5-1989

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Recommended Citation

Magee, James Timothy, "Pebble nest microhabitats of Semotilus species (Pisces: Cyprinidae)" (1989). *Master's Theses.* Paper 554.

PEBBLE NEST MICROHABITATS OF *SEMOTILUS* SPECIES (PISCES: CYPRINIDAE)

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

OF THE UNIVERSITY OF RICHMOND

IN CANDIDACY

FOR THE DEGREE OF

MASTER OF SCIENCE IN BIOLOGY

MAY, 1989

BY

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B.S., OLD DOMINION UNIVERSITY, 1985

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Acknowledgements

I thank my advisor, Dr. William S. Woolcott, for suggesting this research endeavor and providing continuous encouragement and support throughout the study. Thanks also are extended to Dr. Wilton R. Tenny for reviewing the manuscript. Special gratitude is due Dr. Eugene G. Maurakis for his technical advice with the statistics and writing.

I thank my sister and apartment mate, Pam Magee, for her support and understanding during my graduate tenure. Appreciation is expressed to my parents, Mr. and Mrs. James T. Magee, Jr., for their financial support. Finally, I acknowledge the financial assistance provided through a University of Richmond Teaching Assistantship during my final year.

Abstract

The pebble nest microhabitats of four species of *Semotilus* were compared. Pit/mound nests of *Semotilus corporalis* were significantly larger than the pit/ridge nests of *Semotilus atromaculatus*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Nests of *S. corporalis* were in wider and deeper streams. Pits of *S. lumbee* nests were longest of the four species; those of *S. corporalis* were widest and deepest. *Semotilus corporalis* used a greater proportion of larger stones (23 mm or greater) in nest construction than the other three species. There was no significant difference in the electivity index (percentage of nest pebble sizes versus those of the substrate) among the species for the three largest stone sizes (6.0, 11.3, and 23.0 mm). Although the greatest percentage of stones in the nests of *S. corporalis* were 23 mm, they did not represent the greatest electivity index as that stone size was present in the greatest percentage in the substrate. Pebble nests mounds and ridges served as breakwaters, reducing the flow to near zero in the downstream pit below the ridge or mound of the nest.

Males of four species of *Semotilus* (Cyprinidae) build spawning nests by placing pebbles in mounds or ridges at the head of riffles in clear montane or Piedmont streams. *Semotilus corporalis* (fallfish) is a pit/mound nest builder that ranges from the James River drainage in Virginia, north to the Mirimichi and James Bay drainages in Canada (Lee et al., 1980). The other three species, *Semotilus atromaculatus*, *Semotilus lumbee*, and *Semotilus thoreauianus* are closely related pit-ridge nest builders and are known collectively as creek chubs. *Semotilus atromaculatus* (creek chub) is found across most of central and eastern North America, ranging from Manitoba, Montana, and northern New Mexico east to the Atlantic slope, exclusive of the Coastal Plain (Lee et al., 1980). *Semotilus lumbee* (Sandhills chub) is confined to the Carolina Sandhills in south central North Carolina and north central South Carolina in the upper Lumber River system (Peedee drainage) and adjacent tributaries of the Yadkin and Cape Fear drainages. *Semotilus thoreauianus* (Thoreau's chub) inhabits small streams above and below the Fall Line from the Savannah River drainage in northwestern South Carolina to the Pearl River drainage in southeastern Louisiana (Woolcott and Maurakis, 1989).

Prior to spawning, mounds of *S. corporalis* nests are built by a large male that excavates an area and later fills it with stones (Raney, 1969). This species has not been observed constructing nests following the spawning act as is characteristic of the creek chubs. Male creek chubs begin a nest by digging a pit and placing the pebbles from it at its upstream margin. Following spawning, the male moves pebbles from the downstream end of the pit and puts them over the eggs deposited in the upstream end of the pit. Thus, as spawning continues, the ridge increases in length and the pit is displaced downstream (Woolcott and Maurakis, 1989).

As most studies of nest construction have been limited to generalized descriptions of nests, one of the objectives of this study was to compare the materials and construction of the nests among the four species of *Semotilus*. A second objective was to examine the relation of the nests to physical factors of the stream and how the alteration of these factors by the nests affect the eggs of the fishes.

Materials and Methods

Pebble pit-ridge nests of four *Semotilus* species were collected from streams in Georgia, North Carolina, and Virginia in April, May, and June from 1982 through 1988. The number of nests collected for each species were: *S. atromaculatus*, 2; *S. corporalis*, 2; *S. lumbee*, 3; and *S. thoreauianus*, 4. The total number of nests examined for dimensions were: *S. atromaculatus*, 14; *S. corporalis*, 6; *S. lumbee*, 5; and *S. thoreauianus*, 9. Nest materials were stored in plastic bags where they were kept until examined in the laboratory. Nest pebble sizes were determined by sifting air-dried nest materials through five custom-built wire sieves. Mesh sizes, established by availability of commercial screens, were: 23.0 mm, 11.3 mm, 6.0 mm, 2.5 mm, and 0.8 mm. Material that sifted through the smallest size mesh was collected in the pan of the five-screen sieve set. Total weight of pebbles of each nest was recorded prior to screening. Weights of materials in each screen were divided by their total weight and used to calculate the percentage of each size component. Substrate material collected near a nest was analyzed by the procedure used for the nest materials.

