Journal of the Iowa Academy of Science: JIAS

Volume 112 | Number 3-4 Article 5

2005

Threatened by Industry, Saved by Science: Mussel Propagation at the Fairport Biological Laboratory

James Pritchard
Iowa State University, jpritch@iastate.edu

Jour. Iowa Acad. Sci. 112(3,4):36–47, 2005

Threatened by Industry, Saved by Science: Mussel Propagation at the Fairport Biological Laboratory

JAMES PRITCHARD

Department of Natural Resource Ecology and Management & Department of Landscape Architecture,
339 Science II, Iowa State University, Ames, Iowa 50011-3221, jpritch@iastate.edu

During the 1890s, people on the Mississippi River exploited mussel populations to support a thriving button industry. Within a brief time, they noticed significant declines in mussel populations, and called on the U.S. Bureau of Fisheries to save the resource. This paper discusses mussel propagation studies, techniques, and activities carried on in association with the Fairport Biological Laboratory (Iowa) from about 1908 to 1932. While scientists developed sophisticated techniques and had success in mussel propagation, changing habitat conditions in the river (caused mainly by pollution and dam construction) meant limited success in rescuing mussel stocks, while the introduction of plastic and the growth of foreign sources of mussel shells influenced the decline of the button industry on the Mississippi River.

INDEX DESCRIPTORS: Mussels, Fairport Biological Laboratory, history of biological laboratories, mussel propagation, history of U.S. Bureau of Fisheries, history of U.S. Fish and Wildlife Service, Max M. Ellis, Robert E. Coker, George Lefevre, Winterton C. Curtis.

THE BUTTON INDUSTRY'S HOPE FOR PROPAGATION

Beginning around 1886, button manufacture using the shells of freshwater mussels grew quickly on the Mississippi River. The industrial scale of the enterprise, revealed in Iowa photographer Oscar Grossheim's contemporary images, was remarkable. Intense harvesting pressure caused noticeable drops in mussel populations in as few as three years. In a scene repeated all over the Midwest, a single mussel bed (measuring less than 0.75 km^2) near New Boston, Illinois that produced more than 9,000 metric tons of shells from 1894 to 1897, was exhausted and abandoned by 1899. In 1898, Dr. Hugh M. Smith (later Director of the U.S. Bureau of Fisheries) warned that some action would have to be taken or certain commercial species would be wiped out, and others soon echoed this admonition (Smith 1898, Smith 1899, Smith 1919, Josephsson 1909, Danglade 1912, Coker 1918, Roberts 1921, Farrel-Beck and Meints 1983, Claassen 1994, Anthony 2000).

Around 1910, three groups cooperated to create the U.S. Bureau of Fisheries' Biological Station at Fairport, Iowa: button manufacturers, U.S. Bureau of Fisheries officials, and zoologists at the University of Missouri. People referred to the facility alternatively as the Fairport Biological Laboratory or the Fairport Biological Station. Leaders of manufacturing enterprises generally believed (as did fisheries officials) that if the scientists could rear young mussels in quantity and release them into rivers, higher harvest levels would be maintained. Thus they envisioned a sort of put, grow, and take mussel fishery, in much the same way that the U.S. Bureau of Fisheries conceived of fish propagation and rearing (Carlander 1954, Scarpino 1985, Outwater 1999, Taylor 1999).

From 1908 to 1914, Winterton C. Curtis and George Lefevre pioneered techniques for the propagation of fresh-water mussels, giving hope for success. The first director of the Fairport Laboratory, Robert E. Coker, further developed those techniques, and during the 1920s Fairport scientists sought to create industrial-scale methods of mussel propagation. By 1920, Fairport scientists claimed to have infected six million fish with 478,705,000 glochidia, and by 1923, to have reared half a million mussels in troughs. During the later 1920s and into the early 1930s, Max Mapes Ellis claimed success for highly artificial methods of propagating freshwater mussels.

Two things are immediately striking about mussel propagation from 1908 to 1941. Button manufacturers, as well as scientists and the Bureau of Fisheries, adopted an industrial model in thinking about river resources. If humans harvested the mussels, it was a technical matter to supply nature with the raw material to ensure future bountiful harvests. Yet the industrial model limited thinking about what sort of problems needed to be addressed. Secondly, the scientists working on mussel propagation came to understand the problem in broader terms than originally conceived. They began by considering technical problems of mussel propagation, yet ended up noting changes in Mississippi river habitats and the effects of pollution on mussel populations (Pritchard 2001).

LEFEVRE AND CURTIS

Early work on artificial propagation of fresh-water mussels on the Mississippi River was performed by George Lefevre and Winterton C. Curtis, professors of zoology at the University of Missouri. Previous studies had laid out the fascinating oddities of mussel reproduction. The larval form of mussels, or glochidia, attach themselves to the gills (and sometimes fins) of fish until they mature, drop off, and begin their lives as mussels. Yet in 1907, mysteries regarding the natural history of mussels remained, for example, exactly which species of host fish were required for each species of glochidia. At that time, the existing

literature was written in German—the mussel fauna remained virtually unknown to American scientists (Coker et al. 1922).

It's important to note the close connection between the Department of Zoology at the University of Missouri and the Marine Biological Laboratory (MBL) at Woods Hole, Massachusetts, a leader in the development of experimental biology in America. William Keith Brooks, an important figure in embryology, had urged Winterton Curtis to study "something important" fot his dissertation, such as mollusks. Curtis began his connection with the MBL as a student, became an assistant collector in 1897, a member of the Invertebrate Staff in 1899, and in 1908 an instructor in charge. So by 1899, Curtis was already experimenting with propagating mussels, infecting carp with *Anodonta* and *Symphynota*. He performed that and later work associated with the Mississippi River specimens at the amply equipped laboratory at Woods Hole, where he rubbed shoulders with scientists who were introducing the rigor of experiment to biological studies (Curtis 1949, Maienschein 1989).

Lefevre was appointed a professor of zoology at the University of Missouri in 1899, served as chair of the Zoology Department from 1899 until his death in 1923, served on the MBL Board of Trustees from 1909, and was Secretary to MBL staff from 1913. Curtis called Lefevre "a princely entertainer," and his affable nature (Lefevre said "agreement is no criterion of friendship") served him well as he connected with people up and down the Mississippi during the mussel research (Curtis 1949).

Lefevre and Curtis looked to "points in the life history where wholesale destruction of the individuals is most likely to occur." Nature, they surmised, was entirely too wasteful. Glochidia, simply dispersed about on the river bottom, were subject to excessive chance, few of them finding a place on a host fish. Luckily, "Nature is prodigal with the supply of glochidia." Lefevre and Curtis judged that fish could carry many more glochidia than usually found in nature; one fish in the lab might be induced to carry as many glochidia as one thousand fish in their natural state. Taking those two points, "the point of attack for artificial propagation is clear. The fish must be made to carry more glochidia." (Lefevre and Curtis 1908, 1910, Scarpino 1985). They tried a propeller rotated slowly by hand in the bottom of a tub, which didn't work very well, as well as a more promising system of iron pipes with many holes that forced jets of water out at the tank bottom, swirling the glochidia upwards. They relented only when their fish started to die from over-infection (Fig. 1).

Lefevre and Curtis had commercial applications very much in mind. On August 6, 1907, they presented their work to the National Association of Pearl Button Manufacturers' meeting in Chicago, Illinois. They measured mussel growth rates, hopefully noting that "commercial mussels may reach a marketable size in three years from the time they leave the fish." They speculated that even slow-growing mussels such as *Quadrula ebena* (20-30 years to maturation) might be hurried along if science could just discover the necessary conditions for the maximum rate of growth (Lefevre and Curtis 1910 "Studies").

From 1906 through 1914, Lefevre and Curtis supervised the mapping of mussel beds throughout the Midwest, sampling locations in seventeen states (Fig. 2). They claimed to have propagated mussels on the Mississippi River, the White and Black Rivers of Arkansas, the Cumberland, the Ohio, the Wabash and the St. Croix Rivers. The wide distribution of sites probably means they were infecting fish in the field, rather than infecting the fish in a lab and then transporting the fish to the field locations.

