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EVALUATION OF FRESHWATER MUSSEL RELOCATION AS A CONSERVATION AND MANAGEMENT STRATEGY

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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 areas where mussel populations have been eliminated by prior pollution events, to remove mussels from construction zones and to re-establish populations of endangered species. More recently, relocation has been used to protect native freshwater mussels from colonization by the exotic zebra mussel *Dreissena polymorpha*. We conducted a literature review of mussel relocations and evaluated their relative success as a conservation and management strategy. We found that 43% of all relocations were conducted because of construction projects that were forced to comply with the Endangered Species Act 1973 and that only 16% were monitored for five or more consecutive years. Most (43%) relocation projects were conducted from July to September, presumably a period when reproductive stress is relatively low for most species and the metabolic rate is sufficient for reburrowing in the substrate. The mortality of relocated mussels was unreported in 27% of projects; reported mortality varied widely among projects and species and was difficult to assess. The mean mortality of relocated mussels was 49% based on an average recovery rate of 43%. There is little guidance on the methods for relocation or for monitoring the subsequent long-term status of relocated mussels. Based on this evaluation, research is needed to develop criteria for selecting a suitable relocation site and to establish appropriate methods and guidelines for conducting relocation projects.

KEY WORDS bivalves conservation management mussels 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 overharvesting, commercial navigation, pollution and habitat degradation (Neves, 1993). Fifty-eight mussel species (21% of the remaining species) are listed as federally threatened or endangered (Code of Federal Regulations, 1993). Because of the drastic decline in the mussel fauna and the authority of the Endangered Species Act 1973, resource agencies have attempted to mitigate the effects of human activities on unionacean mussels.

Relocation has been used as a conservation and management technique by state and federal agencies to recolonize areas where mussel 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 endangered species (Jenkinson, 1985; Hubbs *et al.*, 1991). More recently, relocation has been used to protect unionid populations from colonization by the zebra mussel (*Dreissena polymorpha*), an invasive introduced species (Ogawa and Schloesser, 1993).

Although relocation projects have been conducted for more than 20 years, their effectiveness for the conservation and management of unionacean populations has not been assessed. Moreover, there is presently little guidance on methods for relocation projects 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, transporting and relocating to a new site. Our objectives were to summarize published work on mussel relocation, to evaluate the relative success of mussel relocation projects and to identify research needs.

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Table I. Summary of ~~published work~~ literature on relocation of unionacean mussels

Delete "published work" and Insert "literature"