The dominant nest-building male and nest associates (species that spawn over the nest but do not contribute to its construction) were collected with a pulsed D.C. electroshocker, or a 3 m, 6.3 mm mesh seine and stored at the University of Richmond.

Stream depth (cm), width (m), and temperature (C) were recorded. Velocity of the water current was measured one centimeter above the nest and substrate with a Marsh-McBirney current meter. Pre-ridge current velocity measurements of the nest were taken 0.5 m upstream to the right, middle, and left of the ridge. Means were used for calculations. Current velocity was measured over the ridge, in the pit, and 0.5 m below the pit. Where anterior, middle and posterior measurements were taken over the ridge, and in the pit, the mean of the three values for each characteristic were used in analyses.

For each nest, multiple measurements were made of ridge length, height, and width and for pit depth, length, and width. Mean values were calculated for each parameter.

An electivity index (Ivlev, 1961) was calculated for each pebble size class per nest of each species. The equation $E=\frac{(r_1 - p_1)}{(r_1 + p_1)}$ (where E = pebbble size selection, r = percentage of a particular pebble size in the nest, and p = the percentage of a particular pebble size in the substrate of the stream) was used to determine if selection of pebble size from the substrate was nonrandom. Electivity index values range from 1 to -1. Values closer to 1 indicate a greater selection of a particular pebble size. Percentages and electivity index values were transformed to arcsin equivalents to get a common denominator for comparison. Analysis of variance (ANOVA) followed by Duncan's Multiple Range Test (alpha=0.05) was used to compare average electivities, percent pebble composition of nests, and stream dimensions between and within species (Steel and Torrie, 1980). Backward stepwise elimination regression/correlation (SAS, 1980) was used to determine if pit depth and length; and ridge height and width contributed significantly in slowing water current within the pit (SAS, 1980).

Results

Nests of *S. corporalis* were in significantly deeper (x, 52.7 cm) and wider (x, 5.7 m) streams than were those of other *Semotilus* species (Table 1). Water temperature at active nests for all species ranged from a mean of 13.2 C (*S. atromaculatus*) to one of 15.0 C (*S. thoreauianus*) and did not differ significantly (Table 1).

Approximately 83 % of the pebbles in nests of *S. corporalis* were either size class 23.0 mm (49.3%) or 11.3 mm (33.6%, Table 2; Fig. 1). Average percentage of pebbles in the 11.3 mm size class followed by those of the 6.0 mm size class were predominant in nests of *S. atromaculatus* (x, 38.5% and 23.0%, respectively), *S. lumbee* (x, 48.7% and 33.5%, respectively), and *S. thoreauianus* (x, 31.2% and 25.1%, respectively, Table 2; Figs. 2-4).

A comparison of percentages of the different pebble size classes among species (Table 3) showed the nests of *S. corporalis* had a significantly larger number of 23.0 mm pebbles. *Semotilus lumbee* nests had the greatest percentage of 11.3 mm pebbles and differed significantly from those of *S. corporalis* and *S. thoreauianus*. *Semotilus lumbee* nests also had the greatest percentage of 6.0 mm pebbles but differed significantly only from those of *S. corporalis*. *Semotilus atromaculatus* and *S. thoreauianus* nests had similar high percentage values for 2.5 mm pebbles and were significantly different from those of *S. corporalis*, which had the lowest percentage of this size pebble in its nests. Comparable high percentages for 0.8 mm pebbles occurred in the nests of *S. thoreauianus* and *S. atromaculatus* and were significantly greater than percentages of nests for the other two species. The average percentage of particles less than 0.8 mm was about three times as great for nests of *S. thoreauianus* than that of the *S. atromaculatus* which had the next highest percentage of this size class (Table 3; Fig. 5).

Substrate material at nests of *S. corporalis* was comprised of 61.1 % of the 23.0 mm size class pebbles. In all other size classes, the percentage of substrate material at *S. corporalis* nests was lowest of the four species (Table 4).

Average electivity indices showed *S. atromaculatus* selected significantly more 23.0 mm pebbles than pebbles 2.5 mm and smaller. Although 23.0 mm size pebbles dominated *S. corporalis* nests (Table 2), they did not have a high electivity index as they also dominated the substrate. Highest electivity index was for pebbles in size classes 11.3 and 6.0 mm, respectively (Tables 5 and 6; Fig. 6).

Numbers of pebble sizes (6.0, 11.3, and 23.0 mm) selected by *S. lumbee* were similar. There were no significant differences among the size classes of pebbles selected by *S. thoreauianus* except for those less than 0.8 mm which appeared to be selected against (Table 5; Fig. 6).

Mean electivity indices among species did not differ significantly for nest pebbles in the 23.0, 11.3, and 6.0 mm size classes. However, average electivity index values for *S. thoreauianus* were significantly greater than were those for *S. lumbee* nests in the 2.5, 0.8, and <0.8 mm pebble size classes even though the <0.8 mm values were negative (Table 6; Fig. 6).

Average pit depths and widths of *S. corporalis* nests were significantly greater than those of nests of *S. atromaculatus* and *S. thoreauianus*. Mean pit length of *S. lumbee* nests was significantly greater than that of the nests of *S. atromaculatus* (Table 7).

Mean ridge length of *S. lumbee* nests was greatest but differed significantly only from that of *S. thoreauianus* nests. Average ridge width and height of *S. corporalis* nests were significantly greater than of nests of the other species of *Semotilus* (Table 7).