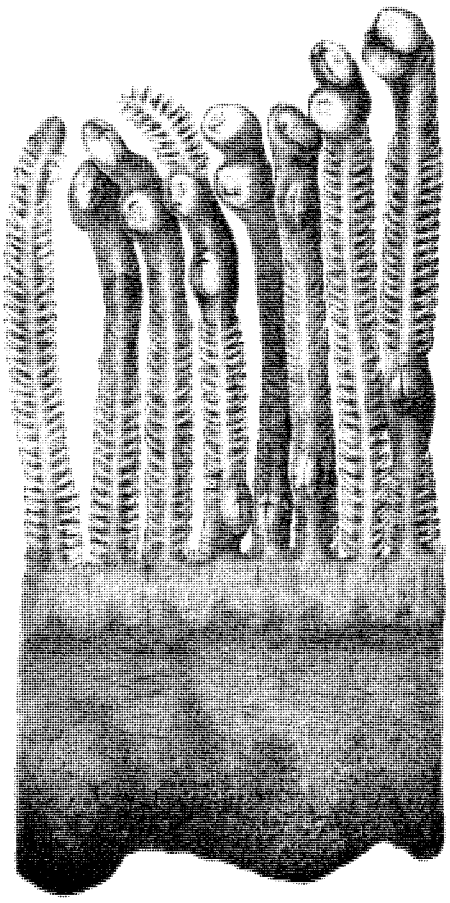

Fig 1. Lefevre and Curtis devoted considerable attention to the natural history of mussels. This black bass gill was infected "above the optimum" with *Lampsilis ligamentina*. From Lefevre and Curtis, 1910.

Lefevre and Curtis glumly noted that "we have not succeeded in keeping the young mussel alive in the laboratory for a longer period rhan six weeks." At first the young mussels would be quite active, but then disappointment ensued. The stages immediately following parasitism were "less known than any orhers.... Indeed, no one has yet succeeded in following individual specimens for more than a few weeks beyond the beginning of life on the botrom" (Lefevre and Curtis 1908). Despite rhese problems, they saw the artificial propagarion of mussels as a technical problem that could be solved (Lefevre and Curtis 1910 "Reproduction").

It's not clear why, but Lefevre and Curtis moved on to other rhings after 1914. Their promising experimental work led directly to the creation of the Fairport Biological Laboratory, and perhaps with its inception the impetus passed to the sration and its first director, R.E. Coker. As the contemporary *History of Muscatine County* put it, "the experimental results were very satisfactory to rhe investigating scientists, hence the hatchery station at Fairport and the growth of flattering hopes in the breasts of the pearl button manufacturers and the thousands of men, women and children dependent upon the industry for a livelihood."

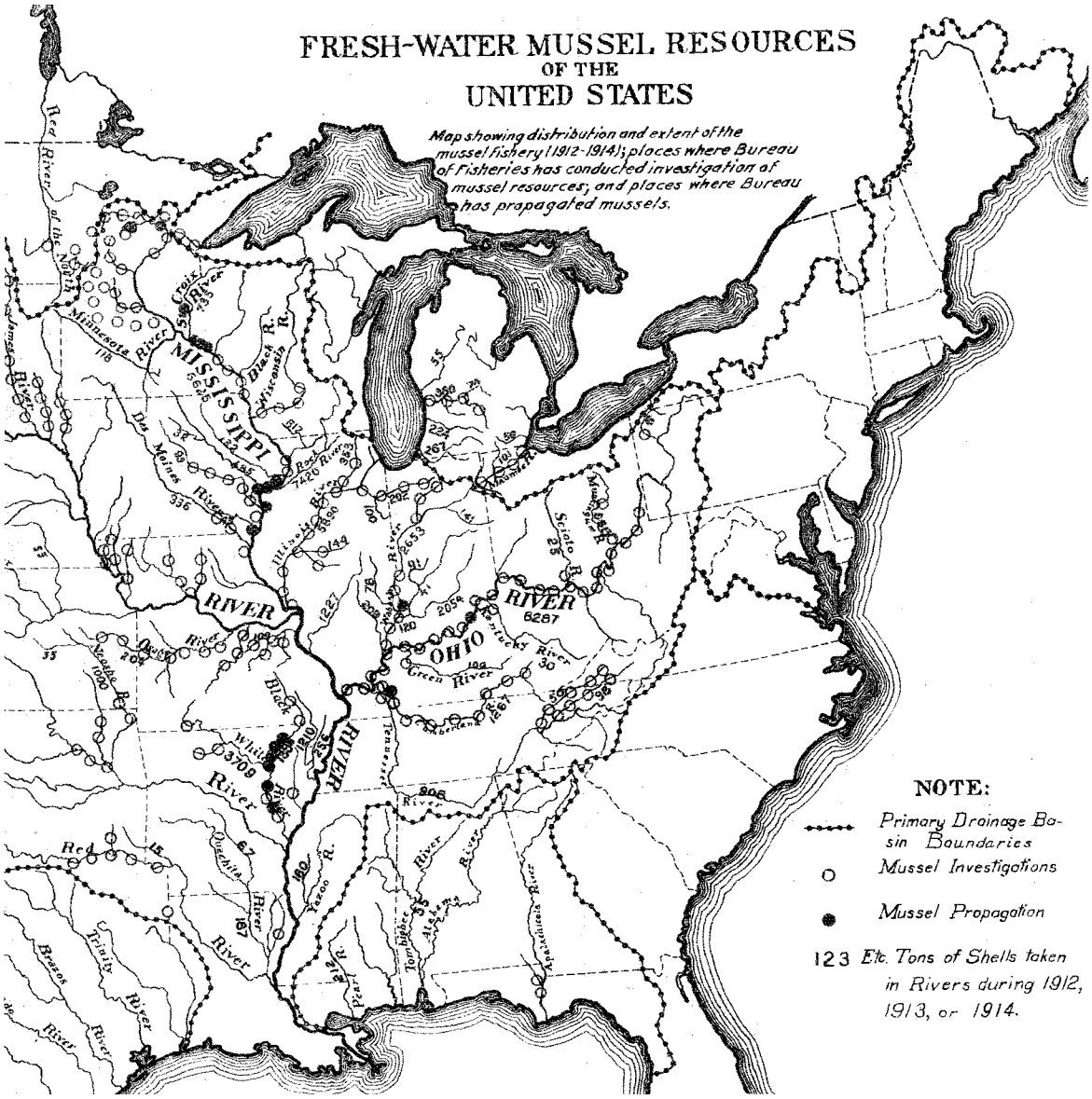

Fig 2. Lefevre and Curtis carried out the first organized surveys of mussel populations from 1906 to 1914. "Fresh-Water Mussel Resources of the United States," 1914. Map courtesy of National Archives and Records Administration, Cartographic Branch, RG 22.

FAIRPORT BIOLOGICAL LABORATORY

In 1908, Congress appropriated funds for the construction of a biological station at Fairport. This was the result of considerable lobbying by officials of the Bureau of Fisheries, the button manufactuters, the cooperation of zoologists, and the support of local congressmen. Barton K. Evermann, an ichthyologist, Bureau official, and director of the California Academy of Sciences, personally helped select the site and arrange details, as did Lefevre. The property, about 60 acres located on the Mississippi River a few miles north of Muscatine, Iowa, was evidently purchased and donated to the government by the National Association of Button Manufacturers. Construction began in 1909, the main laboratory built in 1912–13, and dedicated on August 4, 1914, with Dr. Robert E. Coker appointed the first director (Hunn 1989, REC Papers and WCC Papers).

Some of the important early work at the Station included Thaddeus Surber's work, significant because scientists were still learning which fish species served as hosts during the parasitic stage of many mussel species. Examining fish for their natural infections, Surber described and drew illustrations of fifteen species of fresh-water glochidia. It took three years of experiments to discover the specific host (skipjack, *P. chrysochloris*) of the commercially important *Quadrula ebena*.

The second object in Surber's work lay in developing a human-designed system of propagation that might improve on nature. In 1912, Surber examined 2,815 fish of 38 species taken from the river, finding that only 46 fish of 11 species were naturally infected. Surely, the logic went, humans could improve on that

dismal record. The "advantages of artificial infection can be readily imagined," he wrote, "when the small percentage found infected in a state of nature is considered...all man has to do is find the specific host of a given species, procure that host, and load it to the limit, which may exceed the optimum infection of Lefevre and Curtis in some cases" (Surber 1912, Surber 1914).

Reflecting the close connections between the Bureau and academic scientists, by 1917 the Fairport Biological Laboratory also attracted Professor Charles Branch Wilson, working on dragonflies and damselflies in relation to fish culture as well as the effects of copepod parasites on fish infected with glochidia, Professor Emmeline Moore, studying aquatic plants in relation to fish culture, and five other scientists engaged in projects related to fish or fish culture. By 1920, emphasis on fish culture activities had grown. Fairport scientists studied the "conditions necessary to make individual ponds as productive as possible for market fish," experimented with catfish and buffalofish propagation with an eye to increasing food supplies, and experiments related to "the growing of game fishes in ponds." By 1928, the station also assisted in "development of the fish resources of the Upper Mississippi Wild-Life and Fish Refuge" (Coker 1914 "Fairport," Wilson 1914, Coker 1920).

