Watters 1993



Sampling Freshwater Mussel Populations: the Bias of Muskrat Middens

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Abstract. Muskrat middens of freshwater mussels often are used in unionid survey work as indicative of the population in situ. Diversity in middens was compared with adjacent beds in the lower Muskingum River in Ohio. All middens were found to differ significantly ($p < 0.05$) from the beds from which they were derived in both mussel diversity and relative abundance. Midden material represents a biased sample and may lead to erroneous conclusions concerning the parent bed.

Muskrats have been shown to be important predators on freshwater mussels (Apgar 1887), including endangered taxa. Hanson et al. (1989) reported that muskrats in one lake in Alberta ate an average of 350 mussels a day in the autumn, and over 37,000 a year. Convey et al (1989) reported similar numbers for another Alberta lake. Middens often contain hundreds or thousands of shells, usually in good condition. Sampling middens is extremely time and labor efficient when compared to diving, brailing, or other methods ~~that require~~ finding living individuals ~~in-situ~~. When available, middens may comprise the majority of specimens collected in a survey. It is assumed that middens represent an unbiased estimate of the actual population.

However, there is some evidence to suggest that muskrats are selective in their mussel predation. Neves and Odom (1989) compared middens during different seasons of the year with quadrat studies of eight species of living mussels in the North Fork Holston River, Virginia. Five species were present in approximately the same relative abundance in both middens and quadrats. Individuals of Pleurobema oviforme (Conrad, 1834) and the federally endangered Fusconaia cuneolus (Lea, 1840) were more abundant in middens than in situ. Muskrats avoided the smallest species available, Medionidus conradicus (Lea, 1834), although Bruenderman and Neves (1993) found juveniles of Fusconaia cuneolus to be more common in middens than in collections of live individuals in the Clinch River, Virginia. Conversely, Hanson et al. (1989) found that muskrats primarily ate the largest mussel individuals.

During the fall of 1992, the lower 54 km of the Muskingum River in Ohio were surveyed for mussels by brail, diving, and midden collection (Ecological Specialists, Inc. 1993). This river reach harbors one of the densest and most diverse mussel populations left in North America, with beds having up to 124 individuals $m^{-2}$, and containing a total of 34 species. Middens were common and frequently large, and located next to identified beds. The large sample size and high diversity enables one to ascertain the importance of differential muskrat predation on a greater scale than was available to Neves and Odum (1989).

## Materials

The Muskingum River was sampled during 23 September to 30 October 1992 from river mile 34.1 to the mouth. Beds were located by brailling, and sampled quantitatively and qualitatively by diving. The quantitative work consisted of forty 0.25 $m^{-2}$ quadrats placed at random along five 33. 3 m randomly spaced transect lines within a bed. Each quadrat was excavated to a depth of 15-20 cm. Qualitative work consisted of a diver collecting all specimens found within 1-2 hours. Because the results consist of all individuals encountered, whether within a quadrat (quantitative) or without (qualitative), these data were combined for this analysis. The study area is taken to be a bed, not a quadrat, and only numbers of individuals of each species are relevant, regardless of how obtained. Muskrat middens were found next to these beds and completely enumerated. A total of 11,139 individuals of 34 unionid species was found in the survey, including living specimens of the U. S. federally endangered Cyprogenia stegaria (Rafinesque, 1820), and ten species listed as endangered by the State of Ohio.

Middens were of two types, called here (for lack of better terms) home base and impromptu middens. Home base middens consisted of large middens associated with the muskrat's burrow, usually among the exposed roots of trees lining the shore. Impromptu middens were found along the shore and on exposed island shoals. These were smaller middens that probably represented a single night of predation.

The middens used in this study were chosen by two criteria: size and proximity to a bed. The four largest middens, or series of impromptu middens on a single island, were chosen to generate sufficient numbers for statistically significant results. These middens clearly were associated with existing beds (Beds 3 and 5 of the survey), being located on the nearest shore or on islands within a bed.

Because the purpose of this study was to compare midden diversity with that of the parent bed, it was necessary to reconstruct the diversity of the parent bed. Thus the total for a given bed is the sum of all in-situ individuals as well as all midden material associated with it that was removed by muskrats (Table 1). In situ material was used from both quantitative and qualitative diving studies.

