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The effect of Hurricane Katrina on the mussel assemblage of the Pearl River, Louisiana

Kenneth M. Brown · Wesley Daniel · Gerry George

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Abstract We sampled the mussels of the Pearl River along the eastern border of Louisiana, USA, in 1997 and 2007. Hurricane Katrina followed the pathway of the river in August 2005, and we were interested in detecting any resulting decreases in mussel abundance or diversity. The mussel assemblage was relatively stable, despite the hurricane and a drought in the Pearl River Basin in 2006 and 2007. We detected no change in average species richness per site, and the total number of mussels collected per site (e.g., collection per unit effort) actually increased in 2007. Species importance curves comparing the two studies did, however, suggest a reduction from 29 to 23 species. Monte Carlo simulations and comparisons of assemblage similarity also suggested that *Glebula rotundata* increased at the expense of *Potamilus purpuratus* and *Villosa lienosa*, possibly because it was more tolerant of salt water intrusion. Eight of 13 mussels with adequate sample sizes had different adult size structures in the two surveys, either increasing or decreasing in mean shell length during the 10 years. Large individuals were rare for the two species that decreased in relative abundance in 2007. Semi-quantitative sampling appeared adequate here to compare relatively long-term changes in mussel diversity and adult size structure. However, more research on natural variation in assemblage structure and mussel size distributions is needed to understand the importance of disturbances like hurricanes or droughts.

Keywords Unionids · Hurricane · Disturbance · Pearl River

Introduction

Hurricanes can have dramatic effects on coastal wetlands, re-suspending nutrients and particulate organic material by mixing nutrient-rich deeper water layers with upper layers, resulting in algal blooms and increased biological oxygen demand that may eventually result in fish kills (Paerl et al. 2001; Mallin and Corbett 2006). Effects on the benthos are less clear, and benthic production often recovers quickly after hurricanes (Burkholder et al. 2004; Cebrain et al. 2007). The effects of hurricane disturbances on unionid mussel assemblages occurring in coastal plain rivers have not as yet been studied. These mussel assemblages are already in decline in many rivers in the southeastern United States because of impoundments, habitat alteration, and nonpoint source pollution (Williams et al. 1993; Neves et al. 1998; Strayer 2008). Unionid mussels are somewhat less diverse in Louisiana rivers than in some other

K. M. Brown (✉) · W. Daniel · G. George
Department of Biological Sciences, Louisiana State University, Baton Rouge, LA 70803, USA
e-mail: kmbrown@lsu.edu

southeastern watersheds but have also experienced losses in species richness in some drainages because of impoundments. Threats to Louisiana mussel assemblages also include gravel mining and increased urbanization (Brown and Banks 2001; Hartfield 1993). Unionid mussels are relatively long-lived (McMahon and Bogan 2001), and assemblage composition, or the age and size structure of mussel populations, might be expected to reflect disturbances like hurricanes that can alter mussel habitat and result in reductions in water quality.

This paper assesses changes over a 10 year interval for mussel populations in the Pearl River, Lousiana. In 1997, we sampled the river to locate the federally listed inflated heelsplitter (*Potamilus inflatus*; Brown and Banks 2001). In 2007, we were funded to conduct a second study to determine whether any marked changes had occurred in the mussel assemblage because of Hurricane Katrina. Because hurricanes cause high flows that can alter river geomorphology and re-suspend toxic contaminants or organic matter from the bed that lower dissolved oxygen levels, we were interested in whether the hurricane caused declines in unionid diversity. A second question was whether the method we chose to census the mussel assemblage, semi-quantitative sampling or timed searches, was an adequate technique to determine changes in mussel assemblages.