Relocation site	Total no. of mussels relocated	Estimate of success	Reference(s)
Apalachicola River Jim Woodruff Dam, FL, USA	320	15% mortality of unreported recovery	Hamilton *et al.* (1993)
Buffalo River, TN, USA	1000	100% mortality (estimate based on 10% of relocation area sampled)	Jenkinson (1985) Hubbs *et al.* (1991)
Clinch River, VA, USA	281	No estimate	Ahlstedt (1979)
Clinch River, VA and TN, USA	2238	96% mortality of 4% recovered	Sheehan *et al.* (1989)
Clinch River, VA and TN, USA	475	35% mortality of 14·5% recovered	Sheehan *et al.* (1989)
Clinton River Oakland County, MI, USA	804	No estimate	Trdan and Hoeh (1993)
Detroit River Belle Isle, MI, USA	118	100% mortality of 90% recovered (due to zebra mussel infestation)	Trdan and Hoeh (1993)
Duck River, TN, USA	1000	98% mortality (estimate based on 10% of relocation area sampled)	Jenkinson (1985) Hubbs *et al.* (1991)
Duck River, TN, USA	1213	0% mortality of 20% recovered	Layzer and Gordon (1993)
Inner Long Point Bay Lake Erie, Canada	183	No estimate of mortality from 58% recovered	Hinch *et al.* (1986)
Kankakee River Kankakee, IL, USA	3800	11% mortality of 29% recovered	Berlocher and Wetzel (1988) Berlocher and Wetzel (1989)
Mississippi River Trempeleau, WI, USA	300	3% mortality of 97% recovered	Waller *et al.* (submitted)
Mississippi River Trempeleau, WI, USA	865	11% mortality of 89% recovered	Waller *et al.* (submitted)
Mississippi River Trempeleau, WI, USA	825	11% mortality of 91% recovered	Waller *et al.* (submitted)
Mississippi River Moline, IL, USA	7096	0% mortality of 45% recovered from an 8% sample	Oblad (1980) Nelson (1982)
Mississippi River, MO, USA	2301	89% mortality of 5% recovered	Koch (1993)
Namekagon River, WI, USA	523	5% mortality of 85% recovered	Miller (1994)
Nolichucky River, TN, USA	1000	100% mortality (estimate based on 10% of relocation area sampled)	Jenkinson (1985) Hubbs *et al.* (1991)
N. Fork Holston River, VA, USA	1692	57% mortality of 12% recovered	Sheehan *et al.* (1989)
N. Fork Holston River TN and VA, USA	1000	94% mortality (estimate based on 10% of relocation area sampled)	Jenkinson (1985) Hubbs *et al.* (1991)
Ohio Rivertion Ripley, OH, USA	5158	65% mortality (estimate assumes 100% recovery)	Dunn (1991) Ecological Specialists (1991) Dunn (1993)
Ouachita River Mount Ida, AR, USA	44	0% mortality of 25% recovered	Harris *et al.* (1992)
Reservoir-lake Danvers, MA, USA	87	100% mortality of unreported recovery	Clarke (1967)
Reservoir-lake Danvers, MA, USA	47	100% mortality of 2·1% recovered	Clarke (1967)
Saline River Saline, AR, USA	310	No estimate	Arkansas Highway and Transportation Department (1989)
Salt Creek, IL, USA	134	0% mortality of 65% recovered	Schanzle and Kruse (1994)

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Answer: The manuscript has been accepted and may be cited as "in press".

Delete "tion" should read Ohio River

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Table I. Summary of published work on relocation of unionacean mussels (continued)

Relocation site	Total no. of mussels relocated	Estimate of success	Reference(s)
Salt Creek, IL, USA	178	0% mortality of 71% recovered	Schanzle and Kruse (1994)
Silver Lake Wilmington, MA, USA	66	100% mortality of unreported recovery	Clarke (1967)
South-central Ontario Lakes, Canada	150	No estimate of mortality from 88% recovered	Hinch and Green (1989)
Spring River Ravenden, AR, USA	3372	No estimate	Arkansas Highway and Transportation Department (1984)
St Clair River, MI, USA	85	No estimate	Ogawa and Schloesser (1993)
St Croix River Prescott, WI, USA	7976	90% mortality of 14% recovered	Heath (1989) Bucke (1991)
St Francis River Madison, AR, USA	7825	No estimate	Harris (1986)
St Francis River Madison, AR, USA	2321	53% mortality of 1·4% recovered	Jenkinson (1989)
Tennessee River Kentucky Dam, KY, USA	18 300	No estimate	Jenkinson (1994a)
Tennessee River Pickwick Dam, TN, USA	7300	No estimate	Jenkinson (1994b)
Wolf River Shawano, WI, USA	8120	1% mortality of 1·9% recovered	Havlik (1992) Havlik (1994)

RESULTS

Summary of relocation projects

Our literature search revealed a total of 33 papers on mussel relocation, of which only three appeared in the peer-reviewed literature. The remainder were either in the published grey literature or in unpublished reports which were not widely available. We found that nearly 90 000 mussels have been relocated in a total of 37 discrete projects (Table I).

The main reasons for mussel relocation included protection from construction projects, management efforts such as re-introductions and research (Figure 1a). Most (43%) relocations were conducted because of construction projects that were forced to comply with the Endangered Species Act 1973. 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; 1994b). The remainder of mussel relocations were attributed to management efforts (30%) 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 (27%) (Hinch *et al.*, 1986; Hinch and Green, 1989; Schanzle and Kruse, 1994; Waller *et al.*, submitted).

