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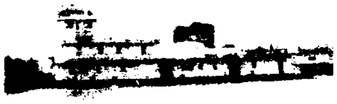

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PHASE I STUDIES: IMPACTS OF COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS--A REVIEW

by

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Turbulence and wave wash from commercial navigation vessels can resuspend sediments, reverse river currents, and cause water drawdown. These physical effects can stress or kill pelagic fish eggs and larvae, bottom-dwelling invertebrates such as freshwater mussels (Family: Unionidae), aquatic insects, worms, and crustaceans. Impacts of navigation traffic have been studied in the field and the laboratory. In field studies, investigators have measured wave height, drawdown, current reversals, and suspended sediment concentrations associated with passage of commercial vessels. These data have been used to make judgments on the effects of traffic on naturally occurring populations and to construct predictive physical models.

The physical effects of tow passage have been simulated and responses to test organisms measured. Stress can be determined by assessing nitrogen excretion, oxygen consumption, and filter-feeding rates or by calculating physical condition indices (i.e.

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length-to-mass relationships). Results of laboratory studies can provide insight into the biology and physiology of test organisms. However, they may be of limited value in predicting traffic impacts since test organisms do not usually obtain appropriate nutrition and the laboratory does not simulate natural conditions. For example, variation in the physical condition of organisms caused by season, climate, frequency, size, number, and type of tow are impossible to duplicate in the laboratory.

Alternatively, naturally occurring populations can be studied at sites affected by commercial traffic. Test sites can be located close to the navigation lane, and control (or reference) sites can be located some distance away. At each site, important biological parameters (individual condition, density, biomass, evidence of recent recruitment, species richness, or species diversity) can be determined for organisms of interest. Changes in water velocity or suspended sediments can be measured before and after tow passage. These studies should be continued for several years to determine if commercial traffic is affecting naturally occurring populations.

PREFACE

In October 1988, the Mussel Mitigation Trust contracted with the US Army Engineer Waterways Experiment Station (WES) under Contract No. 103 to conduct a literature review on the effects of commercial navigation traffic on freshwater mussels. The purpose was to provide information that could be used to evaluate possible impacts of increased barge traffic at the Zimmer Power Plant, owned by The Cincinnati Gas & Electric Company, Columbus Southern Power Company, and The Dayton Power and Light Company, on a dense mussel bed located near the facility.

This report was prepared by Drs. Andrew C. Miller, Barry S. Payne, and Carl M. Way, Aquatic Habitat Group (AHG), Environmental Laboratory (EL), WES.

Mr. Edwin A. Theriot was Chief, AHG; Dr. Conrad J. Kirby was Chief, Environmental Resources Division; and Dr. John Harrison was Chief, EL, during preparation of this report. Mr. Alan Gaulke, Trustee, monitored this contract with WES and reviewed an earlier draft of this report. This report was edited by Ms. Lee T. Byrne of the WES Information Technology Laboratory.

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PHASE I STUDIES: IMPACTS OF COMMERCIAL NAVIGATION TRAFFIC ON FRESHWATER MUSSELS--A REVIEW

PART I: INTRODUCTION

Background

1. Plans to convert the Zimmer Power Plant, located on the Ohio River near Cincinnati, OH, from nuclear to coal power will require construction of a harbor and a barge-loading facility for coal, lime, and fuel oil. It is anticipated that the Zimmer Power Plant will be operational in 1991 and that coal deliveries will commence sometime that year. The barge-loading facility will be near a dense and diverse bed of freshwater mussels (Williams and Schuster 1982, Stansbery and Cooney 1985). As a condition of the permit required by the US Army Engineer District (USAED), Louisville, the owners of the plant relocated 5,000 mussels and established a trust fund to sponsor research on unionid molluscs. A committee composed of the Commissioner of the Kentucky Fish and Wildlife Resources, the Director of the Ohio Department of Natural Resources, and a representative of the American Electric Power Service Corporation was formed to administer the Mussel Mitigation Trust. This committee required that a study be conducted to determine if barge traffic would negatively affect mussels near the facility. This would fulfill a condition of the US Army Corps of Engineers permit for the conversion project.

2. The continued use of inland waterways to transport bulk commodities (Dietz et al. 1983) has caused many biologists and planners in government agencies to express concern over the possible negative effects of commercial traffic (Upper Mississippi River Basin Commission 1982, Rasmussen 1983, US Fish and Wildlife Service (USFWS) 1986). The physical effects of commercial vessel movement includes wave wash, turbulence, benthic scour, drawdown, current reversals, and periods of increased sediment resuspension (Wright 1982). Freshwater mussels, a resource with economic, ecological, and cultural value, could be affected by these disturbances. Their sedentary lifestyle and reliance on suspended particulate organic matter makes them susceptible to fluctuating water levels, sedimentation, and turbulence. Previous authors have suggested that commercial use of waterways has directly and indirectly contributed to a loss of species richness and to areal extent of large-river

mussel populations (Stansbery 1970; Starrett 1971; Anderson, Sparks, and Paparo 1978; Fuller 1978, 1980; Imlay 1980).

3. Although some physical effects of commercial traffic can be partially simulated in the laboratory (Morgan et al. 1976; Holland 1986; Stevenson et al. 1986; Aldridge, Payne, and Miller 1987; Killgore, Miller, and Conley 1987; Payne and Miller 1987; Miller-Way et al., in preparation; Payne, Killgore, and Miller, in preparation; and Way et al., in preparation) and caution must be exercised when using these results to estimate impacts. Responses noted in the laboratory may not occur in the field. In addition, naturally occurring compensatory mechanisms that are not part of laboratory experiments usually exist.

4. Planners and biologists must evaluate the effects of man's activities on populations of species in their natural habitats. As an alternative to laboratory simulation, field studies should be conducted to evaluate the biological impacts of tow-induced disturbances. These results should be used to determine the magnitude and significance of traffic-induced impacts on recruitment, rate of growth, and density of mussel populations. These parameters provide the most useful measures of the overall health and ultimate survival of a mussel community.

Molluscs of the Project Area

5. Molluscs in the Ohio River have not been as well-studied as in the upper Mississippi River or many other large rivers in the Eastern United States. Stansbery and Cooney (1985) reported that Rafinesque conducted a comprehensive survey of the Ohio River in 1820 and Shaffer collected near Cincinnati in 1820. Rhoads (1899) reported on mussels collected in the Ohio River below Pittsburgh. More recently, Taylor (1980) and Zeto, Tolin, and Schmidt (1987) collected mussels in the upper Ohio River (upriver of Pittsburgh) using a brail and shoreline searches by hand. Tolin, Schmidt, and Zeto (1987) reported a new location for *Lampsilis abrupta* (*orbiculata*) in the Ohio River bordering West Virginia. Neff, Pearson, and Holdren (1981) collected mussels in the lower Ohio River as part of an investigation of aquatic and riparian communities for the USAED, Louisville, 1981. Studies specific to the Asiatic clam *Corbicula fluminea* have been conducted by Bickel (1966) and Keup (1964).

6. In a comprehensive survey that included the lower Ohio River, Williams (1969) identified 23 species of mussels near the Zimmer site. In subsequent surveys by Dames and Moore (1980) and Stansbery and Cooney (1985), 16 species were identified. All of these investigators relied principally on the brail; more thorough searches using divers would provide accurate information on species richness (Miller and Payne 1988 and references cited therein). For example, in 1987 divers collected 23 species at the Zimmer site as part of a mussel relocation experiment (Environmental Science and Engineering 1988). Two species of freshwater mussels (*Lampsilis orbiculata* and *Plethobasus cooperianus*) have been collected in the lower Ohio River and are listed as endangered by the Commonwealth of Kentucky (Branson et al. 1981) and Department of the Interior (USFWS 1987).

Purpose and Scope

7. This purpose of this report is to briefly summarize (a) pertinent studies on the physical and biological effects of commercial navigation traffic; (b) recent studies on the effects of sublethal physical stress on freshwater mussels; and (c) the most appropriate techniques for evaluating traffic impacts on freshwater mussels.

PART II: PHYSICAL EFFECTS OF COMMERCIAL NAVIGATION TRAFFIC

Background

8. Movement of a commercial navigation vessel can cause drawdown, turbulence, and waves. These disturbances can erode shorelines, resuspend alluvial sediments, and scour shallow areas. Physical effects of traffic are unique in that although they may last only a few minutes, they are often repeated many times during a 24-hr period. Concern has been expressed that the physical effects of movement of commercial vessels could negatively affect aquatic biota (Rasmussen 1983; Nielsen, Sheehan, and Orth 1986). Temporary periods of turbulence or elevated suspended sediments can stress or kill pelagic fish eggs and larvae, bottom-dwelling invertebrates such as mussels, aquatic insects, worms, and crustaceans.

