom right photo shows unusual growth along the ventral margin of the shell from a mussel at the Pool 2 Site. (photos courtesy of Minnesota Department of Natural Resources and U.S. Fish and Wildlife Service).

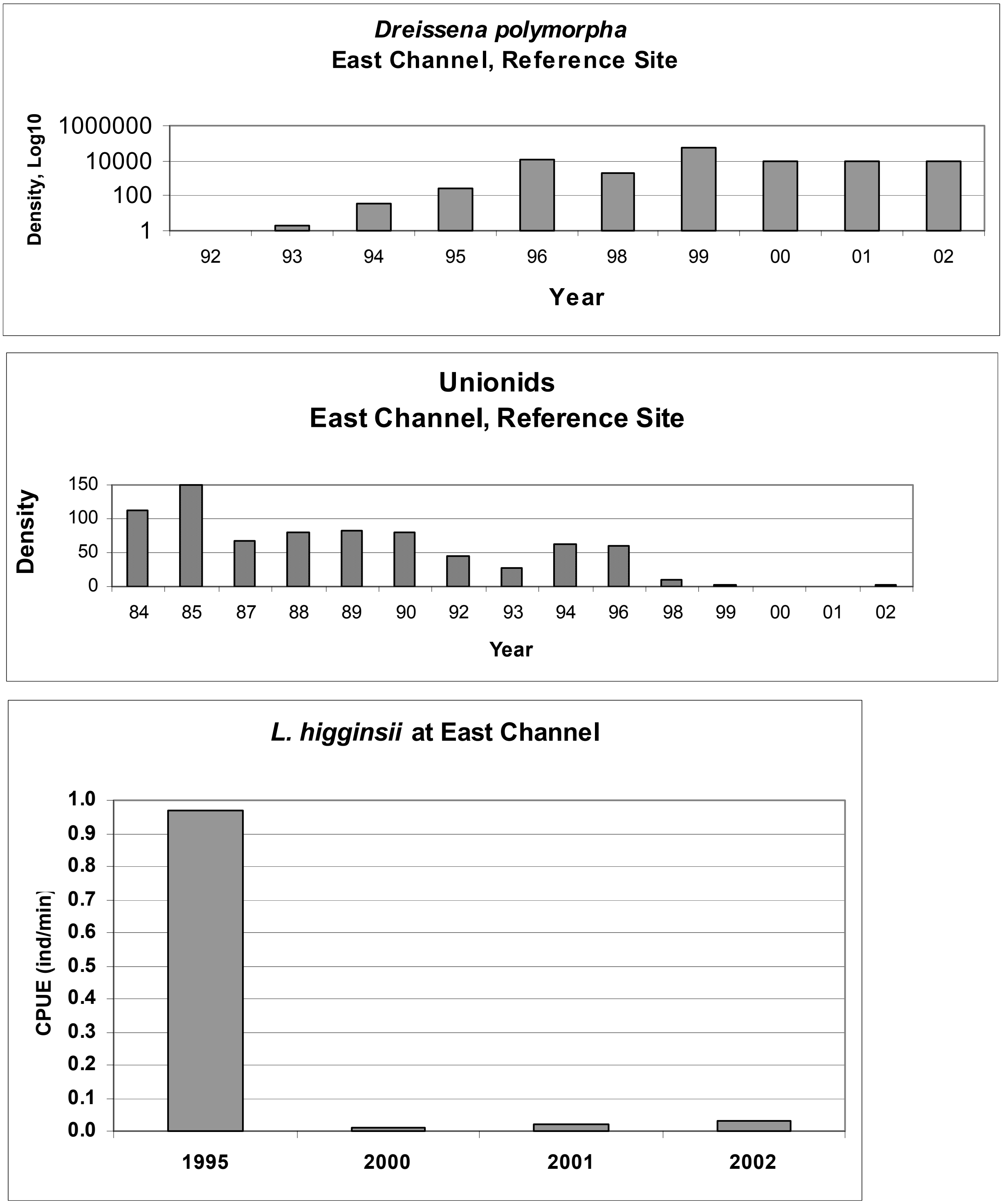

Figure 19. Abundance of native and zebra mussels (*Dreissena polymorpha*) at the East Channel Reference Site within the Prairie du Chien Essential Habitat