The survival of relocated mussels was not routinely monitored on a long-term basis. Only 78% of all relocation projects reported follow-up monitoring. Most (38%) projects were monitored for one year or less and only 16% were monitored for five or more consecutive years (Figure 1b).

The mortality of relocated mussels varied widely among projects and species and was difficult to assess. Because of the lack of uniform reporting of mortality and recovery data in all projects, and to ensure

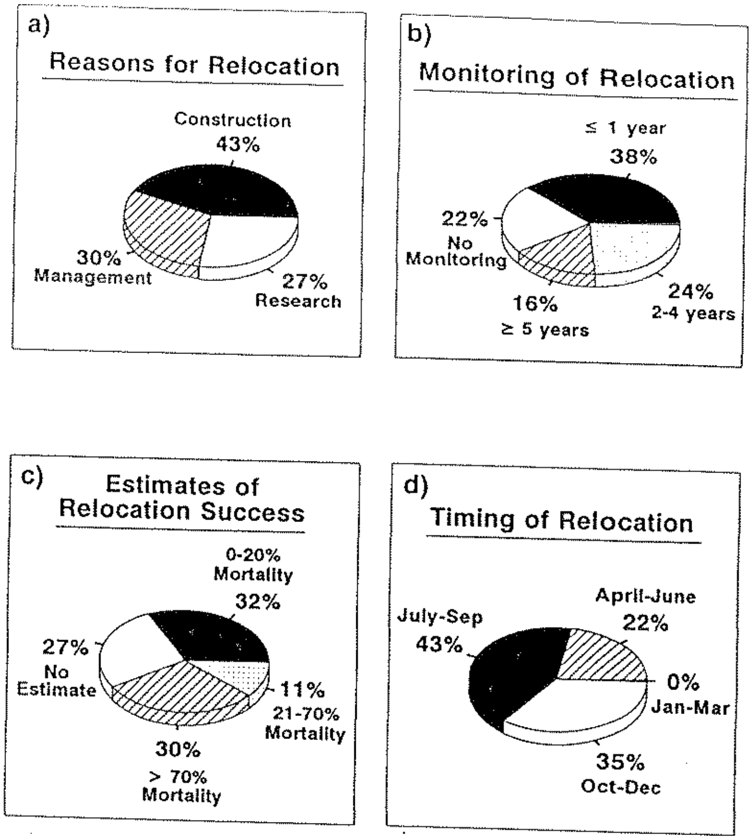

Figure 1. Pie charts showing (a) the primary reasons for mussel relocation, (b) the frequency of monitoring mussel relocation projects, (c) the estimates of success for mussel relocation projects and (d) the timing of mussel relocations

equitable assessment of mortality among projects, we evaluated mortality based on the percentage of mussels recovered relative to the total number of mussels relocated (Table I). Mortality was unreported in 27% of projects and was >70% in 30% of projects (Figure 1c). The mean mortality of relocated mussels was 49%, based on an average recovery rate of 43%. Mortality was >90% in some projects (Table I) and the greatest percentage often occurred within the first year after relocation (Jenkinson, 1985; Heath, 1989; Burke, 1991; Hubbs *et al.*, 1991; Dunn, 1993; Koch, 1993).

About 50% of the mussel relocations occurred in the southern and south-eastern USA, regions that are known to contain the highest diversity of mussel species (Neves, 1993). The timing of relocation projects coincided with the warmest season of a geographical region. Most (43%) relocation projects were conducted from July to September (Figure 1d), presumably a period when reproductive stress is relatively low for most species and the metabolic rate is sufficient for reburrowing in the substrate.

Delete "to" and Insert "through", the data are inclusive of September

DISCUSSION

Many factors influence the survival and reproduction of mussels in their natural environment (Fuller, 1974; McMahon 1991) and relocation adds an additional, and largely anthropogenic, set of stressors that affect mussel survival (Table II). Little is known about many of the variables associated with relocation; however, based on our evaluation, the variables associated with the characteristics of mussel habitat at both the source and destination sites and with the methods of relocation are especially critical to the survival of relocated mussels.

