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AN EVALUATION OF FRESHWATER MUSSEL RELOCATION AS A CONSERVATION AND MANAGEMENT STRATEGY

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Running head: Relocation of Unionacean Mussels

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ABSTRACT

The relocation of unionacean mussels is commonly used as a conservation and management tool in large rivers and streams. Relocation has been used to recolonize mussels in areas where populations have been eliminated by prior pollution events, to remove mussels from construction zones, and to re-establish populations of state and federally endangered species. More recently, relocation has been used as a potential mechanism for protecting native freshwater mussels at risk from colonization by the exotic zebra mussel *Dreissena polymorpha*. We conducted a literature review of mussel relocations and evaluated their relative success to determine the effectiveness of relocation as a conservation and management strategy. We found that 62% of all relocations were conducted because of construction projects that were forced to comply with the Endangered Species Act of 1973, and that only 5% were monitored for more than five consecutive years. Most (41%) relocation projects were conducted ~~from~~ July ~~through~~ September, presumably a period when reproductive stress is relatively low for most species and metabolic rate is sufficient for reburial in the substrate. The mortality of relocated mussels was unreported in 52% of projects; mortality ~~varied~~ among studies and species and was difficult to assess, but averaged 54%. Presently, there is little guidance on methods for relocation or for monitoring the subsequent long-term status of the relocated mussels. Based on our evaluation, research is needed in two main areas: the physical characteristics of mussel habitat at both the source and destination sites, and the methods of relocation.

KEY WORDS Conservation Bivalve Management Mussel Relocation River Translocation Transplant Unionidae

INTRODUCTION

The North American freshwater unionacean mussel fauna, once represented by about 297 taxa (Turgeon *et al.*,1988; Neves, 1993; Williams *et al.*, 1993), has declined to about 276 taxa since the early 1900s due to overharvest, commercial navigation, pollution, and habitat degradation (Neves, 1993). A total of 58 mussel species (21% of remaining species) are listed as federally threatened or endangered (Code of Federal Regulations, 1993). Because of the drastic decline in mussel fauna and the authority of the Endangered Species Act of 1973, resource agencies have attempted to mitigate the impact of human activities on unioncean mussels.

The relocation of mussels is frequently used as a conservation and management tool by state and federal agencies. Relocation has been used to recolonize mussels in areas where populations have been eliminated by prior pollution events (Ahlstedt, 1979; Sheehan *et al.*, 1989), to remove mussels from construction zones (Oblad, 1980; Harris, 1986; Berlocher and Wetzel, 1988; Dunn, 1991), and to re-establish populations of state and federally endangered species (Jenkinson, 1985; Hubbs *et al.*, 1991). More recently, relocation has been used as a potential mechanism for protecting unionid populations at risk from colonization by the zebra mussel *Dreissena polymorpha* (Ogawa and Schloesser, 1993).

Although relocation projects have been conducted for more than 20 years, their effectiveness for conservation and management of unionacean populations has not been adequately assessed. Moreover, there is presently little guidance on methods for relocation studies or for monitoring the subsequent long-term status of the relocated mussels. Little is known about the habitat requirements of mussels or the biological responses of mussels to removal from the substrate, handling and transport, and relocation at a new site. Our objectives were to summarize the literature on mussel relocation, evaluate the

relative success of mussel relocation projects, and to identify research needs.

RESULTS

Summary of relocation projects

Our literature search revealed a total of 31 papers on unionid relocation, of which only three appeared in the peer-reviewed literature. The remainder were either in the published gray literature or in unpublished reports, which were not widely available. We found that nearly 100,000 mussels have been relocated in a total of 29 discrete projects (Table 1).

The main reasons for mussel relocation included construction management, and research. An overwhelming 62% of all relocations were conducted because of construction projects that were forced to comply with the Endangered Species Act of 1973 (Figure 1a). Construction projects included those associated with bridge construction (Arkansas Highway and Transportation Department, 1984, 1989; Heath, 1989; Burke, 1991; Harris *et al.*, 1992; Havlik, 1992; Trdan and Hoeh, 1993; Miller, 1994), bridge demolition (Berlocher and Wetzel, 1988,1989), and dredging and channel maintenance (Jenkinson, 1989; Ecological Specialists Inc., 1991; Dunn, 1993; Hamilton *et al.*, 1993; Trdan and Hoeh, 1993; Jenkinson, 1994a,b). The remainder of mussel relocations were attributed to management efforts (23%) such as re-introductions (Ahlstedt, 1979; Jenkinson, 1985; Sheehan *et al.*, 1989; Hubbs *et al.*, 1991; Koch, 1993; Layzer and Gordon, 1993) and to research (15%) (Hinch *et al.*, 1986; Hinch and Green, 1989; Waller *et al.*, in review; Schanzle and Kruse, 1994).