The physical facilities at Fairport provided the necessary elements for experiments in propagation. Much of the Superintendent's job involved the details of maintaining the physical facilities. By 1914, 17 earthen ponds were constructed, and by 1920 there were as many as 14 small concrete ponds and 22 earthen ponds ranging from one-tenth of an acre to about an acre in size. During 1927, the pump house impelled 108,616,000 gallons of unfiltered water from the Mississippi River and 1,484,805 gallons of filtered water to supply the needs of the station. Reservoirs placed above the ponds received water from the pump house, and then a gravity system was used to feed the various ponds (Coker 1914 "Fairport").

HOWARD AND THE FLOATING CRATES

Beginning in 1913, the Bureau of Fisheries published the work of Arthur Day Howard, the "scientific assistant" whose main concern was the culture of young mussels after their parasitic stage. In 1922, Howard noted the steady but slow progress in keeping captive mussels alive; in 1885–1888, Schmidt and Schierholz had mussels live to four or five weeks, Harms in 1907 had mussels live to seven weeks, and in 1913 Herbers kept mussels alive for two months, and Lefevre and Curtis found a mussel alive two years after it was planted (Howard 1913, Howard 1922).

Howard pursued several methods of mussel culture, measuring rhe growth of mussels in ponds, tanks, and troughs, indoors and outside. Howard claimed "negative results" while testing indoor aquaria supplied with flowing river water, whether they were made of wood, painted and unpainted metal, or cement tanks and troughs. He tried filtered river water in balanced aquaria, in an effort to avoid "destructive turbellarians and other predacious forms." But the mussels only survived a short time in the indoors equipment (Howard 1922).

Howard noticed a dwarfing effect in aquaria and indoor tanks. He did not know if it was silt, or reduced light, or a lack of plankton that made his captive mussels smaller than mussels in the wild. Howard made particular mention of his thoughts on natural versus artificial propagation, speculating that "there must be some vital deficiency under artificial conditions..." He sought a method of propagation "which would depart from the natural habitat only so far as the necessity of mechanical control demanded." In trying to imitate nature, Howard manufactured "a floating crate containing baskets made of wire cloth of sufficient size to hold the fish and of a mesh small enough to retain the [microscopic] mussels" (Howard 1922).

Fig 3. Howard's floating crate with four baskets held fish infected with glochidia and then the juvenile mussels. From Howard, 1922.

Howard's crates or baskets were suspended at the river's surface in small rafts so that water temperature and chemistry would be as close to natural conditions as could be achieved (Fig. 3). The first raft comprised "a floating fish car" with four baskets measuring 1.5 by 2.25 feet. Howard continually improved the raft or "float," making it larger and more stable in the current, and replacing the original metal on the baskets with wood frames, which was less expensive and did not harm the mussels. At the surface, Howard presumed, the young mussels wouldn't encounter their enemies found at the river bottom. Additionally, he thought, the mussels would be spared the harm wrought by excessive silt deposition. Infected fish were placed in the baskets "a few days before the end of the parasitic period of the mussels and were removed as soon as the mussels were shed." The floating crates seemed to pay off. In a rectangular glass aquarium, a plant of juveniles was obtained from two bass *(Micropterus salmoides)* and one calico bass *(Pomoxis sparoides)*. These mussels grew slowly, measuring around 4.2 mm by August, whereas average mussels in the floating crate measured over 10 mm by the same date (Howard 1922). Frederick Isley also carried out experiments on mussel growth at Fairport (Isley 1914).

ROBERT E. COKER

Dr. Robert E. Coker served as the first director of the station (1910–1915), and then directed the Division of Scientific Inquiry in the U.S. Bureau of Fisheries (1915–1922). He acted as a knowledgeable advocate for the mussels during a period of considerable development of river transportation and hydroelectric facilities. In a very short period of time, he began to see a larger picture beyond the technical problem of propagating mussels. He wrote not only about mussel rearing techniques, but also about the button industry, conservation of mussels, river conditions and pollution (Lehman 1968).

In 1914, Coker investigated the effects of the first major dam on the Mississippi, the Keokuk dam, built for power generation. He sought to quantify and prove or disprove the rumors and anecdotal reports that fewer fish of certain species were seen above the dam. Because mussels utilize a parasitic stage on fish, their

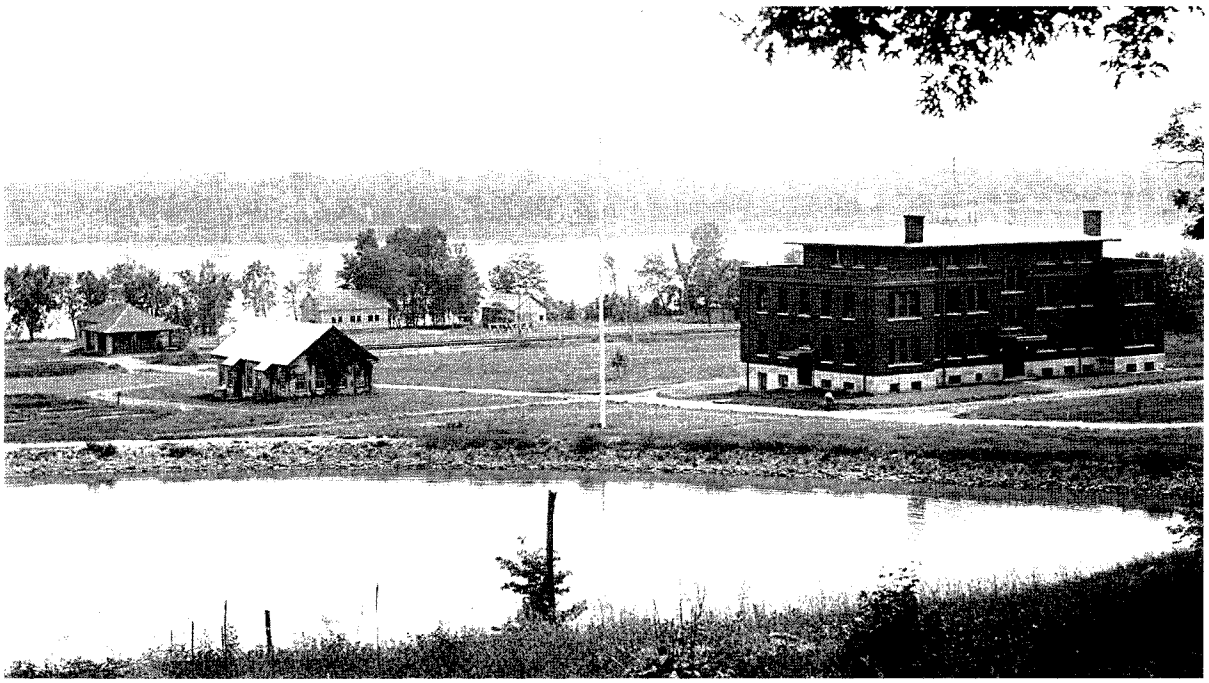

Fig 4. View of Fairport Biological Station. The second (re-built) main laboratory building pictured here was dedicated in 1921. From Coker et al., 1922.

distribution up and down the river system would be affected by a limitation on their host fish's mobility. Coket followed Commissioner Hugh Smith in urging conservation efforts, suggesting "a plan of rotation which will give rest periods to different portions of a river in succession." He suggested that conservation of the mussel beds would not be easy: "ultimate benefits can scarcely be obtained without some temporary sacrifice...It is the unwillingness of individuals to make individual sacrifices, independently, for the good of the mussel beds that makes legislation of any kind necessary" (Coker 1914 "Protection," Coker 1914 "Water-power").