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Table II. Relocation-related variables requiring further investigation

Variable	Reference(s)
Aerial exposure	Walker (1981)
	McMahon (1991)
	Waller *et al.* (submitted)
Air temperature	Imlay (1972)
	Waller *et al.* (submitted)
Collection and handling	Imlay (1972)
	Miller and Nelson (1983)
Depth change	Hanson *et al.* (1988)
Holding and transport	Miller and Nelson (1983)
Positioning	Havlik (1992)
	Schanzle and Kruse (1994)
Relative humidity	McMahon (1991)
Tagging	Oblad (1980)
	Sheehan *et al.* (1989)
	Koch (1990)
	Harris *et al.* (1992)
	Dunn (1993)

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Characteristics of mussel habitat

Habitat is one of the most important factors influencing mussel survival (Neves, 1993). Unfortunately, mussel relocation projects that have combined quantitative analysis of habitat characteristics with the selection of potential relocation sites have been few (e.g. Jenkinson and Heuer, 1986). Existing criteria for the 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, decreased survival of relocated mussels has been attributed to changes in habitat at the destination site, primarily due to substrate instability (Sheehan *et al.*, 1989; Dunn, 1993; Layzer and Gordon, 1993).

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Mussels may have 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 macrohabitat. In his study, mussel communities that were less than one river mile apart were dominated by different species. When mussels are moved from a specific location, one or more of the important microhabitat variables may differ at the destination site and these differences may be very important to the long-term survival of a mussel.

Conversely, other studies have shown that mussels exhibit little preference for a specific habitat type (Strayer, 1981) and that physical habitat characteristics generally overlap among species (Holland-Bartels, 1990). However, subtle differences in physical habitat may be very important when relocating mussels. For example, 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 different from the source habitat.

Because successful reproduction and recruitment of most unionacean mussels requires the presence of a host fish for their parasitic glochidial stage (Fuller, 1974; McMahon, 1991; Watters, 1994), another major habitat factor influencing the long-term survival of relocated mussels is the availability of a suitable fish host. Most relocations (97% in this review) occur within the same river or drainage basin. Therefore, fish assemblages would probably be similar among source and destination sites. However, inter-basin mussel relocations would probably require the assessment of fish populations before the initiation of the project to ensure the presence of the host fish for the species of mussels being moved. In addition, the sampling of fish may also be necessary for intra-basin relocations to ensure that the proposed site is a suitable fish habitat.

Quantitative information on the habitat requirements of unionacean mussels and their fish hosts 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 such as substrate composition and current velocity, sensitive physiological or biochemical indicators could be developed to assess the relative condition of mussels at both the source and destination sites. We believe that determining the condition of resident mussels at a proposed relocation site would facilitate avoidance of areas where 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 published guidance on relocation-related variables such as methods for handling, transporting and tagging mussels, the appropriate time of year to relocate mussels, minimum and maximum allowable water temperatures, maximum allowable time period of aerial exposure and methods for replacing mussels in the substrate (Table II). In fact, we found that the methods described for most 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 (e.g. Imlay, 1972) and the period of time needed for them to reburrow in the substrate. Several workers have examined the effects of various handling and replacement methods on mussel survival after relocation. The timing or season of relocation was also a primary consideration in these studies because of the interaction between air and water temperatures and the metabolic and reproductive condition of the mussels. For example, 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 or after being broadcast from the water surface. Although sample sizes were relatively small ($n = 134$ mussels in spring and $n = 178$ mussels in autumn) in their study, they found no significant difference in recovery rates between placement methods in either spring or autumn. Moreover, the mean recovery of mussels in their study was similar between seasons (65% in spring and 71% in autumn). Waller *et al.* (submitted) also included the time of year in an evaluation of the effects of aerial exposure duration (30 minutes to 8 hours) on the survival and recovery of five species of mussels. They reported minimal (<12%) mortality and relatively high (>88%) recovery of mussels when the aerial exposure duration was <4 hours and the relocations were conducted at moderate air (12–28°C) and water (15–23°C) temperatures, spring or autumn.