Pit depth and length; and ridge height, width, and length were significant in reducing water currents within the pit of all species combined (Table 8). The velocity of water currents before the nests of all four species was similar. Mean current velocity at the ridge of *S. corporalis* nests was significantly greater than it was at the ridge of *S. atromaculatus* nests. Average current velocity downstream of *S. lumbee* nests was significantly greater than average current velocity of *S. atromaculatus* and *S. thoreauianus* nests (Table 9). In nests of all species, average current velocity in the pit was significantly less than average current velocity at other points on or near the nest (Table 10).

The greatest number of nest associates were in streams of *S. corporalis*, followed by those with *S. atromaculatus*, then *S. thoreauianus* (Table 11).

Discussion

This is the first study to systematically examine the microhabitats and composition of spawning nests of nest building species of *Semotilus*. Historically, investigators have described nest dimensions and composition inadequately and have given general and vague statements about the physical characteristics of nests.

Breeding males of *S. corporalis* are larger than those of *S. atromaculatus*, *S. lumbee*, and *S. thoreauianus* and therefore are likely to live in larger streams. This is consistent with Hynes' (1970) statement that larger fish occupy larger streams. Stream dimensions for the three smaller *Semotilus* species are similar to each other and do not differ substantially from those reported by other investigators (Reighard, 1910; Hankinson, 1932; Sisk, 1966; Snelson and Suttkus, 1978; and Ross, 1983).

Nest-building *Semotilus* species spawn in the spring and are among the earliest spawners of nest-building genera (i.e. *Campostoma*, *Exoglossum*, and *Nocomis*). Eggs were found in nests of all species at temperatures (Table 12) comparable to those given for *S. corporalis* by Richardson (1935) and Reed (1971); for *S. atromaculatus* by Reighard (1910), Hankinson (1932), Sisk (1966), Miller (1967), Raney (1969), Moshenko and Gee (1973), and Copes (1978); for *S. lumbee* by Maurakis (unpublished); and *S. thoreauianus* by Maurakis (1987), and Woolcott and Maurakis (1989). However, Miller (1964), in a field study of cyprinids in New York, found *S. atromaculatus* spawning at temperatures as high as

23.9 C; approximately seven degrees higher than those in my study.

Large pebble sizes (i.e. 6.0-23.0 mm) were used in the construction of nests by all *Semotilus* species. Moshenko and Gee (1973), in the only available study that examined pebble sizes in a *S. corporalis* nest, reported fine gravel accounted for more than 50 % of the ridge. As they did not provide actual pebble size, their data could not be compared to those given in this study. In a study of *S. atromaculatus* nests, Miller (1967) found stone diameters ranging from 2.5 cm to 12.7 cm. Miller did not give percentages, so a comparison was not made. Maurakis (unpublished) observed 90 % of the pebbles in the pits and ridges of *S. lumbee* nests measured 11.3 mm or less; and 10 % measured 23.0 mm. These data are consistent with those of my study.

Since all four species, regardless of the size of the male, showed a preference (through the electivity index) for pebble sizes 11.3 amd 6.0 mm, it is possible that interstices created by these sizes provided microhabitats best suited for aeration of the water and protection for eggs and developing larvae. It should be pointed out, however, that even though the nests of *S. corporalis* did not reflect a high electivity index for the largest pebbles (23.0 mm) because of the large numbers of this size class in the substrate, nests were composed of almost 50 % of this pebble size. Apparently, electivity indices are not applicable to this species.

Pit-mound nests of *S. corporalis* are usually larger in all dimensions than the pit-ridge nests of the other three *Semotilus* species. Raney (1969) gave approximate values for the nests of *S. corporalis* of 180.0 cm in diameter and 60.0 cm high. Wilson (1907), and Mansueti and Hardy (1967), gave similar findings to those of Raney (1969). Nest sizes in this study were within ranges reported by other investigators; however, as most *S. corporalis* nests were ridge-like (longer than wide) in this study, measurements for these dimensions could not be compared to those given by the above authors who did not specify the shape of the nests in their studies. Reed (1971) suggested nest shape in *S. corporalis* nests is controlled by current. Nests in the current have a downstream keel and those outside the current are dome shaped. Woolcott and Maurakis (pers. comm.) could not confirm this.

Comparison of ridge sizes within and among the *Semotilus* species may be meaningless as ridge size is a function of time, related to the length of time the male has been spawning. For example, in *S. atromaculatus* ridges there was a difference of about 200 cm (longest, 210.0 cm; shortest, 9.0 cm); in *S. lumbee*, the longest ridge was 120.0 cm and the shortest was 65.0 cm; and in *S. thoreauianus*, the longest ridge was 66.0 cm and the shortest was 11.0 cm. Reighard (1910) reported ridge lengths as long as 5.5 m in *S. atromaculatus*. Woolcott and Maurakis (1989) observed ridge lengths of 4.6 m, and Moshenko and Gee (1973) noted ridges up to 2.0 m long in *S. atromaculatus* nests. Shorter ridge lengths (35.5-76.2 cm) for nests of *S. atromaculatus* were reported by Copes (1978).