On December 20, 1917, the laboratory building was struck by disaster. At 2:30 a.m., W.S. Carter was awakened by smoke, as was Apprentice Fish Culturalist Mr. Schroeder and his wife. Despite the attempts of staff, a fire starting in the walls below the second story's flooring near the east wing chimney destroyed "most of the equipment and practically the entire library." Also lost were "records embodying results of tedious investigations." The scientists "promptly resumed" their work in the close quarters of the old "temporary laboratory," a small building used during the very first years of the station. The original building was razed after the fire and replaced at the estimated cost of $92,000 (Fig. 4). Like the first building, it represented a substantial government investment in science and inland fisheries. Measuring some 100 by 55 ft, the new building accommodated sixteen investigators. The well-attended dedication on October 7, 1921, featured a brass band and speeches by dignitaries, including Hugh M. Smith, Commissioner of Fisheries, Edward A. Birge, President of the University of Wisconsin, Professor Frank R. Lillie, of the University of Chicago and the Marine Biological Laboratory, Woods Hole, George Lefevre, Professor James G. Needham of Cornell University, as well as the local Congressman. Representatives came from twenty-rwo universities and colleges, and from fourteen states.

COKER, SHIRA, CLARK & HOWARD

In 1922, the Bureau of Fisheries published the "Natural History and Propagation of Fresh-water Mussels" by R.E. Coker, chief of the Bureau's Division of Scientific Inquiry, Austin F. Shira, director of the Bureau's Biological Laboratory at Fairport, Iowa, and scientific assistants H.W. Clark and A.D. Howard. The report looked into the natural history of fresh-water mussels, including habits, food, habitat, parasites and enemies, unfavorable conditions for mussels, growrh of shells and the structure of mussels. Secondly, the report examined the life history and propagation of mussels. This summary report is probably most notable in revealing scientists' efforts to systematize and put on terms of mass production the station's prior work in propagating mussels (Coker et al. 1922).

Coker and his associates, like many scientists of their day, made distinctions between natural and artificial conditions. Some natural conditions, such as shifting bottoms, turbidity, sedimentation, drought or floods were unfavorable to mussel life. Artificial conditions "imposed by man" detrimental to mussel life included "the discharge of sewage, industrial wastes, dredging, and the building of wing dams." Coker et al. summarized information on suitable bottom conditions or habitats for 62 species of mussels, noting "luxuriant development of certain mussels in streams where the current is strong," and surveyed locations along the Mississippi River as well as in Indiana, Illinois and Michigan (Coker et al. 1922).

It seemed a simple matter to feed growing mussels, even from the earliest stages. It would be necessary "only to arrange ponds, uncontaminated by sewage or stock, and place in them some of the common water plants and algae. The requisite diatoms, Protozoa, etc., will appear and flourish there, and these, with the detritus from the decay of all the living forms, will supply food for the juvenile mussels in the pond or to which the

water from the pond is conveyed." E.P. Churchill and Sara I. Lewis judged that it was "unnecessary to plan any complicated arrangements to provide special food for them" (Churchill and Lewis 1924).

BEYOND NATURE'S OWN PROVISIONS

Scientists at Fairport continued working on determining the host fish for various glochidia. Like Lefevre and Curtis, they noted the rate of infection was relatively low in nature. In 1913, only 8.9 percent of sampled fish were infected with glochidia. Regrettably, not even 3 percent were infected with 12 commercially valuable species. The average number of glochidia on a fish ranged from 1 to 416 with a mean of 125. "Infection in nature is a matter of chance," they wrote, "with the disturbance of natural conditions by the active pursuit of a commercial shell fishery, nature's fair balance is destroyed, and some compensatory artificial aid to the propagation of mussels is rendered necessary" and "if it were otherwise, artificial propagation might not be necessary" (Coker et al. 1922).

Coker and other Fairport scientists thought that "operations can be conducted extensively and economically only in the field." They argued that personnel needed to go to the immediate vicinity of a place selected for stocking, catch and infect the host fish there, and "liberate them immediately" (Fig. 5). They suggested that artificial propagation of fresh-water mussels therefore was "a very different sort of operation" from fish propagation (Coker et al. 1922).

FISH RESCUE

Each year as the Mississippi River flooded, thousands of fish were left stranded in pools of water isolated from the river, doomed to die as floodwaters receded back into the main channel while the ponds evaporated. This was viewed as a terrible waste of a natural resource used for food as well as sport fishing, and so in 1876 at the instigation of Iowa Fish Commissioner B.F. Shaw, the states (such as Missouri in 1881) began to spend a great deal of time and energy rescuing the fish and returning them to the main river channel. In 1922, around the high point of operations, at least 20 stations participated in the work.

The entire enterprise of infecting host fish became tied to the practice of fish rescue. Quite a bit of the mussel infection work associated with Fairport Biological Laboratory was carried out in the field by crews operating out of fish rescue stations at Homer and La Crosse. By 1913 the two programs were cooperating. In 1914, Bureau personnel "planted" or infected fish with an estimated 227,536,814 glochidia. Carrying those glochidia in 1914 were 167,819 fish liberated into rivers and lakes, and of those, 66,645 had been rescued from overflowed lands. By 1920, U.S. Fish Commissioner Hugh Smith had molded the two programs to serve "two national purposes; it will maintain the valuable food and game fishes of the Mississippi River and will, at the same time, preserve the national resources in clams" (Smith 1920, Carlander 1954).

MUSSEL CULTURE

The second crisis for the aspiring mussel was dropping from the host fish and growing to a sufficient size. Having used techniques of "propagation" to bring the mussels to this stage, Coker et al. (1922) now worked on the techniques of mussel culture. In 1915, Howard had first reared mussels (Lake Pepin muckets) under control in a crate that floated in the Mississippi River. At that time, Coker evidently had some success with the same species in ponds at Fairport. They experimented with several devices and methods of mussel culture: 1) a floating ctate with closed bottom (used mainly in rivers), 2) a floating crate with open (mesh) bottom (for ponds), 3) "the bottom crate," 4) pens with wooden bottoms, 5) concrete ponds, 6) earth ponds, and 7) troughs of sheet metal, wood or concrete tanks, and aquaria (Coker et al. 1922).

Fig 5. The crew pictured here is seining fish in Lake Pepin, then transferring the fish to an infection tank on the boat where the foreman (standing) will pour glochidia from a can into the tank. From Coker et al., 1922.

Special narrow troughs were used at Fairport, beginning by 1916, to rear the Lake Pepin mucket. Eight troughs were constructed outdoors, and covered from the sun with a simple toof. These troughs measured 12 feet long by 1 foot wide by 8 inches deep, were painted with asphaltum, and each had its own water flow ftom "a common screened supply pipe in the pond." Each trough bottom was covered with a half inch of fine sand. In 1919, Dr. F.H. Reuling reared two more species, the yellow sand-shell and river mucket, "in considerable quantities in small troughs supplied with naturally clarified river watet." By 1920, H.C. Minch and T.K. Chamberlain were conducting expetiments in rearing mussels in 28 numbered troughs under a temporary shed (Coker et al. 1922).

By 1923, the Bureau of Fisheries felt that enough was known about survival and growth of juvenile mussels "to warrant the establishment of a small rearing system at Faitport." They added 100 to the 42 existing troughs at Fairport, each one 16 feet long, 15 inches wide, and 12 inches deep (Fig. 6). Black paint covered the bottom of each trough and lids were placed to keep out the light. Darkened troughs, they found, produced twenty-five times as many juvenile mussels as ones open to light. It was assumed that the dark troughs simulated "natural conditions on the bottom of mussel-bearing streams." The troughs were fed by gravity-fed water that had settled out in two ponds before entering the troughs. Lake Pepin or fat muckets were used to infect black bass, and by 1923 the troughs produced 500,000 mussels approximately one half inch in diameter. The 1924 Fairport annual report notes that the new troughs were not sheltered by a shed, as were the original ones. The old troughs produced 160,000 young mussels, but the new ones not protected from the sun experienced a total failure (Report of the Commissioner 1920 & 1923, Carlander 1954).

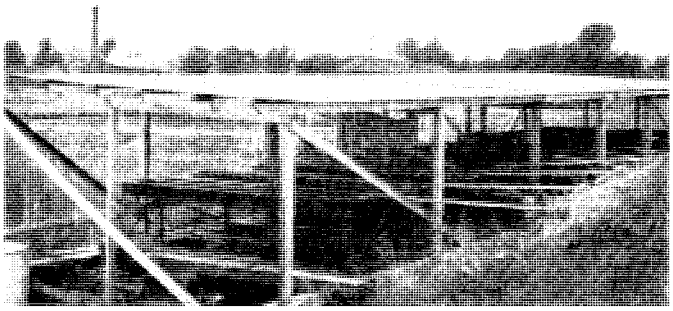

Fig 6. Troughs at Fairport. While suspecting that their techniques lacked something in nature, Fairport scientists created highly artificial aids to propagation that sought industrial scales of production. From *Report of the Commissioner of Fisheries*, 1920.