The material collected by brailing is not included, but represents a negligible fraction of the total number found. The data set used here represents 7,581 individuals of 32 species. The number of muskrats responsible for the middens is not known.

Because the relative abundances of species between a midden and the total for the bed are assumed to be covariant, data were compared with a pairing design test, a type of t-test. The more typically used group comparison test increases the likelihood of accepting a false null hypothesis in this case (Woolf, 1968). Raw species data were expressed as a percentage of the total and arcsin transformed. Middens were not compared with middens from the other bed, or with the other bed itself.

## Results

The results of these comparisons and the level of significance for each are given in Table 2. In every case, the relative abundances of species in middens and their parent beds were significantly different. Middens also were different from each other. The results show that muskrats do not randomly sample the bed.

Three species were found to be underrepresented in middens: Amblema plicata (Say, 1817), Lasmigona complanata (Barnes, 1823), and Pleurobema cordatum (Rafinesque, 1820). Amblema is a heavy species when adult that may be too ponderous for a muskrat to handle, and was underrepresented by at least a factor of ten in three of the middens. However, it was accurately represented in one midden. There was no indication that this species was more common near that midden than any other. The reasons why the remaining two taxa were not selected are unknown. The most massive North American species, Megalonaias nervosa Rafinesque, 1820, also may be underrepresented, but was too rare in the study for this conclusion to be drawn. Three taxa were overrepresented: Leptodea fragilis (Rafinesque, 1820), Obliquaria reflexa Rafinesque, 1820, and Quadrula pustulosa (Lea, 1831). *Leptodea* was overrepresented by a factor of two in three of the middens, but underrepresented by a factor of four in the fourth midden. These species represent both thin and thick shelled taxa, as well as sculptured and unsculptured, and are of medium size when adults. With the possible exception of their taste to the muskrat, these species have little in common that would suggest a cause for their underrepresentation.

## Discussion

Marinelli and Messier (1993) summarized the data on the home range size of muskrats in their study and others. Sizes varied from 0.03 to 4.24 ha. This is substantially smaller than the beds on which the Muskingum River muskrats fed. It is unlikely that the muskrats responsible for the middens bypassed the adjacent bed to travel to a farther one and then transport the shells back. There seems little question that the shells in a midden came from the adjacent bed.

It also is unlikely that the shells within a midden were not gathered the same year that the survey was conducted. Winter and spring high water wash away middens made the previous summer and fall, and new middens are constructed each year (pers. obs.). The shells within the middens are therefore of a comparable age (in terms of when collected) to those in the diving survey.

Muskrats appear to sample mussel beds in a non-random manner. Middens on the Muskingum River often contain many juvenile mussels. Heavy, older individuals presumably are too cumbersome to carry and are often passed over. It did not matter if the shells were thin or thick, or sculptured or smooth. Species seemed to be favored or avoided for reasons not yet known. Taste may be a factor.

Although Hanson et al. (1989) and Convey et al. (1989) found that muskrats selected the largest mussels, their study areas do not have the massive species of the Muskingum River, such as Megalonaias nervosa. Indeed, Narrow Lake supports only the thin-shelled Anodonta grandis simpsoniana. That species is much lighter than most unionids of the same size, and apparently was manageable at large sizes by muskrats.

The results support the conclusion of Neves and Odum (1989) that muskrats selectively prey on certain unionid species more (or less) than others in a bed. This study addresses a widespread and common practice among field malacologists interested in unionid diversity: the use of muskrat middens as estimates of mussel populations. The results indicate that muskrats are biased collectors and that their middens do not represent the actual diversity in situ. Results of other studies suggest that there is a further bias in the sizes of individuals of a species found in middens (Bruenderman and Neves 1993). Interpretations and generalizations about a unionid population based on midden material are apt to be incorrect.

Acknowledgements

I thank the Division of Wildlife, Ohio Department of Natural Resources, and Heidi Dunn, Ecological Specialists, Inc., for permission to use the study results. Brian Armitage, Ohio Biological Survey, kindly suggested and explained the use of the pairing design test. The EDIT group of the Aquatic Ecology Laboratory made valuable suggestions on the manuscript. The Muskingum River survey was made possible by the Division of Wildlife with funds donated through the Do Something Wild! Ohio income tax check-off.