The survival of relocated mussels was not routinely monitored on a long-term basis. Only 68% of all relocation projects reported estimates of relative success, and of those, most (57%) were monitored for one year or less, and only 5% were monitored for more than five consecutive years (Figure 1b).

In addition, only 66% of the projects that were monitored provided estimates of mussel mortality (Figure 1c). The mortality of relocated mussels varied among projects and mussel species and was difficult to assess, but averaged 54%. Mortality was >90% in some projects (Table 1), and the greatest percentage often occurred within the first year after relocation (Jenkinson 1985; Hubbs et al. 1991; Koch 1993; Heath 1989; Burke 1991).

About 50% of the mussel relocations occurred in the southern and southeastern United States, regions that are known to contain the highest diversity of mussel species (Neves, 1993). The timing of relocation projects coincided with the climate of a geographic region. Most (41%) relocation projects were conducted from July through September (Figure 1d), presumably a period when reproductive stress is relatively low for most species and metabolic rate is sufficient for reburial in the substrate.

DISCUSSION

Many factors influence the survival and successful reproduction of mussels in their natural environment, and relocation adds an additional, and largely anthropogenic, set of stressors that affect mussel survival (Figure 2). Little is known about many of these *in situ* factors and even less about those associated with relocation. However, based on our evaluation, the variables associated with the physical characteristics of mussel habitat at both the source and destination sites, and with the methods of relocation are especially critical.

Physical characteristics of habitat

One of the most important factors influencing mussel survival is the physical habitat. Existing criteria for selection of a suitable relocation site have been largely qualitative and observational. The presence of live

mussels or the apparent similarity of habitat have often been used as criteria for site selection (Oblad, 1980; Berlocher and Wetzel, 1988), but do not ensure that a site is suitable for relocation. For example, changes in habitat at the destination site have been attributed to decreased survival of relocated mussels, primarily due to substrate instability (Sheehan *et al.*, 1989; Dunn, 1993; Layzer and Gordon, 1993).

Mussels may have many more specific habitat requirements than previously recognized. For example, Anderson (1993), who characterized the species composition and physical habitat of mussel sanctuaries in the Mississippi River, found that the density and species composition of mussels in adjacent sanctuaries were significantly different despite similarities of habitat. In his study, mussel communities that were less than one river mile apart could be dominated by different species.

Moreover, Hornbach (1992a,b) found that even within a given mussel bed the community varied both longitudinally along the river (upstream vs. downstream) and across the river (inshore vs. outshore). This spatial distribution of mussels was attributed to substrate type and nutrient availability, which are directly related to flow. Hornbach (1992a,b) found that the density of small particles suspended in the water column decreased as they passed over the mussel bed and that mussels tended to reside at a place in a bed that corresponded to their preferred particle size for filtration; the density of larger particles remained relatively unchanged over the length of the mussel bed. Thus, mussels in a given bed can influence both the size and density of particles available for filtration over the bed, which directly influences species composition. These subtle differences in physical habitat may be very important when relocating mussels. When mussels are moved from a specific location, one or more of the important microhabitat variables may

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change; a small change in flow or substrate may be very important to the long-term survival of a mussel.

Finally, Hinch *et al.* (1986) and Hinch and Green (1989) found that a mussel's response to relocation into a new environment was strongly influenced by its previous environment. In their studies, the source habitat of the mussels had significant effects on shell growth and tissue metal burden after relocation. They attributed this "source effect" to genetic differences in populations or to acclimation to a specific habitat over several years, which can only be slowly reversed. Given that differential selection pressures may be present in different habitats, relocated mussels, particularly older organisms, may never completely acclimate to the destination habitat if it is significantly different from the source habitat.

Quantitative information on the habitat requirements of unioncean mussels would greatly facilitate the identification of suitable sites for relocation. Moreover, site selection criteria could be developed for several species of mussels or for a single species of mussel. In addition to characterization of the physical habitat, sensitive physiological or biochemical indicators could be developed to assess the relative condition of mussels at both the source and destination sites. The latter is important to prevent relocation of mussels to a site where resident mussels are already stressed from pollution or other factors.

