Designing a Riverine Mussel Survey

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Abstract. Experience gained from mussel surveys conducted since 1983 in medium to large rivers throughout the Mississippi and Ohio River drainages allows insight into the design of mussel surveys. Survey objectives must be clearly defined. A considerable amount of information is already available on the distribution, approximate abundance, and community structure of mussels in many rivers, although reports of historic surveys are sometimes accessible only through offices of state and federal agencies that funded such studies. Limitations of time, personnel, and funds nearly always dictate that some combination of quantitative and qualitative sampling methods be used. Interest in uncommon, rare, threatened, or endangered species is often a stimulus of surveys. It must be realized that density or other quantitative aspects of population demography of such species typically cannot be quantified. However, confirmation of presence of such species may be reasonable. The virtual impossibility of establishing a species' absence must be recognized. In nearly all instances, a combination of qualitative and quantitative survey methods can be used to provide important information on the health of mussel communities, including estimates of species richness, diversity, density, and recruitment patterns. Such parameters can be meaningfully employed to assess and monitor the welfare of riverine mussel assemblages.

Introduction

Since 1983, we have conducted mussel surveys throughout the Mississippi and Ohio River drainages (Miller et al. 1993 and references within), allowing insight into both practical and technical constraints affecting particular survey objectives. A successful survey depends on a design and commitment of effort commensurate with objectives set for the survey. Almost always, a combination of less rigorous qualitative sampling and more rigorous quantitative sampling is appropriate. This combination of sampling methods is required by the spatial distribution and community characteristics of typical mussel beds. Pilot surveys or quantitative analysis of results of similar surveys can be especially important to the establishment of reasonable objectives and designs.

Objectives of mussel surveys range greatly. Since 1983, surveys we have been involved with have included one or more of the following objectives:

1. Map distribution of mussels within a river reach
2. Map boundaries of a particular mussel bed
3. Determine if a federally endangered or other rare species is present
4. Quantitatively estimate community composition, including information on richness and diversity
5. Quantify mussel density
6. Quantify recent recruitment

Mapping Objectives

Surveys to map the distribution of mussels throughout a long river reach must evaluate expansive areas; thus, not much time or effort can be spent at particular sites. Surveys to map the boundaries of a particular mussel bed must identify where a contiguous and dense assemblage of mussels becomes less contiguous and less dense — often a difficult distinction.

It is not unreasonable to suggest that the distribution of major mussel beds within most large inland rivers already has been described in reasonable detail (e.g., Williams and Schuster 1989). Such reports of previous surveys are an important starting point. If previous mapping efforts were reasonably good and large-scale changes are not likely to have transpired, then the need to repeatedly invest in mapping surveys is questionable. Detailed monitoring of strategically selected beds probably is a better investment of the limited funds available for mussel conservation and management. However, if mapping surveys must be conducted, they are best done during periods of sustained low water. At such times, evidence of mussel beds is more apparent, with shell debris along the shore providing a good indicator of the approximate location of beds. Where shoreline evidence is noted, brail hauls, skimmer dredge hauls (Miller et al. 1989), or reconnaissance dives (Miller et al. 1993) can be made at regular intervals to confirm and better delineate mussel beds. Global positioning systems can enhance such surveys (McClane 1993). However, navigation, bottom elevation profile, and land topographic maps can be used in conjunction with carefully kept notes on river stages during sampling to map mussel beds with reasonable accuracy.

Mapping the boundaries of a particular mussel bed is an extremely demanding task; the need for such a map must be clear. Although it is relatively simple to recognize sites within the central portions of mussel beds (only a bit of reconnaissance diving is typically required [Miller et al. 1993]), precisely defining bed boundaries is far more difficult. Determining upstream, downstream, farshore, and nearshore limits of a mussel bed is done by a systematic area survey (Yates 1981; Isom and Gooch 1986). Probably the most commonly employed approach is to establish a series of transects running perpendicular to river flow across the mussel bed. The first few transects must be upstream of the actual bed and the last few downstream of the bed; similarly, some samples along each transect must be taken beyond the nearshore and farshore limits of the bed.

