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The freshwater mussels (Bivalvia: Unionoidea) of the upper Delaware River drainage

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Abstract. We surveyed the unionoidean fauna of 44 sites in the upper Delaware River drainage of New York during 1990. Seven species of unionoideans were found living in the basin, including the endangered *Alasmidonta heterodon* (Lea, 1829). Four other species are known historically from the upper Delaware basin, but now are either absent from the area or restricted to a few local sites. Neither calcium concentration nor stream size is a good predictor of unionoidean species richness in the study area. We hypothesize that sediment stability could regulate the occurrence of unionoideans in the streams of the upper Delaware drainage.

The Delaware River is one of the major rivers of the northern Atlantic Slope. Ortmann (1919) showed that the lower Delaware basin contained a rich Atlantic Slope fauna, including the endangered species *Alasmidonta heterodon* (Lea, 1829) and the southernmost known population of *Margaritifera margaritifera* (Linneaus, 1758). Because the upper Delaware is known for its high water quality, we felt that similarly rich communities of unionoideans could live upstream of the area surveyed by Ortmann. There is little published information on the unionoideans of the upper Delaware basin. Marshall (1895) reported six species from unspecified sites in the Delaware River system in New York. Harman (1975) published a brief article focusing on the effects of anthropogenic disturbances on the molluscan community of the Delaware's headwaters. We surveyed the waters of the upper Delaware drainage in New York in 1990 to determine whether *A. heterodon* lived in this area and to assess the current status of the freshwater mussel community in general.

THE STUDY AREA

Our survey covered the streams in the Delaware River basin in New York (Fig. 1). Streams range in size from headwater brooks to the Delaware River itself, which has a mean annual discharge of 160 m^3/sec at Port Jervis (our station 1) (Zembrzuski *et al.*, 1983). Most streams in the study area have fairly high gradients, and sediments consist chiefly of cobbles, gravel, and coarse sand. The water in most streams is very clear and somewhat soft (Table 1).

Most of the watershed is forested, although there is some agriculture, and villages and small cities are scattered along the Delaware River and its major tributaries. The largest municipalities in the basin are Port Jervis (pop. 8699), Monticello (6306), and Hancock (1526), so urban pollution is not pronounced. The larger streams in the upper Delaware basin are used heavily for recreation (boating, fishing). The major current anthropogenic impacts on the streams in the drainage probably arise from the three large reservoirs of the New York City water supply system. These reservoirs alter the hydrological and thermal characteristics (all three reservoirs are hypolimnetic release) of downstream waters (the lower East and West Branches of the Delaware River, the upper mainstem of the Delaware River, and the middle Neversink River). About 30 m^3/sec of water is diverted out of the basin from these reservoirs to supply drinking water for New York City (Zembrzuski *et al.*, 1983).

METHODS

We visited 44 sites on the upper Delaware River drainage during periods of low, clear water between July and September, 1990, collecting mussels by handpicking while wading or snorkeling. Most specimens were identified and returned immediately to the stream. Voucher specimens (chiefly dead shells) have been deposited in the New York State Museum (NYSM) and Academy of Natural Sciences at Philadelphia (ANSP). In addition to our field collections, we searched the collections of the National Museum of Natural History (USNM), American Museum of Natural History (AMNH), and NYSM for specimens of unionoideans from the upper Delaware basin. Mussel nomenclature follows that of Turgeon *et al.* (1988). Water samples were collected in clean polyethylene bottles and analyzed for calcium by plasma emission using a Perkin-Elmer ICP/6000.