Methods of relocation

Currently, standard protocols for conducting mussel relocations ~~do not exist~~. Moreover, there is little guidance in the literature regarding ~~relocation-related variables such as~~ methods for the handling, transport, and tagging of mussels; the time of year to conduct relocations; minimum and maximum water temperatures, maximum time period of aerial exposure for

mussels, and methods for replacing mussels in the substrate (Figure 2). In fact, we found that the the methods described in the relocation projects in our review were generally insufficient in detail to repeat the project.

Mussels are often considered tolerant of handling and disturbance, but there are few data that demonstrate the effects of disturbance on freshwater mussels and the period of time needed for them to return to a non-stressed state. Recently, several investigators have examined the effects of various handling and replacement methods on mussel survival after relocation. The timing or season of relocation is a primary consideration in these studies because of the interaction between air and water temperature and the metabolic and reproductive condition of the mussels. Schanzle and Kruse (1994) examined the effect of time of year on a mussel's ability to re-establish after hand placement in the substrate and broadcasting from the water surface. Waller *et al.* (in review) also included time of the year in an evaluation of the effects of different periods of aerial exposure on the survival of five species of mussels. Both studies reported minimal (<11%) mortality and relatively high (>65%) recovery rates associated with the handling and placement methods when the relocations were conducted under moderate temperature conditions in spring or fall. The recommendations from these two studies were to conduct relocations during periods of moderate air and water temperatures, such as spring or fall; limit aerial exposure to less than 4 h; and use the broadcast method for placement of mussels.

Further research is needed to establish complete and comprehensive protocols or guidelines for conducting relocation projects. There are many variables that remain to be examined (Figure 2). In addition, the effects of many of these key variables are currently evaluated on mussel survival; there may be significant differences in the effects of handling methods on rate of glochidial abortion or stress response versus organismal survival. Mussels

may elicit sublethal responses to anthropogenic and environmental perturbations long before changes in the community and population structure are manifested. Therefore, sensitive sublethal measures of mussel condition need to be developed and used to assess mussel health.

Monitoring of relocation success

The greatest obstacles to evaluating the relative success of the mussel relocation projects that we reviewed were the lack of long-term, quantitative monitoring and the universal reporting of mortality data. A large majority (57%) of relocation projects were monitored for one year or less, and only 5% were monitored for five years (Figure 1b). An estimated 50,000 mussels perished in the 29 relocation projects summarized; however, this number is an underestimate of actual mortality because only 66% of the projects that were monitored reported mortality. Ironically, although some of the relocation projects are conducted at great expense (e.g., $300,000; G. P. Helgeson, Wisconsin Department of Transportation, Eau Claire, WI, pers. comm.), long-term, follow-up evaluations of relocation success have been rare. The cost of monitoring is relatively minor ($60,000) relative to the cost of the relocation, yet only three relocation projects have been monitored for four years or longer (Sheehan *et al.*, 1989; Hubbs *et al.*, 1991; Dunn, 1993). The cost of conducting future mussel relocations will certainly be questioned unless the overall success of the effort can be demonstrated through long-term, quantitative monitoring.

Monitoring efforts have generally focused exclusively on recovery or mortality of the population of mussels relocated. We suggest that these measures are crude estimates of the success of a relocation project. If relocation is to be recommended as a conservation and management tool, the condition of individual organisms and the long-term status of the resident and

relocated mussel populations should be assessed. Growth of mussels before and after relocation to the destination site, and reproduction and recruitment of the relocated population could also be measured.

SUMMARY AND RECOMMENDATIONS

Our review of the literature on mussel relocation revealed: mussels are frequently moved; the methods of relocation, when reported, varied widely among projects; the survival of the relocated mussels was generally poor (<50%); and the factors influencing survival of relocated mussels are poorly understood.

We believe that for relocation to be a successful conservation and management technique, more consideration must be given to habitat characterization, both at the source and destination sites. Optimally, the condition of water and sediment should be characterized and monitored at both the source and destination sites over at least an annual cycle, not just at a single point in time such as in summer, because conditions may change with winter flow regime and with other key variables.

In addition, we believe that all future mussel relocation projects should be monitored on a long-term basis, and that the monitoring should be done quantitatively. Preferably, a minimum of two years of monitoring, but five years would be the amount of time needed to determine if recruitment has occurred--the true test of a successful relocation. Species-specific mortality and recovery should be measured to assess the sensitivity of relocation among species.