9. Characteristics of large rivers, which include size, shape, bed and bank material grain size, ambient velocity, and suspended sediment concentrations, influence the nature and magnitude of traffic effects. Shallow, narrow, sinuous waterways will be more susceptible to physical forces than large waterways. Sediment is more likely to be resuspended from alluvial substrates than from cobble or bedrock. Sediment resuspension resulting from commercial traffic is usually most noticeable during low-flow conditions. During higher flow, sediment resuspension caused by traffic generally cannot be detected because of naturally high suspended sediment concentrations.

10. In the following sections, the commonly reported physical effects of commercial navigation vessels are discussed. Secondary developments (i.e. storage and handling of dangerous materials) or disturbances to terrestrial habitats (e.g. elevated noise, air pollution, and loss of aesthetic value, etc.) have not been included.

Physical Effects

Turbulence

11. A spinning propeller causes turbulence, which is measurable velocity in more than one direction. Turbulence can resuspend sediments and create waves. The effects of turbulence on sediment resuspension is related to water depth and particle size, speed and horsepower of the vessel, and frequency of

traffic (Karaki and Van Hoften 1974, Johnson 1976, Yousef et al. 1978). Turbulence can cause a temporary increase in water velocity or a change in the direction of current (Environmental Science and Engineering 1981). The following water velocity changes were recorded following passage of commercial vessels: 0.5 to 1.0 fps (0.15 to 0.30 m/sec) (Upper Mississippi River Basin Committee (UMRBC) 1981); 0.69 to 1.95 fps (0.21 to 0.59 m/sec) (Herricks et al. 1982); changes in ambient water velocity from 10 to 100 percent (UMRBC 1981); and changes from 55 to 64 percent at the surface and middepth, respectively (Johnson 1976).

Impingement

12. In shallow water, a propeller can physically disrupt the substrate and injure or kill freshwater mussels and other benthic invertebrates. A moving propeller can strike fish larvae and invertebrates in the water column. In addition, a moving hull causes friction and shear forces that can affect fish eggs, fish larvae, and other small organisms. These physical effects are difficult to study in the field, although they can be simulated in the laboratory and responses to test organisms measured (see Part III).

Elevated suspended sediments

13. Turbulence from commercial vessels can resuspend fine-grained sediments in alluvial channels. Factors affecting suspension of benthic sediments include hull design and size (Johnson 1958, Das 1969), vessel speed (Berger Associates, Ltd. 1980), and channel morphometry (Hay 1968, Liou and Herbich 1976). Sediment resuspension declines with increased distance between the ship and bottom and also is a function of grain size. Sediment resuspension from tow passage has been measured at 2 g/ℓ (Academy of Natural Sciences of Philadelphia 1980) and 190 mg/ℓ (Sparks, Thomas, and Schaeffer 1980). Bhowmik et al. (1981a, 1981b) collected suspended sediment data for up to 90 min following commercial tow passage in the Illinois and Mississippi Rivers. They reported increases that ranged from approximately two to four times ambient sediment concentrations. Although data were highly variable, typically suspended sediment levels increased from 100 to 200 mg/ℓ up to about 500 or 600 mg/ℓ. In most cases, values returned to ambient levels within 90 min, although data were dependent on water velocity and sediment characteristics. Typically sedimentation was greater in channel border than in main channel habitats. Data from the above studies could be used to develop regression equations to relate tow passage to quantities and duration of resuspended

sediments. However, the large number of variables (sediment type, water level, channel configuration, seasonal considerations, distances to the sailing line, water depth and velocity, etc.) would make this difficult. This approach would have little useful predictive value if data from a variety of sites were used. If done, only physical data from a single site should be used.

14. Claflin et al. (1981), Link and Williamson (1976), Karaki and Van Hoften (1974), and Eckblad (1981) also studied the effects of vessel passage on sediment resuspension. The biological implications of sediment resuspension were not thoroughly analyzed by these investigators. In addition, it would be difficult to separate effects of vessel passage from natural effects (i.e. elevated suspended sediments as a result of hydrologic events).

Sedimentation

15. Sediment resuspended by a tow can settle in the main channel, channel border, or backwater areas. Johnson (1976) reported that commercial tows did not appreciably increase sedimentation in selected backwaters in the Illinois and upper Mississippi Rivers. Additional studies on the effects of tow passage on sedimentation rates in backwaters have been conducted by Bhowmik et al. (1981a, 1981b) and Simons et al. (1981). Bhowmik et al. (1981b) concluded that sediment inputs into side channels were relatively small compared with the background main channel discharge and sediment loads.

Waves

16. The bow and stern are responsible for most of a ship's wave-making ability (Helwig 1966), although wave height is mainly a function of vessel speed and hull shape (Gates and Herbich 1977). Empirical relationships can be used to predict wave heights in a restricted channel regardless of geometry (Balanin and Bykov 1965). The physical effects of ship-generated waves have been investigated by Sorenson (1967, 1973) and Fuehrer and Romisch (1977). In the latter study, mathematical models were used to analyze distribution of displacement currents, the squat of ships and damages to waterways and hydraulic structures from propeller jets. Bhowmik, Demissie, and Osakada (1981) measured wave heights and drawdown in the Mississippi and Illinois Rivers as part of a study designed to investigate possible causes of bank erosion. Although waves can resuspend sediments and increase turbidity, the biological effects of these impacts have not been investigated (Ecology Consultants, Inc. 1979).

Drawdown

17. Passage of a vessel in a restricted channel usually causes drawdown, a temporary decrease in water level. Drawdown can be measured electronically or by training a videocassette recorder camera on a stationary gage to record water level. (Wave heights can be measured using the same technology). The magnitude of drawdown is affected mainly by vessel speed (Wuebben, Brown, and Zabilansky 1984). Vessel length has essentially no effect on this phenomenon (McNown 1976). Vessel displacement, direction, and channel morphometry also affect drawdown. It has been suggested that drawdown could temporarily expose benthic organisms in shoreline areas. However, these communities are usually adapted to water level fluctuations.

Erosion

18. Ofuya (1970) used graphical techniques to estimate decay of wave height with respect to distance from the sailing line. A direct relationship between ship wave characteristics and sediment transport from erosion could not be found. Hurst and Brebner (1969) determined that bank erosion problems were mainly the result of a combination of vessel speed and size of the waterway. Hagerty, Spoor, and Ullrich (1981) concluded that erosional mechanisms were complex and episodic, and the principal causative agent was floods. Waves generated by tow and recreational vessels had little effect on bank stability, although land use changes affected slope stability and erosion.

19. Resource agency personnel are often concerned that tow-generated waves can erode banks and detrimentally affect terrestrial habitat. However, many rivers had eroding banks before they were affected by commercial vessels. The Monongahela River was described by the Indians as having "many landslides," with "high banks or bluffs, breaking off and falling down at places" (Bartlett 1984). River banks can be protected from erosion by riprap, which has been used extensively on the Tennessee-Tombigbee Waterway.

Mixing

20. Yousef et al. (1978) studied the mixing effects of recreational boats with motors that ranged from 28 to 165 hp. Stefan and Riley (1985) noted that thermal stratification could be disrupted by passage of barges. However, since most large rivers are well-mixed, this is probably of little consequence.

Chemical changes

21. Shifts in oxygen tension in the water column have been associated with tow-induced increases in suspended sediment (Lubinski 1981). Simons et al. (1981) reported that barge passage could induce a 50-percent decrease in dissolved oxygen at the water surface, but no effect was found at a depth of 3 m. Oxygen concentrations returned to near ambient levels within 60 min. Similar results were reported for the Illinois River (Sparks 1975) and the Kaskaskia River (Herricks et al. 1982). Johnson (1976) and Berger Associates, Ltd. (1980) reported a slight increase in dissolved oxygen following tow passage, probably caused by turbulence from the propeller. Environmental Science and Engineering (1981) concluded that the effects of tow passage on dissolved oxygen, specific conductance, pH, water temperature, and transmissivity adjacent to the navigation channel were nearly undetectable. It should be apparent from these studies that it is very difficult to make general predictions concerning effects of vessel passage on dissolved oxygen. This information is best obtained from site-specific studies.

PART III: TECHNIQUES FOR STUDYING COMMERCIAL TRAFFIC EFFECTS

Field Studies

Cessation of traffic

22. Sparks, Thomas, and Schaeffer (1980) conducted studies in the Illinois River to determine if cessation of traffic, caused by temporary closure of a lock for repair, was related to changes in suspended sediment concentrations. Their results showed that suspended sediment concentrations in the Illinois River were higher during periods with traffic than periods without traffic. However, a review of their data reveals that river discharge was low when barge traffic had ceased and high when traffic was present. Thus, from their results it is impossible to assign tow traffic, as opposed to discharge, as the variable responsible for increased suspended sediment levels.