The minimum density used to categorize an assemblage of mussels as a "bed" will vary among locations. Although minimum population densities for reproductive success of mussel species surely exist, such densities have not been ascertained. Thus, relatively strict biological criteria to define mussel beds are not possible. Mussel beds must be defined in a more utilitarian way by trying to answer the question, Is there some density above which a relatively concentrated local assemblage of mussels can be distinguished from a surrounding and less concentrated assemblage? For example, we found that the upstream, nearshore, and farshore limits of a major mussel bed in the lower Ohio River were reasonably well-defined using a density criterion of at least 5 individuals per m^2. Maximum densities were greater than 100 individuals per m^2 and typically were greater than 30 individuals per m^2 throughout the most of the bed. Beyond the upstream, nearshore, and farshore boundaries of the bed, density was essentially zero. However, a criterion to define the downstream limit of the bed was less obvious because low densities (5-10 individuals per m^2) continued to occur throughout transects sampled far downstream of the moderate-to-high-density portions of the bed.

Mapping the boundaries of a mussel bed in a large river virtually precludes paying much attention to other potential survey objectives. Repeatedly positioning and anchoring boats during large river surveys, combined with inefficiencies associated with repeatedly bringing divers out of the water, makes such surveys among the least efficient that we have conducted in terms of data returned per unit time invested. Reiterating, the need for such maps must be clear in order to justify the high level of inefficiency inherent in such surveys.

Characterization of Community Composition

Nearly all mussel surveys include among their objectives acquisition of information on species richness and relative abundance, and thus, diversity. Of these three parameters, richness is most difficult to accurately estimate. The total number of species collected at a site is a function of sampling effort. As more area is sampled or more individuals are obtained, the likelihood of including locally rare species is increased. Rarely is sampling effort great enough that all species present are likely to be obtained (Figure 1). Species richness estimates always should be presented with corresponding information on the number of individuals included in the sample (Magurran 1988). If intersite comparisons of species richness are desired, then a reasonably standardized effort is required with respect to both number of individuals collected and collection method.

A practical solution arrived at by a number of investigators is to estimate community parameters primarily from results of qualitative sampling methods (Miller et al. 1993), thus allowing a greater number of individuals to be acquired in a given amount of time. In large river surveys, we have "standardized" the method and amount of qualitative sampling by having divers make incremental collections using search-by-feel methods (and sight if conditions allow). Two divers work simultaneously to collect a total of 12 samples (nylon bags of mussels) at each site. Approximately 5 mussels are placed in each of three bags and approximately 20 mussels are placed in the remaining nine bags. Thus, a total of approximately 195 individuals are collected per site (without intentional bias as to species or size). Divers are instructed to avoid collecting nonindigenous species (*Corbicula fluminea* and *Dreissena polymorpha*). The three bags with only 5 mussels each are used to help define the expected initial steep slope of the species-effort curve, and the remaining nine bags of 20 mussels each define the less steeply sloping portion of the species-individual curve (Figure 2).

Using this qualitative method, a site is typically a small area, about 20 or 30 m on a side. The 12 samples taken come from the area immediately under and adjacent to the dive boat. Depending on substrate and water velocity, these qualitative searches require 0.5 to 2 hours. In a single day, it is reasonable to collect such samples at a minimum of five sites. Variants of this method can be employed that rely on wading or snorkeling in shallow water. Without the need of repositioning and anchoring a large dive boat, many more sites can be sampled in a day.

Endangered Species

Searches for endangered or other locally rare species of special interest are often a principal objective in a mussel survey. Obviously, a species' absence cannot be proven without collecting the entire assemblage of mussels. Thus, some uncertainty always surrounds a species list. One practical approach (Wilcox et al. 1993) is to define a minimum density that can be accepted as indicative of a species' absence. A reasonable range of such minimum density values is 0.001 to 0.01 individuals per m^2. Immobile, dioecious animals that generally require cross fertilization are likely to encounter problems with reproductive success when densities are in this low range. Obviously, research is needed to establish an empirical relationship between reproductive success and population density.

Average density of individuals in a mussel community varies among sites. Consequently, sampling effort required to indicate that a population's density is less than a particular value varies among sites. For example, indication that the density of a species not collected is less than 0.001, 0.005, and 0.01 individuals per m^2 requires collection of 5,000, 1,000, and 500 mussels at sites with 5 mussels per m^2. However, a site with 50 mussels per m^2 would require that 10 times more mussels be collected to support the same determinations. Density of mussels in most beds we have sampled ranges from 10 to 100 individuals per m^2, requiring a range of 1,000 to 10,000 mussels to indicate that density of a particular species not obtained averages less than 0.01 individuals per m^2. Obviously, intensive sampling is required to yield such large numbers of individuals.