Our literature search demonstrated the need for better access to methods and results of relocation studies. The majority of relocation projects were available only as intra-agency reports, which are not widely available. Studies evaluating mussel relocation, as well as those evaluating mussel

communities, should be designed to yield quantitative and statistically valid results, which should be published in the peer-reviewed literature so that others may benefit from this information.

ACKNOWLEDGEMENTS

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Figure Legends

Figure 1. Pie charts showing a) the primary reasons for mussel relocation, b) the frequency of monitoring mussel relocation projects, c) the manner of estimating success of mussel relocation projects which were monitored, and d) the timing of mussel relocations

Figure 2. Diagram of factors influencing the survival of unionacean mussels in their natural environment and those associated with relocation

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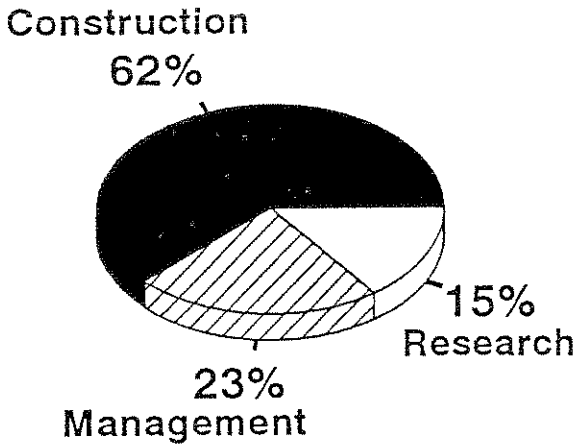
unorganized
you forgot the price of tea
in China

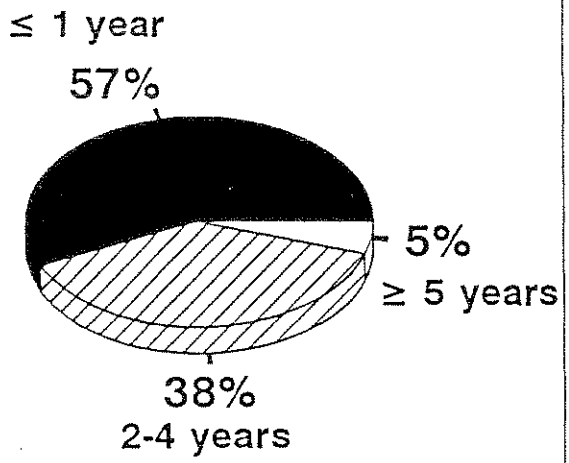
a)

Reasons for Relocation



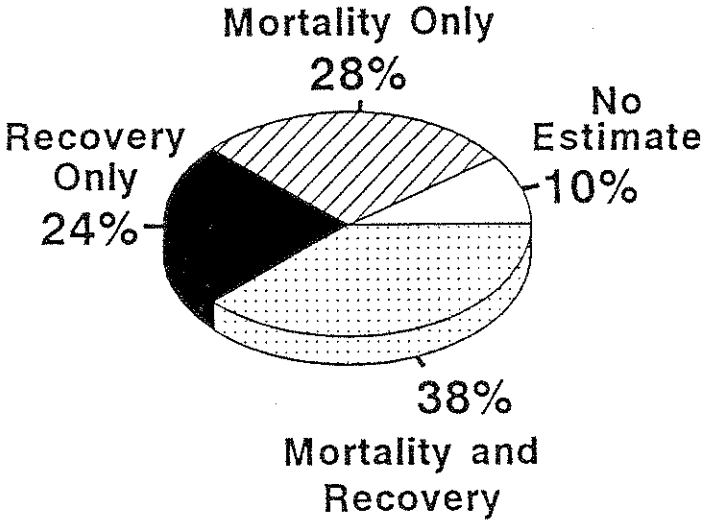
b)

Monitoring of Relocation



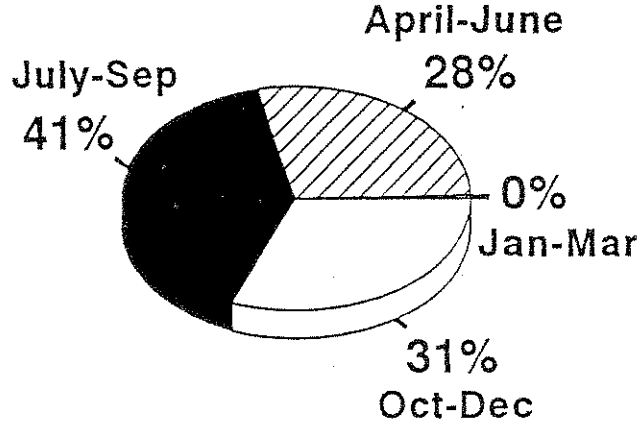
c)