No consistent relationship could be made between ridge widths and lengths and other nest measurements in nests of any species. Widths varied as much as 28.0 cm for *S. atromaculatus*; 5.0 cm for *S. lumbee*; and 12.0 cm for *S. thoreauianus*. Heights for *S. atromaculatus* had a span of 10.0 cm; *S. lumbee* over 16.0 cm; and *S. thoreauianus*, 15.0 cm. Moshenko and Gee (1973) did not give ranges for ridge widths and heights of *S. atromaculatus* nests but said typical ridge width was 25.0 cm and height was 5.0 cm for nests ranging from 0.5 to 2.0 m long. Reighard (1910) gave approximately 30 cm and 8.0 cm for width and height, respectively, for a ridge 5.5 m long. Woolcott and Maurakis (1989) reported a range of 5.0 cm for ridge width, and 2.6 cm for ridge height. Copes (1978) observed ridge widths ranging from 25.4 cm to 35.6 cm in *S. atromaculatus*. For *S. lumbee*, Woolcott and Maurakis (1989) gave 31.0 cm and 5.0 cm for width and height variations, respectively. Woolcott and Maurakis (1989) also reported a range of 6.5 cm for ridge width, and 18.0 cm for ridge height in *S. thoreauianus* nests. Although ridge width, height, and length, and pit depth and length varied among nests, all contributed significantly in slowing water currents in the pit.

All four *Semotilus* species excavate a pit at the posterior portion of the nest mound or ridge. Pit depths, lengths, and widths in *S. atromaculatus* nests examined by Reighard (1910); Raney (1969); Moshenko and Gee (1973); Copes (1978); and Woolcott and Maurakis (1989) were comparable to those found in this study (Table 12). Woolcott and Maurakis (1989), however, reported a pit approximately 15.0 cm longer than the longest in this study. The deepest pit in *S. lumbee* nests was approximately 8.0 cm deeper than those seen by Woolcott and Maurakis (1989), the only reference to the nests of this species. The shortest pit observed was approximately 8.5 cm less than the shortest pit examined by Woolcott and Maurakis (1989). Pit widths were similar to those given by Woolcott and Maurakis (1989). Pits in *S. thoreauianus* nests were approximately 6.0 cm deeper, 7.0 cm shorter, and 10.0 cm longer than pits described by Woolcott and Maurakis (1989), as with *S. lumbee*, the only authors to describe the nests.

Regardless of the dimensions of the pit in nests of any species, current velocity is slowed significantly.

Typically, average current velocity upstream of the nest was slightly slower than average current velocity over the mound or ridge and much slower than current velocity downstream in nests of all four *Semotilus* species. The slowest current was in the pit, thus allowing vertical descent of the eggs and milt during spawning. Comparable data on current velocity within the microhabitats was not available from the literature.

Reports by Reighard (1910), Raney (1969), and Moshenko and Gee (1973) indicate that *S. atromaculatus* spawns over the pit. In a report by Maurakis (unpublished), *S. lumbee* was observed spawning over the pit. *Semotilus thoreauianus* was observed by Woolcott and Maurakis (1989) also spawning over the pit. Ross and Reed (1978) mention *S. corporalis* moved to the mound to elicit spawning. This account is vague, as it does not indicate whether the fish stayed on the mound or moved to the pit during spawning. Raney (1969), however, observed *S. corporalis* spawning over the pit. Further investigation of breeding behavior in *S. corporalis* is necessary to reconcile this controversy.

During the daylight, the only other species that were tolerated over the nest by *Semotilus* species were those having a red-orange coloration. Miller (1967) observed male *Notropis pilsbryi* jockeying over the posterior portion of a nest being worked by one to six large mature *S. atromaculatus* in a creek in Oklahoma. A similar maneuvering behavior was observed by Woolcott and Maurakis (pers. comm.) of *Phoxinus oreas* over a *S. atromaculatus* nest in Virginia. Ross and Reed (1978) observed *Catostomus commersoni*, *Rhinichthys atratulus*, and *Notropis cornutus* around the active nests of *S. corporalis* in Massachusetts. *Notropis cornutus* had spawning coloration but apparently were not actually seen spawning. *Rhinichthys atratulus*, however, was observed spawning over a *S. corporalis* nest. Reed (1971) noted spawning by *N. cornutus* and *R. atratulus* over *S. corporalis* nests in Massachusetts. *Notropis rubricroceaus* was observed by Woolcott and Maurakis (1989) over *S. thoreauianus* nests. These investigators also suggested *Hybopsis rubrifrons* and species of *Notropis* and *Campostoma* may be nest associates of *S. thoreauianus*. There are no reports of nest associates in streams inhabitated by *S. lumbee*.

In summary, the ridge or mound of the nests of all *Semotilus* species acts as a breakwater, reducing the current over and through the nest, providing for the vertical deposition of non-adhesive, demersal eggs in the spawning pit. Although *S. corporalis* is a large fish that builds larger nests in larger streams, electivity indices indicate that all four species select the same size pebbles, a function probably related to the size of the interstices rather than the size of the fish.

The greater number of nest associates in streams of *S. corporalis* probably results from greater diversity of habitats in larger streams. Further investigation is necessary to determine if the present taxonomic relationships between the four nest-building species of *Semotilus* is adequate.

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Table 1. Results of Duncan's Multiple Range Test for stream characteristics among *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

Stream depth

Species	*thoreauianus*	*atromaculatus*	*lumbee*	*corporalis*
Mean (cm)	12.5	15.5	20.7	52.7

Stream Width

Species	*thoreauianus*	*lumbee*	*atromaculatus*	*corporalis*
Mean (m)	1.7	1.9	2.7	5.7

Water Temp.