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| Taxa | Bed 3 | | | | Bed 5 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Midden 1 | | Total | | Midden 1 | | Midden 2 | | Midden 3 | | Total | |
| | # | % | # | % | # | % | # | % | # | % | # | % |
| *Actinonaias ligamentina* | 1 | 0.09 | 4 | 0.14 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 3 | 0.06 |
| *Alasmidonta marginata* | * | * | * | * | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.02 |
| *Amblema plicata* | 9 | 0.79 | 353 | 12.38 | 2 | 0.27 | 4 | 0.81 | 155 | 11.23 | 504 | 10.66 |
| *Anodonta grandis* | 1 | 0.09 | 4 | 0.14 | 1 | 0.13 | 1 | 0.20 | 3 | 0.22 | 5 | 0.11 |
| *Anodonta imbecillis* | 1 | 0.09 | 1 | 0.04 | 0 | 0.00 | 0 | 0.00 | 1 | 0.07 | 1 | 0.02 |
| *Cyprogenia stegaria* | * | * | * | * | 2 | 0.27 | 0 | 0.00 | 0 | 0.00 | 6 | 0.13 |
| *Ellipsaria lineolata* | 5 | 0.44 | 16 | 0.56 | 53 | 7.07 | 19 | 3.84 | 42 | 3.04 | 150 | 3.17 |
| *Fusconaia flava* | * | * | * | * | 0 | 0.00 | 1 | 0.20 | 0 | 0.00 | 1 | 0.02 |
| *Fusconaia maculata* | 1 | 0.09 | 7 | 0.25 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 2 | 0.04 |
| *Lampsilis radiata luteola* | * | * | * | * | 0 | 0.00 | 1 | 0.20 | 0 | 0.00 | 1 | 0.02 |
| *Lampsilis ventricosa* | 0 | 0.00 | 3 | 0.11 | 0 | 0.00 | 0 | 0.00 | 2 | 0.14 | 8 | 0.17 |
| *Lasmigona complanata* | 0 | 0.00 | 2 | 0.07 | 0 | 0.00 | 0 | 0.00 | 5 | 0.36 | 18 | 0.38 |
| *Lasmigona costata* | 0 | 0.00 | 2 | 0.07 | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.02 |
| *Leptodea fragilis* | 29 | 2.56 | 46 | 1.61 | 2 | 0.27 | 14 | 2.83 | 36 | 2.61 | 51 | 1.08 |
| *Megalonaias nervosa* | 0 | 0.00 | 1 | 0.04 | 2 | 0.27 | 0 | 0.00 | 2 | 0.14 | 19 | 0.40 |
| *Obliquaria reflexa* | 430 | 37.89 | 856 | 30.01 | 306 | 40.80 | 250 | 50.51 | 568 | 41.16 | 1610 | 34.05 |
| *Obovaria subrotunda* | 3 | 0.26 | 8 | 0.28 | 19 | 2.53 | 4 | 0.81 | 1 | 0.07 | 25 | 0.53 |
| *Plethobasus cyphyus* | * | * | * | * | 1 | 0.13 | 0 | 0.00 | 0 | 0.00 | 2 | 0.04 |
| *Pleurobema cordatum* | 42 | 3.70 | 202 | 7.08 | 3 | 0.40 | 35 | 7.07 | 127 | 9.20 | 781 | 16.52 |
| *Pleurobema rubrum* | * | * | * | * | 0 | 0.00 | 0 | 0.00 | 0 | 0.00 | 1 | 0.02 |
| *Pleurobema sintoxia* | 1 | 0.09 | 5 | 0.18 | 2 | 0.27 | 0 | 0.00 | 0 | 0.00 | 6 | 0.13 |
| *Potamilus alatus* | 5 | 0.44 | 16 | 0.56 | 2 | 0.27 | 13 | 2.63 | 26 | 1.88 | 51 | 1.08 |
| *Potamilus ohiensis* | 0 | 0.00 | 2 | 0.07 | 0 | 0.00 | 0 | 0.00 | 5 | 0.36 | 7 | 0.15 |
| *Quadrula metanevra* | 0 | 0.00 | 1 | 0.04 | 43 | 5.73 | 0 | 0.00 | 2 | 0.14 | 61 | 1.29 |
| *Quadrula pustulosa* | 576 | 50.75 | 1222 | 42.85 | 199 | 26.53 | 99 | 20.00 | 209 | 15.14 | 695 | 14.70 |
| *Quadrula quadrula* | 15 | 1.32 | 52 | 1.82 | 111 | 14.80 | 41 | 8.28 | 166 | 12.03 | 638 | 13.49 |
| *Strophitus undulatus* | 0 | 0.00 | 2 | 0.07 | * | * | * | * | * | * | * | * |
| *Truncilla donaciformis* | 16 | 1.41 | 47 | 1.65 | 0 | 0.00 | 13 | 2.63 | 25 | 1.81 | 71 | 1.50 |
| *Truncilla truncata* | * | * | * | * | 2 | 0.27 | 0 | 0.00 | 5 | 0.00 | 10 | 0.21 |
| Totals | 1135 | | 2852 | | 750 | | 495 | | 1380 | | 4729 | |