Sedimentation

23. Johnson (1976) collected water samples for suspended sediments and measured dissolved oxygen concentrations following passage of commercial vessels at sites in the upper, middle, and lower Illinois River and in the upper Mississippi River. Results from the upper Mississippi River indicated that tow-induced elevated suspended sediment at normal pool elevation was small compared with suspended sediment concentration during flood stage. With the exception of one multiple tow, which consisted of the largest number of loaded barges encountered during the study, suspended sediments caused by tow passage in the Illinois River were not elevated above those that occurred during floods. Since the quantity of sediment carried by moving water is finite, the effects of man-made disturbances will be most noticeable during periods of low flow when water is relatively clear. In the study by Johnson (1976) there were no observed additive effects due to the passage of multiple tows at sites on the Mississippi River. However, additive effects were observed during three of six events along the Illinois River. The most important difference between those events that produced additive effects and those that did not appeared to be related to the number of barges being transported. Recovery time varied considerably with each event in both rivers. This response appeared to be related to shoreline waves produced by smaller tows. Faster moving tows had a greater effect on resuspending sediments than did slower tows.

Wave height

24. Bhowmik, Demissie, and Osakada (1981) and Bhowmik, Demissie, and Guo (1982) collected wave and drawdown data from the Illinois and Mississippi Rivers in 1981. Wave data were collected for 59 tow passages, and drawdown data were collected for 27 events. The maximum wave heights ranged from a low of 0.1 ft (0.03 m) to a high of 1.08 ft (0.33 m), whereas the maximum drawdown ranged from 0.05 to 0.69 ft (0.015 to 0.21 m). Wave heights for wind-generated waves were also calculated for 2- and 50-year return periods and 6-hr duration winds. On the Illinois River, the significant wave heights were found to be in the range of 0.9 and 1.6 ft (0.27 and 0.49 m) for the 2- and 50-year winds of 6-hr duration, respectively, whereas on the Mississippi River the corresponding values were 1.3 and 2.4 ft (0.40 and 0.73 m), respectively.

Barge fleeting

25. Sparks and Blodgett (1988) studied effects of barge fleeting on mortality and growth of three species of freshwater mussels (*Amblema plicata*, *Proptera* (=*Potamilus*) *laevissima*, and *Leptodea fragilis*) in the Illinois River near Naples. Mussels were collected, identified, weighed, and measured from a site on the Illinois River near Naples, IL. They were then placed in exclosures at a control site with no fleeting, a site where barges were tied to pilings, and a second experimental site where barges were frequently grounded. The investigators noted a significant decrease in growth ($P \leq 0.055$) for *A. plicata* and *L. fragilis* in the fleeted areas. However, this was a short-term experiment (June-October 1984), and growth rates were less than 1.0 mm, which could be within (or close to) the error of remeasuring shell lengths. In addition, the change in growth rates for small individuals, which grow rapidly, were not separated from rates for large individuals. Although this study was plagued by several problems, which were exacerbated by lack of funds, it provides a model for design of future studies (see Part V and Appendix A).

Application of results

26. A biologist or planner can use field data on physical effects to make judgments on biological impacts of commercial navigation traffic. Many standard ecological texts (Hynes 1970, Merrit and Cummins 1984) provide lists of species likely to be found in certain habitats and the range of physical factors they can tolerate. These evaluations can be improved if the investigator knows the approximate density and species composition of species

assemblages in the areas to be affected by vessel passage. However, often the investigator finds that species of interest are very uncommon and little published data are available. A possible solution to this problem would be to place species of interest in groups or guilds where species all have similar life requisites. More information on predicting navigation traffic effects using site-specific biological and physical data appear in Part IV of this report.

27. Investigators must ensure that it is possible to separate effects of navigation traffic from normal seasonal and hydrologic events. Separation of the navigation-induced impacts such as alteration of velocity structure or increase in suspended sediment concentration could require collection and analyses of data before, during, and after vessel passage. It is likely that there is normal variation in physical parameters regardless of the presence of traffic.

Laboratory Studies

28. Laboratory simulation has been used to investigate the lethal and sublethal effects of commercial traffic on aquatic organisms. These studies have the advantage of allowing the investigator to control and replicate experiments and to measure responses more accurately than can be done under field conditions. Laboratory studies that dealt with traffic effects on larval fishes have been conducted by Morgan et al. (1976); Holland (1983); Killgore, Miller, and Conley (1987); Payne, Killgore, and Miller (in preparation); Way et al. (in preparation). Field experiments on larval fishes have been conducted by Morgan et al. (1976), Holland and Sylvester (1983), and Holland (1986).

29. The use of laboratory experiments to investigate navigation effects on mussels will be discussed in Part IV. In addition, the difficulty of extrapolating laboratory results (regardless of the species of interest) to the field will be discussed.

Habitat and Ecosystem-Based Methods

30. The USAED, Louisville, is developing a technique to predict future effects of commercial navigation traffic. Equations to describe forces

generated by tows in varying channel geometries are being developed to predict these forces. Biological models for key aquatic species are being developed for use in a method based on the Habitat Evaluation Procedures and Instream Flow Incremental Methodology. If this method proves to be feasible, it will be used in the USAED, Louisville, to assess impacts among various alternative traffic scenarios. It will be used on actions in planning stages, primarily during feasibility stage analysis (Siemsen, in preparation). However this method is mainly predictive; separate studies are needed to determine if negative effects to the biota actually exist. Therefore, this method could not be used to determine if commercial traffic is negatively impacting mussels at the Zimmer site.

31. Personnel of the USAED, Huntington, contracted with Virginia Polytechnic Institute to investigate commercial navigation traffic effects on the Kanawha River using an "Energy Flow Model." This was an attempt to account for allochthonous and autochthonous sources of carbon and to determine if passage of commercial vessels (through resuspension of sediments) would disrupt photosynthetic processes. Since allochthonous carbon is not limiting and autochthonous energy sources are not of primary importance in rivers (Hynes 1970, Cummins 1974, Vannote et al. 1980), this procedure is of little use for studying commercial traffic impacts.

Modeling Studies

32. Simons et al. (1981) modeled backwater sedimentation and increases in suspended sediments caused by commercial navigation vessels in the upper Mississippi River. These predictions were based on existing hydrologic, hydraulic, geomorphic, and suspended sediment data. The model estimated the effects of tow passage on water velocity in the main channel. Predicted changes in suspended sediment concentrations were made using equations that related concentrations of four sizes of suspended particles to water velocity. Velocity was assumed to return to ambient levels immediately after tow passage. According to the model, the sediment resuspended by the tows settled in the same manner as did naturally suspended sediments. Suspended sediments were carried into side channels and backwaters at a rate directly dependent on water velocity and suspended sediment concentration. Baseline levels of sediment volume entering backwaters under natural conditions (i.e., no

commercial traffic) were predicted using existing hydrologic, hydraulic, geomorphic, and sediment data.

33. Miller-Way et al. (in preparation) have developed a model that uses laboratory data on filter-feeding rates (Way et al., in preparation), mollusc density data from the lower Ohio River (Payne and Miller 1989), information on suspended sediment loads from the US Geological Survey, with physical effects of traffic.* Their model demonstrates that nutrient processing by mussels is affected by total suspended solids, particle size, water temperature, and river discharge. Natural habitat variability appears to have a greater impact on the feeding activity of mussels than habitat changes associated with barge traffic.

Effects of Toxic Materials

34. Spills or runoff from barge-loading facilities could negatively affect freshwater mussels or other biota. Because these biota are sedentary, long-lived filter-feeders, mussel tissue and shell material can accumulate heavy metals and other toxic materials; therefore, they are appropriate organisms to record levels of pollutants (National Research Council 1980). The accumulation of metals has been studied in mussels collected from natural habitats (Fox and Ramage 1931; Nelson 1962; Gaglione and Ravera 1964; Ravera 1964; Brungs 1965; Merlini et al. 1965; Brungs 1967; Harvey 1969; Wolfe and Schelske 1969; Mathis and Cummins 1973; Claeys et al. 1975; Smith, Green, and Lutz 1975; Bates and Dennis 1976; Renzoni and Bacci 1976; Lord, McLaren, and Wheeler 1977; Manly and George 1977; Anderson, Sparks, and Paparo 1978; Foster and Bates 1978; Price and Knight 1978; Jones and Walker 1979; Forester 1980; Heit, Klusek, and Miller 1980; Adams, Atchison, and Vetter 1981; Gardner, Miller and Imlay 1981; Pruiskma et al. 1981; Schmitt and Finger 1982; Czarnezki 1983; Joy, Pritchard, and Danford 1983), and in laboratory organisms (Gardner and Skulberg 1965; Gabay, Dapolito, and Sax 1966; Pauley and Nakatani 1968; Harrison 1969; Short et al. 1969; Harrison and Quinn 1972; Terhaar et al. 1977).

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* Personal Communication, 1988, Dr. N. G. Bhowmik, Hydrologist, Illinois Department of Energy and Natural Resources, Champaign, IL.