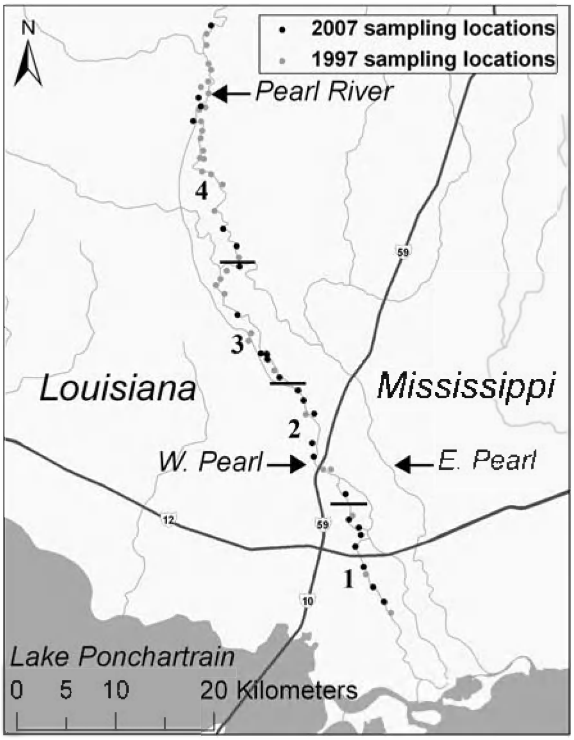

Fig. 1 Map of the Pearl River, with sampling sites for both studies indicated. Lines indicate the four stretches used in the Anosim analysis

Methods

Site description

The Pearl River originates in east-central Mississippi and flows 790 km south to the Gulf Coast, with a watershed area of 22,700 km^2 (Felley 1992). About 80 km from its mouth, the river splits into the East and West Pearl Rivers. We sampled sites on the combined East and West Pearl River, from below Bogalusa, Louisiana (Fig. 1) down along the West Pearl River. Substrata in the study section vary from mostly sand and gravel in the upper reaches to sand overlain by silt in the lower reaches (Felley 1992). Normal discharges are highest during winter and spring and lowest during summer and fall. Longitudinally along coastal plain alluvial rivers, most physico-chemical factors change little although flow rates and dissolved oxygen tend to decrease at sites in the lower basins (Brown and Curole 1997).

Hurricane Katrina in August 2005 caused extensive damage to the Pearl River. Bottom sediments and marsh vegetation, including uprooted trees, blocked the mouth of the West Pearl River and other parts of the channel, preventing navigation and diverting flow (Federal Emergency Management Agency 2006; Fritz et al. 2008). The Louisiana Department of Wildlife and Fisheries and other state agencies removed 27,000 m^3 of debris from the river. The path of Katrina roughly followed the Pearl River north (Fig. 2). A 4–9 M storm surge also resulted in salt water being pushed as far as 20 km upstream into coastal rivers in the area.

Sampling methods

Assignment of sampling sites in both studies was by a systematic sampling design (Strayer and Smith 2003). We selected a series of sites (Fig. 1) that were ca. 2 km apart. This allowed us to travel to

Fig. 2 Path of Hurricane Katrina

launch sites, navigate between sites in a 5-m boat, and sample for 45 min at three sites per sampling day. Sites were also selected to provide a variety of substrata (gravel, sand, and silt) and habitat types (sand bars, depositional areas, backwaters, etc.). Our original plan was to visit the same sites in the second study, but channel alterations that had occurred made it hard to find the same sites based on GPS (global positioning system) coordinates. We therefore selected another set of sites along roughly the same length of river (Fig. 1). At each site in both studies, two snorkelers spent 45 min moving along littoral zones (<1 m depth) locating mussels by tactile search (e.g., carefully searching the bottom by hand for mussels). All mussels were identified by keys in Vidrine (1993) and Stern (1976), measured and returned to their original positions. We then determined GPS location and measured water temperature, dissolved oxygen, and conductivity with a YSI model 85, and current velocity with a Marsh-McBirney electronic current meter at each site.

The relative merits of different mussel sampling techniques have been reviewed by a number of authors (Vaughn et al. 1997; Strayer et al. 1997; Obermeyer 1998; Strayer and Smith 2003). Quantitative sampling is considered best for estimating population density or dynamics but requires considerable effort, including excavation and sieving of sediment to adequately measure mussel size distributions, recruitment, and abundance. Quadrat sampling, unless extensive, may underestimate species richness by missing rare species. Semi-quantitative sampling (e.g., timed search) is considered better for estimating species richness and relative abundance but does tend to underestimate the abundance of smaller species or species buried in the sediment. Since timed searches often also have high variances and may involve different researchers, Strayer and Smith (2003) questioned their use in studies of temporal changes in mussel populations. Smith (2006) argued for a modification of semi-quantitative sampling where timed searches were made of delineated transects perpendicular to river flow, and argued that a large number of small transects should be spaced throughout the population. He predicted that searching 632 m^2 would give an 85% chance of finding relatively rare species with densities of 0.01 per m^2. We consider his estimate of about 2 min to adequately search a square meter to be fairly accurate, and reflect our own effort. We therefore searched ca. 45 m^2 at each site. However, since we searched multiple sites per study (e.g. 25 sites would cover about 1,125 m^2), we consider that we sampled enough area per study to find rarer species. However, we placed our transects parallel to shore in the shallow littoral zone in both studies, instead of crossing the whole river bed, as earlier studies of these river systems (Brown and Curole 1997; Brown and Banks 2001) found mussels to be more abundant and diverse in shallow, muddy habitats that experienced less disturbance during spates than in more coarse sediments in the main channel. To compare our semi-quantitative sampling to quadrat-based sampling, we selected one site with a fairly diverse mussel assemblage and also collected sixteen 1 m^2 quadrat samples.