Estimates of Relocation Success



d)

Timing of Relocation



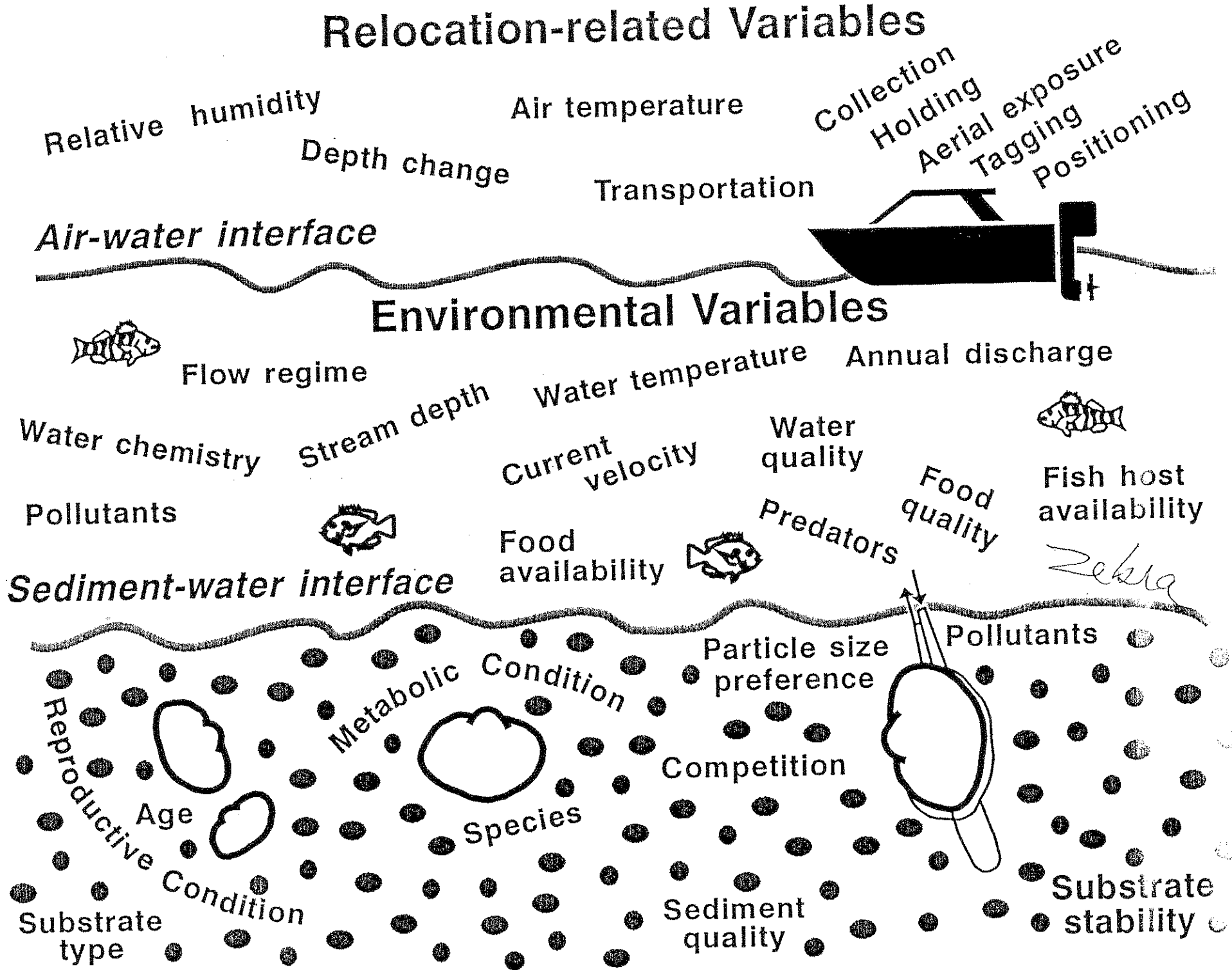

Relocation-related Variables
Relative humidity
Depth change
Air temperature
Transportation
Collection
Holding
Aerial exposure
Tagging
Positioning
Air-water interface
Environmental Variables
Flow regime
Water temperature
Annual discharge
Water chemistry
Stream depth
Current velocity
Water quality
Fish host availability
Pollutants
Food availability
Predators
Food quality
Sediment-water interface
Particle size preference
Pollutants
Metabolic Condition
Reproductive Condition
Age
Species
Competition
Substrate type
Sediment quality
Substrate stability