35. There are comparatively few published studies on the lethal or sublethal doses of metals and other pollutants on freshwater mussels. Millington and Walker (1983) determined that 20 mg/ℓ of zinc curtailed siphon activity of an Australian species. Copper was lethal to freshwater mussels at 25 ppb (Imlay 1971), and copper complexes were toxic at 2 mg/ℓ to *Anodonta pisinalis* and two species of *Unio* and in 7 to 10 days of exposure (Kapkov 1973). Salanki, Balogh, and Berta (1982) conducted tests with lethal and sublethal concentrations of $CuSO_4$, $PbCl_2$, and $Pb(NO_3)_2$ on *Anodonta cygea* and determined that copper sulfate was lethal at 10 mg/ℓ after 10 hr of exposure.

PART IV: EFFECTS OF NAVIGATION TRAFFIC ON FRESHWATER MUSSELS

Laboratory Studies on Turbulence and Suspended Sediments

36. Filter-feeders are especially sensitive to increased levels of turbulence and resuspended sediments (Widdows, Fieth, and Worral 1979). Most impact studies have concerned marine bivalves and have involved the continuous exposure to constant and often unnaturally high sediment levels (Moore 1977, Wilber 1983). However, vessel passage intermittently exposes freshwater mussels to turbulence and resuspended sediments. In addition, proximity to the navigation channel and ambient suspended sediment levels (which are affected by discharge) determine if or to what degree a specific habitat will be impacted.

37. The major effect of increased levels of turbulence and resuspended sediments on bivalves is to reduce the rate and/or efficiency of feeding (Moore 1977). This reduced feeding efficiency can result in long-term physiological changes. Typically, starving or semistarved invertebrates show changes in metabolic rates (Barnes, Barnes, and Finlayson 1963; Bayne 1973; Logan and Epifanio 1978; Cappuzzo and Lancaster 1979; Dawirs 1983; Page 1983) and shifts to alternate catabolic substrates (Ansell and Sivadas 1973, Bayne 1973, Ikeda 1977, Russell-Hunter et al. 1983). Such shifts have been shown to be useful indicators of sublethal environmental stress in molluscs (Widdows 1978, Bayne et al. 1979; Bayne, Clarke, and Moore 1981).

38. The physical effects of traffic such as elevated suspended sediments and disruption of benthic substrates could negatively affect freshwater mussels in large waterways. Many studies on freshwater mussels have stressed the importance of sediment free water and clean stable substrates to maintain dense and diverse beds of freshwater mussels (Ellis 1931, 1936; Parmalee 1967; Stansbery 1970; Starrett 1971; Yokely 1976; Horne and McIntosh 1979). Although these observations cannot be disputed, it is also true that few cause-and-effect studies have been conducted that fully relate physical effects of traffic to long-term success of mussel populations.

39. The following section describes experiments designed to measure the effects of sublethal stress, likely to be caused by passage of commercial navigation vessels. The first part describes laboratory experiments on the effects of low to moderate levels of increased water velocity or elevated

suspended sediments on freshwater bivalves. The second part describes field studies designed to investigate the effects of commercial traffic on growth and recruitment of naturally occurring assemblages of freshwater mussels.

Effects of intermittent exposure species to suspended solids and turbulence on three freshwater mussels

40. Aldridge, Payne, and Miller (1987) and Payne, Miller, and Aldridge (1987) studied the effects of turbulence and suspended sediments on three species of freshwater mussels (*Quadrula pustulosa* (Lea), *Fusconaia cerina* (Conrad), and *Pleurobema beadleanum* (Lea)) that occur throughout the Mississippi River drainage. The mussels were exposed to four treatments designed to mimic physical effects of vessel passage:

a. Treatment 1--infrequent turbulence and suspended solids. Clams were exposed to suspended sediments (average maximum value of 750 mg/ℓ) created by low levels of turbulence maintained for 7 min every 3 hr.

b. Treatment 2--infrequent turbulence. This was a control for Treatment 1 with the mussels exposed to low levels of turbulence (7 min every 3 hr) with no suspended sediments.

c. Treatment 3--frequent turbulence and suspended solids. Clams were exposed to suspended sediments (average maximum value of 600 mg/ℓ) created by low levels of turbulence (7 min every 0.5 hr).

d. Treatment 4--frequent turbulence. This was a control for Treatment 3 where mussels were exposed to low levels of turbulence (7 min every 0.5 hr) with no suspended sediments.

41. Following a 10-day exposure period, rates of filter-feeding, nitrogen excretion, and oxygen consumption were measured on all of the organisms. The ratio of oxygen consumption to nitrogen excretion (O:N ratio) was used as an index of the relative contribution of protein to total catabolism (Corner, Cowey, and Marshall 1975; Ikeda 1977; Widdows 1978; Bayne and Newell 1983; Russell-Hunter et al. 1983). Protein-based catabolism occurs when O:N values are less than 30 (Bayne and Widdows 1978) and indicates that organisms are feeding rather than metabolizing stored carbohydrate reserves. An O:N ratio greater than 30 would indicate that the mussels were metabolizing mainly carbohydrates (which do not contain nitrogen). The filter-feeding rate was determined by measuring the amount of time required to remove a yeast suspension (a high-protein food) from water.

42. All three species responded to frequent turbulence (Treatment 4) by lowering nitrogen excretion rates and hence increasing the ratio of oxygen to nitrogen (O:N). These organisms did not obtain nutrition from the yeast in the water but metabolized stored carbohydrates. However, infrequent exposure to turbulence (Treatment 2) did not have a major effect on the mussels. All three species yielded O:N values averaging 13, which is an indication of their ability to base metabolism on the proteinaceous yeast.

43. Exposure of all three species of mussels to infrequent (once every 3 hr, Treatment 1) and frequent elevated suspended sediments (once every 0.5 hr, Treatment 3) at levels of 750 and 600 mg/ℓ, respectively, caused reduced food-clearance rates. The reduced food-clearance rates by freshwater mussels exposed intermittently to high concentrations of suspended sediments are supported by work on the bivalves *Crassostrea virginica* (Loosanoff and Tommers 1948), *Mytilus edulis* (Widdows, Fieth, and Worral 1979), and *Spisula solidissima* (Robinson, Wehling, and Morse 1984) as well as in the filter-feeding gastropod *Crepidula fornicata* (Johnson 1971). Widdows, Fieth, and Worral (1979) and Robinson, Wehling and Morse (1984) indicated that concentrations of inorganic suspended sediments equaling 100 mg/ℓ can have a major effect on food-clearance rates in *M. edulis* and *S. solidissima*. The fact that reductions in food-clearance rates were ultimately translated into reductions in growth rates is seen in the suspended solids research on *Mercenaria mercenaria* (Pratt and Campbell 1956; Bricelj, Malouf, and de Quillfeldt 1984). However, reduced growth rates could not be observed in the very brief 10-day period of the present study.

44. Frequent exposure to suspended sediments resulted in reduced nitrogenous excretion rates in all three species and higher O:N ratios. The response to infrequent exposure to elevated suspended sediments was more variable, only two species (*Quadrula pustulosa* and *Pleurobema beadleanum*) showing major responses. The fact that some animals exposed to infrequent periods of elevated sediments showed no shift in the O:N ratio indicates that they were less affected than mussels exposed frequently to sediments.

45. The combined effects of suspended sediments and turbulence exposure were more severe at high frequencies of exposure (Treatment 3 as compared with Treatment 1). *Quadrula pustulosa*, *Fusconaia cerina*, and *Pleurobema beadleanum* all showed significant reductions in nitrogen excretion rates, which caused major shifts in ratios of oxygen to nitrogen. Their catabolism had become

entirely based on nonproteinaceous body stores as indicated by O:N ratios in excess of 145.

46. Less work has been done with filter-feeders on the effects that suspended sediments have on other aspects of their physiology (e.g., oxygen uptake and nitrogen excretion). However, it appears that imposed starvation or semistarvation is the major impact of high levels of suspended sediments and, indeed, other environmental stresses on filter-feeders. Generally, the long-term response of most poikilotherms to reduced food availability is to lower metabolic rates (Bayne 1973, Bayne et al. 1979, Russell-Hunter et al. 1983) and to shift to alternative catabolic substrates (Russell-Hunter and Eversole 1976, Widdows 1978, Bayne et al. 1979). Lower oxygen uptake rates are universally an indicator of lower metabolic rates in aerobic organisms (Prosser 1973).

47. In some organisms, such as overwintering *M. edulis*, starvation shifts the animal from its normal catabolic energy sources of carbohydrates and lipids (high O:N ratios) to a more proteinaceous catabolism (low O:N ratios) (Widdows 1978). In these studies on freshwater mussels, however, mussels exposed to frequent suspended sediments and turbulence shifted from catabolism based heavily on protein (O:N < 20) to a catabolism presumably based on stored carbohydrates and lipids (O:N > 100), which would be used in reproduction or overwintering. Summer O:N ratios for unionids in nature are normally less than 50 (Dr. Barry S. Payne, unpublished data) as are summer O:N ratios for other freshwater molluscs (Aldridge 1985).