Community analyses

To compare assemblages between the pre- and post hurricane surveys, we calculated a number of assemblage characteristics. To compare diversity, we recorded species richness and total mussel abundance at each site and compared them among surveys, using *t* tests. We also constructed species importance curves, comparing the relative abundances of assemblages in the two studies. To determine whether the importance curves differed between studies, we used Ecosim (Gotelli and Entsminger 2001), which uses Monte Carlo simulation methods to create null assemblages and iteratively creates a species richness versus sample size ("rarefaction") curve with associated confidence intervals for both studies. As sample size is increased, if confidence intervals no longer overlap, diversity is assumed to differ between the two communities (Gotelli and Entsminger 2001).

To determine whether species associations across sampling sites differed between surveys, we used procedure Anosim (Primer Package v6, Plymouth Marine Laboratories, Clarke and Warwick 2001) to calculate Bray–Curtis similarity indices of species compositions across both surveys and among several reaches of the river. We divided the Pearl into four reaches (Fig. 1), so that the number of sites sampled in each reach was 6–7 during both sampling periods. The lowest reach was from the mouth of the river in Lake Ponchartrain to Morgan Bluff, the second reach was from Morgan Bluff to Homes Bayou, the third was from Homes Bayou to the entrance of the Bogue Chitto River, and the most northern reach was from the Bogue Chitto to the entrance of Bogalusa Creek into the Pearl River. This procedure is basically a two-way (surveys vs. reaches) analysis of similarity and indicates whether species associations vary across surveys, as well as reaches. We then used Procedure Simper in the same package to determine which mussel species contributed the most to dissimilarity between the surveys and reaches.

Finally, we compared size distributions of the most common mussel species ($n > 50$ individuals total) between the two studies to see whether the size distribution of adult mussels had changed. While timed searches underestimate the abundance of juvenile mussels that often burrow in the substrate (Schwalb and Pusch 2007), they can be used to determine differences in the size distributions of larger, adult mussels.

Results

We collected 29 species of unionid bivalves from 29 sites in 1997 and 23 species from 23 sites in 2007. Shannon-Wiener diversity indices were lower in 2007 than in 1997 (Table 1). However, the average number of species collected per site was virtually identical, and not significantly different between years (Table 1; $F_{1,74} = 0.04$; $P = 0.85$). The average total abundance of mussels per site actually increased between 1997 and 2007 (Table 1; $F_{1,74} = 5.80$; $P = 0.02$).

Comparing species importance curves between studies (Fig. 3), the 2007 curve has fewer species with intermediate abundances, indicating a lower diversity. While *Glebula rotundata*, *Plectomerus dombeyanus*, and *Fusconaia ebena* increased in relative abundance, the other mussel species decreased (Table 2). Comparing the simulated species accumulation curves with increasing sample sizes between studies (e.g., the Ecosim results, Fig. 4), the 95% confidence intervals suggested higher diversity in the 1997 survey after about 2,000 mussels had been added to the simulation.

Procedure Anosim indicated significant differences in similarity of mussel assemblages both between surveys (Total $R = 0.111$; $P = 0.03$) and reaches ($R = 0.222$; $P = 0.001$). Procedure Simper indicated three mussel species contributed the most to dissimilarity between the two surveys: *Glebula rotundata* contributed 10.3% to dissimilarity, increasing from about 25 per sampling site on average in 1997 to 126 in 2007. *Potamilus purpuratus* contributed 9. 2% to dissimilarity, decreasing from 200 per sampling site in 1997 to 23 on average in 2007.