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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 (Table II). In addition, the effects of many of these key variables are currently evaluated only on mussel survival. There may be substantial differences in the effects of handling methods on rate of glochidial abortion or stress response versus survival. Anthropogenic and environmental perturbations may elicit sublethal responses in mussels before changes in the community and population structure are manifested. Therefore, sensitive measures of mussel condition and reproductive and recruitment success 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 and recovery data. A majority (60%) of relocation projects were not monitored or were monitored for one year or less. Only 16% of projects were monitored for five or more consecutive years (Figure 1b). An estimated 22 000 mussels (25% of those relocated) perished in 37 relocation projects; however, this number is an underestimate of actual mortality because 22% of projects were not monitored and only 68% of the projects that were monitored reported mortality estimates. The overall mean mortality of relocated mussels was 49% based on an average recovery rate of 43%. The relatively low recovery rate of relocated mussels does not necessarily correspond with mussel mortality (e.g. Layzer and Gordon, 1993), but may be partially attributed to sampling design, the selection of an inadequate relocation site or other factors. Alternatively, the lack of recovery may be due to mussel mortality and the movement of empty valves downstream with water currents.

Ironically, although many relocation projects are conducted at great expense (e.g. $110 000 for a project to relocate 8000 mussels; G. P. Helgeson, Wisconsin Department of Transportation, Eau Claire, WI, USA, pers. comm.), long-term follow-up evaluations of relocation success have been rare. The cost of monitoring is relatively minor ($12 000 for two years; G. P. Hegleson, pers. comm.) compared with the cost of the relocation, yet only nine relocation projects have been monitored for four years or longer (Clarke, 1967; Jenkinson, 1985; Sheehan *et al.*, 1989; Hubbs *et al.*, 1991; Dunn, 1993; Trdan and Hoeh, 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 the 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, measured by physiological and biochemical endpoints, and the long-term status of the resident and relocated mussel populations should also be assessed. The growth of mussels before and after relocation to the destination site, and reproduction and recruitment of the relocated population, could also serve as additional measures.

SUMMARY AND RECOMMENDATIONS

Our view of ~~published work~~ on mussel relocation revealed that the methods of relocation, when reported, varied widely among projects, the survival of the relocated mussels was generally poor (~50%) and the factors influencing the survival of relocated mussels were poorly understood. For mussel relocation to be a successful conservation and management technique, more consideration must be given to habitat characterization, at both the source and destination sites. Optimally, the water and sediment conditions should be monitored before relocation at both the source and proposed destination sites over at least an annual cycle, not just once during the year, because the flow regime and other key variables may change seasonally. Moreover, this type of information could be used to develop a complete set of site selection criteria.

In addition, future mussel relocation projects should be monitored on both a long-term and quantitative basis. Monitoring should be conducted for at least two years, but five years would allow documentation of recruitment—the true indicator of a successful relocation. Mortality, recovery and sublethal indicators of relative condition should be measured for each species to assess variations in the sensitivity to relocation. Based on our evaluation, research is needed to develop the criteria for selecting a suitable relocation site and to establish appropriate methods and guidelines for conducting relocation projects.

Lastly, our literature search demonstrated the need for better access to methods and results of relocation projects. Most results from 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.

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REFERENCES

Ahlstedt, S. 1979. 'Recent mollusk transplants into the North Fork Holston River in southwestern Virginia', *Bull. Am. Malacol. Union*, 21–23.

Anderson, R. V. 1993. 'Illinois mussel sanctuaries on the Mississippi River: community composition' in Cummings, K. S., Buchanan, A. C., and Koch, L. M. (Eds), *Conservation and Management of Freshwater Mussels, Proceedings of a UMRCC Symposium, 12–14 October 1992, St Louis, MO, USA*. Upper Mississippi River Conservation Committee, Rock Island. p. 177.

Arkansas Highway and Transportation Department 1984. 'Relocation of the pink mucket pearly mussel, *Lampsilis orbiculata* in the Spring River near Ravenden, Lawrence County, Arkansas', Environmental Division, Arkansas State Highway and Transportation Department, Little Rock, AR, 9 pp.

