The Environmental Impacts of Commercial Navigation Traffic In Large Waterways—Is There Really A Problem?

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Abstract. Studies on the physical and biological effects of commercial navigation traffic at five dense and species-rich mussel beds in the upper Mississippi River (UMR) were conducted from 1988 to 1994. The purpose was to analyze the effects of movement of commercial navigation vessels on ambient water velocity, suspended solids, and freshwater mussels, including the endangered Higgins eye mussel, *Lampsilis higginsii* (Lea). The present studies were conducted for the Melvin Price Locks and Dam, Second Lock Project, which will increase the capacity of the UMR for commercial navigation vessels. Based upon 60 passages of commercial vessels, 20% had a major effect (an increase in velocity 2-3 times ambient levels), 37% had a minor effect, and 43% had no measurable effect on ambient velocity. Vessel-induced changes in turbidity and suspended solids were minor and usually lasted 1-3 minutes. Each year, divers collected qualitative and quantitative (0.25 m^2 total substratum) samples to assess temporal trends in community and population parameters. Biotic criteria, chosen to reflect the overall health of mussel beds, were established to provide a basis for detecting change. All criteria—species richness, evidence of recent recruitment, growth rates and mortality, and presence of *L. higginsii*—were met at each bed. Regardless of within-year variation in criteria, UMR mussel populations appear stable and unaffected by movement of commercial navigation vessels.

Introduction

Background

In 1978, the Inland Waterways Authorization Act (Public Law 95-502) authorized the U.S. Army Corps of Engineers (USACE) to replace Locks and Dam 26 (now known as the Melvin Price Locks and Dam Project) at Alton, Illinois, by constructing a new dam and a single 1,200-ft (366-m) lock approximately 3.2 km downriver of the existing dam. Public Law 95-502 also directed the Upper Mississippi River Basin Commission to prepare a "Comprehensive Master Plan for the Management of the Upper Mississippi River System" (Master Plan) in cooperation with appropriate federal, state, and local interests. The Commission completed the Master Plan report and submitted it to Congress on 1 January 1982. The Master Plan recommended construction of a second lock chamber, 600-ft (183-m) long, at the Melvin Price Locks and Dam Project.

The St. Louis District of the USACE prepared an Environmental Impact Statement (EIS) for the second lock in compliance with the National Environmental Policy Act. As described in the EIS, the physical effects of tow movement (tow boat plus barges), associated *only* with the second lock, were major impact factors. A commercial vessel produces a brief period of turbulence, increased water velocity, and elevated suspended solids caused by propeller wash, water displacement, and hull friction. Environmental groups and state conservation agencies have expressed concern over consequences to the biota of these cyclic physical disturbances (Virginia Polytechnic Institute and State University 1975; Academy of Natural Sciences of Philadelphia 1980; Berger Associates, Ltd. 1980; Lubinski et al. 1980, 1981; Environmental Science and Engineering 1981, 1988; Simons et al. 1981, 1987; Wright 1982; Rasmussen 1983; Wuebben et al. 1984; Nielsen et al. 1986; Brookes and Hanbury 1990; Haendel and Tittizer 1990).

On 20 November 1987, the U.S. Fish and Wildlife Service (FWS) completed its Biological Opinion, in accordance with Section 7 of the Endangered Species Act, on the second lock of the Melvin Price Locks and Dam project. The Biological Opinion and attached Incidental Take Statement recommended an extensive 7-year baseline study of Upper Mississippi River (UMR) mussel populations. The FWS determined that increased commercial traffic, as a result of the second lock, would negatively impact the federally endangered Higgins eye pearly mussel (*Lampsilis higginsii* Lea). Their sedentary lifestyle and reliance on suspended particulate organic matter for food make mussels particularly susceptible to traffic-induced physical disturbances.

Thus, a research project was developed to monitor physical and biological effects of commercial vessel movement on unionid mussels. Results of this study would be used to evaluate temporal and spatial trends occurring between 1988 and 1994. In addition, data from this baseline study, in conjunction with results of future studies, would be used to analyze impacts of the second lock.