Species	*atromaculatus*	*lumbee*	*corporalis*	*thoreauianus*
Mean (C)	13.2	13.3	14.7	15.0

Table 2. Results of Duncan's Multiple Range Test for average percentage of nest material according to size class (mm) within *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

S. corporalis						
Stone size	<0.8	0.8	2.5	6.0	11.3	23.0
Mean	0.20	0.60	4.6	11.8	33.6	49.3
S. atromaculatus						
Stone size	<0.8	0.8	2.5	23.0	6.0	11.3
Mean	2.6	5.1	15.3	15.7	23.0	38.5
S. lumbee						
Stone size	<0.8	0.8	23.0	2.5	6.0	11.3
Mean	0.70	1.7	6.8	8.6	33.5	48.7
S. thoreauianus						
Stone size	<0.8	0.8	23.0	2.5	6.0	11.3
Mean	6.3	7.2	10.1	14.0	25.1	31.2

Table 3. Results of Duncan's Multiple Range Test for average percentage of nest material according to size class (mm) among *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

23.0				
Species	*lumbee*	*thoreauianus*	*atromaculatus*	*corporalis*
Mean	6.8	10.0	15.7	49.3

11.3				
Species	*thoreauianus*	*corporalis*	*atromaculatus*	*lumbee*
Mean	31.2	33.6	38.5	48.7

6.0				
Species	*corporalis*	*atromaculatus*	*thoreauianus*	*lumbee*
Mean	11.8	23.0	25.0	33.5

2.5				
Species	*corporalis*	*lumbee*	*thoreauianus*	*atromaculatus*
Mean	4.6	8.6	14.0	15.3

0.8				
Species	*corporalis*	*lumbee*	*atromaculatus*	*thoreauianus*
Mean	0.6	1.7	5.1	7.2

<0.8				
Species	*corporalis*	*lumbee*	*atromaculatus*	*thoreauianus*
Mean	0.2	0.7	2.6	6.3

Table 4. Results of Duncan's Multiple Range Test for average percentage of substrate material according to size class (mm) among *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

23.0

Species	*lumbee*	*atromaculatus*	*thoreauianus*	*corporalis*
Mean	2.5	6.8	8.9	61.1
	———	———	———	

11.3

Species	*corporalis*	*atromaculatus*	*thoreauianus*	*lumbee*
Mean	19.8	24.9	25.7	33.6
	———	———	———	———

6.0

Species	*corporalis*	*thoreauianus*	*atromaculatus*	*lumbee*
Mean	10.9	15.7	17.7	25.1
	———	———	———	
		———	———	———

2.5

Species	*corporalis*	*thoreauianus*	*lumbee*	*atromaculatus*
Mean	4.8	10.4	13.2	14.8
	———	———		
		———	———	———

0.8

Species	*corporalis*	*thoreauianus*	*lumbee*	*atromaculatus*
Mean	1.5	7.3	8.9	9.8
		———	———	———

<0.8

Species	*corporalis*	*lumbee*	*atromaculatus*	*thoreauianus*
Mean	1.8	16.7	26.0	32.0
		———	———	
			———	———

Table 5. Results of Duncan's Multiple Range Test for average electivity according to size class (mm) within *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

S. atromaculatus

Size class	<0.8	0.8	2.5	6.0	11.3	23.0
Mean	-0.90	-0.30	0.0	0.10	0.20	0.50
	———	———	———			
			———	———	———	
				———	———	———

S. corporalis

Size class	<0.8	0.8	23.0	2.5	6.0	11.3
Mean	-0.80	-0.50	-0.10	-0.02	0.03	0.30
	———	———				
		———	———	———		
			———	———	———	———

S. lumbee

Size class	<0.8	0.8	2.5	6.0	11.3	23.0
Mean	-0.90	-0.70	-0.20	0.20	0.20	0.30
	———	———		———	———	———

S. thoreauianus

Size class	<0.8	0.8	11.3	2.5	6.0	23.0
Mean	-0.70	0.07	0.10	0.10	0.20	0.50
		———	———	———	———	———

Table 6. Results of Duncan's Multiple Range Test for average electivity according to size class (mm) among *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

23.0

Species	*corporalis*	*lumbee*	*atromaculatus*	*thoreauianus*
Mean	-0.10	0.30	0.50	0.50

11.3

Species	*thoreauianus*	*lumbee*	*atromaculatus*	*corporalis*
Mean	0.10	0.20	0.20	0.30

6.0

Species	*corporalis*	*atromaculatus*	*lumbee*	*thoreauianus*
Mean	0.03	0.10	0.20	0.20

2.5

Species	*lumbee*	*corporalis*	*atromaculatus*	*thoreauianus*
Mean	-0.20	-0.02	0.00	0.10

0.8

Species	*lumbee*	*corporalis*	*atromaculatus*	*thoreauianus*
Mean	-0.70	-0.50	-0.30	0.07

<0.8

Species	*lumbee*	*atromaculatus*	*corporalis*	*thoreauianus*
Mean	-0.90	-0.90	-0.80	-0.70

Table 7. Results of Duncan's Multiple Range Test for nest characteristics (cm) among *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

Ridge length

Species	*thoreauianus*	*atromaculatus*	*corporalis*	*lumbee*
Mean	35.2	68.6	81.6	96.2

Ridge width

Species	*thoreauianus*	*atromacualtus*	*lumbee*	*corporalis*
Mean	18.2	21.6	28.0	60.9

Ridge height

Species	*thoreauianus*	*atromaculatus*	*lumbee*	*corporalis*
Mean	4.0	4.2	6.9	38.1

Pit depth

Species	*atromaculatus*	*thoreauianus*	*lumbee*	*corporalis*
Mean	6.7	7.6	9.4	14.5

Pit length

Species	*atromaculatus*	*corporalis*	*thoreauianus*	*lumbee*
Mean	21.3	32.0	32.3	36.3

Pit width

Species	*atromaculatus*	*thoreauianus*	*lumbee*	*corporalis*
Mean	16.2	25.5	29.6	39.0

Table 8. Results of Backward Stepwise Elimination Regression Test (SAS, 1980) for effects of pit depth and length; and ridge height, length, and width on current flow in the pit of nest-building *Semotilus* species.