Arkansas Highway and Transportation Department 1989. 'Relocation of the Arkansas Fatmucket, *Lampsilis powelli* (Lea, 1852), at the Arkansas Highway 291 bridge, Saline River, Saline-Grant Counties, Arkansas', Environmental Division, Arkansas State Highway and Trasnportation Department, Little Rock, AR, 9 pp.

Berlocher, J. M. K. and Wetzel, M. J. 1988. *Relocation and Monitoring of Mussel Populations from the Vicinity of the Washington Avenue Bridge, Kankakee River, Illinois*. Illinois Natural History Survey, Champaign. 17 pp.

Berlocher, J. M. and Wetzel, M. J. 1989. *Relocation and Monitoring of Unionid Mussels in the Kankakee River, IL: Recovery and Growth of Relocated Mussels After One Year*. Illinois Natural History Survey, Champaign. 12 pp.

Burke, P. J. 1991. *Issue Paper on the Apparent Failure of a Mussell Relocation Project on the St. Croix River Near Prescott, Wisconsin*. US Fish and Wildlife Service, Twin Cities Field Office, Bloomington. 4 pp.

Clarke, A. H. 1967. 'Unionid introduction in Massachusetts: results', *Nautilus*, **80**, 106–108.

Code of Federal Regulations 1993. 'Part 17—Endangered and threatened wildlife and plants', *Section 17.11, Endangered and Threatened Wildlife*, US Government Printing Office, **50**, 108–110.

Dunn, H. L. 1991. 'Unionid mollusk survival and movement following relocation', *MSc Thesis*, Southern Illinois University at Edwardsville, Edwardsville, 127 pp.

Dunn, H. L. 1993. 'Survival of unionids four years after relocation' in Cummings, K. S., Buchanan, A. C., and Koch, L. M. (Eds), *Conservation and Management of Freshwater Mussels, Proceedings of a UMRCC Symposium, 12–14 October 1992, St Louis, MO, USA*. Upper Mississippi River Conservation Committee, Rock Island. pp. 93–99.

Ecological Specialists, Inc. 1991. 'Final report on the 1990 relocated unionid mollusk monitoring near Ripley, Ohio', *Report prepared for the Mussel Mitigation Trust Fund Committee*, Ecological Specialists Inc., St Peters, 60 pp.

Fuller, S. L. H. 1974. 'Clams and mussels (Mollusca: Bivalvia)', in Hart, C. W., Jr and Fuller, S. L. H. (Eds), *Pollution Ecology of Freshwater Invertebrates*. Academic Press, New York. pp. 215–273.

Hamilton, H., Brim-Box, J., Williams, J. D., and Lattimore, R. 1993. 'Relocation of candidate unionids in the Apalachicola River, Florida' in Biggins, R. G. (Ed.), *Triannual Unionid Report No. 2*, US Fish and Wildlife Service, Asheville, p. 4.

Hanson, J. M., MacKay, W. C., and Prepas, E. E. 1988. 'The effects of water depth and density on the growth of a unionid clam', *Freshwater Biol.*, **19**, 345–355.

Harris, J. L. 1986. *Relocation of the Fat Pocketbook Pearly Mussel, Proptera capax (Green), in the St. Francis Rivr at Madison, St. Francis County, Arkansas*. Environmental Division, Arkansas State Highway and Transportation Department, Little Rock. 14 pp.

Harris, J. L., Doster, R. H., and McLean, J. 1992. *Relocation of the Arkansas Fatmucket, Lampsilis powelli (Lea), at the U.S. Highway 270 Bridge in Mount Ida, Montgomery County, Arkansas*. Environmental Division, Arkansas Highway and Transportation Department, Little Rock. 15 pp.

Havlik, M. E. 1992. 'Translocation of unionid mollusks (Mollusca: Bivalvia: Unionidae) Wolf River, Old County A Bridge, North of Shawano, Shawano County, Wisconsin, 17–26 August 1992', *Final Report prepared for Lunda Construction Co.*, Malacological Consultants, La Cross, 34 pp.