Six parameters, designed to reflect the overall health of a mussel bed, were chosen by an interagency team to determine if mussels were being negatively affected by commercial traffic. These six parameters were:

1. **Decrease in density of five common-to -abundant species.** Negative effects will be assumed if there is a significant ($p<0.1$) decline in density, sustained over each of at least two consecutive sampling periods (a study year) at a mussel bed, for five common-to-abundant species. Analysis at the 0.1 level is conservative; typically, a larger number of significant differences will be found among a set of means than when comparisons are made at the 0.05 level (see parameter 6).
2. **Absence of *Lampsilis higginsii*.** If *L. higginsii* is not collected during two consecutive sampling periods, it will be assumed that this species is declining in abundance. This criterion applies only to beds in Pools 10, 12, and 14, which are within its historical range.
3. **Decrease in live-to-recently-dead ratios for dominant species.** Negative effects will be assumed at the bed if there is a continual decrease in the live-to-recently-dead ratio for three consecutive sampling periods.
4. **Loss of more than 25% of the mussel species.** Negative effects will be assumed if subsequent sampling (sustained over two sampling periods at a bed) reveals a loss of more than 25% of the mussel species.
5. **No evidence of recent recruitment.** If there are no signs of recruitment for two consecutive sampling periods for five common-to-abundant species at a bed, negative effects will be assumed.
6. **Significant reduction in growth rates or increase in mortality.** If a significant reduction (0.05 level) at the bed is identified, negative effects will be assumed.

Tow Traffic in the UMR

Annual vessel passages (upriver and downriver combined for this period of study) ranged from 2,014 tows in Pool 10 (in 1990) to 3,757 tows (in 1990) in Pool 24 (U.S. Army Corps of Engineers, Water Resources Support Center 1995). Since 1990 there has been a gradual decline in daily passages at all locks (Figure 1). The extremely low numbers of

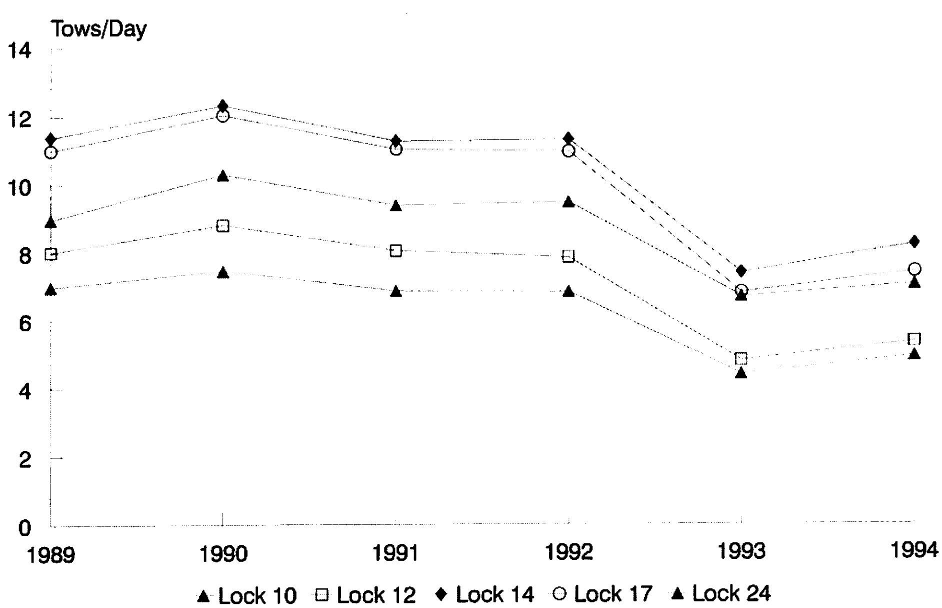

Figure 1. Number of commercial tows per day, upriver and downriver combined, for five navigation pools in the UMR, 1989-94.

events in 1993 resulted from the temporary suspension of traffic during the extremely high water experienced in spring and summer.

The Master Plan provided commercial traffic projections for 1990, 2000, and 2040 with and without the second lock in place (U.S. Army Engineer District, St. Louis 1988). For Pool 10 it was estimated that the second lock would cause one additional tow per day by the year 2040 (17% increase). By the year 2040 there would be an additional two tows per day in Pools 12 (29% increase), Pools 14 and 17 (17% increase), and Pool 24 (13% increase).

