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Dennis W. Schlicht
Cedar Rapids Washington High School

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Aspects of an Interior Stream Clam Midden from 1915 at Quasqueton, Buchanan County Iowa

DENNIS W. SCHLICHT

Cedar Rapids Washington High School, 2205 Forest Drive SE., Cedar Rapids, Iowa 52403

During clam surveys on the Wapsipinicon River in 1991 buried clams were observed in a bank of the river at Quasqueton, Buchanan County, Iowa. An interview with the landowner revealed that the clams were from a 1915 local clamming operation. Excavation and examination of many of the clams reveal interesting differences in species composition and size, when compared to more recent specimens from the river. Observations on the midden were recorded, species determinations were made and measurements were taken. Comparisons are made to two other modern surface surveys on the river. Differences were observed in both species composition and shell size.

INDEX DESCRIPTORS: mussels, midden, historic clamming, Wapsipinicon River.

From 1989 through 1998 the Central City High School Field Biology students and I surveyed the clams in the Wapsipinicon River and Buffalo Creek in Buchanan and Linn Counties in Iowa. In 1991 we stumbled onto a clam midden at Quasqueton, Iowa. Quasqueton is a community in SE Buchanan County of about 580 people.

The Wapsipinicon River is a small river that starts in Mower County Minnesota and ends in the Mississippi at Clinton, a distance of 410 kilometers (255 miles). It drains 1687 km^2 (1048 miles^2) and the channel slope is approximately 1 m/1.5 km (3.58 feet/mile). The bottom is limestone at the midden.

The midden is about 209 km (130 miles) from the headwaters, near 42′23″.46 North and 91′45″.66 West (Fig. 1). It is situated within the waterfront span of a single property that may be a hectare in area. This made me suspicious that the site was historic. The elderly man who lived on the property at 319 South Second Street was Stewart Aldrich. He had lived on the property his whole life and told me he knew about the clams. They were from a clam operation from 1915 when he was a young boy.

METHODS

Identification of the shells was accomplished using Cummings and Mayer (1992), Buchanan (1980), Oesch (1995) and Parmalee (1967). Due to the erosion of the periostacum and the fading of the nacre a few valves remain unidentified and there is some degree of uncertainty as to the taxa of several other specimens.

Measurements of the area of the midden are rather arbitrary in that the clams and soils have moved due to the slope and constant removal of bank talus by the river. The clams appear to be at the bottom of about a meter of alluvial soils and just above fractured limestone. They are about 2 meters above the present riverbed. Nearly 300 shells were collected in 1996 and 2002. Other shells can be seen but are buried in tree roots or are too fragile to remove.

The shell length was measured and most were massed. The masses are problematic because much of the shell was eroded away. Few have any of the outer periostracum and in many shells, layers of shell material are missing. I have concluded that the masses are not useful. Other diagnostic features were intact on most shells. A few dozen of the shells remain unidentified.

RESULTS

We identified about 246 shells of 14 species from the midden, the most common being the mucket (*Actinonaias ligamentina*), the spike (*Elliptio dilatata*), and the flutedshell (*Lasmigona costata*) comprising 26%, 17%, and 13% of the total, respectively. Half of the species make up only 12% of the total diversity (Table 1). A survey from Independence to Quasqueton in 1998 yielded seven species. The most common were the Plain Pocketbook (*Lampsilis cardium*), the Pimpleback (*Quadrula pustulosa*), and the Elktoe (*Alasmidonta marginata*) which comprised 47%, 21%, and 11% respectively (Table 2). A similar survey downstream from Troy Mills to Paris in 1996 yielded 14 species with the most common being the Pimpleback (*Quadrula pustulosa*), the Plain Pocketbook (*Lampsilis cardium*), the Elktoe (*Alasmidonta marginata*), and the Round Pigtoe (*Pleurobema coccineum*) which comprised 33%, 21%, 11%, and 11% of the total (Table 3). In the midden the pimpleback (*Quadrula pustulosa*) comprised only 2% and the Plain Pocketbook (*Lampsilis cardium*) 16% of the total.

For a comparison, in a study of the Upper Iowa watershed and the similar Turkey river watershed, Eckblad et al. (2002) reported nine species in the Turkey. The most frequent was the Ellipse (*Venustaconcha ellipsiformes*) and the White Heelsplitter (*Lasmigona complanata*).

DISCUSSION

The differences in relative diversity between the midden and current diversity may be due to sampling methods. Did they dig the clams or find them in shallow sediments? I assume that they were eating the clam flesh or looking for pearls. Some species may be more edible than others and some may have had more valuable pearls than others. The species composition of the river may have