48. In summary, the intermittent exposure of freshwater mussels to high levels of suspended sediments (600 to 750 mg/ℓ) and turbulence disrupted feeding and caused shifts to catabolism of endogenous nonproteinaceous energy reserves. These shifts were obvious from measurements of O:N ratios. Such measurements of responses to intermittent periods of elevated sediments should be useful in evaluating the ecological consequences of navigation (as well as dredging) on freshwater mussels.

Effects of continous and intermittent exposure to turbulence on freshwater mussel *Fusconaia ebena*

49. For this experiment *F. ebena*, a thick-shelled unionid that dominates mussel communities in the lower Ohio River, were divided into three groups of approximately equal size distribution (for more detail, see Payne

and Miller 1987). Groups were exposed to one of three conditions: continuous-low, continuous-high, and cyclic-high water velocity. The experiment was conducted in three 200-ℓ Plexiglas chambers connected by a central mixing reservoir. The three conditions were created by manipulating the magnitude and duration of velocities of water flowing over gravel in which mussels were positioned. Low-velocity flow (7 cm/sec, a level similar to that experienced by a natural assemblage of mussels in the Ohio River during summer and fall) was created by continuous operation of a small centrifugal water pump submersed in each tank. A larger pump ran continuously in the continuous-high velocity treatment, creating a 27-cm/sec flow. This fourfold increase is similar to navigation-induced velocity increases that have been observed adjacent to navigation channels. In the cyclic-high velocity treatment, the larger pump was activated for 5 min each hour with a programmable electronic timer. Water was maintained at 18° to 26° C and contained an ad libitum but nonfouling suspension of brewer's yeast for the duration of the 37-day experiment.

50. A tissue condition index (TCI), the ratio of dry tissue mass to shell length, was used as an indicator of stress. Heavily stressed individuals would have a comparatively low TCI, reflecting metabolism of stored reserves. For more information see Payne and Miller (1987) and Payne, Miller, and Aldridge (1987).

51. The TCI of juvenile *F. ebena* in the continuous-low and cyclic-high velocity treatments was 20 and 22 percent less than the TCI of field-fixed juveniles. Continuous exposure to high-velocity water caused a 34-percent reduction in TCI. Comparison of the mean TCI 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, but weight loss was significantly less in these two treatments than in the continuous-high velocity group. Respiration rates, measured in still water, did not differ significantly among mussels from the three treatments.

52. Sustained changes in hydrologic conditions are known to affect pumping and filtration rates of marine lamellibranchs. Those molluscs are sensitive to changes in flow (Kirby-Smith 1972, Walne 1972) and to small differences in pressure between the inhalant and exhalent siphons (Hildreth 1976). In addition, differences in the shape of unionids can be attributed to hydrologic conditions (Van der Schalie 1941, Clarke 1982, and references cited

therein). With respect to turbulence, Brown, Clark, and Gleissner (1938) observed that the degree of stunted growth in unionids from the western basin of Lake Erie was positively correlated to the extent of exposure to waves.

53. A set of data on tow-induced changes in spatial and temporal patterns of flow near the bottom of the river in channel border habitats was obtained during studies of the Mississippi River and Illinois Rivers (Environmental Science and Engineering 1981). These studies are directly relevant to the laboratory study discussed above. In the Illinois River, Environmental Science and Engineering (1981) showed that tow passage on average caused 8- to 18-cm/sec changes in the magnitude of longshore velocity vectors at both nearshore and near-channel monitoring stations. Barges and tows moving upstream generated a downstream increase in velocity, but traffic moving downstream forced velocity changes in the reverse direction. Because the ambient flow was only about 6 cm/sec, most downstream traffic caused a flow reversal at the monitoring stations. Longshore velocity changes were greater and in a consistent direction relative to onshore changes.

54. Results in the Mississippi River portion of the study were more complex. Focusing on longshore velocity changes at the near-channel monitoring station, upbound tows caused ambient downstream currents at the near-channel station to increase, whereas downbound tows had an opposite effect. On average, the maximum change in velocity was about 20 cm/sec, compared with an average ambient flow of about 25 cm/sec. However, nearshore changes in velocity were different from near-channel changes. Nearshore velocity patterns could not easily be interpreted with respect to barge and tow passage. At least 8 of 23 barge and tow passage events could not be discerned from velocity readings at the nearshore station. Those measurements which demonstrated a fairly clear relationship to tow passage showed that velocity changes at the nearshore station were opposite in direction and less in magnitude than those at the near-channel station. Nearshore velocities changed by an average of 10 cm/sec. Because ambient velocity at the nearshore station was generally close to 0 cm/sec, upbound tows often caused brief upstream currents and downbound tows caused significant downstream currents. The duration of changes in nearshore or near-channel velocities averaged 1 to 2 min.

55. These field studies by Environmental Science and Engineering (1981) showed that tow traffic could cause substantial intermittent changes in velocity at shallow areas tens to hundreds of metres from the sailing line (on

average, 180 and 75 m in the Illinois and Mississippi studies, respectively). The same studies showed that site-specific conditions determine to what extent and even in what direction velocity vectors may be changed. The magnitude of velocity change in the second laboratory study reported herein (Payne and Miller 1987) are within the range of changes observed in the field by Environmental Science and Engineering (1981). The laboratory studies discussed previously showed that a 5-min increase in velocity of 18 cm/sec once per hour did not significantly reduce the TCI of juvenile *F. ebena* relative to mussels continuously exposed to a velocity of 8 cm/sec. The laboratory data suggest that *F. ebena* is not likely to be deleteriously affected by velocity changes induced by routine traffic (i.e. no more than one vessel per hour) that are likely to be experienced in channel border habitats where this species thrives (Miller, Payne, and Siemsen 1986). However, both field variability in the effects of barge and tow traffic (as apparent in the data from Environmental Science and Engineering (1981)) and the general caution that should be taken when interpreting the results of laboratory experiments argue for field validation of these results.

56. Way et al. (in preparation) studied filter-feeding rates of the Asiatic clam *Corbicula fluminea* collected from habitats with low, medium, and high suspended sediment levels. It was found that suspended sediments above yearly ambient levels initiated pseudofeces production of all sizes of *Corbicula*. In addition, large-sized particles also initiated pseudofeces production. The production of pseudofeces is a natural process for organisms with a ciliary feeding apparatus that is overloaded. Although this can stress bivalves, laboratory results cannot necessarily be used to predict population level changes.

57. The most difficult aspect of any laboratory experiment on physiological stress is to evaluate the results in relation to naturally occurring populations. These laboratory studies were not intended to exactly mimic turbulence and suspended sediment disturbances caused by navigation traffic that could be experienced by naturally occurring mussel population. Rather, the studies were designed to determine the nature of sublethal physiological effects on freshwater mussels of intermittent pulses of turbulence and suspended sediments. Even if the laboratory studies had been perfect mimics of navigation-related increases in turbulence and turbidity, other factors (such as food availability) would still differ from natural conditions.

Man-induced impacts to natural habitats cannot be reproduced in the laboratory. Therefore, the results of the laboratory studies cannot be directly used to quantitatively predict specific impacts of natural populations of mussels.

58. Field studies (Environmental Science and Engineering 1981) have shown that some channel border habitats may be periodically exposed to changes in water velocity as a result of barge passage in the main channel. In the laboratory, the normal feeding mechanism of mussels is impaired by velocity changes of a magnitude within the range of changes that have been observed in some field studies. However, brief episodes of impaired feeding, such as could be associated with routine navigation traffic, does not appear to have a significant deleterious effect on the bioenergetic balance of individual mussels. It was noted that continuous disruption does have a significant effect, and mussels may be forced to depend on stored reserves when feeding impairment is sustained. In addition, suspended sediment exposure may be expected to have an additive effect to turbulence exposure.

59. Areas proposed for barge fleeting, where traffic can occur at higher levels than normally occurs in waterways, should be evaluated to ensure that mussel populations are not negatively affected by vessel movement. Site-specific studies should be performed to determine the frequency and magnitude of localized physical effects of traffic. Physiological indices of stress, such as those used in the laboratory studies reported herein, can be used in field-monitoring studies to provide an early warning of adverse biological impacts. However, specific biotic parameters that indicate long-term success of natural populations, such as evidence of recent recruitment and rate of growth, provide the best measures of the likelihood of success of the mussel assemblage. These studies will be discussed in the next sections.