Study Area

Five stable beds were chosen that were subject to the effects of traffic, did not appear to be overly impacted by commercial clam harvesting, and were not immediately downriver of existing or proposed loading facilities or waste discharges. Studies were conducted at historically prominent mussel beds at the following river miles: 299.6 (Pool 24), 450.4 (Pool 17), 504.8 (Pool 14), 571.5 (Pool 12), and the main channel of the UMR at river mile 635.2 (Pool 10) (Figure 2).

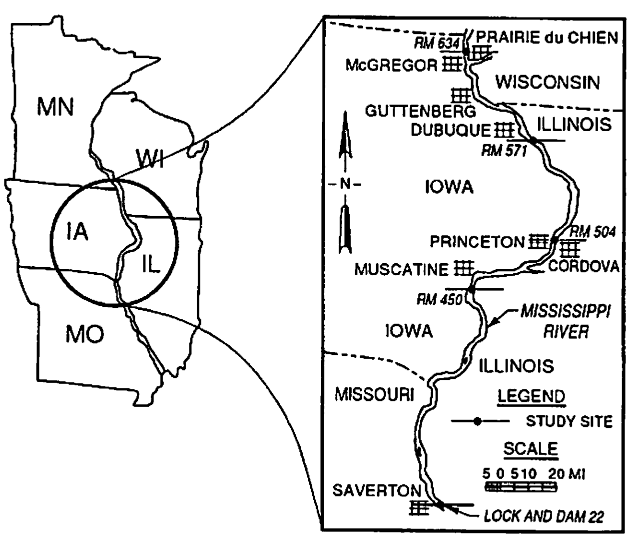

Figure 2. Studies were conducted at five mussel beds in the UMR.

Methods

Study sites at each bed were located at a farshore (affected by commercial traffic) and a nearshore site (affected to a lesser degree by traffic). Quantitative sampling consisted of having two divers retrieve all sand, gravel, and shells from within a 0.25-m^2 aluminum quadrat (see Miller et al. 1994). At each nearshore and farshore site, 10 quantitative samples were taken at each of three closely placed subsites. All substrata within the quadrat was sent to the surface in a 20-liter bucket, taken to shore, sieved through a nested screen series (finest screen with apertures of 6.4 mm), and picked for mussels. All mussels were identified, and then total shell length (SL) was measured to the nearest 0.1 mm. Qualitative samples were taken each year at all beds; typically, quantitative samples were collected every other year at each bed. Nomenclature was consistent with Williams et al. (1993).

Water velocity was measured approximately 23 cm above the substratum-water interface using Marsh McBirney model 527 current meters. Water velocity in two directions and compass readings were taken at 1-sec intervals and stored on a model CR10 data logger (Campbell Scientific, Inc., Logan, UT). Up to four sensors were deployed at distances ranging from 15 to 152 m from the riverbank. The meters and data logger were turned on 250 sec before the vessel reached the sensors, and continuous data were recorded during vessel passage.

Water was collected 10 cm above the substratum-water interface with a 7.6-m length of rubber hose attached to a concrete block. Suction was provided by a 12-volt Water Puppy pump. The pump ran continuously, and a 500-ml bottle was filled every 2 min during passage. Turbidity was measured in the field with a Hach portable turbidimeter; total suspended solids were measured in the laboratory using gravimetric procedures.

Results and Discussion

Physical Effects of Vessel Passage

Water velocity changes. Velocity data were collected for 60 events; 12 (20%) had a major effect on ambient conditions. An effect was considered major if a vessel caused velocity changes of 2-3 times ambient conditions. Thirty-seven percent produced a minor effect and 43% produced no measurable change. A major event caused by a downbound vessel caused ambient velocity to change from 18.2 to -54.6 cm/sec for approximately 100 sec (Figure 3a). Displaced water from the moving tow caused