Table 1 A comparison of species richness (total number of species collected, *S*), number of specimens (*N*), Shannon Wiener diversity index (*H'*), and mean species richness and mean total abundance between the two surveys

Date	*S*	*N*	*H'*	Mean *S* per site + standard error	Mean total abundance per site + standard error
1997	29	3,383	2.335	8.4 + 0.6	60.8 ± 9.6
2007	23	2,661	2.182	8.2 + 0.9	111 ± 22.7

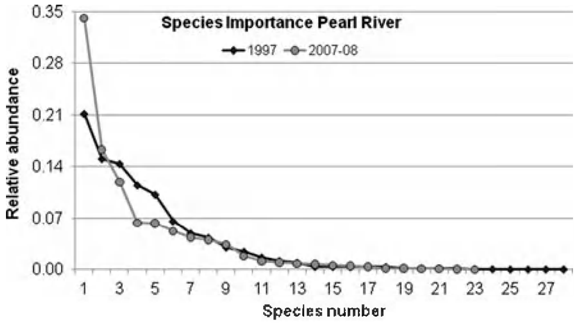

Fig. 3 Species importance curve for both studies. Data are the ranked relative abundances (number of individuals of each species collected/total sample size)

Table 2 Number of mussels collected in the two studies

Species	1997	2007
Quadrula nobilis	716	434
Quadrula refulgens	510	168
Potamilus purpuratus	487	91
Glebula rotundata	389	907
Obliquaria reflexa	346	168
Plectomerus dombeyanus	223	318
Lampsilis teres	167	170
Leptodea fragilis	146	108
Villosa lienosa	102	31
Quadrula apiculata	82	26
Tritogonia verrucosa	55	49
Lampsilis claibornensis	39	11
Pyganodon grandis	31	20
Uttebackia imbecilis	13	2
Andodonta suborbiculata	13	14
Toxolasma texasensis	12	0
Elliptio crassidens	12	5
Lampsilis ornata	11	21
Megalonaias nervosa	6	4
Toxolasma parva	6	0
Fusconaia ebena	6	17
Ligumia recta	3	0
Amblema plicata	2	16
Arcidens confragosus	2	0
Strophitus radiatus	1	0
Obovaria unicolor	1	0
Villosa vibex	1	0
Truncilla donaciformis	1	0

Mussel species are arranged by declining relative abundance in the 1997 study

Quadrula nobilis contributed 9.9%, increasing from 26 per sample to 43 per sample in 2007. So far as differences between reaches, Simper indicated that the species composition of reaches 1 versus 2 and 3 versus. 4 were not statistically different (P values of 0.6 and 0.12, respectively), but all other comparisons among reaches were different ($P < 0.02$). In other words, the mussel assemblages in upper and lower reaches differed from each other.

Of the 13 species of unionids with a reasonable sample size, 8 differed in mean shell length between the two studies (Fig. 5). Of these, *Quadrula apiculata*, *Q.nobilis*, *Q.refulgens*, *Lampsilis teres*, and *Obliquaria reflexa* had fairly similar size distributions, but with mean size increasing 2–5 mm over the interval, perhaps because of growth in individual size of a cohort of mussels. *Lampsilis claibornensis*, in comparison, increased in mean size by 9 mm, and the size distribution was shifted upwards at the expense of smaller individuals, suggesting higher mortality in these size classes (Fig. 5). In contrast, both *Villosa lienosa* and *Potamilus purpuratus* had fairly large decreases in mean shell length, with many fewer large *Potamilus purpuratus* in particular collected in 2007 (Fig. 5).

At the one site where we used both methods, we found 15 species and 290 individual mussels during our regular, semi-quantitative sampling, but only a total of 7 species and 81 individuals in the quadrat sampling. The average number of species per quadrat was 2.3 ± 0.4, and we actually spent close to 10 min per quadrat, for a total effort of 160 min.