	B value	F value	Probability > F
Intercept	-0.36955		
Pit depth	0.08840	999999.9	0.0001
Pit length	-0.00412	999999.9	0.0001
Ridge length	-0.00126	999999.9	0.0001
Ridge height	-0.02258	999999.9	0.0001
Ridge width	0.03155	999999.9	0.0001

Table 9. Results of Duncan's Multiple Range Test for average current velocity (m/sec) before ridge, over ridge, in pit, and after pit among *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*. Underscored means do not differ significantly (alpha = 0.05).

Before ridge				
Species	*atromaculatus*	*thoreauianus*	*corporalis*	*lumbee*
Mean	0.05	0.13	0.16	0.16
Ridge				
Species	*atromaculatus*	*lumbee*	*thoreauianus*	*corporalis*
Mean	0.08	0.15	0.17	0.22
Pit				
Species	*atromaculatus*	*corporalis*	*lumbee*	*thoreauianus*
Mean	0.02	0.02	0.03	0.05
After pit				
Species	*atromaculatus*	*thoreauianus*	*corporalis*	*lumbee*
Mean	0.13	0.17	0.28	0.37

Table 10. Results of Duncan's Multiple Range Test for average current velocity (m/sec) among ridge, over ridge, in pit, and after pit for all nest-building species of *Semotilus*. Underscored means do not differ significantly (alpha = 0.05).

Location	Pit	Upstream of ridge	Ridge	Downstream of pit
Mean current	0.04	0.13	0.16	0.23

Table 11. Nest associates found in streams with *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*.

Species	Nest Associate
S. atromaculatus	*Clinostomus funduloides* *Notropis cerasinus* *Phoxinus oreas* *Rhinichthys atratulus*
S. corporalis	*Campostoma anomalum* *Clinostimus funduloides* *Notropis cornutus* *Notropis ardens* *Phoxinus oreas*
S. lumbee	None reported
S. thoreauianus	*Notropis rubricroceaus*

Table 12. Minimum and maximum values for selected stream and nest characteristics for *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*.

Parameter	Species			
	atromaculatus	*corporalis*	*lumbee*	*thoreauianus*
Temp. (C)	8.5-16.7	13.0-15.6	12.5-16.1	9.0-21.0
Stream				
Depth (cm)	8.9-30.5	20.0-100.0	18.4-22.9	6.0-23.0
Width (m)	1.0-5.3	4.5-6.0	1.8-2.1	1.0-3.0
Ridge				
Length (cm)	9.0-210.0	38.0-135.0	65.0-120.0	11.0-66.0
Height (cm)	1.0-11.4	9.3-100.0	2.2-18.3	1.3-16.5
Width (cm)	7.6-45.7	45.7-81.3	25.4-30.0	10.7-22.9
Pit				
Depth (cm)	3.5-17.8	6.0-23.0	4.5-16.5	3.0-15.0
Length (cm)	7.6-45.7	24.0-40.0	27.0-40.6	13.0-41.0
Width (cm)	7.0-30.5	22.0-56.0	23.0-38.0	15.0-40.6

Figure 1. Percentages of pebble sizes in nests and surrounding substrate of *Semotilus corporalis*.