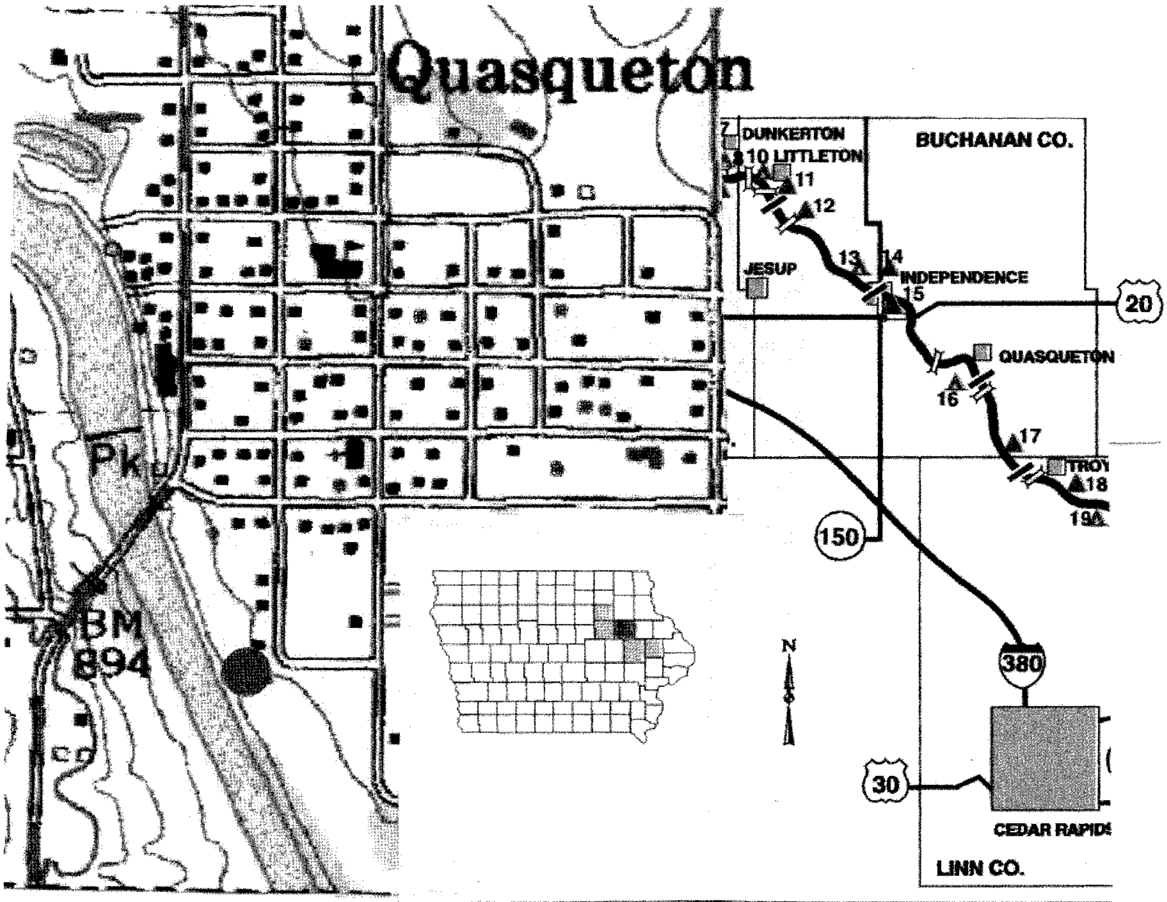

Fig. 1. Location of the Quasqueton clam midden.

been different in 1915, which might account for the differences between the midden and what we see today. In this case the difference may well indicate changes in the ecology of the river. Further, thorough surveys will be necessary to verify if there has been any real change.

As described in the methods section the shells show considerable erosion. While the shells were for the most part not exposed to current they have lost their outer surface, which could be because they may have been cooked to open them. If it is not the case that they were cooked, the rate of deterioration of these shells

Table 1. Distribution of clams in the 1915 midden at Quasqueton, Iowa.

Species	Number Complete	Size (cm) Mean	Number Incomplete	Total	%
Washboard *Megalonaias nervosa*	5	13.5	0	5	2
Pimpleback *Quadrula pustulosa*			2	2	1
Threeridge *Amblema plicata*	2	10.9	1	3	1
Wabash Pigtoe *Fusconaia flava*			4	4	1.6
Elephant Ear *Elliptio crassidens*	1	8.2		1	< 1
Spike *Elliptio dilatata*	27	10.8	14	41	17
Elktoe *Alasmidonta marginata*			16	16	6.6
White Heelsplitter *Lasmigona complanata*			8	8	3
Fluted-shell *Lasmigona costata*	17	12.7	15	32	13
Mucket *Actinonaias ligamentina*	37	13.0	27	64	26
Black sandshell *Ligumia recta*	16	13.9	10	26	10.7
Ellipse *Venustaconcha ellipsiformes*			10	10	4
Fat mucket *Lampsilis siliquoidea*	8	11.4	10	18	7
Plain pocketbook *Lampsilis cardium*	7	12.1	9	16	6.6
Totals:	120		126	246	

Table 2. Distribution of clams from a surface survey between Independence and Quasqueton, Iowa, 1998.

Species	Single	Paired	Sub-fossil	Total	%
Wartyback *Quadrula nodulata*	16	2		18	8
Pimpleback *Quadrula pustulosa*	43	1		44	21
Wabash Pigtoe *Fusconaia flava*	1	2		3	1.5
Round Pigtoe *Pleurobema coccineum*	2	2	3	7	3
Giant Floater *Anodonta grandis*	10		1	11	5
Elktoe *Alasmidonta marginata*	18	2	3	23	11
Plain pocketbook *Lampsilis cardium*	68	18	10	96	47
Totals:	158	20	17	202	

Table 3. Distribution of clams from a surface survey from Troy Mills to Paris on the Wapsipincon River, September 1996.