Field Studies on Recruitment and Growth

Prairie du Chien, WI

60. The US Army Engineer Waterways Experiment Station is conducting a navigation effects study in the East Channel of the Mississippi River near Prairie du Chien, WI (River Mile (RM) 635). At this location, a dense and diverse mussel bed supports commercially valuable (*Amblema plicata*) and endangered species (*Lampsilis higginsi*). Studies are being conducted at two

sites, a turning basin used by barges approaching a loading facility and a reference site located 1 km downriver. In 1986 there were a total of 518 commercial tow events (passage of a vessel) in the East Channel. The barge turning basin was dredged in 1976 to provide access to the loading facility. No dredging occurred at the reference site, and the turning basin has not been dredged since 1976.

61. Divers collected 30 quantitative samples (0.25 m^2) for mussels at each of the two sites (a total of 60 samples were obtained). At each site there were three subsites; 10 samples were collected at each. Samples were sieved and picked for live organisms. All mussels were identified, weighed, and measured.

62. The purpose of this work was to determine if barge movement at the turning basin affects recruitment of freshwater mussels. A population that is recruiting successfully produces viable juveniles. Evidence of recent recruitment (presence of juveniles) was used as an index of the health of the mussel bed and a measure of physical conditions of habitat. Juvenile mussels were defined as being ≤35-mm total shell length.

63. The density of large mussels (i.e. individuals > 35 mm) was significantly less ($P < 0.01$, Duncan's multiple range test) at the barge turning basin than at the reference site. The dredging that took place in 1976 removed a substantial number of large-sized mussels. However, the number of juvenile mussels was not significantly different between sites. This demonstrates that mussels were able to reproduce successfully and colonize a previously dredged area and that recruitment was unaffected by commercial navigation traffic.

64. The study at Prairie du Chien provided information on the environmental effects of commercial navigation traffic. A determination of recent mussel recruitment provides a useful indicator of past and present conditions of habitat. Commercial navigation traffic, at least at these levels, did not have a detrimental effect on mussel recruitment at the barge turning basin.

Lower Ohio River near Olmsted, IL

65. In the lower Ohio River near Olmsted, IL, is a dense and diverse mussel bed first identified by Williams (1969). The unionid fauna is dominated by *F. ebena*, a commercially valuable species. This bed has been studied since 1983 to evaluate the effects of commercial traffic on freshwater

mussels. Replicate quantitative samples of substrate were collected in the fall of 1983, 1985, and 1987 by divers equipped with scuba and were sieved to obtain all mussel regardless of size. The shell length (SL) of each mussel was measured, and measurements of tissue and shell mass were also made. More detailed descriptions of the site, bivalve community, sampling methods, and data analysis are provided in Miller and Payne (1988) and Payne and Miller (1989).

66. Seventy-one percent of all *F. ebena* collected in 1983 belonged to a single cohort of individuals with an average SL of 15.8 mm (range = 12.8 to 19.5 mm). The average SL of the dominant 1981 cohort had increased to 29.5 mm (ranging from 23.0 to 38.4 mm) by the fall of 1985. The 1981 cohort still comprised 71 percent of the total sample in 1985, due to low mortality combined with lack of strong recruitment since 1981. The average SL of the 1981 cohort had increased to 47.3 mm (range = 35.5 to 56.0 mm) by late September 1987, and the relative abundance remained undiminished at 74 percent. The 1987 survey also yielded two minor cohorts of recent recruits, centered at 15.2 and 23.3 mm, representing recent but light recruitment.

67. This population of *F. ebena* has existed for decades (Williams 1969) in a shoal bordering the commercial navigation lane. Recruitment success determines the abundance of unionids in this shoal. It is very unlikely that navigation traffic determines recruitment patterns. Traffic rates have not substantially changed from 1981 through 1987; however, mussel recruitment has varied annually by several orders of magnitude. In addition, growth rate and survival of the dominant 1981 cohort are high despite the proximity of this shoal to a major commercial navigation lane.

PART V: SUMMARY AND CONCLUSIONS

68. Lubinski et al. (1981) reviewed over 900 documents pertaining to navigation effects; however only 56 were considered relevant and were not related to activities such as dredging, channel maintenance, lock and dam operation, etc. It was found that the majority of these were judgmental and did not adequately test the hypothesis that commercial traffic significantly affects aquatic resources. Although much has been said and written, there have been few well-designed laboratory or field studies that clearly document biological effects of navigation traffic.

69. Some reasons for a paucity of information on navigation traffic are the following: (a) difficulty in conducting a controlled experiment in rivers where navigation traffic has been taking place for years; (b) the confounding effects of levees, dikes, and other structures in addition to channel maintenance and operation of locks and dams; (c) problems with collecting samples and making observations in large rivers as compared with streams and lakes; and (d) a general lack of experience by most state and Federal biologists with techniques to study important attributes of natural populations. Since the passage of the National Environmental Policy Act, there has been considerable interest in documenting environmental effects of man's actions. However, much impact analysis is judgmental and anecdotal, based upon natural history studies or directly keyed to physical losses of habitat. The chronic or sublethal effects of low levels of stress, a major concern of impact analysis, are usually poorly accounted for or else completely ignored.

70. In the existing literature on navigation traffic, one encounters many studies like that of Rosen and Hales (1980). They reported that paddlefish in the Missouri River were scarred or physically damaged, which resulted in low condition factors. These scars were caused by collisions with recreational or commercial vessels or were from snag fishing. The authors were unable to identify commercial traffic as a causative factor. Studies by Kiorbee, Mohlenbwerg, and Nohr (1981) and Morgan et al. (1976), as well as others, illustrate that fish eggs and larvae are sensitive to suspended sediments and turbulence. However, in these studies the link between the effects of commercial traffic and biological impacts were not clearly demonstrated.

71. Existing information indicates that large-river fish populations are affected by factors other than commercial navigation traffic. Abatement

of pollution in the upper Ohio River following closure of steel mills in July 1959 led to an improvement in water quality accompanied by an increase in the variety and abundance of fishes (Krumholz and Minkley 1964). Pitlo (1987) analyzed fisheries standing-stock data from the upper Mississippi River that were collected between 1948-1952 and 1983. During this time, he determined that predators and catfish decreased, whereas panfish and forage fish increased. There did not appear to be specific declines in the fisheries data that paralleled the increase in commercial navigation traffic. However, the high degree of variability within and between pools may have masked some of the year-to-year trends.

72. There is no doubt that the physical effects of movement of commercial vessels could detrimentally affect naturally occurring biotic communities. However, few field studies have been conducted that clearly demonstrate a relationship between movement of commercial vessels and loss or degradation of significant biotic resources. Waterway modification, such as increased water levels, decreased water velocity, and altered substrates, affects aquatic biota. Well-designed field studies on the effects of commercial traffic are needed to clearly identify cause-and-effect relationships. Evaluation of such studies will provide information on the effects of commercial traffic and could suggest methods for protection or even enhancement of natural resources.

73. The effects of navigation traffic can be assessed through laboratory studies in which physical effects of traffic can be simulated and the response of target organisms to these effects measured. Results of these studies provide insight into the biology and physiology of test organisms; however, they may be of limited value in predicting traffic effects. In the laboratory, it is not possible to reproduce naturally occurring physical and chemical conditions of water and substrate. In addition, the many variables associated with movement of commercial vessels, changes in water levels, number and size of tows, and location of the sailing line, make it impossible to predict the exact nature of physical impacts that sedentary biota could receive.

74. Bivalves can be caged and transferred to habitats for studies on water quality (Curry 1977; Foster and Bates 1978; Adams, Atchison, and Vetter 1981; Czarnezki 1983), radionuleotides (Harvey 1969), or temperature (Smith 1984). Caged organisms can be held at the sites for several years while

specific life functions (growth, mortality, or appropriate physiological indices) are monitored. Sparks and Blodgett (1988) studied the effects of fleeting on mussel growth in the Illinois River using transfer techniques.

75. The most appropriate method for studying commercial navigation traffic effects is to design field experiments in which significant population or community or population parameters are measured on natural populations exposed to various intensities of commercial traffic. It may not be possible to identify true control sites that are not affected by commercial traffic. However, sites can be identified that differ in the intensity of physical disturbance caused by traffic. Test sites should be close to the navigation lane, and control or reference sites should be as far from the physical effects of traffic as possible.

76. Appendix A of this report contains a plan of study designed to determine if movement of commercial vessels negatively affects mussel populations located near the Zimmer Power Plant barge facility. Before the facility becomes operational, important biotic (mussel condition, density, biomass, evidence of recent recruitment, species richness, or species diversity, etc.) and abiotic parameters (change in water velocity, increased suspended sediments, etc.) will be measured. After the facility becomes operational, studies will continue for at least 3 years. An assessment of effects will be based on the change (or lack of change) in these biotic parameters.