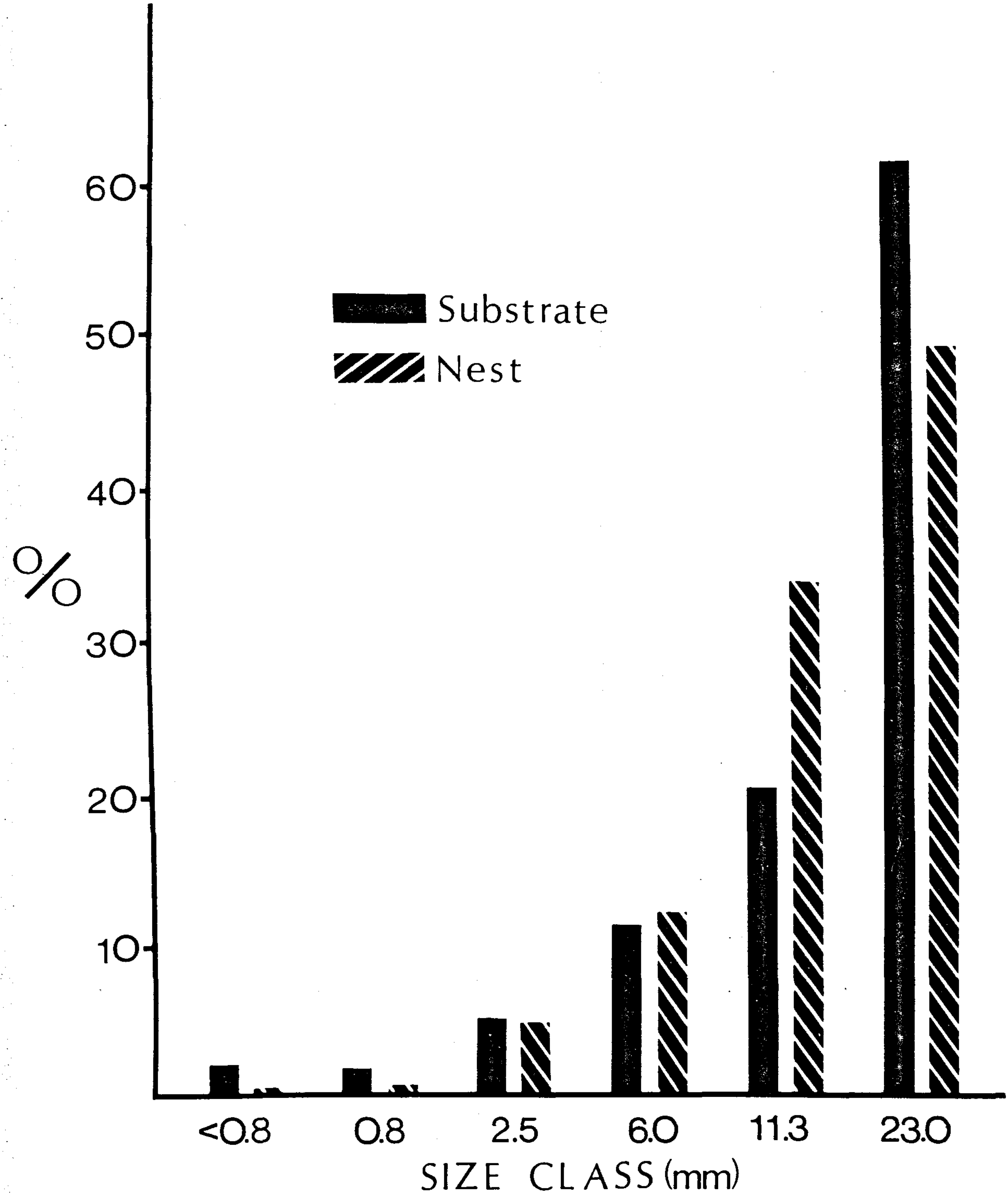

%
60
50
40
30
20
10
Substrate
Nest
<0.8
0.8
2.5
6.0
11.3
23.0
SIZE CLASS (mm)

Figure 2. Percentages of pebble sizes in nests and surrounding substrate of *Semotilus atromaculatus*.