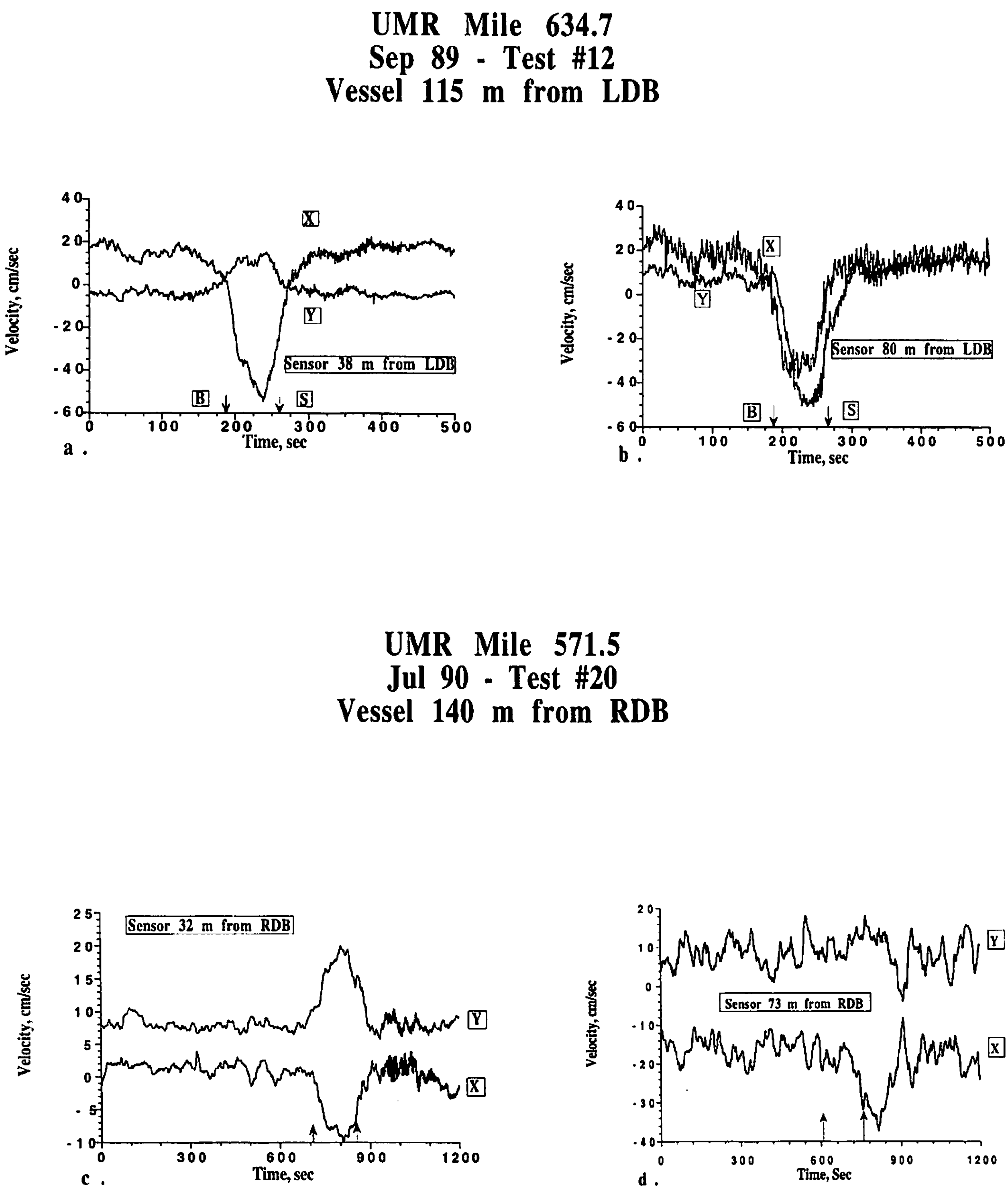

Figure 3. Changes in velocity in the UMR associated with passage of commercial navigation vessels.

flow reversal. A major event by an upbound vessel caused ambient velocity 32 m from the bank to change from 10.6 cm/sec to 21.9 cm/sec for approximately 100 sec (Figure 3c). Flow reversal from this upbound vessel was minor; farshore impacts were much less than nearshore impacts.

Similar results were described in a study of traffic in the Illinois River (Environmental Science and Engineering 1981). On average, tow passage caused 8-18 cm/sec changes in the magnitude of longshore velocity vectors at both nearshore and farshore sites. As with results of our studies, upbound tows generated a downriver increase in velocity and downbound tows tended to force velocity changes in the reverse direction. In a later study, Environmental Science and Engineering (1988) reported that on average the maximum change in velocity was about 20 cm/sec, compared with average flow of about 25 cm/sec. For 8 of 23 events (34%) at nearshore sites, change in water velocity immediately following passage could not be discerned from ambient conditions.