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APPENDIX A: INVESTIGATION OF THE EFFECTS OF BARGE TRAFFIC ON FRESHWATER MUSSELS AT THE ZIMMER POWER PLANT, OHIO RIVER PHASE II AND III STUDIES

Scope of Work

Introduction

1. Currently there are plans to convert the Zimmer Power Plant on the Ohio River near Cincinnati, OH, from nuclear to coal power. This conversion would require construction of a harbor and a barge-loading facility for coal, lime, and fuel oil. It is anticipated that the power plant will be operational in 1991 and that coal deliveries will begin sometime that year. The barge-loading facility is at a mussel bed known to support a dense and diverse assemblage of freshwater mussels (Williams and Schuster 1982*).

2. As a condition of the permit required by the US Army Engineer District, Louisville, the owners of the plant set up a trust fund to sponsor research on unionid molluscs and relocated 5,000 mussels (Environmental Science and Engineering 1988). A committee composed of the Commissioner of the Kentucky Fish and Wildlife Resources, the Director of the Ohio Department of Natural Resources, and a representative of the Zimmer Power Plant was formed to administer the trust fund. This committee required that a study be conducted to determine if barge traffic would negatively affect freshwater mussels downriver of the loading facility.

3. The physical effects of commercial navigation traffic include wave wash, turbulence, benthic scour, and periods of increased suspended solids (Rasmussen 1983). Freshwater mussels, a resource with economic, ecological, and cultural value, could be affected by these disturbances. Their sedentary lifestyle and reliance on suspended particulate organic material for food make them particularly susceptible to fluctuations in water level, sedimentation, and periods of turbulence. These physical effects can be studied in the laboratory (Holland 1986; Aldridge, Payne, and Miller 1987; Killgore, Miller, and Conley 1987; Payne and Miller 1987). However, caution must be used when

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* See References at the end of the main text.

extrapolating results of laboratory experiments to the field (Payne and Miller 1987). Physiological responses of individuals noted in the laboratory may not occur under natural conditions. In addition, mortality or stress of individuals may have little influence on the long-term success of populations.

4. Planners and biologists must evaluate the effects of physical disturbances on populations of species, not individual organisms. Laboratory studies are a useful means of better understanding physiological causes of effects observed on natural populations, but field studies are necessary to evaluate the effects of tow-induced turbulence and elevated suspended sediments on freshwater mussel populations. Field studies can be designed to evaluate the effects of traffic on recruitment, rate of growth, density, species richness, and diversity. These parameters provide the most useful measures of the overall health and ultimate survival of a mussel community.

Objective

5. The objective is to characterize important abiotic variables (water velocity, sediment characteristics, and suspended sediment concentration) and biotic variables (density, evidence of recent recruitment, and community structure) at a mussel bed near the Zimmer Power Plant, Ohio. These data, to be collected before and after the facility becomes operational, will be used to determine if movement of commercial vessels negatively affects resident mussels.

Approach

6. The effects of barge traffic at the Zimmer site will be studied in three phases. Phase I studies, of which this proposal is a part, consisted mainly of a literature review and development of a plan of study. The purpose of Phase II studies, to be conducted in 1989 (and 1990, if deemed appropriate) before the barge-loading facility becomes operational, will be to obtain baseline data on existing biological and physical conditions. Phase III, to be conducted after coal deliveries commence (projected for 1991), will consist of monitoring previously measured abiotic and biotic parameters. Phase III studies will last for approximately 3 (not necessarily consecutive) years. Data from Phases II and III will be used to determine if barge traffic is

negatively affecting mussels. If negative effects are identified, recommendations will be made (Phase III) on the best methods for reducing impacts.

7. This document contains a discussion of methods, equipment required, schedule, and reporting requirements for a study of mussels at the Zimmer Power Plant on the Ohio River near Cincinnati. Funding requirements are not included.

Phase II: Collection of Baseline Physical and Biological Data

Task I: Preliminary data

8. Divers equipped with scuba or surface air supply will be used to qualitatively collect mussels at approximately 10 sites adjacent to and downriver (along the right descending bank) of the Zimmer facility. Results of the survey by Stansbery and Cooney (1985) will be used to assist in identifying sampling sites. Samples will be obtained by having a diver search a specific area to obtain mussels recognized by touch. Mussels will be collected in increments of 10 or 20; at least 200 mussels will be obtained at each site. These results will provide information on the presence of rare species and the relationship between sampling effort and number of species present (Isom and Gooch 1986; Kovalak, Dennis, and Bates 1986). In addition, information on water depth and velocity, distance to shore, and substrate type (i.e., relative percentages of silt, sand, and gravel) will be obtained at each site.

9. Based on this information, three permanent sites will be identified for quantitative sampling (see Table A1 for a summary of sites required for this study). It is anticipated that one site will be immediately downriver of the barge-fleeting area and may be directly impacted by the physical effects of barge movement. The other two sites will be located farther downriver from the facility. Each site will consist of two or three subsites and will be used for detailed biological studies for the baseline (Phase II, Tasks II and III) and monitoring studies (Phase III). Experimental design for biological studies will be based on Green (1979) and Hurlbert (1984).

Task II: Physical data

10. In Phase III studies, data on changes in water velocity at the substrate water interface and suspended sediments (at three depths) will be obtained as barges approach the facility. Sampling protocol will be based on Johnson (1976) and Bhowmik, Miller, and Payne (in preparation). During

Phase II, approximately three sites (to correspond to the sites for Task II) will be identified, and preliminary (baseline) data on water velocity and suspended sediments will be obtained.

11. Water depth and velocity (at the surface, middepth, and substrate-water interface) will be obtained at each site. A Model 527 Marsh-McBirney Current Velocity (which consists of a two-directional sensor plus underwater compass) coupled to a data logger (to obtain continuous measurements) will be used. This instrument will be required to assess the effects of vessel passage on water velocity (see Phase III for more details). Water samples will be collected at approximately three depths (bottom, middepth, and surface) using a MasterFlex pumping system. These samples will be used to measure concentration of suspended sediments. The purpose of this task will be to obtain baseline information on the natural fluctuation in suspended sediments and water velocity in the river. This will be done by collecting water velocity and sediment data for specific time increments (i.e., once every 5 min) for a specific period (1 to 2 hr). This will provide a basis for interpreting the physical effects of barge movement (Phase III, Task I).

12. A hand-held coring device (Miller and Bingham 1987) will be used to collect sediment samples at each site. These will be used for determination of particle sizes and total organic content (loss on ignition). Water for basic chemical tests (dissolved oxygen, water temperature, total hardness and alkalinity, total suspended and dissolved solids, etc.) will be collected. It is anticipated that these samples for general water quality parameters will be collected from just beneath the surface; however, if appropriate, samples from two to three depths will be obtained. In addition, historical data on water chemistry, stage height, discharge, etc., will be obtained from appropriate sources (US Geological Survey, US Army Corps of Engineers, American Electric Power Service Corporation, Cincinnati Water Supply, Ohio River Valley Sanitation Commission, etc.).

Task III: Characterization of community and population parameters

13. Mussels will be collected at three permanent sites using quantitative and qualitative methods. Qualitative sampling will consist of incremental collections as described previously. The actual number of quantitative samples needed to estimate species richness and density of dominant species will be based on conditions at each site. Based upon previous studies (Miller

and Payne 1988), 10 quantitative samples at each of two or three subsites are likely to be sufficient. Thus, a total of 20 to 30 quantitative samples will be obtained at each of three sites.

14. Quantitative samples will be obtained by having a diver collect all substrate within a 0.25-m^2 quadrate. Sediments will be brought to the surface and sieved through nested screens with mesh size ranging from 3.0 cm to 5 mm. Live mussels will be removed, identified, counted, and shell length and wet mass determined.

15. Approximately 30 individuals of three to five common species from each site will be preserved in 10-percent buffered formalin for determination of shell morphometrics and tissue dry mass. This will be used to calculate various indices, such as ratios of shell length and shell mass to tissue dry mass, etc. Specimens for this work will be obtained from either the quantitative or qualitative sampling. In addition, approximately five individuals of three to five common species will be obtained from each site and stored (frozen) for later tissue analysis. This will be done only if deemed appropriate as a result of Phase III studies.

Task IV: Manipulative experiments

16. The purpose of this task is to collect and place mussels at selected sites near the facility to obtain data on growth rates, mortality, and physical condition of mussels. Approximately six sites will be chosen for this work. Three will correspond to previously identified sites for quantitative samples; the other three will be located in the immediate vicinity of the loading facility. This information will be used to corroborate information on growth and survival of mussels.

17. Divers will collect one or more dominant species of mussels (as part of Task III). Each mussel will be marked with an identifying number, and total length and wet mass measured. Three exclosures (approximately 1- by 1-m aluminum quadrates) will be placed at each of the six sites. All sediments within each exclosure will be collected and brought to the surface. Sediments will be sieved, and all live mussels removed. Approximately 25 marked mussels will be replaced (along with sieved substrate) into each exclosure. These mussels will be retrieved during Phase III for study (see below).