A DISTINCT DEPARTURE

Fairport scientists thought their techniques "a distinct departure from the methods previously used [giving] the operator complete control of conditions throughout." They were encouraged and wished to expand the operations, as well as perform more research into what exact conditions (enemies in troughs, food, artificial feeding, and bottom material) might encourage their growth. Fine sand, they thought, was probably the best bottom material. Coker et al. closed their 1922 report by stating their belief that "the valuable Lake Pepin mucket can be reared in quantities, under conditions of control." In 1923, the Bureau felt that the experiments with the troughs, among other things, gave "an indication of the possible usefulness of controlled methods over the present method" of infecting fish and simply releasing them, "where it is unlikely that more than a 2 or 3 per cent survival results." Mussel rearing, they believed, could be conducted "with results more tangible, cheaper, and less limited by natural physical, chemical, and biological factors." The Fairport Station had other successes. In 1927, the Fairport Laboratory sent several shipments of *L. luteola* (fat muckets) to Japan to restock depleted mussel beds (Coker et al 1922, Report of the Commissioner 1923).

MAX MAPES ELLIS

The fourth major character in the attempt to rear mussels at Fairport, and perhaps one of the most persistent personalities in this story, was Max Mapes Ellis (Fig. 7). He confidently predicted he could propagate ten to a hundred times more than his predecessors. Like Coker, he statted inventing technological solutions and ended up working on more general problems, notably pollution. A physiologist at the University of Missouri, Ellis began work on mussels at Fairport by 1925, and maintained absolute confidence in this work until 1942, when Elmer Higgins at the Washington office of the U.S. Fish and Wildlife Service cut off funding.

We know that Ellis began his work at Fairporr by 1925, when Thomas K. Chamberlain directed the station. Ellis found that ultraviolet rays of sunlight were fatal to glochidia, clearing up the reasons why mussels seemed to do better in the dark. Secondly, he discoveted that the "acid-alkali balance of the blood of the fish to the glochidia encysted in its gills" was important. This factor had significance for developing Ellis's pet project, propagating mussels without the parasitic cycle. By 1926, Ellis believed he was well on the way to eliminating the parasitic stage of the mussel life cycle in laboratory propagation. This concept can be found mentioned as early as 1916 in the *Report of the U.S. Fish Commissioner*, under the activities of the biological laboratories. It's fair to imagine that the idea may have come out of the Woods Hole Marine Biological Laboratory. Lefevre and Curtis had experimented with transforming glochidia in a nutritive solution (Lefevre and Curtis 1910).

Working with his spouse, Marion D. Ellis, Max Ellis started with an artificial infection of *L. fallaciosa* Smith (the Creeper or Slough Sand-shell) on its natural host, the short-nosed gar, *Lepisosteus platostomus* Rafinesque. He then dissected glochidia out of their cysts at 18 and at 96 hours after encystment, and transferred to one of several experimental solutions. The successful solution, he wrote in a 1926 issue of *Science*, contained "sodium chlorid, potassium chlorid, calcium chlorid, sodium bicarbonate, dextrose and a mixture of amino-acids, together with small quantities of phosphates and traces of magnesium salts" (Ellis and Ellis 1926).

In the summer of 1926 at Fairport Station, Ellis completed his nutrient solution "which would carry mussel glochidia through the same metamorphosis they would normally undergo as parasites upon fish." Only individual glochidia "were so carried through, difficulty being experienced with bacteria associated with the glochidia," but in 1927 Ellis employed "a method of sterilizing the glochidia directly after being taken from the marsupia of the parent mussels" which did not injure the glochidia. He then was able to carry through groups, first dozens, then hundreds at a time. By 1927, he felt his nutrient solution was perfected (Records of the Bureau).

In the fall of 1927 and the spring of 1928, Ellis took a sabbatical leave to tour European laboratories and work with colleagues. He used what he learned to improve Fairport's lab techniques and increase the numbers of mussels produced. He based himself out of the University of Glasgow in Scotland, working under the direction of Professor D. Noel Paton and with the daily cooperation of Professor E.P. Cathcart, a protein-chemist. Ellis visited the Marine Laboratory on the Island of Great Cumbrae, Frith of Clyde where he enjoyed the privileges of the "Coates Research Room and Table." He visited several medical labs in England, and then traveled to Holland, Germany, Czechoslovakia, Austria, Switzerland, and Belgium. Paton's personal introductions made "our sojourn here in Europe pleasant as well as profitable," in the sense of all that he learned at several European research laboratories. Upon his return, Ellis designed six units of apparatus to culture mussels, each to handle "upwards of half a million glochidia." (School of Medicine Records).

During 1928, Ellis reported almost all the gravid mussels collected from the field were infected with a protozoan parasite known as Clark's bug, believed to belong to the genus *Conchotherius*. This was harder to get rid of than other bacteria infecting glochidia. The protozoa seemed to multiply rapidly and foil Ellis's new equipment. Ellis and Chamberlain ttaveled to several states but had difficulty finding mussels free of the parasite. In the lab at the University of Missouri, Ellis and his assistants devised a method to separate healthy ftom infected glochidia.

Archival evidence suggests Ellis did indeed produce juvenile mussels. The first plants of juvenile mussels were planned for 1928, at least nine and perhaps as many as 15 to be conducted 50 miles apart in Minnesota, Wisconsin, Indiana, Kentucky (the Ohio River and the Cumberland), Arkansas (the White and the Black Rivers), and on the Mississippi River between Iowa and Illinois. Ellis hoped to plant one million cultured mussels during the summer of 1929 (Records of the Bureau). In 1929, Ellis

Fig 7. Max M. Ellis (right) "collecting bottom samples from cruiser with Peterson dredge." From Ellis, 1937.

reported that he intended to develop "individual mussel culture units" to handle more glochidia. He claimed to have tripled the capacity of the units over six months, so now each unit would handle 1.5 million at a time. Ellis wrote that "several such units have been operated to capacity, several times producing some five or six million young mussels" over the summer and fall. By producing so many young mussels in the "few mussel culture units," Ellis assumed "that the large-scale production of mussels is established as economically feasible." He removed 2 million mussels produced at Fairport to Columbia by automobile, "where they arrived in perfect condition," showing that they could be "transported safely to streams for planting." The best survival rate, he thought, could be obtained by transporting young mussels during the first three days following metamorphosis, or three weeks after that time (Report of the Commissioner 1930).

By 1930, Ellis had a staff of eleven working at the Bureau of Fisheries' Columbia field unit, housed in eight rooms of the University of Missouri's Medical Building. Max Ellis, Marion Ellis, and Amanda Merrick evaluated the blood of fresh-water mussels, comparing stressed populations to groups theoretically not under stress. They were attempting to assess the effects of "progressive changes in stream conditions," including navigational improvements in the river, and particularly municipal and industrial pollution that had "materially altered the natural habitats" in the Mississippi drainage. By 1930, Max Ellis had disproved a rumor that mussels did well in polluted water, showing that mussels were very sensitive to water quality, and were "fundamentally clean-water animals and that their ability to adjust themselves to conditions of stream pollution is sharply limited" (Ellis et al. 1930).

THE ELLIS METHOD

In early 1930, The Bureau decided to put the "Ellis method" on a producing basis. Fish Commissioner Henry O'Malley wrote "it is our intention to operate this apparatus on a commercial basis at the Fairport, Iowa, Laboratory of the bureau as rapidly as a supply of healthy glochidia can be obtained." Elmer Higgins, Chief of the Division of Fishery Biology, planned to put two mobile units into the field, each capable of producing 25,000,000 to 50,000,000 juvenile mussels. Higgins wrote that assistants, "oddly enough, will probably be women trained in hospital and bacteriological technique," since the task required a "great degree of manual skill as well as training in sterile procedure." Ellis and crew were on the lookout for favorable localities "in waters of suitable chemical composition known to be definitely free from deleterious domestic or trade wastes, and free from sudden fluctuations in water level." The Bureau wanted assurances from the states that mussels would enjoy protective legislation (Records of the Bureau).

The U.S. Bureau of Fisheries seized upon Ellis's new method with enthusiasm. By 1930, the Bureau clearly distinguished between the "controlled natural propagation" method, and the new "artificial propagation" or Ellis method. The older method called for infecting rescued fishes, was practiced exclusively from 1915 to at least 1925, and was materially improved by Ellis. The natural infection method continued to be used during the 1930s, but the Bureau wanted to switch to rhe Ellis method because of the pollution situation in the rivers. The button manufacturers preferred the original method, believed it worked well, and distrusted the new-fangled technology. For its part, the Bureau came to doubt the reported numbers of planted (encysted) glochidia prior to 1924.