Suspended solids changes. Vessel-induced changes in turbidity and suspended solids at mussel beds in the UMR were minor, of short duration, and lasted no more than several minutes. Typically, a commercial vessel caused an increase in total suspended solids of less than 2 times ambient conditions for several minutes. In one event, mean suspended solids changed from 20.4 $\pm$ 5.3 (SD) to 21.1 $\pm$ 5.7 mg/l and 37.4 $\pm$ 12.4 mg/l at a nearshore and farshore site, respectively. In the UMR, mussels are found in firmly packed substratum that is relatively free of recently settled sediments; therefore, movement of commercial vessels had minimal effects on ambient suspended solids and turbidity.

Herricks et al. (1982) collected samples in 1-m-deep water in a section of the Kaskaskia River. Following commercial vessel passage, suspended sediment values increased from 91 to 362 mg/l and from 124 to 253 mg/l. In Pool 2 of the UMR, North Star Research Institute (1973) reported changes of 30-70 and 20-80 Jackson Turbidity Units in surface waters following vessel passage. Bhowmik et al. (1981) reported that tows increased suspended solids for 60 to 90 min in the Illinois River, which is comparatively slow moving, shallow, and carries a higher suspended solid load than the UMR.

Biological Effects of Commercial Traffic

The following is a summary of results from the mussel studies and how they relate to the six criteria:

Decrease in density of five common-to-abundant species. This criterion was tested for *Amblema plicata plicata* (Say), *Quadrula pustulosa pustulosa* (I. Lea), *Truncilla truncata* Rafinesque, *Quadrula quadrula* (Rafinesque), *Obliquaria reflexa* (Rafinesque), *Ellipsaria lineolata* (Rafinesque), and *Leptodea fragilis* (Rafinesque). A total of 29 species/bed density evaluations were possible; not all species could be tested at each bed. Nine species had significant density decline and two species had significant density increase. However, this criterion was met because there was not a significant decline for five common-to-abundant species at a single bed, sustained for at least 2 years.

Amblema plicata plicata in Pool 24 and *Truncilla truncata* in Pool 17 exhibited significant density declines (Figure 4). Density declines of the former species were attributed to mortality following an extensive period of recruitment; in 1989, 90% of *A. p. plicata* were less than 30 mm total shell length. Density fluctuations for *T. truncata*, a species that lives no more than 5 years, are not unusual. *Ellipsaria lineolata*, a moderately thick-shelled species that lives longer than *T. truncata*, exhibited a gradual density increase since 1990. For organisms that live from 5 to 30 or more years, a 7-year study could not provide enough time to evaluate long-term trends. However, these density changes are probably natural and cannot be related to traffic patterns (Figure 1). In addition, it appears that unusually high water in 1993 did not affect these parameters.

Absence of *Lampsilis higginsii*. Based on this criterion, there were no negative effects at beds in Pools 10 and 14. At the beds in Pools 12 and 17, *L. higginsii* was much less common and was not collected each year; this criterion was met at the bed in Pool 12 but was not met in Pool 17. The beds in Pools 17 and 24 are outside the range of *L. higginsii.*

Decrease in live-to-recently dead ratios for dominant species. This criterion was met. Recently dead organisms were rarely collected and always made up less than 1% of the sample.

Loss of more than 25% of the mussel species. Although there was year-to-year variation in this criterion, species richness remained relatively constant during the study. At the bed in Pool 24 the total number of species collected each year, based on qualitative and quantitative sampling, was 18 (1988), 22 (1989), 22 (1991), 13 (1992), and 20 (1994); 26 species were at the bed. At the bed in Pool 10 the total number of species collected each year was 27 (1988), 22 (1989), 25 (1991), 18 (1992), 26 (1993), and 25 (1994); 31 species were at the bed. Similar results were found at the other beds. Although richness varied among years, no dramatic changes were