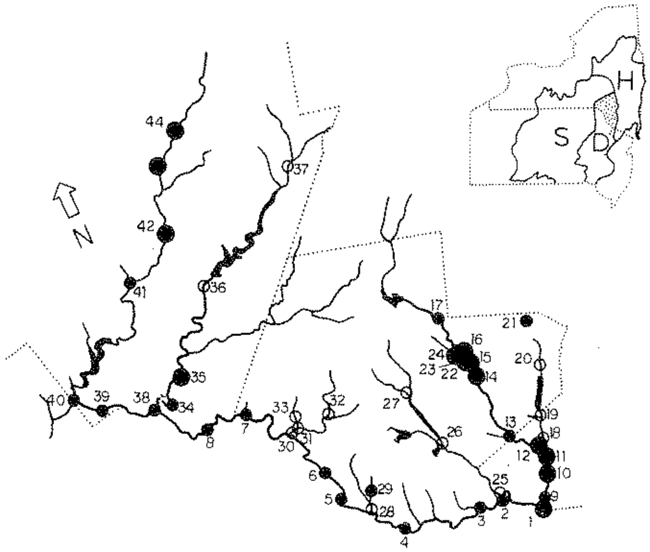

Fig. 1. Location of the Delaware River basin and sampling sites on the upper Delaware River basin. Inset shows the Delaware (D) and nearby drainages (H = Hudson, S = Susquehanna) in New York, New Jersey, and Pennsylvania; the study area is stippled. Site numbers on the main figure correspond to those given in Table 1. Open circles show sites where unionoideans were not found, small black circles show sites where only *Elliptio complanata* was found, and large black circles show sites where at least two species of unionaceans were found. Dotted lines are county boundaries.

RESULTS AND DISCUSSION

The waters of the upper Delaware River drainage now support seven species of unionoideans (Table 1). Four other species are known only through historical records. Marshall (1895) reported *Ligumia nasuta* (Say, 1817), *Lampsilis cariosa* (Say, 1817), and *L. radiata* (Gmelin, 1791) from the upper Delaware system, but we saw no trace of these species in 1990 [Marshall's report of *Anodontoides ferussacianus* (Lea, 1834) probably is based on a misidentification of an *Anodonta* sp.]. *Margaritifera margaritifera* is represented by a single shell (AMNH 164659) taken from "lake at Camp Welmet near Narrowsburg, Sullivan Co., NY" by H. S. Feinberg in 1949. Unfortunately, we were unable to get access to the lake at Camp Welmet (Silver Lake, not Lake Welmet, which, confusingly enough, is not on the property of Camp Welmet) in 1990 to assess the status of this population.

Of the seven species still living in the upper Delaware basin, *Elliptio complanata* is by far the most abundant and widespread. In fact, we found *E. complanata* at every site where unionoideans were present. Although many authors have commented on the broad ecological tolerances of this species (e.g. Ortmann, 1919; Clarke and Berg, 1959; Strayer, 1987), we know surprisingly little about what behavioral, physiological, or ecological adaptations allow this species to succeed over such a broad range of habitats.

There are old, indefinite reports of *Alasmidonta heterdon* from New York (Marshall, 1895; Letson, 1905), but ours are the first reliable records of this species from New York (there are no museum lots of this species from New York in the NYSM, AMNH, USNM, ANSP, University of Michigan Museum of Zoology, or Museum of Comparative Zoology collections.) There is apparently a healthy population of this species in the lower 12-18 km of the Neversink River. Our findings raise the obvious possibility that *A. heterdon* could still persist in other tributaries of the upper Delaware (or in the river itself) in New Jersey or Pennsylvania.

The other two species of *Alasmidonta* (*A. undulata* and *A. varicosa*) also were abundant in the Neversink River drainage. In addition, we found *A. undulata* in the West Branch of the Delaware River above Cannonsville Reservoir. It is possible that small numbers of *A. varicosa* may live in the upper West Branch as well, although we did not find it there in 1990. Harman (1975) reported *A. marginata* Say, 1818, a species that resembles *A. varicosa*, but which probably does not occur in the Delaware basin, in the upper West Branch.

Anodonta implicata is found in small numbers in the lower Neversink River near Port Jervis. *A. implicata* is parasitic on anadromous shad and herring (*Alosa* spp.), and is found typically in low-gradient coastal rivers and ponds (Johnson, 1946; Davenport and Warmuth, 1965; Smith, 1985; Strayer, 1987). Our records from the upper Delaware River system are interesting for two reasons. First, the reach of the Neversink River occupied by *A. implicata* is a relatively high-gradient, stony, upland river, unlike the coastal sites typically frequented by this species. Second, although large numbers of American shad [*Alosa sapidissima* (Wilson, 1811)] run upstream to well above the junction of the East and West Branches of the Delaware, we found no trace of *A. implicata* in most of the mainstem, even in such apparently suitable habitat as the huge, quiet pool at Narrowsburg. This observation suggests that some ecological factor other than the distribution of the host fish determines the current distribution of *A. implicata* in the Delaware system.