Havlik, M. E. 1994. 'Are unionid translocations a viable mitigation technique? the Wolf River, Wisconsin, Experience: part 3, August 1994' in Biggins, R. G. (Ed), *Triannual Unionid Report No. 5*, US Fish and Wildlife Service, Asheville, p. 6.

Heath, D. J. 1989. *Saint Croix River U.S. Highway 10 Bridge Freshwater Mussel Relocation Project at Prescott, Wisconsin, Phase I: Mussel Removal*. Ayres Associates, Madison. 28 pp.

Hinch, S. G. and Green, R. H. 1989. 'The effects of source and destination on growth and metal uptake in freshwater clams reciprocally transplanted among south central Ontario lakes', *Can. J. Zool.*, **67**, 855–863.

Hinch, S. G., Bailey, R. C., and Green, R. H. 1986. 'Growth of *Lampsilis radiata* (Bivalvia: Unionidae) in sand and mud: a reciprocal transplant experiment', *Can. J. Fish. Aquat. Sci.*, **43**, 548–552.

Holland-Bartels, L. E. 1990. 'Physical factors and their influence on the mussel fauna of a main channel border habitat of the upper Mississippi River', *J. North Am. Benthol. Soc.*, **9**, 327–335.

Hubbs, D., Hunt, T., and Kathman, R. D. 1991. '*Lemiox rimosus* transplant site survey', *Report prepared for the Upper Duck River Development Agency*. Young-Morgan & Associates, Inc., Franklin, 26 pp.

Imlay, M. J. 1972. 'Greater adaptability of freshwater mussels to natural rather than to artificial displacement', *Nautilus*, **86**, 76–79.

Jenkinson, J. J. 1985. 'Freshwater mussel transplants evaluated', *Am. Malacological Union News*, **16**, 3.

Jenkinson, J. J. 1989. 'Relocation of *Potamilus capax* from a 4-mile reach of the St. Francis floodway in Arkansas', *Report prepared for Memphis District, US Army Corps of Engineers*, Tennessee Valley Authority, Norris, 53 pp.

Jenkinson, J. J. 1994a. 'TVA mussel relocation: Kentucky mooring cells project' in Biggins, R. G. (Ed), *Triannual unionid Report No. 3*, US Fish and Wildlife Service, Asheville, p. 11.

Jenkinson, J. J. 1994b. 'TVA mussel relocation: Pickwick channel widening project' in Biggins, R. G. (Ed), *Triannual Unionid Report No. 3*, US Fish and Wildlife Service, Asheville, p. 11.

Jenkinson, J. J., and Heuer, J. H. 1986. *Cumberlandian Mollusk Conservation Program, Activity 9: Selection of Transplant Sites and Habitat Characterization*. Tennessee Valley Authority, Norris. 120 pp.

Koch, L. M. 1990. *Reintroduction of Potamilus capax to Portions of the Upper Mississippi River in Missouri*. Missouri Department of Conservation, Jefferson City. 11 pp.

Koch, L. M. 1993. *Status of Fat Pocketbook Mussels (Potamilus capax) Three Years After Re-introduction to the Upper Mississippi River, Missouri*. Missouri Department of Conservation, Jefferson City. 12 pp.

Layzer, J. B. and Gordon, M. E. 1993. 'Reintroduction of mussels into the Upper Duck River, Tennessee' in Cummings, K. S.,