Table 1

| | | Bed 3 (n = 22) | | Bed 5 (n = 29) | | | |
|---|---|---|---|---|---|---|---|
| | | Midden 1 | Total | Midden 1 | Midden 2 | Midden 3 | Total |
| Bed 3 | Midden 1 | | 2.21 | | | | |
| | Total | <0.05 | | | | | |
| Bed 5 | Midden 1 | | | | 3.35 | 3.06 | 2.79 |
| | Midden 2 | | | <0.01 | | 2.47 | 2.58 |
| | Midden 3 | | | <0.01 | <0.02 | | 2.26 |
| | Total | | | <0.01 | <0.02 | <0.05 | |

Table 2

CAPTIONS

Table 1. Species and numbers found in each midden and in parent bed. * - species not found in bed.

Table 2. Comparison of middens and parent beds by pairing design test. Values above diagonal are t-test values. Values below diagonal are probability levels of t. NS - not significant at $p = 0.05$.

CANADIAN JOURNAL OF ZOOLOGY
*JOURNAL CANADIEN DE ZOOLOGIE*

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*COMMENTAIRES À L'INTENTION DU DIRECTEUR SCIENTIFIQUE (remarques confidentielles, noms d'autres spécialistes, etc.)*

This paper is somewhat trivial, begins with a false assumption, and simply confirms what most mussel collectors already know. It would need more depth even for perhaps Ohio Journal of Science. Definitely not of CJZ quality.

REVIEWER'S NAME / *NOM DU LECTEUR*: Richard J. Neves
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This manuscript contains some corroborative evidence for what has previously been documented; namely, that muskrats are species selective in their depredation on mussels in rivers. The author's initial assumption, "that middens represent an unbiased estimate of the actual population" is false, as judged by previously published studies. Are there any citations in peer-reviewed literature that support this assumption? None are given in the manuscript. All citations indicate species and/or size selectivity, and therefore a biased sample of resident mussel populations in muskrat middens. It seems to me that the author is simply confirming what is already known and adds no new science to the subject.

In addition to corrections in the text, I provide the following general comments.

1. The Muskingum River and mussel beds are of such size that an individual muskrat will not feed over the entire bed. More likely, because of mussel densities, he/she will feed in proximity to the burrow or feeding site. Because mussel species are not randomly distributed, one would not expect to see concurrence between diversity in midden shells and the entire mussel bed.

2. There is undoubtedly some bias in the samples of living mussels, particularly combining quadrat-collected specimens with those qualitatively sampled by a diver. The latter method is very size selective; i.e., divers tend to see and collect the larger mussels. The sample of living mussels added to the 'total number' therefore is biased. I suspect that if the author compared diversity in quadrats with diversity in qualitative samples, he would see this difference.

3. The statistically significant difference in diversity among middens is

further corroboration that no midden can be expected to represent diversity in the bed. Most mussel collectors use cumulative collections of middens from a site over time to approach actual diversity at that site. Over time, consumption of young and adult specimens of resident species by muskrats will reveal nearly all species. An examination of cumulative species in middens 1, 2, 3 of Bed 5 demonstrates this.

In summary, because species selectivity is already documented in the literature, and is common knowledge among freshwater malacologists who collect muskrat middens along rivers, this manuscript offers no new insights to the problem of adequately sampling mussel populations.