Species	Single Valves	Paired Valves	Sub-fossil	Total	%
Washboard *Megalonaias nervosa*	5		2	7	1
Wartyback *Quadrula nodulata*	1			1	< 1
Pimpleback *Quadrula pustulosa*	131	12	2	145	33
Threeridge *Amblema plicata*	1	2		3	1
Wabash Pigtoe *Fusconaia flava*	21	9	1	31	7
Round Pigtoe *Pleurobema coccineum*	42	3	3	48	11
Spike *Elliptio dilatata*	3			3	1
Giant Floater *Anodonta grandis*	10	5	1	16	3
Squawfoot *Strophitus undulates*	1			1	< 1
Elktoe *Alasmidonta marginata*	33	14	1	48	11
White Heelsplitter *Lasmigona complanata*	5	3		8	1
Mucket *Actinonaias ligamentina*	12		6	18	4
Fat mucket *Lampsilis siliquoidea*	3	6		9	2
Plain pocketbook *Lampsilis cardium*	13	78		91	21
Totals:	281	84	365	429	

gives us an example of shell deterioration in 76 years. Further, and of interest to archeologists who often find shells in their sites, is that they have been buried for much of that time.

The Quasqueton clam midden of 1915 may provide a glimpse into the past condition of the river. Further studies of this material may indicate changes in biotic community or water quality in the past 90 years. The specimens for this study are at Iowa State University and with the author in Center Point, Iowa.

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

GARY J. WEGE

U.S. Fish & Wildlife Service, 4101 East 80th Street, Bloomington, Minnesota 55425-1665

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 underwarer objects including large boats using the federal navigation system of locks and dams on the UMR. In April, 2000, the U.S. Fish & 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 establish populations of Higgins eye in areas with no or 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, propagarion in cages in the UMR and tributaries, stocking juveniles, relocating adults, stocking glochidia-inoculated fish, cleaning and stockpiling adults, and survey/monitoring activities.

INDEX DESCRIPTORS: mussels, Mississippi River, glochidia, Higgins eye.

The historic range of the Higgins eye pearlymussel (*Lampsilis higginsii*) includes the Upper Mississippi River (UMR) and major tributaries. It was listed as a federally-endangered species in 1976 under the Endangered Species Act. A recovery plan was completed in 1982 which may have been successful if the exotic zebra mussel (*Dreissena polymorpha*) had not appeared. 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.

Zebra mussels attach to nearly all underwater objects. They encrust hard objects and can form a thick "carpet" on the bottom of the river. They also attach to native freshwater mussels. 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.

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 2003. 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 thirty mussel species have been collected 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 U.S. Army Corps of Engineers (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) described 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"

After the decline in mussels at 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 Genoa National Fish Hatchery (NFH) in Wisconsin. In the Spring of 2000, 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 3 juvenile Higgins eye (Davis 2001).

Between 1998 and 2000, the Corps and 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. In their April,

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 (U.S. Army Corps of Engineers unpubl. data).

Year	Number of Qudrants	% Ind. <30 mm	% Species <30 mm	Unionids/m^2	Zebra Mussels/m^2
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

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. To avoid jeopardy, the Service recommended the Corps establish populations of Higgins eye in areas with no or 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.

MCT members include the Wisconsin, Minnesota, Illinois and Iowa Departments of Natural Resources, U.S. Geological Survey, U.S. Coast Guard, National Park Service, Science Museum of Minnesota, Corps and Service. 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 (U.S. Army Corps of Engineers 2000). An 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 or few zebra mussels. The long-term goal of the plan is restore Higgins eye populations to year 2000 levels with at least four geographically separate EHA's using a combination of five relocation methods at ten sites to reach the interim goal of five new populations over the next 10 years (See Below).

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

RESULTS & DISCUSSION

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 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 Genoa NFH are described in Steingraeber (2002) and Welke et al. (2000).

Like many freshwater mussels, Higgins eye requires a host fish to complete its life cycle. 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. The lure attracts predatory fish such as 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 "lures" a host fish to her glochidia. In the hatchery, glochidia are brought to the fish. Gravid female Higgins eye were collected in the field by divers and transported to the hatchery. Females used for propagation were measured and marked. Glochidia were flushed from the gills of the female with a syringe and water into a glass container. Glochidia were tested for viability with a microscope and table salt (viable glochidia quickly "snap shut" their shells when contacting salt water). A quantity of viable glochidia (2–10 ml) were added to a bucket containing host fish, water and an airstone. Contents were mixed for a period of time (2–5 minutes) and a sample fish examined under a microscope to estimate the number of attached glochidia. If the gills appeared adequately inoculated with glochidia (50–100), fish were placed in a holding tank. If not, the sample fish was returned to the bucket, the contents stirred, and the process continued until inoculation occurs.