Discussion

Our results suggest that unionid mussel diversity has decreased, but only moderately, over a 10 year interval in the Pearl River, although the path of Hurricane Katrina of 2005 roughly paralleled the course of the river. Even though the studies did not significantly differ in average species richness per site, abundance per site actually increased, while overall estimated species richness dropped from 29 to 23 species. These changes are reflected by a decline in H' and a reduction in the number of species with intermediate abundances in the species importance curve. However, all five species that were rare in 1997 were not found in 2007, and rare species are

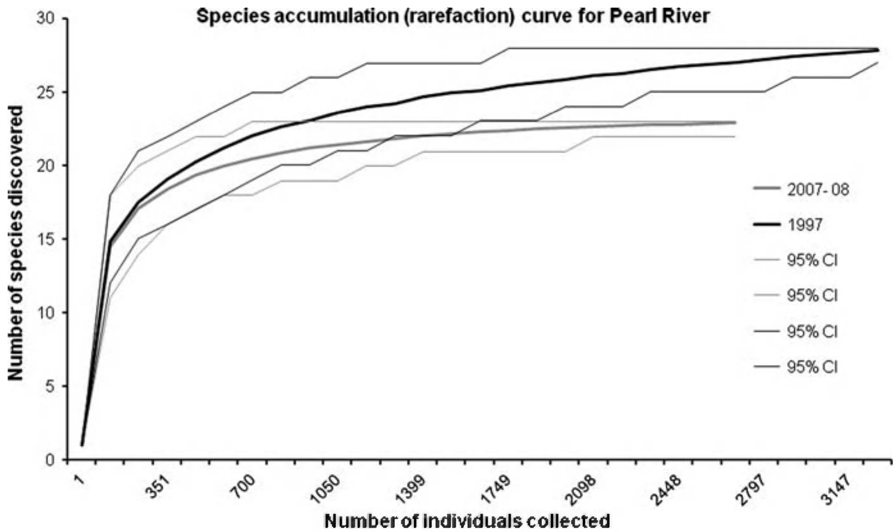

Fig. 4 Plots of the number of species of mussels versus sample size resulting from Monte Carlo simulations of null models constructed by Ecosim. Nonoverlap of confidence intervals indicates differences in diversity at a particular sample size

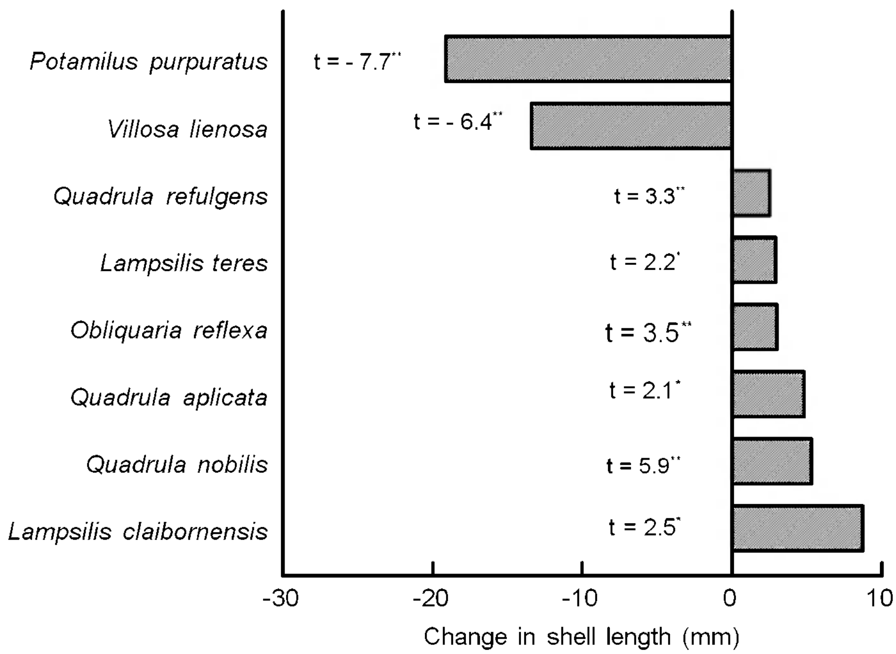

Fig. 5 Difference in mean shell length between surveys for eight species where *t* tests indicated a significant difference in average adult size between the two studies. The *t* values and associated probabilities are also given

again often missed in collections. The 2007 mussel assemblage was more dominated by one species, *Glebula rotundata*, particularly at the expense of two other species, *Potamilus purpuratus* and *Villosa lienosa*. A Monte Carlo simulation comparing the differences in the two species importance curves to null models also supported the conclusion of reduced diversity in 2007. Procedures Anosim and Simper suggested differences in the mussel assemblages between studies and also indicated that the changes in the relative abundance of *Glebula rotundata* and *Potamilus purpuratus* were important in explaining differences in the assemblages. The increase in relative abundance for *Glebula rotundata* could be caused by salt water intrusion into the Pearl River, because of the storm surge associated with Katrina. *G. rotundata* is known to have a more estuarine distribution and rely more on estuarine fish species for glochidial dispersal (Parker et al. 1984), and *Glebula rotundata* is much less sensitive to salinity than other unionids (Johnson et al. 2009).