Sometimes it is possible to use selective searches to obtain rare or endangered species. For example, we used a combination of nonselective and selective methods in a lower Ohio River survey to determine if the endangered orange-footed pimpleback (*Plethobasus cooperianus*) was present. Nonselective qualitative and quantitative methods (described in detail in Miller and Payne 1988 and Miller et al. 1993) did not yield any specimens of this species in a 4-day survey effort. However, three relatively brief dives by a single diver instructed to collect only large, pustulose mussels yielded three live individuals of the endangered species (Miller et al. 1986).

Density Estimation

Quantitative samples (i.e., a sample that collects all individuals from a known area) are required to estimate mussel density. Two methods of quantitative sampling of mussels are now commonly employed: searching within a quadrat by sight and feel

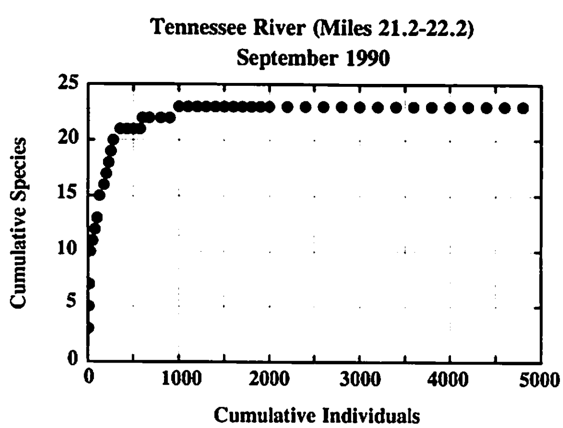

Figure 1. Cumulative species in relation to cumulative individuals collected from many sites within a bed in the lower Tennessee River. Intensive sampling yielded all species present at this location.

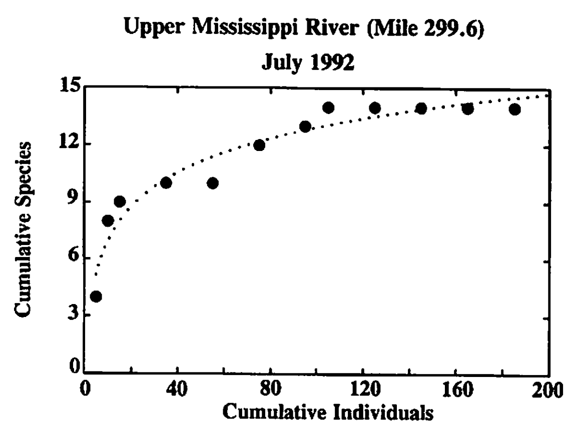

Figure 2. Cumulative species in relation to cumulative individuals collected from a single site within bed in the upper Mississippi River. Typically, species increase as a linear function of the logarithm of individuals collected at a site.

to locate all mussels or removing all substrate from within a quadrat and sieving the substrate sample to obtain mussels. The advantage of substrate removal is that small, young mussels are obtained. Search by feel or sight risks missing such individuals. Replicate samples must be taken at replicate sites to allow statistical inferences concerning spatial or temporal comparisons. If, for example, nearshore is to be compared to farshore, at least two nearshore and two farshore sites should be sampled with replication. If only one of each site type is sampled, a significant difference might be detected, but the inference that spatial difference reflects a nearshore vs. farshore pattern cannot be drawn (i.e., the same difference might have occurred in an upstream vs. downstream direction). See Hurlbert (1984) for a detailed discussion of pseudoreplication in relation to field studies.

The ability to detect significant spatial or temporal density differences depends on the magnitude of difference, the level of uncertainty accepted in the statistical comparison, and the number of replicate samples per site. Like most benthic organisms, mussels tend to be aggregated in their distribution, resulting in relatively high variance-to-mean ratios of density estimates. As variance-to-mean ratios increase, the required sample size to detect a given magnitude of difference at a given level of certainty also increases. Downing and Downing (1992) evaluated the relationship of variance-to-mean mussel density, using primarily lake population data, and compared this relationship to one applicable to most other aquatic organisms. Then they computed the required number of replicate samples to detect significant density differences of various magnitudes and with different levels of statistical certainty. Little difference was found between the relationship for mostly lake populations of mussels and the general relationship that applies to most aquatic benthos. The latter is:

equation 1: $s^2 = m^{1.5}$

where s^2 is variance in individuals per quadrat, and m is mean number of individuals per quadrat. For mussel populations mostly in lakes, the following relationship applied:

equation 2: $s^2 = 1.49m^{1.17}$

We evaluated this relationship for riverine mussel communities (Figure 3), with the following result:

equation 3: $s^2 = 6.5m^{1.15}$

Thus, our data for riverine mussel beds suggest approximately four-fold more aggregation than that indicated by mostly lake population data.