Area, Pool 10, Upper Mississippi River, Wisconsin. The bottom graph shows catch per unit effort of Higgins eye pearlymussels (*Lampsilis higginsii*). From Farr and Miller (2003) unpublished data.

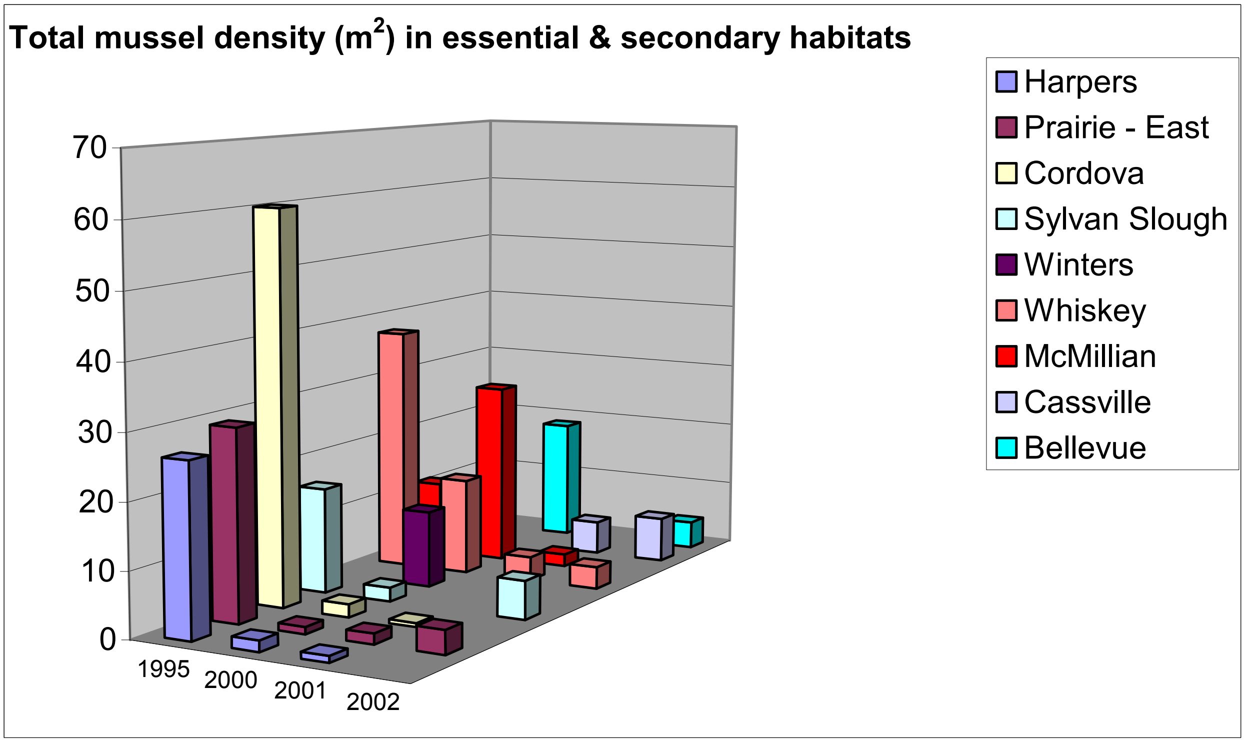

Figure 20. Density of native mussels at Essential Habitat Areas and secondary habitats on the Upper Mississippi River (Farr and Miller 2003 unpublished data).