Because the unionid mussels are relatively long-lived invertebrates, the change in size distributions of 8 of the 13 species over 10 years is fairly interesting. Relatively little is known of the life span of these species, but given the fairly large sample sizes for many species, an increase of <5 mm in average shell length could represent growth of a dominant cohort over the interval or could also result from mortality to smaller size classes. Growth rates of unionid mussels are fairly plastic, e.g. have been reported to vary among habitats (Kesler et al. 2007). Much work involving tagging mussels and following growth in rivers is necessary to understand the potential for size structure changes naturally over time, if changes can be caused by a dominant cohort, and understanding life span differences among species.

The decrease in the relative frequency of large adults for *Potamilus purpuratus* and *Villosa lienosa* is more problematic. Larger mussels would presumably be more prone to dislodgement in high-current velocities associated with spates, because of increased drag, and presumably also the scouring caused by the hurricane's tidal surge, unless they were buried in the sediment. Larger *P. purpuratus* may have been removed by commercial shell collectors over the past few years, but shell collection would have to be fairly widespread, and *V. lienosa* has little commercial value. One would also expect the size distributions of some other species, e.g. the *Quadrula* spp. (which also have fairly thick shells) to reflect commercial harvest.

Hurricane Katrina is certainly a possible cause of the reduced mussel diversity, as high flows, and the relative stability of substrata or habitats to current extremes may explain mussel diversity and distributions more than traditionally measured microhabitat factors (Strayer and Ralley 1993; Strayer 1999; Gangloff and Feminella 2007; Vaughn et al. 2008; Newton et al. 2008). However, Katrina may not have been the only disturbance occurring over the time interval. In 2006 and 2007, relatively little rainfall occurred in the Pearl River Basin, resulting in low flows (Fig. 6). Mussel diversity is also very sensitive to drying events and reduced flow (Golladay et al. 2004).

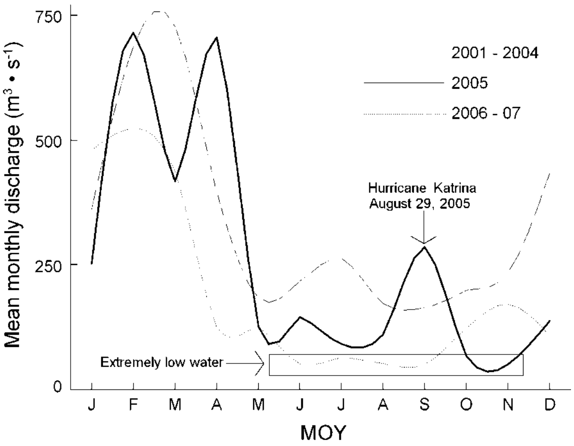

Fig. 6 Temporal changes in discharge patterns at a site half way up the segment of the Pearl River surveyed in both studies. Average monthly (MOY = month of year) discharges over several years before Hurricane Katrina, in 2005 when Katrina occurred in August, and for the 2 years subsequent to the hurricane (notice low flows caused by a drought in the Pearl River Basin)

Finally, the 2007–2008 semi-quantitative sampling technique seemed to be adequate to track the changes in mussel assemblages over the sampling interval. Quantitative sampling underestimated the diversity found using the semi-quantitative sampling, even though we invested more sampling effort than with the semi-quantitative sampling. Semi-quantitative sampling allows collection of a large number of mussels, increasing the chances of collection of relatively rare species, and thus gives a better estimate of the diversity of mussels in a river. Obviously, quantitative sampling is more appropriate for following the population dynamics of individual species, but we conclude that semi-quantitative sampling is an adequate technique for comparing the diversity of mussel assemblages across sites or time intervals, especially when many species are fairly rare. However, we also consider it important that more basic work be done on unionid mussel survivorship, life cycle length, reproductive activity, and growth, to allow better interpretation of potential changes in size distributions and relative abundances caused by disturbances.

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