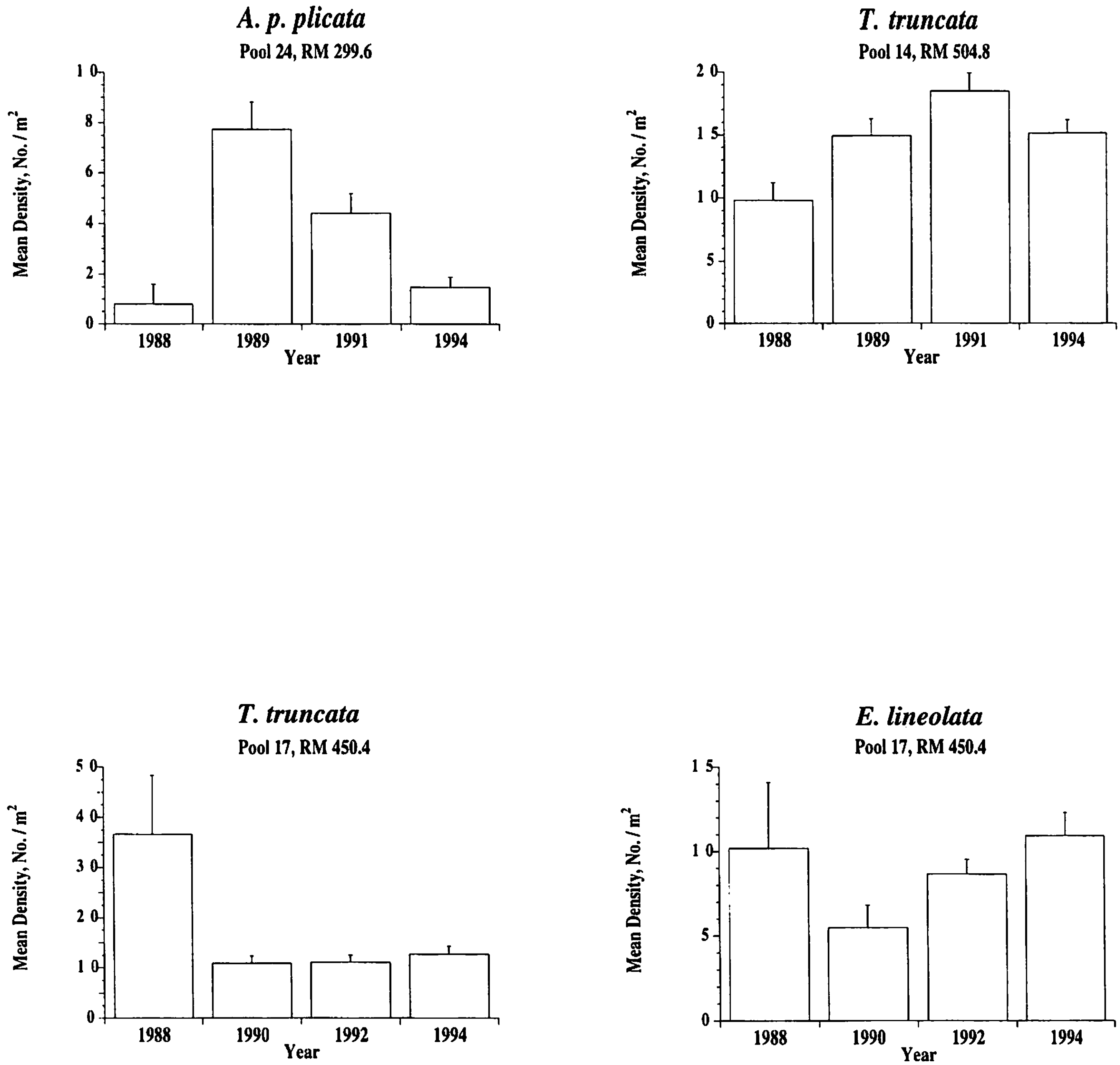

Figure 4. Changes in density (individuals/m²) in the UMR, 1988-94.

noted. The annual variation in species richness results from collecting different numbers of individuals each year.

Evidence of recent recruitment. No indication of recruitment problems existed among UMR mussels, in terms of either species or total individuals. At least some recent recruitment was always evident. Depending on the pool, the location of the site (nearshore or farshore), and the year, between 10% and 55% of all individuals collected in quantitative samples were less than 30-mm total shell length. Approximately 10% to 75% of species present showed evidence of recent recruitment in any particular pool, site, or year.