Figure 21. News articles on mussel propagation/relocation efforts, and zebra mussels on the Upper Mississippi River. (photos courtesy of U.S. Fish and Wildlife Service)

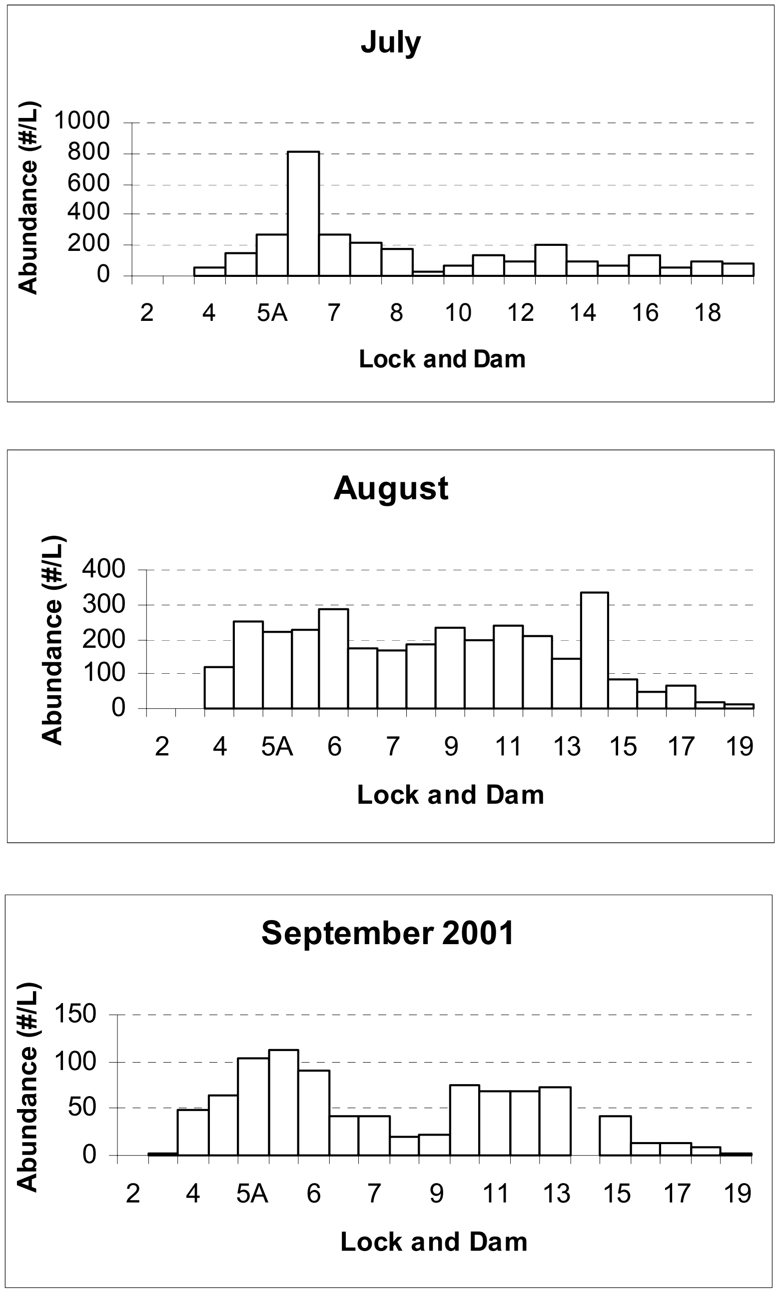

Figure 22. Abundance (number/liter) of zebra mussel veligers on the Upper Mississippi River, Locks and Dams 2 through 19 (Stoeckel 2002).