18. A summary of biotic and abiotic parameters to be measured in Phase II, Tasks II-IV, appears in Table A2. These data will be used to describe existing conditions at the mussel bed.

Phase III: Monitoring Studies

19. Phase III studies will consist of detailed analyses of biotic and abiotic conditions to determine if barge traffic is negatively affecting mussels. These studies could be conducted for a total of 3 (not necessarily consecutive) years after the loading facility is operational (projected to take place in 1991). The design and schedule for Phase III could be modified after results from Phase II studies are analyzed. The criteria used to identify negative effects are described in Phase III, Task IV.

Task I: Measure physical effects

20. Changes in water velocity at the substrate-water interface and changes in suspended sediment concentrations at three depths (surface, mid-depth, bottom) caused by barge movement will be measured at approximately three sites. The Model 527 Marsh-McBirney Current Velocity Meter (which consists of a directional sensor plus underwater compass) will be required for this work. Two instruments will be used simultaneously, one at the study site, the other located a specific distance (approximately 50 m) away. A data logger will be coupled to each meter to obtain continuous velocity readings. Water samples will be collected at three or more levels (bottom, middepth, and surface using a MasterFlex pump) for analysis of resuspended sediments. Phase II studies will be used to establish baseline conditions (i.e., without barge traffic).

Task II: Monitor biological conditions

21. The purpose of this task is to obtain data on mussel density, evidence of recent recruitment, and population structure with the barge-loading facility operational. Quantitative data will be collected using the same methods and procedures as in Phase II, Task III. An appropriate number of mussels will be collected and preserved in 10-percent buffered formalin for morphometric data (as in Phase II, Task III). In addition to tissue and shell indices, gill structure will be examined to determine if coal particles are collecting on the gills or are causing abnormal conditions (lesions). Information will be used to determine if operation of the loading facility is detrimentally affecting mussels.

22. In addition to the mussels preserved in formalin, a selected number of mussels will be frozen for possible later tissue analysis. These studies would be conducted only if results of monitoring suggested that toxic

materials are entering the water and that analysis for specific compounds in mussel tissue is required.

Task III: Manipulative experiments

23. During each study year, all sediment will be removed from the exclosures (placed in Phase II) and sieved to obtain live mussels. Marked mussels will be reweighed, and their total shell length measured, and then they will be replaced in the exclosures. Information from this task will be used to assess mortality, growth, and recruitment rates. This information, in conjunction with results from Phase II, Task III, will be used to assess the effects of commercial navigation traffic on freshwater mussels. Some specimens from exclosures will be sacrificed to determine if coal is negatively affecting gill structure (as Task III above).

24. Changes in water velocity and suspended sediments following barge movement will be assessed at one or more of these sites as part of this task. Sampling protocol will be similar to that used in Phase III, Task I.

Task IV: Determine negative effects

25. Following completion of field studies, a determination of negative effects will be made. This will be based upon results of physical and biological studies. It is anticipated that the committee for the mussel mitigation trust and US Army Engineer Waterways Experiment Station personnel will discuss research findings and evaluate effects of barge movement. The following parameters, indicative of the health of a mussel bed, will be used to determine if negative effects have occurred:

a. Decrease in density of five common-to-abundant species. Density of common-to-abundant species will be determined during Phase II studies. Negative effects will be assumed if there is a significant ($P < 0.1$) decline in density, sustained over each of two sampling periods, for at least five common-to-abundant species during Phase III studies. ("Sampling period" refers to a single study year.)

b. Loss of more than 25 percent of the mussel species. Total species richness will be determined during the Phase II and Phase III studies. Negative effects will be assumed if subsequent sampling (sustained over two sampling periods) reveals a loss of more than 25 percent of the mussel species known to occur at the site.

c. Significantly different growth rates or mortality. Results of the exclosure experiments will be used to evaluate the effects of barge movement on mortality and size-specific growth rates. If a significant reduction (0.1 level) at the affected site is identified, it will be assumed that the bed is being negatively affected.

Task V: Recommend
mechanisms to reduce harm

26. The purpose of this task will be to suggest reasonable and prudent measures that could be employed to reduce harm to mussels at the Zimmer site. This task will be initiated only if deemed appropriate by members of the committee to administer the trust.

Reporting Results

27. Results of this study will be transmitted in the following manner:

a. Progress reports. A progress report, to include a brief description of methods and a discussion of major findings will be presented by 15 February of each study year.

b. Annual meeting. A meeting to discuss results and future plans will be held in March or April of each study year. The committee to administer the trust and other interested individuals can provide comments.

c. Final reports. A final report, to include a complete synthesis of data and discussion of results, will be prepared at the completion of each phase of this work. If more than a single year of data are obtained during a phase, then the report will summarize results of all study years.

Schedule

Phase II

28. Field studies will be completed during a low-water period in July-September before the facility becomes operational. At least 1 study year will be sufficient (1989); however if deemed appropriate by the committee formed to administer the trust, additional baseline studies could be conducted.

Phase III

29. This phase will be conducted during a low-water period (July-September) for at least 3 (not necessarily consecutive) years after the barge-loading facility is operating at full capacity. A determination on the number of study years should be made following completion of Phase II.

Table A1

Summary of Sample Sites for Mussel Study at the Zimmer Site

Study	Description
Quantitative mussel studies	Three permanent sites to be located downriver of the facility. Site I will be as close as possible to the facility; the other two will be at specific distances downriver to be removed from the physical effects of traffic.
Physical studies on the effects of barge movement	Three sites will be chosen for the majority of this work. These sites will correspond to those chosen for the quantitative mussel studies. Short-term physical studies will also be done at selected sites where the manipulative studies are being conducted (see below).
Manipulative experiments	The manipulative experiments consist of placing mussels in exclosures for later collection and analysis. Approximately six sites will be used for this work. It is anticipated that three of these sites will correspond to the sites used for quantitative mussel studies (above), and the other three will be close to the coal unloader.

Table A2

Physicochemical and Biological Data To Be Obtained at Control and Experimental Sites

Parameters	Data
	Physical
Substrate characteristics (grain size and organic content)	Turbulence and benthic scour can alter substrate conditions. These data will be collected to characterize the study sites to evaluate impacts of barge passage.
Water depth and velocity	Water velocity is affected by movement of vessels. Information on velocity will be needed to characterize study sites and to evaluate effects of barge passage.
Turbidity and total and dissolved solids	These parameters are affected by movement of vessels. These data will be used to characterize study sites and to evaluate effects of barge passage.
Chemical data	Data on total hardness and alkalinity, water temperature, and dissolved oxygen will be obtained at the site. In addition, information on the availability of physical and chemical data will be obtained from the US Geological Survey, US Army Corps of Engineers, or other sources. Movement of commercial vessels is unlikely to affect these parameters. However, this information will be obtained to characterize the aquatic habitat where mussels are found.
	Biological
Species richness	The number of species at a mussel bed is affected by presence of host fishes and habitat conditions. The ability to find rare species is related to density and community composition. This parameter can be used to evaluate physical conditions of habitat, substrate conditions, and presence of host fishes.

(Continued)

(Sheet 1 of 3)

Table A2 (Continued)

Parameters	Data
	Biological
Relative abundance species	Usually three or four species comprise 80 to 90 percent of all mussels at a bed. If relative abundance of species changes through time, this can be an indication of strong recruitment of a rapidly growing species or loss of one or more common species. Relative abundance of species can be used as an indicator of the habitat conditions as well as the presence of host species.
Density of dominant species (adults and juveniles)	Because mussels are long-lived, densities should not fluctuate over short periods. An unexplained decrease in density of a dominant species could indicate that habitat is being negatively affected. A decrease in density of juvenile mussels indicates lack of recent recruitment.
Size distribution of dominant species	Length-frequency histograms will be prepared for dominant species. A successful population usually exhibits evidence of recent recruitment, as well as adults and at least several intermediate age classes.
Evidence of recent recruitment	Recruitment will be measured by determining the number of mussels less than 30-mm total shell length. To successfully inhabit an area, mussels do not have to recruit each year. However, lack of recruitment for an extended period of time could eliminate the mussel bed. Successful recruitment requires presence of host fishes and appropriate physical conditions of habitat.
Sex ratios for dominant species	Sex ratios and size at first reproduction will be measured for dominant species. This information can be used to characterize the biological condition of dominant species.
Physical condition indices for dominant species	Preserved specimens will be used to calculate ratios of shell length and mass to tissue dry mass and shell cavity volume. These data provide a measure of individual condition that may relate to population characteristics.

(Continued)

(Sheet 2 of 3)

Table A2 (Concluded)

Parameters	Data
	Biological
Total wet biomass	Each specimen will be weighed and total weight per square meter will be calculated. This information can be used to evaluate the overall health of the bed in comparison to other mussel beds in large rivers.

(Sheet 3 of 3)