Aggregation of individuals within riverine mussel beds has important implications for sampling. To achieve a particular level of precision in estimating mean density, many replicate samples are needed per site. Assuming equation 3 applies in general to riverine mussel beds (an assumption that should be tested by pilot studies at a bed), some specific guidance is possible concerning required sample sizes. It is possible to predict the number of samples required to estimate mean density with a specified precision (D, equal to the standard error divided by mean of density estimates) according to the following equation (Downing and Downing 1992):

equation 4: $n = 6.5m^{(1.15-2)}\Sigma 0.2^{-2}$

Assuming use of 0.25 m^2 quadrats, estimation of mean density with 20% precision requires 41, 23, and 13 replicate samples for average mussel densities of 20, 40, and 80 individuals per m^2, respectively. Roughly twice as many samples are needed to detect, at a 0.05 probability level, a halving or doubling of mussel density.

Because of special interest in endangered species, it is of some value to point out the virtual impossibility of precisely estimating or monitoring the density of uncommon species. Sampling requirements are extremely imposing if one attempts

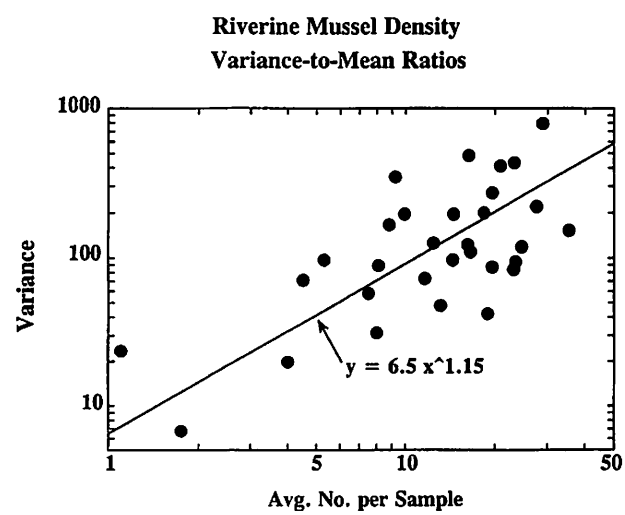

Figure 3. Relationship of variance to mean density of mussels based on substrate removal from replicate 0.25 m^2 quadrats (n ranged from 10 to 60 per site) at mussel beds throughout the upper Mississippi and Ohio rivers since 1983.

to precisely estimate the average density of species occurring at a density of 0.5 individuals per m^2 (still higher than a value that would apply to most populations of endangered species). Estimating the average density of such populations with 20% accuracy using 0.25 m^2 requires 952 samples per site! Thus, other parameters must be estimated as surrogate measures with respect to endangered species populations.

Even with respect to the total mussel community, moderately large sample sizes are required to precisely estimate mussel density. Such sampling requirements may be beyond the limits of what is practical for some surveys. If so, then less precise density estimation or less ability to detect spatial differences or temporal changes must be accepted.

Recruitment

Among the most useful of information on a mussel community is evidence of recent recruitment. The long-term health of a mussel community obviously depends on successful recruitment. We have used substrate removal methods to quantify recruitment patterns at a number of medium and large river mussel beds (e.g., Payne and Miller 1989). Size structure of dominant populations has included no evidence of recent recruitment (e.g., Big Sunflower River, Figure 4), evidence of very sporadic but strong recruitment (lower Ohio River, Figure 5), and successful recruitment in most but not all years (upper Mississippi River, Figure 6). Presumably, the former pattern is indicative of an unhealthy situation while both of the latter patterns are sufficient to sustain populations of these long-lived species.

In addition to analyzing the size structure of dominant populations, a simple yet useful indicator of community-wide recruitment is simply to determine the percent of individuals less than 30 mm long. This percent includes moderately large individuals of some species that grow only to small adult size, such as *Truncilla donaciformis* and *Toxolasma parvus*. Nonetheless, it measures recent recruitment to the community, because any individual, regardless of species, less than 30 mm long probably is no more than 2-3 years old.