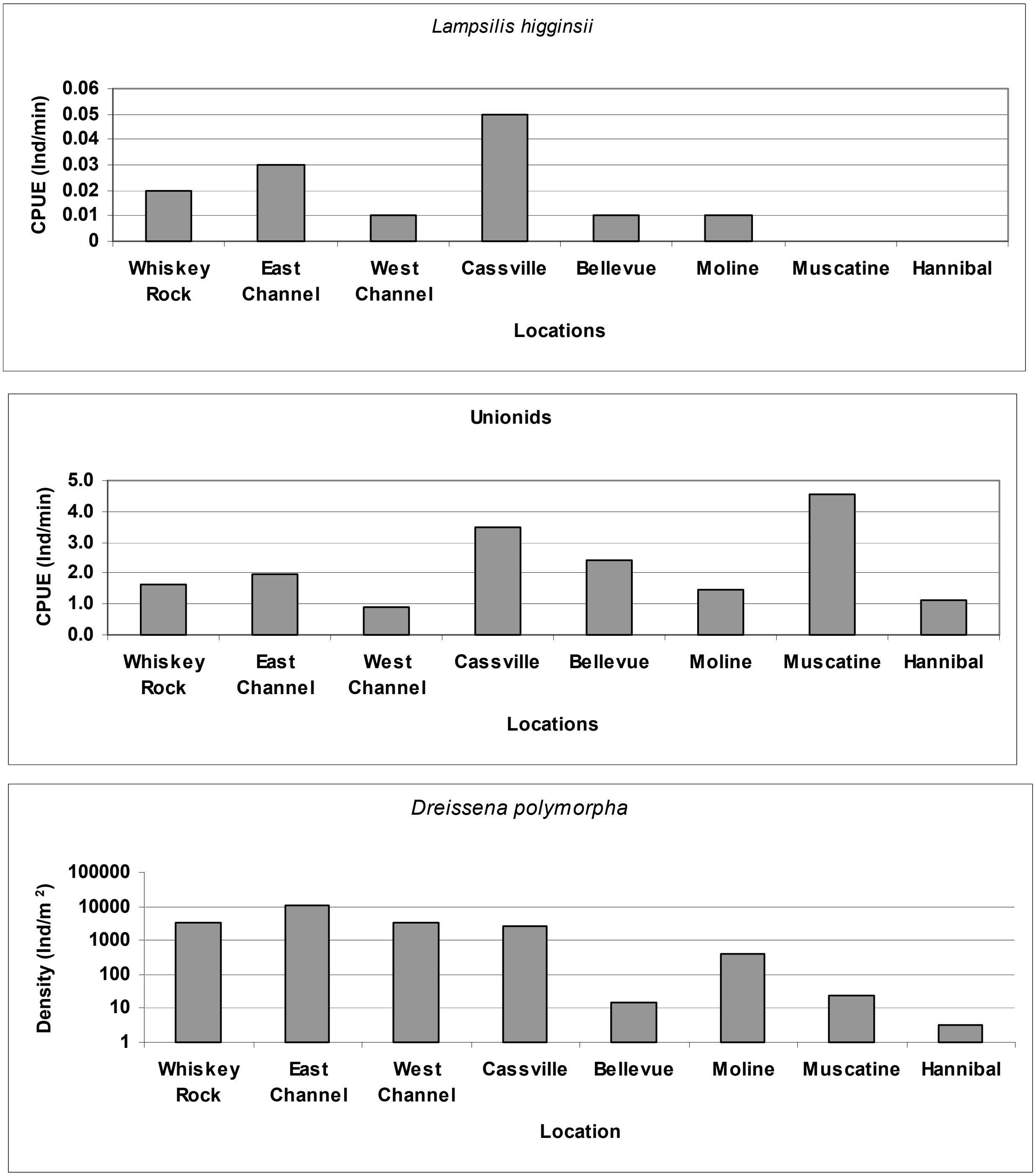

Figure 23. Catch per unit effort of Higgins' eye pearlymussels (*Lampsilis higginsii*) and other native mussels, and density of zebra mussels (*Dreissena polymorpha*) in 2002 at several locations on the Upper Mississippi River. From Farr and Miller (2003) unpublished data.