The button manufacturers had funded a part of Ellis's work, and as early as 1929 they wanted an informational presentation of his progress. Ellis advanced various excuses, reluctant to give a demonstration. His biggest concern was that his method of mussel propagation, particularly his innovation of skipping the parasitic stage, might be stolen. In a letter to the chief of the Bureau of Fisheries, Elmer Higgins, he shared his worry regarding the "constant effort of reporters and certain spies to get into my laboratory and make away with the method...we have to be constantly on our guard." This was hardly in the spirit of scientific inquiry. After all, Ellis had taken a sabbarical leave in Europe, where he gained ideas for his laborarory techniques. Yet the story did not end there, as Ellis left important clues to his formula in two publications. In 1982, Billy G. Isom and Robert G. Hudson devised a solution for in vitro culture of *Ligmia recta* and *Lampsilis ovata*, derived in part from Ellis's published work (Isom and Hudson 1982, Pekkarinen and Hansten 1998).

THE PROBLEM OF HABITAT

The early 1930s seemed tumultuous at Fairport. The staff was re-organized in 1930. One of the assistants, Richard Zalesky, wrote to Elmer Higgins in Washington, calling Dr. A.H. Wiebe "the bunk" as well as an "unhuman supervisor," and resigned his position. In 1933, Frank Bell was appointed Commissioner of Fisheries. When he resigned six years later, the *Fisheries Service Bulletin* noted that "a shake-up in the fish cultural activities of the Bureau followed Mr. Bell's appointment, which resulted in the closure of unproductive stations." Bell's actions may well

have affected the Fairport Biological Laboratory. By 1933, fish culture operations at Fairport began to increase, while efforts aimed at the propagation of mussels clearly decreased (Records of the Bureau).

Within the Bureau of Fisheries, it seemed there was debate about the relative success of the mussel propagation program that may have stemmed from inter-departmental competition for funds. Although scientists had claimed success for their methods of mussel propagation, by 1926 the Bureau's Washington office reported that "natural causes have contributed more to the increased production of sand shells than has the inoculation of fishes with the young of this species" (Records of the Bureau).

Despite the 1929 official optimism of Bureau of Fisheries Director Elmer Higgins, it seems that at Fairport itself, gloom seemed to set in as it became apparent that mussel populations had been devastated. Thomas K. Chamberlain, Fairport Station director in 1930, wrote that Pepin was "simply gone" as a mussel producing body of water. He wrote to Elmer Higgins of the Bureau's Division of Scientific Inquiry in February of 1930, conveying data showing "the complete breakdown of all fisheries in Lake Pepin." Evidence included reported declines in the catches of the regular commercial fishery, the infection crew's declining catch of game fish intended for infection, and a detailed mussel survey. Apprentice Fish Culturist George W. Davis reported that the upper end of Lake Pepin was filling in with silt of a foul nature, most probably from packing plants in south St. Paul. Scientists had been aware of pollution problems from as early as 1913, when S.A. Forbes, director of the Illinois Natural History Survey, had written to Dr. H.F. Moore, in charge of the Bureau of Fisheries' Division of Scientific Inquiry. He worried that the subject of pollution "is so infinitely complex...that I fear life is too short for me ever to complete this work according to my first intention..." From St. Paul to Keokuk, the Mississippi River in 1930 appeared to Chamberlain "just about a thing of the past" as a producer of fish and mussels. He reported the fishermen "as bitter against the Keokuk Dam as ever, claiming that no fish come up through the locks." As early as 1926, the host fish (skipjack) for the ebonyshell mussel (*Quadrula ebenus*, a highly valuable species for button manufacture) was evidently missing above the Keokuk dam. Without the host fish, there was no hope for the glochidia. It seemed mussels in the wild were doomed. In 1930, Chamberlain urged Higgins to drop the work in Lake Pepin and "advise the states to throw the entire river open to unlimited shelling," giving as a reason the failure of the Minneapolis sewage control project. Chamberlain noted "the nine foot channel proposition" (for navigation) as "an additional reason for throwing the river wide open pending the completion of the engineering work" (Records of the Bureau, Coker 1917, Coker 1929, Grier 1926).

Notwithstanding his perennial optimism, by 1930 Max Ellis found difficult conditions for mussels in the Mississippi River. In the portions of the Mississippi, Ohio and Tennessee Rivers that he studied, Ellis found no replacement of yellow sandshells less than 6 years of age or ebonyshells less than 9 years of age. This was distressing because these were two of the most important commercial species. In the upper Mississippi he found only two of fifteen commercial species, the maple-leaf and the hickory-nut, replacing themselves fast enough to maintain the species. The Bureau of Fisheries reported a "startling decline in mussel production" in the Upper Mississippi river. Lake Pepin was the prime example: in 1914–15, the lake had produced 3,000–4,000 tons of commercial shells (*Lampsilis luteola* a primary species), in 1919, 200 tons; in 1924 after the four year closure, it produced 2,000 tons, but the catch again fell off rapidly, in 1926 producing 164 tons and in 1927 only 50 tons. In 1929, areas that had been closed for five years were re-opened, and officials estimated production of commercial species at a disappointing 600 tons. With detailed sampling, the Bureau estimated a 70 per cent drop in the total mature mussel population in just one year. In 1931, Ellis reported "no conditions suitable for planting yellow sandshells" on the Ohio River between Cairo, Illinois, and the mouth of the Green River, or on the Tennesee River across Kentucky (Records of the Bureau, Southall 1925, Ellis 1931 "Some factors," Ellis 1931 "A Survey").

Furthermore, Ellis was having great difficulty finding enough brood-stock, because the brood pouches of gravid yellow sandshell, slough sandshell, Lake Pepin mucket, river mucket and pocketbook mussels "were found to be heavily infested with bacteria and infusoria." The unit inspected over 6,000 gravid mussels in 1930, finding few suitable for propagation work, many of them having "black masses filling units of the marsupium normally occupied by conglutinates of glochidia." Ellis wrote that "in addition the usual bacterial flora to be expected in any decomposing mass of tissue, one particular organism" similar to *Bacillus proteus* comprised the main organism in these infections. Finding enough healthy gravid mussels was one of Ellis's biggest problems in mussel propagation (Records of the Bureau, Report of the Commissioner 1931).

The first problem was pollution. As early as 1923, Fairport reported that its mussels had become infected with a ciliate (Conchopthirius) that invaded the marsupia and destroyed glochidia. Sewage entering the Mississippi from Davenport, Rock Island, and Moline was thought to be the cause. Fairport scientists feared that pollution of the Mississippi River would negatively affect their trough experiments "by destroying the juveniles as soon as [they were] dropped" from their host fish. Around 1930, A.H. Wiebe studied levels of manganese, phosphorus and nitrogen in the Mississippi River at Fairport. In 1930, Elmer Higgins (director of the Division Of Scientific Inquiry) thought "the outstanding need" was "a thorough physical, chemical, and biological study of all actual or potential mussel-producing waters in the Mississippi and Gulf drainage to discover waters favorable to the extension of mussel culture" and "an urgent need for a thorough study of the biological and physiological effects of the various polluting substances found in streams." Progress in mussel culture, wrote Ellis, was limited by not knowing "the fitness of inland waters to support aquatic life...Conditions are becoming so serious in these waterways that prompt action is needed in providing ways and means for disposing of domestic sewage and trade wastes other than by using the rivers as open sewers" (Records of the Bureau, Ellis 1937).

The second problem was erosion silt. Ellis judged that silt directly smothered mussels "in localities where a thick deposit of mud is formed," and young mussels were particularly vulnerable to oxygen deprivation brought on by silt "blanketing the sewage and other organic material which in turn produce an oxygen want..." Pollution and silt added up to a serious situation that threatened "extensive and rapid reduction of the mussel fauna...almost to extermination...if the erosion and pollution problems are not solved, in view of various improvements for navigation now existing or already authorized throughout the Mississippi, Ohio and Tennessee drainages." Because of the great changes in river conditions from 1925 to 1930, Ellis wrote, "the present problem of mussel culture is not one of propagation, either natural or artificial, but the maintenance of a suitable

habitat for a period of at least five years to allot maturing of the mussels planted" (Records of the Bureau, Ellis 1936).