Approximately 8,600 host fish (largemouth bass, smallmouth bass, walleye) were inoculated with Higgins eye glochidia at

Table 2. Inoculation of host fish in 2002 with glochidia from the Higgins' eye pearlymussel (*Lampsilis higginsii*) at the Genoa National Fish Hatchery, Wisconsin. Attachment is the range of glochidia that encysted on the gills of each fish. Transformation is the range of encysted glochidia that transformed into juvenile mussels from each fish (Gordon 2002).

Variable	Walleye	Smallmouth Bass	Largemouth Bass
Number of fish inoculated	1,700	1,780	1,750
Attachment (glochidia/fish)	149–170	146–166	165–283
Transformation (juveniles/fish)	57–65	60–68	78–133
Mean survival to juvenile stage	38%	41%	47%
Mean production of juveniles	100,400	106,540	176,600

Genoa NFH (Table 2). These fish were used in cage propagation activities, released into the wild, or transforming juveniles in the hatchery. It takes approximately two to four weeks for transformation from glochidia to juvenile mussel.

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 areas of the St. Croix and Upper Mississippi Rivers studied. However, to preserve this high level of genetic variation, we used 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 were inoculated with glochidia from the St. Croix River; likewise, fish released into cages or the wild in lower reaches received glochidia from Pools 11 or 14 depending on which was closer to the release site. Tissue samples were taken from each female used to inoculate fish.

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. In June, 2000, two propagation cages (wooden and metal frames) were installed in Lake Pepin. 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). 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, bottom, and ½-inch wire mesh screen (18″×24″×36″). 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 have a 3/8-inch plywood board attached to the front to give host fish a refuge from currents.

Closed cages are larger and have a 3/8-inch plywood bottom to collect juvenile mussels (24″×24″×36″). In closed cages, a three to six-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, 2002). To date, 84 cages with 3,365 host fish have been placed in the Pools 1, 2, 3 and 24 of the UMR, Lower St. Croix and Lower Wisconsin Rivers. This represents approximately 238,700 potential juveniles.

Monitoring. Cage monitoring activities are described in Davis (2001, 2002). With one exception, we have not monitored open cages; monitoring will begin in 2003 when mussels are large enough to collect.

We started monitoring closed cages in 2001. To date, closed cages have produced 1,465 mussels representing 15 species (Table 3) of which 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 Genoa NFH and 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 through the cage in currents and settle to the bottom. Another explanation is that there may be a natural drift of glochidia in the river; glochidia passing through the cage may inoculate 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 between 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 (25 walleye each) which had been inoculated with standard methods at Genoa National Fish Hatchery and randomly collected from a holding tank.

Likewise, production of juvenile Higgins eye in cages varied between sites (Table 4). We can explain some of this variation; most of the eleven 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 which 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 8–22 mm at the Hudson Site, 5–10 mm at the Prescott Site, 9–22 mm at the Lake Pepin Site, and 15–26 mm 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 was excellent. For example, in June, 2002, fifteen Age 1 juveniles

Table 3. Species collected from closed 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	

19–27 mm 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 25–35 mm. Growth was approximately 7 mm over these three months.

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

Overall, Total Shell Length of Higgins eye at Age 1, 2 and 3 was approximately 10–20 mm, 20–40 mm, and 40–50 mm, respectively. In comparison, we have been unable to produce similar results in hatchery conditions at Genoa NFH (Gordon 2002). Juveniles at three months of age in the hatchery were less than 1-mm long, versus 8–22 mm 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. Based on monitoring data in September 2002, there are approximately 1,097 Higgins eye mussels being held in propagation cages in the UMR and St. Croix River; 547 Age 1, 547 Age 2, and 3 Age 3 mussels. There are also nine cages at the Lake Pepin Site which 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 mussels 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 and a source population for the Upper Mississippi River. In 2002, zebra mussels were found attached to subadult Higgins eye inside propagation cages in the Lower St. Croix River and Upper Mississippi River 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. Propagation cages may

Table 4. Propagation of Higgins' eye pearlymussels (*Lampsilis higginsii*) in closed cages in the Upper Mississippi and St. Croix Rivers. SCR = St. Croix River; UMR = Upper Mississippi River; CR = closed bottom rectangular cage; WAE = walleye; LMB = largemouth bass; SMB = smallmouth bass; TSL = total shell length in millimeters; Age = approximate age of mussels in months.

Date Cage Placed	Location	No-Type Cages	Host-Number	Monitor Date	No. *L. higginsii*	TSL (mm)	Age (mo)
6-5-01	SCR0.2	2-CR	SMB-75	9-26-02	222(37–185)	20–42	16
6-5-01	SCR16.5	4-CR	SMB-75	6-20-02	196(0–96)	17–31	12
5-31-02	UMR848.2	16-CR	LMB-30	9-30-02	8(0–6)	15–26	4
6-5-01	UMR810.6	4-CR	SMB-75	6-20-02	9(0–5)	15–33	12
5-25-00	UMR779.4	2-CR	LMB-75	5-31-01	3(0–3)	9–13	12
5-29-02	UMR779.4	11-CR	WAE-25	9-24-02	547(6–153)	9–22	4

Table 5. Juvenile Higgins' eye pearlymussels (*Lampsilis higginsii*) 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	Number of Juveniles	Host Species
7-10-00	WIR-RM6.5	3750	WAE, LMB
8-1-00	WIR-ORION	1100	WAE, LMB
7-20-01	BLR-RM60.62	1914	SMB, LMB
6-20-02	BLR-RM60.62	1200	WAE, LMB

protect zebra mussels from fish predation. Magoulick and Lewis (2002) found that freshwater drum and other species significantly reduced densities of larger (>5 mm) zebra mussels that were attached to the surface of clay tiles in Lake Dardanelle, Arkansas.