One of the most striking impressions from our work was just how poor the unionoidean communities were over large parts of the upper Delaware basin. Unionoideans apparently were absent at many (30%) of the sites that we surveyed, even though the streams were large enough to support unionoideans and were not obviously polluted. In some of these cases (e.g. stations 30, 33), the sediments consisted mainly of well rounded cobbles, and probably are too coarse and too unstable for unionoideans. Other sites (e.g. stations 18-20) apparently have suitable substrata, high water quality, and diverse fish communities, but no trace of unionoideans. We do not know what is keeping unionoideans out of these sites. One obvious possibility that we believe we can rule out is inadequate dissolved calcium. Although many waters in the basin are soft, there is no relationship between calcium con-

Table 1. Distribution of unionid bivalves in the upper Delaware River basin in 1990 (numbers show numbers of living animals collected; d, old, dead shells found; D, recently dead shells found).

	calcium concentration (mg/l)	*man-hours searching*	*Elliptio complanata* (Lightfoot, 1786)	*Alasmidonta heterodon* (Lea, 1829)	*A. undulata* (Say, 1817)	*A. varicosa* (Lamarck, 1819)	*Anodonta cataracta* Say, 1817	*A. implicata* Say, 1829	*Strophitus undulatus* (Say, 1817)
1. Delaware River, Port Jervis	8.7	1.5	2					d	
2. Delaware River, Mongaup		1.2	28						
3. Delaware River, Pond Eddy		1	26						
4. Delaware River at Roebling Bridge near Minisink	7.5	0.5	D						
5. Delaware River, Narrowsburg	7.2	2.2	d						
6. Delaware River, Skinner's Falls		1	2						
7. Delaware River, Stalker (PA)		1	D						
8. Delaware River, Lordsville	7.7	0.5	d						
9. Neversink River, Port Jervis		2.2	4						
10. Neversink River, Huguenot	7.8	3	128	7	2	1		2	2
11. Neversink River, Graham Road		6	64	10	1	20		3	5
12. Neversink River, Roses Point		6	52	7	3	76		1	26
13. Neversink River, Oakland Valley	5.8	1.5	1						
14. Neversink River, Bridgeville	5.6	1.5	D		1				
15. Neversink River at mouth of Sheldrake Stream		2.5	57		51	2			
16. Neversink River, Ranch Hill Road		2	2		11	1			
17. Neversink River, Woodbourne	3.9	1.5	D						
18. Basher Kill, Galley Hill Road		0.7							
19. Basher Kill, Westbrookville		1							
20. Basher Kill, Wurtsboro	7.4	0.8							
21. Delaware and Hudson Canal, Bova Road		0.7	5						
22. Sheldrake Stream at mouth	7.8	1.3	41		18		1		
23. Sheldrake Stream, Thompsonville		1	2						
24. Sheldrake Stream, Ranch Hill Road		1	9		D		D		
25. Mongaup River, Route 97		0.3							
26. Mongaup River south of Swinging Bridge Reservoir	5.9	0.8							
27. West Branch Mongaup River, Gale Road	7.9	0.5							
28. Ten Mile River below Route 97		0.2							
29. East Branch Ten Mile River, County Rte. 23	3.6	0.5	2						
30. Callicoon Creek at mouth	9.2	0.5							
31. Callicoon Creek, Hortonville		0.5							
32. East Branch Callicoon Creek below Route 52	8.2	0.5							
33. North Branch Callicoon Creek 2 miles above Hortonville	9.6	0.2							
34. East Branch Delaware River, Peas Eddy	7.5	1	60						
35. East Branch Delaware River, Fish's Eddy		1.5	11						2
36. East Branch Delaware River, Downsville	5.8	0.5							
37. East Branch Delaware River, Margaretville	8.7	0.5							
38. West Branch Delaware River, Hancock		1	D						
39. West Branch Delaware River, Hale Eddy	6.8	1	1						

Table 1. (continued)

	calcium concentration (mg/l)	man-hours searching	*Elliptio complanata* (Lightfoot, 1786)	*Alasmidonta heterodon* (Lea, 1829)	*A. undulata* (Say, 1817)	*A. varicosa* (Lamarck, 1819)	*Anodonta cataracta* Say, 1817	*A. implicata* Say, 1829	*Strophitus undulatus* (Say, 1817)
40. West Branch Delaware River, Deposit		0.5	d						
41. West Branch Delaware River, Walton	11.5	1	D						
42. West Branch Delaware River, Hamden		2.5	2		1				1
43. West Branch Delaware River, Delhi	14.9	2	55		12				3
44. West Branch Delaware River, Bloomville	14.9	1	d		D				

centration and either unionoidean density or species richness (Fig. 2). Harman (1975) believed that the operation of the New York City water supply reservoirs eliminated most unionoideans from tailwater reaches, but our richest sites were downstream of such a reservoir on the Neversink River.