Here we note an important transition in thinking about the chances for recovery of mussels in their native habitat. In 1930, Bureau Commissioner Henry O'Malley had written that "the maximum production without recourse to artificial propagation apparently has been reached." "The particular objective," Ellis wrote in 1932, "is the determination of the maximum number of fresh-water mussels which may be raised successfully in a given area by artificial propagation." Thus by the early 1930s, the Bureau was looking not to the river for the salvation of industries based on mussels, but to completely artificial propagation, what we might call "mussel farms." This is substantiated by the 1931 Annual Report of the U.S. Bureau of Fisheries, which mentions that the "transfer of attention from the reestablishment of the mussel beds in the natural habitats in the larger rivers, as the Mississippi and Tennessee, to the production of artificial beds in controlled habitats has made necessary extensive studies on the physiology of the fresh-water mussel" (Report of the Commissioner 1932).

From 1932, Max Ellis was placed in charge of "investigations in interior waters," consisting of the mussel propagation and the pollution studies. From 1934, the pollution study was called F.P. 41, "Stream Pollution Studies in the Middle West." The work was centered in Ellis's lab at the University of Missouri in Columbia. Scientists surveyed 800 miles of the Mississippi, various streams in 21 states, as well as mining and natural alkali pollution in Idaho, North Dakota, and Montana. Mining, mine wastes, and the processing of metals were perceived as problematic, as well as other industrial processes such as tanneries that created wastes ending up in rivers. Ellis developed assay techniques, detected, measured and documented chemicals in rivers, and published studies on measuring stream pollution (Ellis 1937, Ellis, Westfall and Ellis 1946, Platner 1946).

END OF MUSSEL PROPAGATION AT FAIRPORT

The pollution studies must have taken quite a bit of time, reducing the amount of energy Ellis could put into the mussel propagation work. Similarly, the attention of the Bureau of Fisheries was increasingly diverted toward the pollution studies. These investigations on the Mississippi River were first mentioned in the Bureau's 1930 *Annual Report*. Beginning in 1934, we see that the Bureau's *Annual Report* has more to say about pollution studies than about mussel propagation, and beginning in 1938, the report simply does not mention mussel propagation. Through 1947, Ellis continued to publish on the subject of water pollution with the Fish and Wildlife Service.

In 1932, with no fanfare, Ellis began mussel propagation activities at the U.S. Bureau of Fisheries' Ft. Worth, Texas station. In short, he moved mussel propagation from Fairport Lab to Texas. The science of mussel propagation came to a halt at Fairport Biological Station. Each year during the 1930s the Bureau of Fisheries' Annual Report included Elmer Higgins's "Progress in Biological Inquiries," the report of the Division of Scientific Inquiry. In 1933, Higgins wrote that "Research activities at the Fairport (Iowa) laboratory...have been entirely discontinued, owing chiefly to a lack of sufficient funds." Budget cuts due to the Great Depression could have restricted the Bureau's options in the early 1930s. At this time the U.S. Bureau of Fisheries' Division of Fish Culture began to use the station predominantly for propagating warm-water pond fishes. As of July 1st, 1933, foreman Leslie H. Bennett took charge "with a view to raising as many fish as possible with what money could be utilized for that purpose." The large lab was closed and all its equipment stored or transferred. The cottages stood unoccupied by 1934, and cottage #4, "formerly occupied by the shell expert," looked in bad shape. Foreman Bennett suggested that in the local climate "unoccupied buildings are susceptible to rapid decay," and noted that in the large lab "the dampness is penetrating." In 1945, the lab building evidently housed POWs and their guards, who did some repair, painting and upkeep. The main lab may have been torn down by 1955 (Fairport Annual Reports 1933–42, Carlander 1954).

Ellis struggled on in Texas with uncertain funding for propagation until March 1942, when Bureau Chief Higgins wrote Ellis without ceremony that "no funds for this purpose will be available after July 1, 1942." Certainly, an economic depression and war may have ended all but the most essential operations. It does seem curious that despite changing river conditions, Higgins and Bailey seemed officially optimistic about propagation through the fall of 1941. Perhaps Higgins was frustrated with Ellis's refusal to make a demonstration, or possibly he felt Ellis's new method (or mussel propagation in general) was ineffective. Finally, perhaps the pleas of the button manufacturers fell on deaf ears as people decided the better days of that industry were gone.

The U.S. Bureau of Fisheries' Biological Laboratory at Fairport represented a significant social investment in the inland fisheries. Scientists propagating mussels found that imitating natural conditions in the laboratory was very difficult. As human activities altered mussel habitats in the Mississippi River, notably through water pollution and the construction of dams for navigation, scientists at Fairport Biological Station devised increasingly sophisticated techniques to propagate and rear mussels in the laboratory. Hope for the mussel fishery swung from releasing fish infected with glochidia toward artificial methods involving rearing mussels in troughs on an industrial basis.

As historians Arthur MacEvoy and Joseph Taylor have pointed out (in Pacific and Northwest fisheries), scientists could not solve a large-scale problem with social roots using technique alone, however sophisticated (MacEvoy 1986, Taylor 1999). The efforts of the scientists at Fairport remain significant today, as recovery teams use similar methods to prevent the extinction of several mussel species in the Mississippi River system. It is ironic that a good share of the mussel species now threatened used to be quite common. Over thirty freshwater mussel species in North America are now reported extinct. Those seeking the restoration of riverine ecological communities might take heart in the story of persistence among the scientists who propagated mussels at the Fairport Biological Laboratory (Madson 1985, Neves 1999).

ACKNOWLEDGEMENTS

The U.S. Army Corps of Engineers provided generous financial support for this project as well as helpful review. This paper is adapted from the resulting December 2001 report titled "An Historical Analysis of Mussel Propagation and Culture: Research Performed at the Fairport Biological Station," Contract No. DACW-25-01-m-0312. The full report is available at the D.C. Booth National Historic Fish Hatchery, or electronically at: http://unionid.smsu.edu/Documents/fairport.pdf, and at http://www.fws.gov/midwest/mussel/documents/an_historical_analysis_of_mussel_propagation_and_culture.pdf.

I thank the many people who communicated with me regarding this project, including John Downing, Mark Cornish, Randi Smith, Phil Scarpino, Bill Stoltz, Kevin Cummings, Pam

Thiel, Bob Howells, Jeff Janvrin, Dick Neves, David H. Stansbery, Marian Havlik, Sue Bruenderman, David Heath, Debbie Landi, Robert Chapel, JoAnn Jacoby, Walter Bennick, Judy Mathison, Scott Gritters, Kevin Hanson, Ken Snyder, Warren Johnson, Gary Wege, and Kurt Welke.

Photographs originally appeared in the *Bulletin of the United States Bureau of Fisheries*.

LITERATURE CITED

ANNUAL REPORTS. Annual Reports for Fairport, La Crosse and Homer Stations, 1928–1941, Boxes 6 & 16, Fish-42, D.C. Booth National Historic Fish Hatchery, U.S. Fish & Wildlife Service, Spearfish, South Dakota.

ANTHONY, J. L. 2000. Growth and longevity of freshwater mussels (Bivalvia: Unionidae) with application to their commercial fisheries. Master's thesis, Iowa State University.

CARLANDER, H. B. 1954. History of fish and fishing in the Upper Mississippi River. Rock Island, Illinois: Upper Mississippi River Conservation Committee.

CHURCHILL, E. P. Jr. and S. I. LEWIS. 1923–1924. Food and Feeding in Fresh-water Mussels. Bulletin of the United States Bureau of Fisheries 39:439–71.

CLAASSEN, C. 1994. Washboards, pigtoes, and muckets: Historic musseling in the Mississippi watershed. Historical Archaeology 28:1–145.

COKER, R. E. 1914. The Fairport Fisheries Biological Station: Its Equipment, Organization, and Functions. Bulletin of the U.S. Bureau of Fisheries 34:383–406.

COKER, R. E. 1914. The protection of fresh-water mussels. U.S. Bureau of Fisheries Special Document No. 793. Washington, D.C.: U.S. Bureau of Fisheries.

COKER, R. E. 1914. Water-power development in relation to fishes and mussels of the Mississippi. U.S. Bureau of Fisheries Document No. 805. Washington, D.C.: U.S. Bureau of Fisheries.

COKER, R. E. 1917–1918. Fresh-water mussels and the mussel industries of the United States. Bulletin of the U.S. Bureau of Fisheries 36:11–89.

COKER, R. E. 1920. The Fisheries Biological Station at Fairport, Iowa. Appendix I to the Report of the U.S. Commissioner of Fisheries for 1920, 1–12.