Stocking Juveniles

Stocking juvenile Higgins eye is a relocation method we have tried in several UMR tributaries. In July and August, 2000, juveniles were taken from Genoa NFH and placed by a diver into wooden-framed, screen covered trays that were anchored to the bottom of the Lower Wisconsin River. On 20 July 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 two meters of each other in an area previously identified as a mussel bed. To date, approximately 8,300 juveniles from Genoa NFH have been released into the Lower Wisconsin and Lower Black Rivers in Wisconsin (Table 5). Monitoring will begin in 2003 when mussels are large enough to collect using methods described by Kelner and Heath (2003).

A major challenge at 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% of juveniles in one hatchery treatment survived over 60 days. Average size of juveniles after 60 days in the hatchery was less that one millimeter, compared to 8–22 mm 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. However, this may not help reduce mortality. In 2001, juveniles from Genoa NFH were placed in two small screen cages in the St. Croix River to attempt to minimize predation. Only one juvenile Higgins eye was later recovered from the cages.

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 seven species were inoculated with Higgins eye glochidia (Gritters 2001). Glochidia were 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 Genoa NFH and 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. 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%, 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 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 juveniles Higgins eye.

To date, approximately 7,000 glochidia inoculated fish have been released into the Wapsipinicon, Cedar and Iowa Rivers in Iowa, and Lower Wisconsin River in Wisconsin (Table 6). Host fish released were inoculated and held at Genoa National Fish Hatchery, or captured from the receiving water and inoculated in the field. While this technique is simple to conduct, monitoring will be difficult because it is not known where fish travel over the three to four-week period when transformation occurs. In 2004, we will radio tag some host fish to determine where host fish travel.

Table 6. Host fish inoculated with glochidia of the Higgins' eye pearlymussel (*Lampsilis higginsii*) and released into the Upper Mississippi River and tributaries. WAP = Wapsipinicon River, Iowa; IAR = Iowa River, Iowa; CDR = Cedar River, Iowa; WIR = Wisconsin River, Wisconsin; W = wild fish; GFH = Genoa National Fish Hatchery; RFH = Rathbun State Fish Hatchery. Female strain identifies location of adult female *L. higginsii* used for glochidia collection. * = 60 wild freshwater drum, 577 wild white bass, unknown number of wild spotted and smallmouth bass.

Release Date	Location Released	No. Released Female Strain.	Smallmouth Bass	Largemouth Bass	Walleye
10-10-01	IAR- Iowa City	1800 CORDOVA	*	500 GFH 500 RFH 76 W	37 W 50 RFH
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 GFH	—	405 GFH
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	—	—

Table 7. 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

Cleaning and "Stockpiling" Adults

One way to keep adult Higgins eye is to periodically clean them of zebra mussels and return them to their habitat. Often, Higgins eye and other mussels are completely covered with zebra mussels. We currently have three clean and stockpile sites (Pool 11, 14 and Lower Wisconsin River) totaling 547 adult mussels. Anderson and Delphey (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, sex determined, individually marked and photographed. They are returned to river and hand-placed on the bottom 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 be easily collected for fish inoculation.