Buchanan, A. C., and Koch, L. M. (Eds), *Conservation and Management of Freshwater Mussels, Proceedings of a UMRCC Symposium, 12–14 October 1992, St Louis, MO.* Upper Mississippi River Conservation Committee, Rock Island. pp. 89–92.
McMahon, R. F. 1991. 'Mollusca: bivalvia' in Thorp, J. H. and Covich, A. P. (Eds), *Ecology and Classification of North American Freshwater Invertebrates.* Academic Press, San Diego. pp. 315–399.
Miller, G. A. 1994. 'Mussel relocation project, Peterson Bridge, Namekagon River, Sawyer County, Wisconsin', *Progress Report prepared for the National Biological Survey, La Crosse,* 4 pp.
Miller, A. C. and Nelson, D. A. 1983. 'An instruction report on freshwater mussels', *Instruction Rep. EL-83-2,* US Army Engineer Waterways Experiment Station, Vicksburg, 198 pp.
Nelson, D. 1982. 'Relocation of *Lampsilis higginsi* in the upper Mississippi River' in Miller, A. C. (Ed.), *Report of Freshwater Mussels Workshop.* US Army Engineer Waterways Experiment Station, Vicksburg. pp. 104–107.
Neves, R. J. 1993. 'A state-of-the-unionids address' in Cummings, K. S., Buchanan, A. C., and Koch, L. M. (Eds), *Conservation and Management of Freshwater Mussels, Proceedings of a UMRCC Symposium, 12–14 October 1992, St Louis, MO.* Upper Mississippi River Conservation Committee, Rock Island. pp. 1–10.
Oblad, B. R. 1980. 'An experiment in relocating endangered and rare naiad mollusks from a proposed bridge construction site at Sylvan Slough, Mississippi River near Moline, Illinois' in Rasmussen, J. L. (Ed.), *Proceedings of the UMRCC Symposium on Upper Mississippi River Bivalve Mollusks.* Upper Mississippi River Conservation Committee, Rock Island. pp. 211–222.
Ogawa, R. E. and Schloesser, D. W. 1993. 'Community action called to rescue the riffleshell' in Biggins, R. G. (Ed.), *Triannual Unionid Report No. 1,* US Fish and Wildlife Service, Asheville, p. 19.
Schanzle, R. W. and Kruse, G. W. 1994. *The Effect of Artificial Relocation on Freshwater Mussels (Bivalvia: Unionidae) in a Small Illinois Stream.* Illinois Department of Conservation, Springfield. 19 pp.
Sheehan, R. J., Neves, R. J., and Kitchel, H. E. 1989. 'Fate of freshwater mussels transplanted to formerly polluted reaches of the Clinch and North Fork Holston Rivers, Virginia', *J. Freshwater Ecol.,* 5, 139–149.
Strayer, D. 1981. 'Notes on the microhabitats of unionid mussels in some Michigan streams', *Am. Midland Nat.,* 106, 411–415.
Trdan, R. J. and Hoeh, W. R. 1993. 'Relocation of two state-listed freshwater mussel species (*Epioblasma torulosa rangiana* and *Epioblasma triquetra*) in Michigan' in Cummings, K. S., Buchanan, A. C., and Koch, L. M. (Eds), *Conservation and Management of Freshwater Mussels, Proceedings of a UMRCC Symposium, 12–14 October 1992, St Louis, MO.* Upper Mississippi River Conservation Committee, Rock Island. pp. 100–105.
Turgeon, D. D., Bogan, A. E., Coan, E. V., Emerson, W. K., Lyons, W. G., Pratt, W. L., Roper, C. F. E., Scheltema, A., Thompson, F. G., and Williams, J. D. 1988. *Common and Scientific Names of Aquatic Invertebrates from the United States and Canada: Mollusks. Am. Fish. Soc. Spec. Publ. 16,* 277 pp.
Walker, K. F. 1981. 'Ecology of freshwater mussels in the River Murray', *Australian Water Resources Council, Tech. Pap. No. 63,* 110 pp.
Waller, D. L., Rach, J. J., and Cope, W. G. 'Effects of aerial exposure in spring and fall on survival of relocated unionid mussels', J. *Freshwater* ~~*Biol.*~~ Ecol. (submitted.)
Watters, G. T. ~~1994. An~~ *Annotated Bibliography of the Reproduction and Propagation of the Unionoidea (Primarily of North America).* Ohio Biological Survey, Columbus. 158 pp.
Williams, J. D., Warren, Jr, M. L., Cummings, K. S., Harris, J. L., and Neves, R. J. 1993. 'Conservation status of freshwater mussels of the United States and Canada', *Fisheries,* 18(9), 6–22.

Au: Any news?

Should read J. Freshwater Ecol.

Answer: The manuscript has been accepted and may be cited as "in press".