Table I. Summary of literature on relocation of unionacean mussels

Relocation site	Reason for relocation	~~Total~~ no. of mussels relocated	Time of year	Monitored/frequency
St. Croix River Prescott, WI	Construction (Bridge)	7,976	November 9-22, 1988	Yes, September 16, 1991
St. Francis River Madison, AR	Construction (Boat Launch)	7,825	August 4-27, 1986	No
St. Francis River Madison, AR	Construction (Dredging)	2,321	September 7-29, 1988	Yes, November 1988
Saline River Saline, AR	Construction (Bridge)	310	September 28-29, 1989	No
Spring River Ravenden, AR	Construction (Bridge)	3,372	May 28-June 22, 1984	No
Ouachita River Mount Ida, AR	Construction (Bridge)	44	May 5-6, 1992	Yes, June 19, 1992
Mississippi River Moline, IL	Construction (Bridge)	7,096	September 12-15, 1978	Yes, September 8, 1979
Kankakee River Kankakee, IL	Construction (Bridge Demolition)	3,800	August-September 1987	Yes, Summer 1988
Ohio River Ripley, OH	Construction (Dredging)	5,158	May 4-12, 1987	Yes, October 1987, August 1988, August 1989, August 1990
Wolf River Shawano, WI	Construction (Bridge)	8,120	August 17-26, 1992	No
Tennessee River	Construction (Mooring Cells)	18,300	June 1993	No
Tennessee River	Construction (Dredging)	7,300	October, 1993	No
Apalachicola River FL	Construction (Dredging)	320	July 29-30, 1993	Yes, November 1993
Detroit River, MI	Construction (Dredging)	7,877	July-August, 1988	Yes, annually through 1992
and Clinton River, MI	Construction (Bridge)	2,113	October 1-4, 1992	Yes

United States Department of the Interior

NATIONAL BIOLOGICAL SURVEY

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June 7, 1994

Dr. Richard J. Neves
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Dear Dr. Neves:

I would appreciate your critical appraisal of all aspects of the enclosed manuscript, entitled "An evaluation of mussel relocation as a conservation and management strategy." This paper will be submitted for publication in Regulated Rivers.

Please provide a summary statement concerning the overall quality and merit of the manuscript and list your major criticisms (i.e., those that you believe to require a mandatory response) on the attached review form. If you have no comments requiring a mandatory response, please indicate this in your summary statement. Feel free to make minor comments and editorial changes directly on the manuscript copy. It is requested that you complete your review within three weeks of receipt. If this period is not convenient, please return the manuscript immediately so that another reviewer can be selected.

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MS
Mandatory Response

NFLX MANUSCRIPT REVIEW FORM FOR MANDATORY RESPONSE ITEMS

Author(s): W. G. Cope and D. L. Waller

Title: An evaluation of mussel relocation as a conservation and management strategy

Reviewer: Richard J. Neves

Date:

Page number	Line number	Reviewer's comments	Author's response
1	Title	Specifically freshwater mussel	
2	Abstract	a. Relocation projects conducted between July and Sept., not the entire time period (from-through) b. Is reburial the proper word? c. Mussels burrow vs bury. Reference to physical characteristics is generic.	
3	Intro	Avoid use of 'tool'	
4	Results	Protection from construction projects	
5	Results	Clarify 'coincided with climate'	
6	Discussion	Narrative on Hornbach (1992 a,b) seems very speculative; until it is peer-reviewed in a publication, I'm not sure that inclusion is warranted.	
7	Discussion	Speculation is too great on acclimation and source effect. There is evidence to refute this 'source effect' as a limiting factor to recolonization. See enclosed reprint	
8	Discussion	What is the broadcasting method? Cite studies to support statements.	
9	Discussion	Source of $60 K statement. Monitoring can be done for a lot less.	
10	Summary	Recommendation on how environmental data should be used? How should a monitoring study be done?	
21	Fig. 2	I don't like this hodge-podge of words. In general, the Recommendations are limited and conservative. A concensus from the folks who have moved mussels, using the Delphi Technique or Social Judgement Analysis (i.e. expert opinion) would make	