COKER, R. E. 1929. Keokuk Dam and the Fisheries of the Upper Mississippi River. Bulletin of the U.S. Bureau of Fisheries 45:87–139.

COKER, R. E., A. F. SHIRA, H. W. CLARK, and A. D. HOWARD. 1922. Natural history and propagation of fresh-water mussels. Bulletin of the U.S. Bureau of Fisheries 37:75–181.

CURTIS, W. C. 1949. History of the Department of Zoology, University of Missouri. Bios 20, No. 3, October 1949.

DANGLADE, E. 1912. Condition of the mussel fishery of the Illinois River in 1912. United States Bureau of Fisheries Economic Circular 2. Washington, D.C.: U.S. Bureau of Fisheries.

ELLIS, M. M. [Max Mapes]. 1931. Some factors affecting the replacement of commercial fresh-water mussels. United States Bureau of Fisheries Economic Circular 57. Washington, D.C.: U.S. Bureau of Fisheries.

ELLIS, M. M. 1931. A Survey of conditions affecting Fisheries on the Upper Mississippi River. Fishery Circular No. 5, United States Bureau of Fisheries.

ELLIS, M. M. 1935. Water Purity Standards for Fresh Water Fishes. Fish and Wildlife Service Special Scientific Report No. 2.

ELLIS, M. M. 1936. Erosion Silt as a Factor in Aquatic Environments. Ecology 17(1): 29–42.

ELLIS, M. M. 1937. Detection and Measurement of Stream Pollution. Bulletin of the U.S. Bureau of Fisheries 48:365–437.

ELLIS, M. M. and M. D. ELLIS. 1926. Growth and Transformation of Parasitic Glochidia in Physiological Nutrient Solutions. Science 64(1667): 579–80.

ELLIS, M. M., A. D. MERRICK, and M. D. ELLIS. 1930. The Blood of North American Fresh-Water Mussels Under Normal and Adverse Conditions. Bulletin of the Bureau of Fisheries 46:509–542.

ELLIS, M. M., B. A. WESTFALL, and M. D. ELLIS. 1946. Determination of Water Quality. Fish and Wildlife Service Research Report No. 9, pp. 1–122.

FAIRPORT ANNUAL REPORTS. Contained in Boxes 2 and 3, Fish-42, at the D.C. Booth Historic Fish Hatchery (U.S. Fish and Wildlife Service), Spearfish, South Dakota.

FARREL-BECK, J. A. and R. H. MEINTS. 1983. The role of technology in the fresh-water pearl button industry of Muscatine, Iowa, 1891–1910. Annals of Iowa 47:3–18.

GRIER, N. M. 1926. Report on the study and appraisal of mussel resources in selected areas of the Upper Mississippi River, 1920–1925. The American Midland Naturalist 10:1–46.

HOWARD, A. D. 1913. Experiments in Propagation of Fresh-Water Mussels of the Quadrula Group. Report of the U.S. Commissioner of Fisheries for 1913, Appendix IV.

HOWARD, A. D. 1921–1922. Experiments in the Culture of Fresh-Water Mussels. Bulletin of the Bureau of Fisheries 38.

ISLEY, F. B. 1914. Experimental study of the growth and migration of fresh-water mussels. U.S. Bureau of Fisheries Document No. 792. Washington, D.C.: Government Printing Office.

ISOM, B. G. and R. G. HUDSON. 1982. In vitro culture of parasitic freshwater mussel glochidia. The Nautilus 96(4): 147–51.

JOSEPHSSON, A. 1909. Fresh-water pearl-button industry. Scientific American Supplement 65:386.

LEFEVRE, G. and W. C. CURTIS. 1908. Experiments in the artificial propagation of fresh-water mussels. Bulletin of the U.S. Fish Commission 28:616–626.

LEFEVRE, G. and W. C. WINTERTON. 1910. Studies on the reproduction and artificial propagation of fresh-water mussels. Bulletin of the U.S. Bureau of Fisheries 30:105–202.

LEFEVRE, G. and W. C. CURTIS. 1910. Reproduction and parasitism in the Unionidae. Journal of Experimental Zoology 9:79–115.

LEHMAN, H. E. 1968. Robert Ervin Coker. The Journal of the Elisha Mitchell Scientific Society 84(No. 2, Summer): 332–37.

MACEVOY, A. 1986. The Fisherman's Problem: Ecology and Law in the California Fisheries, 1850–1980. Cambridge: Cambridge University Press.

MADSON, J. 1985. Mississippi Shell Game. Audubon (March), 46–68.

MAIENSCHEIN, J. 1989. 100 Years Exploring Life, 1888–1988: The Marine Biological Laboratory at Woods Hole. Boston: Jones and Bartlett Publishers.

NEVES, R. J. 1999. Conservation and commerce: Management of freshwater mussel (Bivalvia: Unionioidea) resources in the United States. Malacologia 41:461–474.

OUTWATER, A. 1996. Water: A Natural History. New York: Basic Books.

PEKKARINEN, M. and C. HANSTEN. 1998. Success of metamorphosis of the lake mussel *(Anodonta anatine)* glochidia in different hosts and in vitro. Proceedings of the 50th Annual Meeting of the Scandinavian Society for Electron Microscopy. Helsinki, Finland, 7–10 June 1998.

PLATNER, W. S. 1946. Water Quality Studies on the Mississippi River. Fish and Wildlife Service Special Scientific Report No. 30, c. 1946.

PRITCHARD, J. A. 2001. An Historical Analysis of Mussel Propagation and Culture: Research Performed at the Fairport Biological Station. Clear Cteek Historical Research/ U.S. Army Corps of Engineers Contract No. DACW-25-01-m-0312.

REC PAPERS. Papers of Robert E. Coker. Especially Box 1. Located at the University of North Carolina, Chapel Hill, NC.

RECORDS OF THE BUREAU. Letters, reports, memos, etc., found especially in Boxes 11 & 19 Entry 121, and in Box 672 Entry 269, Record Group 22 (U.S. Bureau of Fisheries), National Archives and Records Administration, Lanham, Maryland.

REPORT OF THE COMMISSIONER. Various titles (e.g., Report of the Commissioner of U.S. Fisheries) produced by the U.S. Bureau of Fisheries and successive agencies, found at depository libraries.

ROBERTS, S. G. 1921. America's fresh-water pearl-button industry. Scientific American Monthly 4:200–203.

ROUSMANIERE, K. 1982. The Muscatine button workers' strike of 1911–1912: An Iowa Community in Conflict. Annals of Iowa 46:243–262.

SCARPINO, P. V. 1985. Great River: An Environmental History of the Upper Mississippi, 1890–1950. Columbia, Missouri: University of Missouri Press.

SCHOOL OF MEDICINE RECORDS. File 74, Collection 3651, School of Medicine Records, Western Historical Manuscripts Collection, University of Missouri.

SMITH, H. M. 1898. The mussel fishery and pearl button industry of the Mississippi River. Bulletin of the U.S. Bureau of Fisheries 18:289–314.

SMITH, H. M. 1899. The pearl-button industry of the Mississippi River. Scientific American 81:86–87.

SMITH, H. M. 1919. Fresh-water mussels. A valuable national resource without sufficient protection. U.S. Bureau of Fisheries Economic Circular 43. Washington, D.C.: U.S. Bureau of Fisheries.

SMITH, H. M. 1920. When the Father of Waters Goes on a Rampage. National Geographic (April), 369–83.

SOUTHALL, J. B. 1925. Mussel survey of Lake Pepin in 1924 with a discussion of the effects of the system of the alternate closure of sections of the lake to the taking of mussels. United States Bureau of Fisheries Economic Circular 57. Washington, D.C.: U.S. Bureau of Fisheries.

SURBER, T. 1912. Note on the Natural Hosts of Fresh-water Mussels. Bulletin of the United States Bureau of Fisheries 32:101–116.

SURBER, T. 1914. Identification of the Glochidia of Fresh-Water Mussels. Report of the U.S. Commissioner of Fisheries for 1914, Appendix 5.

TAYLOR, J. E. 1999. Making Salmon: An Environmental History of the Northwest Fisheries Crisis. Seattle: University of Washington Press.

WCC PAPERS. Papers of Winterton C. Curtis. Especially File 77. Located at the Western Historical Manuscripts Collection, University of Missouri.

WILSON, C. B. 1914. Copepod Parasites of Fresh-water fishes and their Economic Relations to Mussel Glochidia. Bulletin of the United States Bureau of Fisheries 34:331–74.