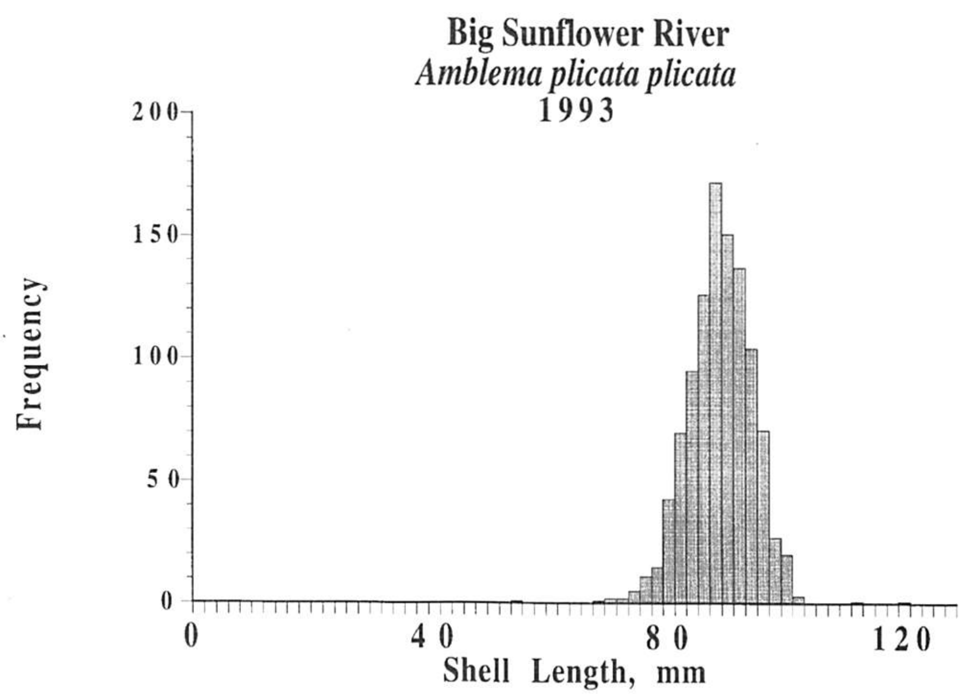

Figure 4. A population of *Amblema plicata plicata* in the Big Sunflower River, Mississippi. There is no evidence of recent recruitment.

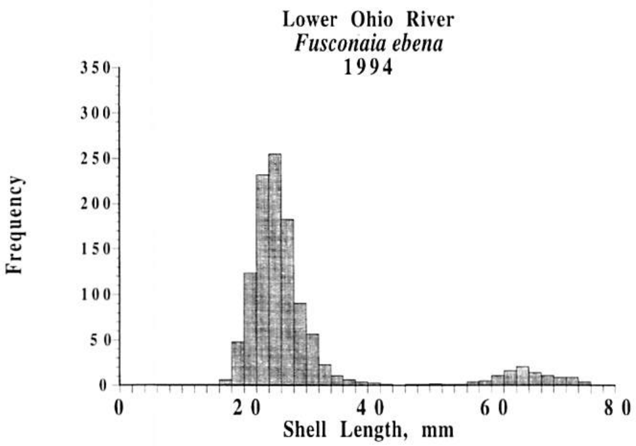

Figure 5. A population of *Fusconaia ebena* from the Lower Ohio River. Exceptionally strong year classes, represented by individuals centered at 25 mm and 65 mm, make up virtually all of this population.

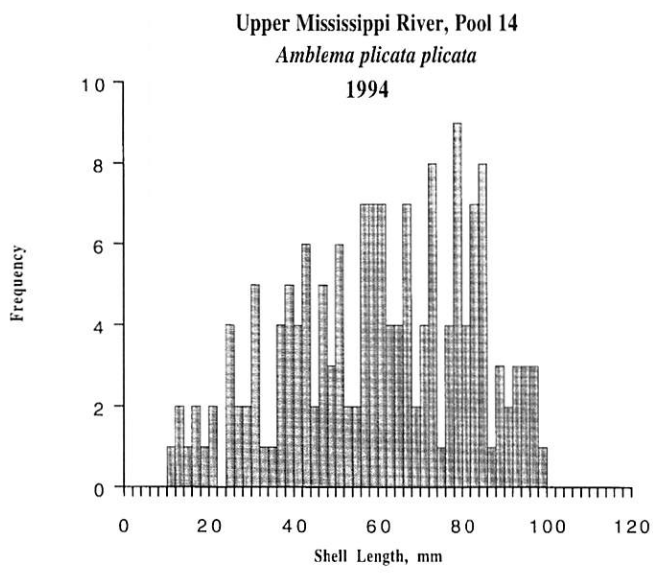

Figure 6. A population of *Amblema plicata plicata* from the Upper Mississippi River characterized by moderately strong recruitment in nearly all years.