Laboratory Simulation Studies

Laboratory simulations have been used to evaluate the biological consequences of physical disturbance caused by passage of commercial vessels. For example, the effects of cyclic exposure to unnaturally high levels of turbulence and turbidity on *Q. p. pustulosa, Fusconaia cerina* (Conrad), and *Pleurobema beadleanum* (I. Lea) were studied by Aldridge et al. (1987). Intermittent exposure of freshwater mussels to high levels of suspended solids disrupted feeding and caused shifts to catabolism of endogenous nonproteinaceous energy reserves. Exposure of all three species to infrequent (once every 3 hr) and frequent elevated suspended solids (once every 0.5 hr) at levels of 750 and 600 mg/l, respectively, caused reduced food clearance rates. Frequent exposure to elevated suspended solids resulted in reduced nitrogenous excretion rates in all three species and higher 0:N ratios. However, field studies show that levels of suspended solids (600-750 mg/l) used in these laboratory experiments designed to elicit physiological stress responses are rarely caused by navigation vessels in the UMR.

The effects of continuous versus intermittent exposure to turbulence on *Fusconaia ebena* (I. Lea) were studied in a laboratory experiment (Payne and Miller 1987). Mussels were exposed to one of three conditions: continuous-low, continuous-high, and cyclic-high water velocity. Comparison of mean tissue condition index (a ratio of tissue dry mass to shell mass) by Duncan's multiple range test indicated that weight loss was not significantly different ($p>0.05$) between continuous-low and cyclic-high velocity treatments. In contrast, weight loss was significantly less in these two treatments than in the continuous-high velocity group. Juvenile *F. ebena* were unaffected by 5-min exposure to high-velocity water once per hour, a result directly relevant to evaluating the environmental effects of commercial navigation traffic since rates rarely exceed one tow per hour. Thus, turbulence caused by routine traffic is not likely to deleteriously affect mussels.

Summary and Conclusions

Kelly and Harwell (1990) argue that variability can be so high in key endpoints of concern (population levels, recruitment rates, etc.) that they have limited value for detecting a response. Often an economic indicator (for example, the size of the striped bass population in the Hudson River [Kelly and Harwell 1990]) is the most suitable indicator to monitor. An appropriate indicator for navigation traffic could be density and marketability of commercially valuable mussels, such as *A. p. plicata* and *Megalonaias nervosa* (Thiel and Fritz 1993). While linking economic exploitation of a resource with commercial traffic intensity could be met with disfavor by resource agencies, it would eliminate the difficulty of determining whether fluctuations in key biotic parameters were the result of hydrologic events or natural fluctuations. Data on water velocity and suspended solids that change immediately following tow passage are comparatively easy to obtain and interpret.

Periods of increased velocity, flow reversal, and elevated suspended solids associated with vessel passage were not of a frequency or magnitude to negatively affect mussels. An exception would be barge fleeting areas, unlike navigation lanes, where vessels work almost continuously. Results of laboratory simulation studies indicated that extremely high traffic intensities would be required to negatively affect food clearance rate, utilization of stored energy, or physical condition. Much can be learned about the physiological ecology of organisms exposed to laboratory-induced sublethal stress. However, caution must be used when extrapolating results to the field.

Results of field studies indicated that easily measured parameters, such as total density, recruitment, and species richness, exhibited considerable variation among beds and years, and from nearshore to farshore. These changes gave no indication that they were the result of anything other than variation in hydrologic events, life cycles, and habitat requirements. The importance of long-term field studies, designed to regularly monitor key attributes of biotic populations and communities, cannot be ignored (Likens et al. 1983; Strayer et al. 1986; Likens 1987; Franklin 1987). Field studies are still the best means of understanding effects of physical disturbances on naturally occurring populations and should not be discounted as "mere monitoring" (Taylor 1987). Instead, they provide an opportunity to investigate the effects of waterway operation, introduction of nonindigenous species, or hydrologic events on a resource with ecological, economic, and cultural value. Perhaps the greatest value of the mussel monitoring program has been to establish a baseline of biotic conditions for the freshwater mussels. These results can be compared with data collected in the future when vessel passages reach the level predicted for the second lock.

Acknowledgments

Funds for this project were provided by the U.S. Army Engineer District, St. Louis. The authors acknowledge the assistance provided by divers from the U.S. Army Engineer District, St. Paul, and the Tennessee Valley Authority; students and others from MacAlester College, Winona State College, University of Southern Mississippi, Millsaps College, Jackson State University, Illinois Natural History Survey, Wisconsin Department of Natural Resources, Missouri Department of Conservation, Loras College, Stanley Consultants, and Malacological Consultants. Permission was granted by the Chief of Engineers to publish this information.

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