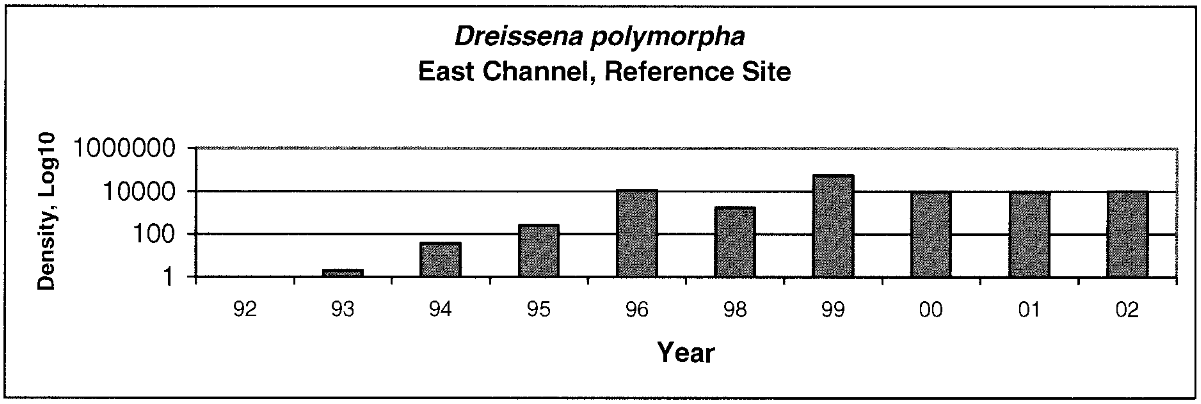
Cleaning and Relocating Adults

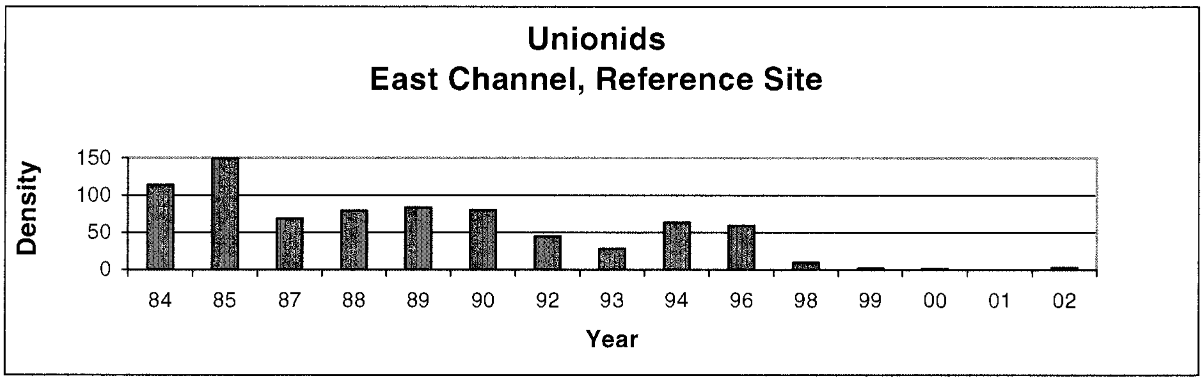
At locations where zebra mussels are considered a serious infestation, adults are cleaned of zebra mussels and relocated to areas of the UMR having no/few zebra mussels (i.e. we move them out of harms way). We have two adult relocation sites; Pool 2 Adult Relocation Site above the confluence of the Minnesota River in the Twin Cities, Minnesota, and Pool 3 Adult Relocation Site near Hastings, Minnesota. These two sites were chosen because recent mussel surveys found good populations with no/few zebra mussels. For unknown reasons, zebra mussels have not infested the UMR upstream of Lock and Dam 3. Adult zebra mussels are transported upstream by towboats and are collected in all navigation lock chambers. We also know they successfully reproduce; veligers have been collected at Lock and Dam 2. The Minnesota River enters the UMR approximately two 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 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 Metro Area to Upper Pool 4 in Lake Pepin has a diverse mussel community which 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. Mussels came from Pool 11 at Cassville, Wisconsin (2000), and Pool 14 at Cordova, Illinois (2001). We relocated 317 adult Higgins eye to the Pool 2 Site and 100 to the Pool 3 site. The Cordova relocation project is described in Anderson et al. 2002; this relocation was conducted

Table 8. 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 U.S. Army Corps of Engineers (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.<30 mm	–	–	–	–	9	0	11	17	0	14
No. *L. higginsii*	0	2	12	0	0	0	0	0	0	1





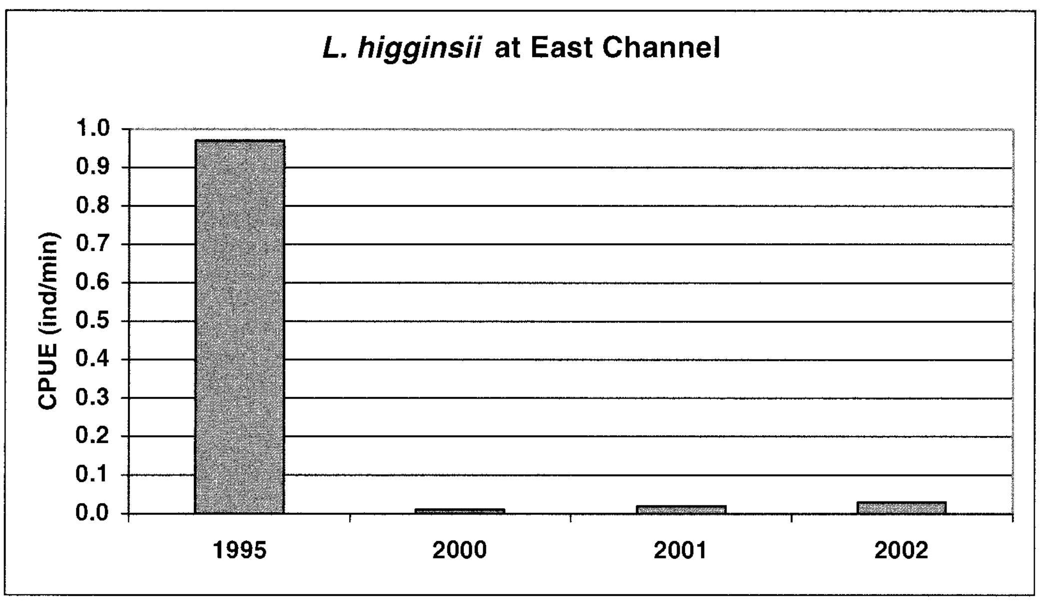


Fig. 1. Density (individuals/m^2) of native and zebra mussels (*Dreissena polymorpha*) at the East Channel Reference Site within the Prairie du Chien Essential Habitat Area, Pool 10, Upper Mississippi River, Wisconsin. The bottom graph shows catch per unit effort of Higgins eye pearlymussels (*Lampsilis higginsii*) (U.S. Army Corps of Engineers unpubl. data).