A second piece of evidence that shows the poverty of the upper Delaware River unionoidean community is that 58% of the sites that contain unionoideans contain only one species, *Elliptio complanata*. The dominance of *E. complanata* is especially striking in the main Delaware River, where we found only a single, old shell of *Anodonta implicata* along with more than 500 living or recently dead specimens of *E. complanata*. The main Delaware is a large river with a rich fish fauna, and would be expected to support several (6-10) species of unionoideans, as was the case on the Susquehanna and lower Delaware rivers (Ortmann, 1919; Clarke and Berg, 1959; Harman, 1970). Clarke (1986) recently found that parts of the upper Connecticut River that formerly supported several species of unionoideans now contain only *E. complanata*. He suggested that the operation of hydroelectric dams could have eliminated most of the unionoidean species without, however, suggesting why *E. complanata* would be resistant to these recent environmental changes. Marshall's (1895) old records of species such as *Lampsilis cariosa* from the basin suggest that some unionoidean species could have likewise been extirpated from the mainstem Delaware River. It is possible that past episodes of pollution, perhaps from wood processing industries in the Delaware basin (Myers, 1986), could have destroyed the unionid fauna in some streams, but it is unclear why only *E. complanata* would be able to recolonize these reaches once the pollution stopped.

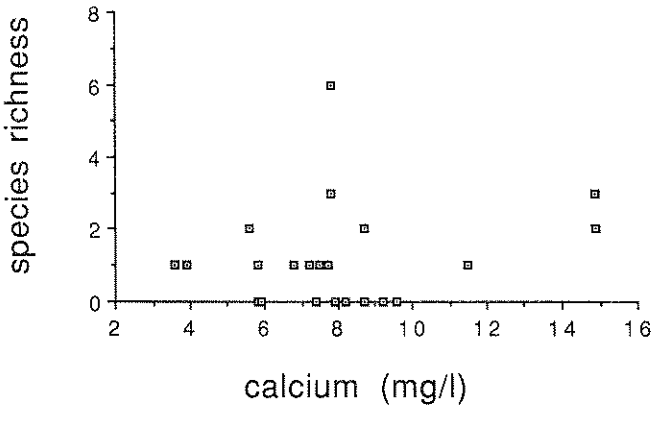

Fig. 2. Species richness of unionoideans in streams of the upper Delaware basin as a function of calcium concentrations (r = 0.22, NS).

Finally, unionoideans are highly localized even in sites where several species are present (e.g. stations 10-12). At these sites, there often are sharp boundaries between dense (> 1 individual/m^2), multispecific beds of mussels and areas entirely devoid of mussels. These sharp boundaries do not generally correspond to obvious changes in environmental conditions (e.g. sediment grain size, current velocity, water depth), although a detailed, quantitative study like that of Salmon and Green (1983) probably would uncover statistically significant differences in environmental conditions between mussel beds and nearby areas devoid of mussels. An alternative hypothesis is that the mussel beds represent areas of relatively stable sediments. It is well known (e.g. Leopold *et al.*, 1964; Richards, 1982) that most stream sediments are set in motion by floods every year or two. The instability of sediments poses obvious problems for the long-lived Unionoidea, which could be displaced, crushed, or buried when the sediments in which they live are moved. Vannote and Minshall (1982) showed that sediment stability was a major factor regulating the local distribution of mussels in the Salmon River canyon, Idaho. We suggest that sediment stability is generally important to mussels in streams, and that the highly local mussel beds that we observed in the Neversink and elsewhere represent not particularly favorable conditions of sediment grain size, current velocity, and so on, but rather areas in which the sediments have not been moved for some time (a decade or so?), or are stable during critical periods such as during recruitment of juveniles.

We have devoted some space to this speculative discussion of potential controlling factors because we feel that, despite a large volume of research on unionoidean ecology, there is little real understanding of what controls unionoidean distribution and abundance in streams. Why does the lower Neversink River contain a rich community of unionoideans, including an endangered species, while other apparently suitable sites nearby support only one species or no unionoideans at all? Until we can answer questions like these, it will be difficult to formulate intelligent management schemes to protect our remaining unionoidean communities.

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