Summary

Mussel surveys are conducted with a number of objectives. Typically, a given survey tries to satisfy more than one objective. Mapping mussel distribution within a particular river reach is a demanding task. Historic information should be relied upon to the maximum extent feasible. Determining the boundaries of a particular mussel bed is a tedious and somewhat subjective problem. The need for such maps must clearly justify the considerable effort and expense required. Most surveys of a prominent mussel resource involve an attempt to quantify community characteristics, such as richness, diversity, relative abundance, and density. Pilot surveys, or analysis of variance-to-mean ratios of density data that already exists, can be used to optimize the design of surveys in which density estimates are desired. Careful consideration is needed to determine the required level of precision in such density estimates; sampling requirements are high if precise estimates must be obtained. Such consideration must also be given to required confidence levels in detecting spatial or temporal differences in density. An important aspect of mussel community and population evaluations is quantification of recruitment patterns. Such data are probably as important as any in evaluating the health of mussel resources.

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Literature Cited

Downing, J.A., and W.L. Downing. 1992. Spatial aggregation, precision, and power in surveys of freshwater mussel populations. Canadian Journal of Fisheries and Aquatic Science 49(5):985-991.

Hurlbert, S.H. 1984. Pseudoreplication and the design of ecological field experiments. Ecological Monographs 54:187-211.

Isom, B.G., and C. Gooch. 1986. Rationale and sampling design for freshwater mussels, Unionidae, in streams, large rivers, impoundments, and lakes. Pages 46-59 *in* B.G. Isom, ed. Rationale for sampling and interpretation of ecological data in the assessment of freshwater ecosystems. American Society for Testing and Materials, STP 894, Philadelphia.

Magurran, A.E. 1988. Ecological diversity and its measurement. Princeton University Press, Princeton, New Jersey. 179 pp.

McClane, M.B. 1993. Global Positioning System — a new tool for the field. Pages 159-162 *in* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, 12-14 October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Miller, A.C., and B.S. Payne. 1988. The need for quantitative sampling to characterize size demography and density of freshwater mussel communities. American Malacological Bulletin 6(1):49-54.

Miller, A.C., B.S. Payne, D.J. Shafer, and L.T. Neill. 1993. Techniques for monitoring freshwater bivalve communities and populations in large rivers. Pages 147-158 *in* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, 12-14 October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Miller, A.C., B.S. Payne, and T. Siemsen. 1986. Description of habitat of the endangered mussel, *Plethobasus cooperianus*. Nautilus 100(1):18-23.

Miller, A.C., R. Whiting, and D.B. Wilcox. 1989. An evaluation of a skimmer dredge for collecting freshwater mussels. Journal of Freshwater Ecology 5(2):151-154.

Payne, B.S., and A.C. Miller. 1989. Growth and survival of recent recruits to a population of *Fusconaia ebena* (Bivalvia: Unionidae) in the lower Ohio River. American Midland Naturalist 121(1):99-104.

Wilcox, D.B., D.D. Anderson, and A.C. Miller. 1993. Survey procedures and decision criteria for estimating likelihood that *Lampsilis higginsi* is present in areas within the upper Mississippi River system. Pages 163-167 *in* K.S. Cummings, A.C. Buchanan, and L.M. Koch, eds. Conservation and management of freshwater mussels. Proceedings of a UMRCC symposium, 12-14 October 1992, St. Louis, Missouri. Upper Mississippi River Conservation Committee, Rock Island, Illinois.

Williams, J.C., and G.A. Schuster. 1989. Freshwater mussel investigations of the Ohio River, mile 317.0 to mile 981.0. Kentucky Department of Fish and Wildlife Resources, Division of Fisheries, Frankfort. 57 pp.

Yates, F. 1981. Sampling methods for censuses and surveys. MacMillan Publishing Co., Inc., New York. 458 pp.