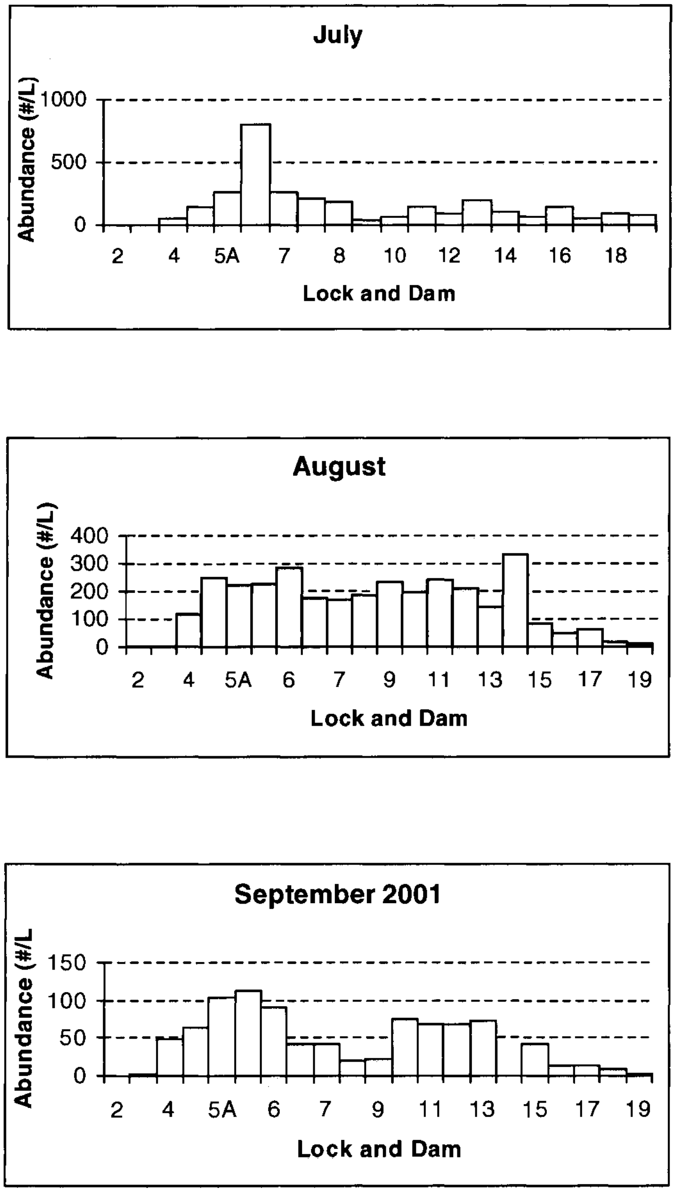


Fig. 2. Abundance (number/liter) of zebra mussel (*Dreissena polymorpha*) veligers on the Upper Mississippi River, Locks and Dams 2 through 19 (Stoeckel 2002).

as part of a mussel workshop conducted by the Illinois Chapter of the American Fisheries Society. Cleaning and processing methods are the same as described above; mussels are then placed in burlap sacks suspended in water in a hatchery truck, and transported to the relocation site. They are transported by boat and hand-placed in the riverbottom by divers. The location of the site is noted by GPS coordinates, rope/buoys and shoreline references.

Survival of relocated adults is high; 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 individuals may already be creating new or enhancing existing populations. We observed unusual growth (exaggerated growth arrest lines and inturning) along the ventral margin of shells from

Table 9. 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

several individuals at the Pool 2 Site. Otherwise they appeared to be in good health and grew an average of 3.3 mm from July 2001 to September 2002 (14 months). Starting next year, methods described by Kelner and Heath (2003) will be used 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 (Table 7 and 8). Of particular interest are results from the Prairie du Chien EHA (U.S. Army Corps of Engineers unpubl data). Density of Higgins eye and other native mussels remains low in comparison to high abundance of zebra mussels (Fig. 1).

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 371 adult Higgins eye were collected from the Cordova EHA; most came from shallow water by wading. We also collected 197 adults this summer from the Cassville Site; again, nearly all were collected by wading in shallow water versus diving in deeper water.

Zebra Mussel Control Plan

In 1991, the first zebra mussel was collected on the UMR in Pool 8 near La Crosse, Wisconsin. While densities have declined in lower reaches of the UMR and IL 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 locks and dams from St. Anthony Falls to Pool 10. In 1993, densities in the lockworks ranged from zero to 6.5/m2 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, veliger studies were expanded by the Corps to include the UMR downstream of Locks and Dams 2 through 19 (Stoeckel 2002; Fig. 2). They also sampled veligers from major tributaries in hopes of finding potential relocation areas for Higgins eye that

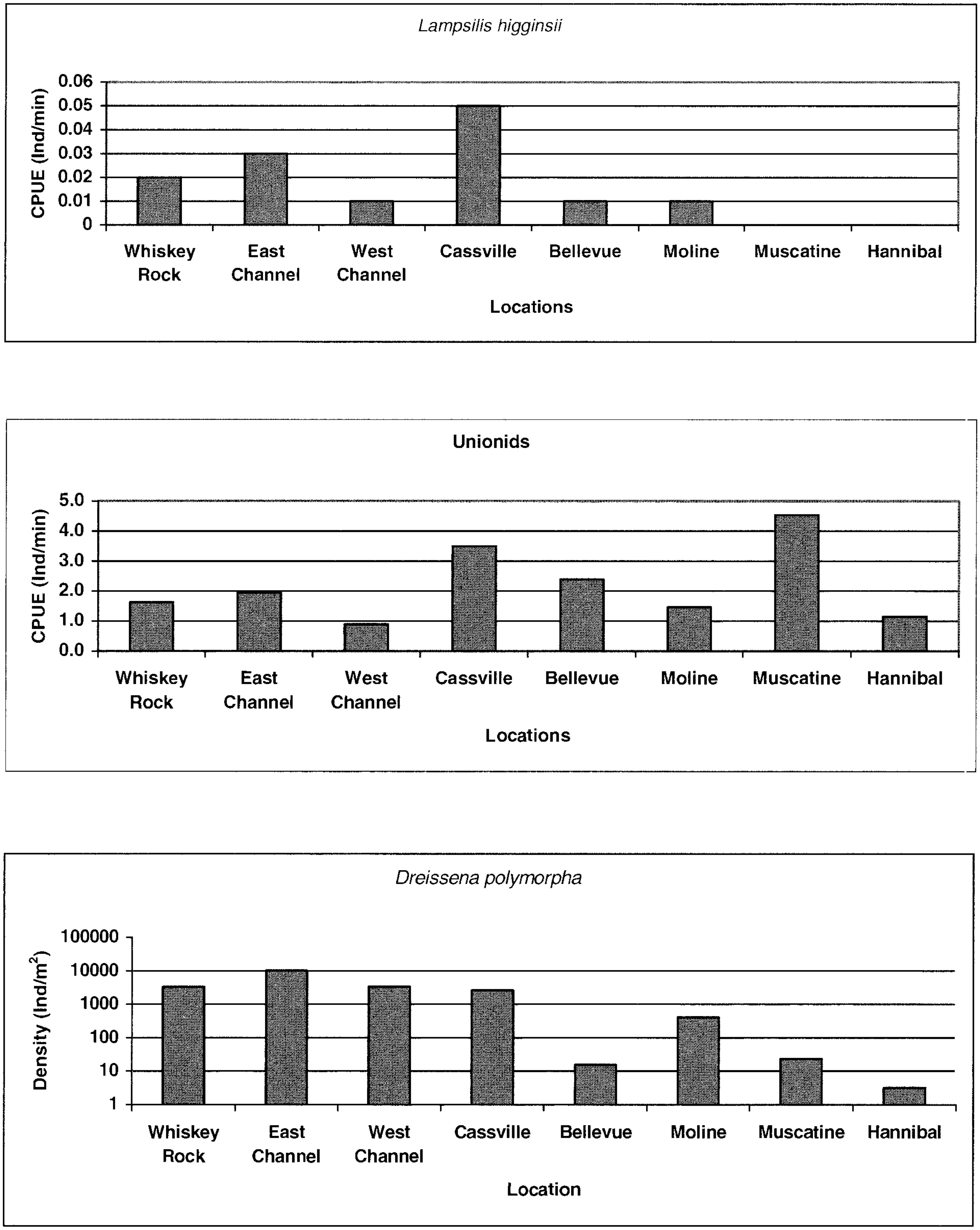


Fig. 3. Catch per unit effort of Higgins' eye pearlymussels (*Lampsilis higginsii*) and other native mussels, and density of zebra mussels (*Dreissena polymorpha*) in 2002 at several locations on the Upper Mississippi River (U.S. Army Corps of Engineers unpubl. data).

had no/few zebra mussels. Unfortunately, veligers were collected at nearly all sites; at this time, only the Chippewa River and UMR above Upper St. Anthony Falls Lock and Dam are free of zebra mussels (Table 9).

Zebra mussels appear to be expanding their range on the UMR and tributaries within the historic range of Higgins eye resulting in fewer places for possible relocation. Figure 3 shows abundance of native and zebra mussels in 2002 at several important mussel habitats on the UMR. However, there appears to be a significant reduction in abundance of zebra mussels on the Illinois River and 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 in including Adult Clean and Stockpile Sites in Pools 11 (Cassville) and 14 (Cordova). This phenomenon did not last, however, and zebra mussels returned in 2002. However, the potential exists that zebra mussel abundance may significantly decline in portions of the historic habitat of Higgins eye offering the potential for relocation and establishment of new/enhancement of existing populations.

One recent concern is the exotic quagga mussel (*Dreissena bugensis*) which is similar in appearance and potential harm to native mussels as the zebra mussel. Approximately nine years ago, zebra mussels outnumbered quaggas by 100 to one in Lake Erie. Today, this trend is reversed and quaggas now outnumber zebra mussels by 10 to one (Mississippi Interstate Cooperative Resource Association 2002). Unfortunately, quaga 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.

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