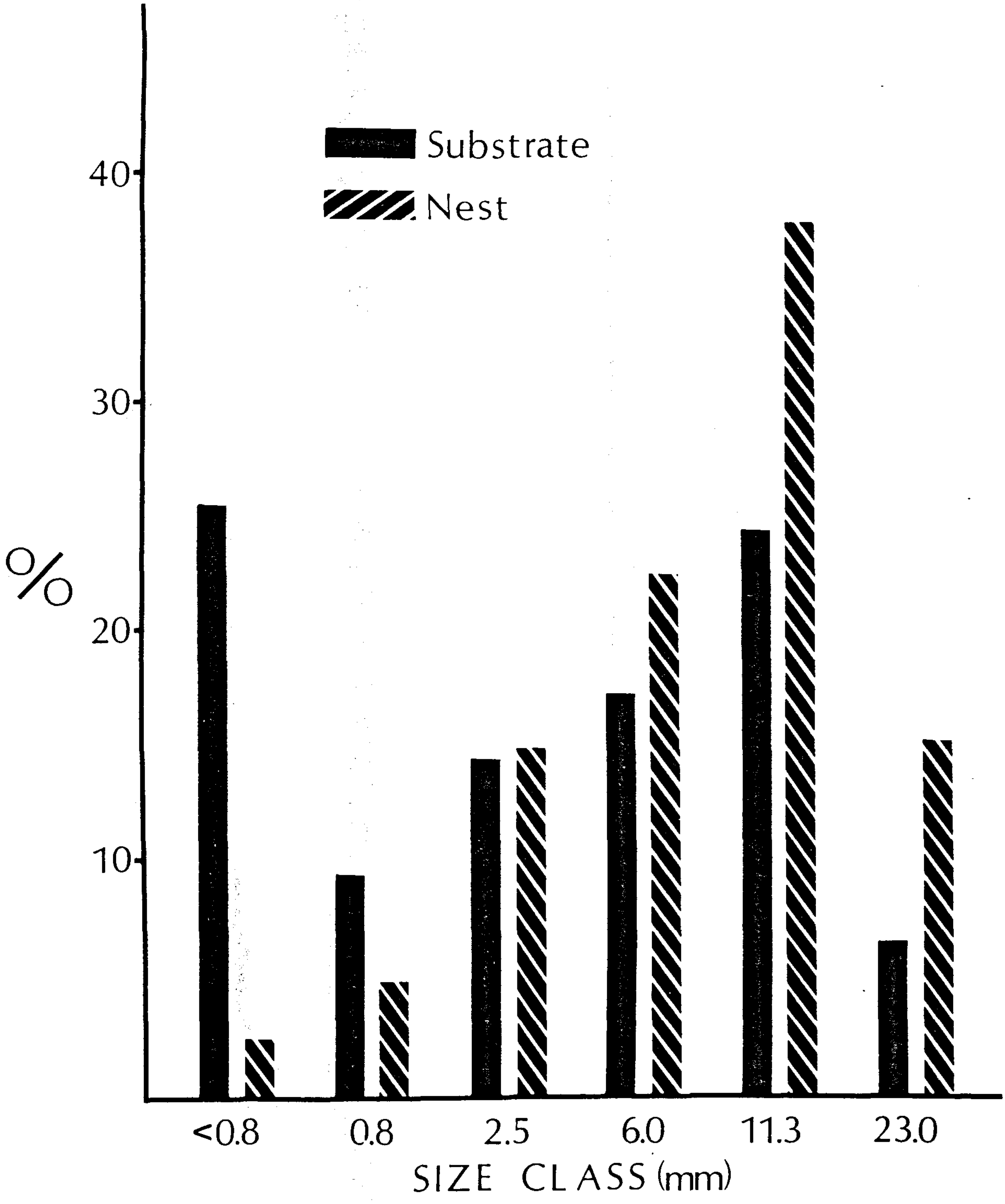

Substrate
Nest
40
30
20
10
%
<0.8
0.8
2.5
6.0
11.3
23.0
SIZE CLASS (mm)

Figure 3. Percentages of pebble sizes in nests and surrounding substrate of *Semotilus lumbee*.

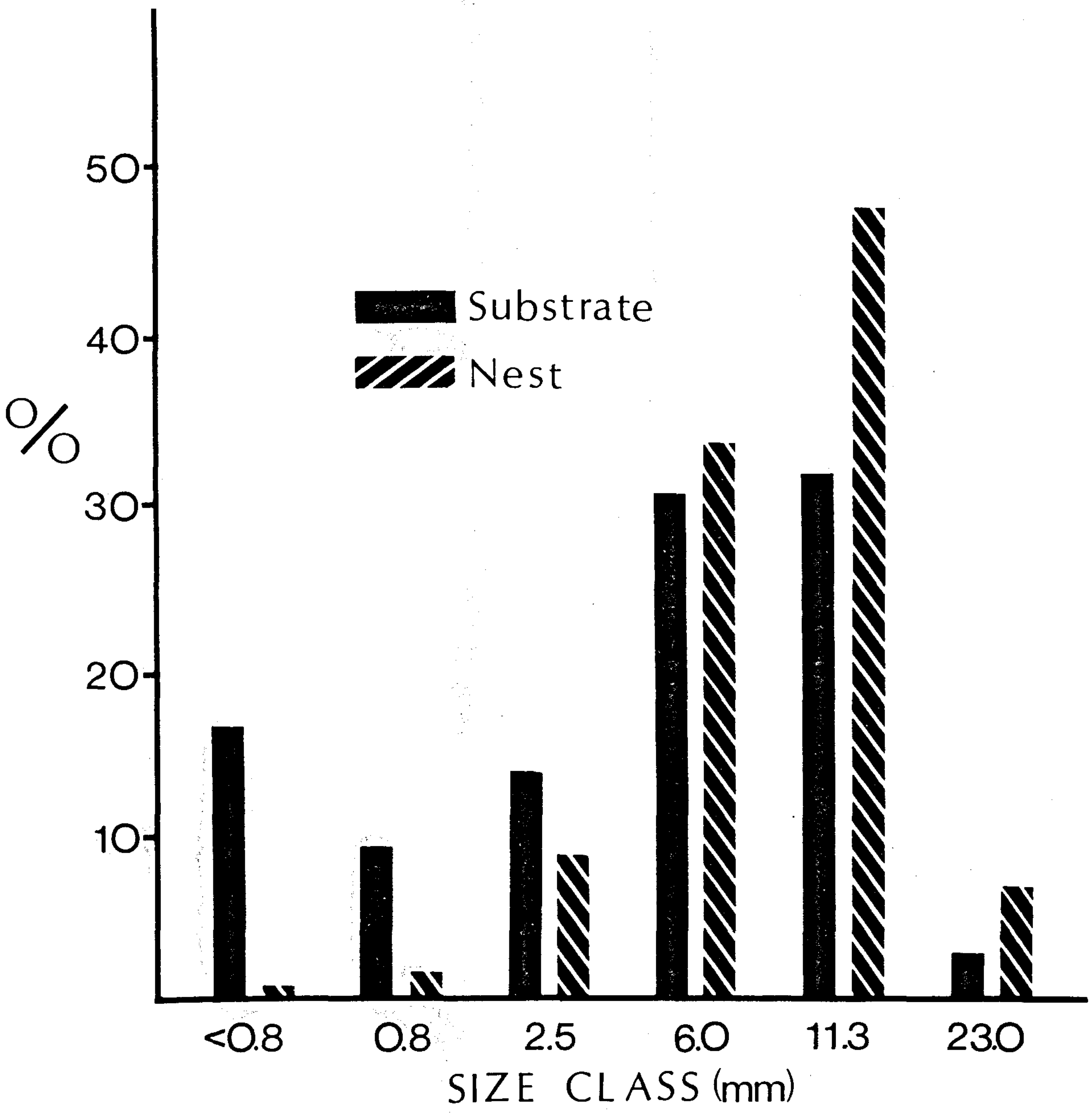

50
40
30
20
10
%
Substrate
Nest
<0.8
0.8
2.5
6.0
11.3
23.0
SIZE CLASS (mm)

Figure 4. Percentages of pebble sizes in nests and surrounding substrate of *Semotilus thoreauianus*.

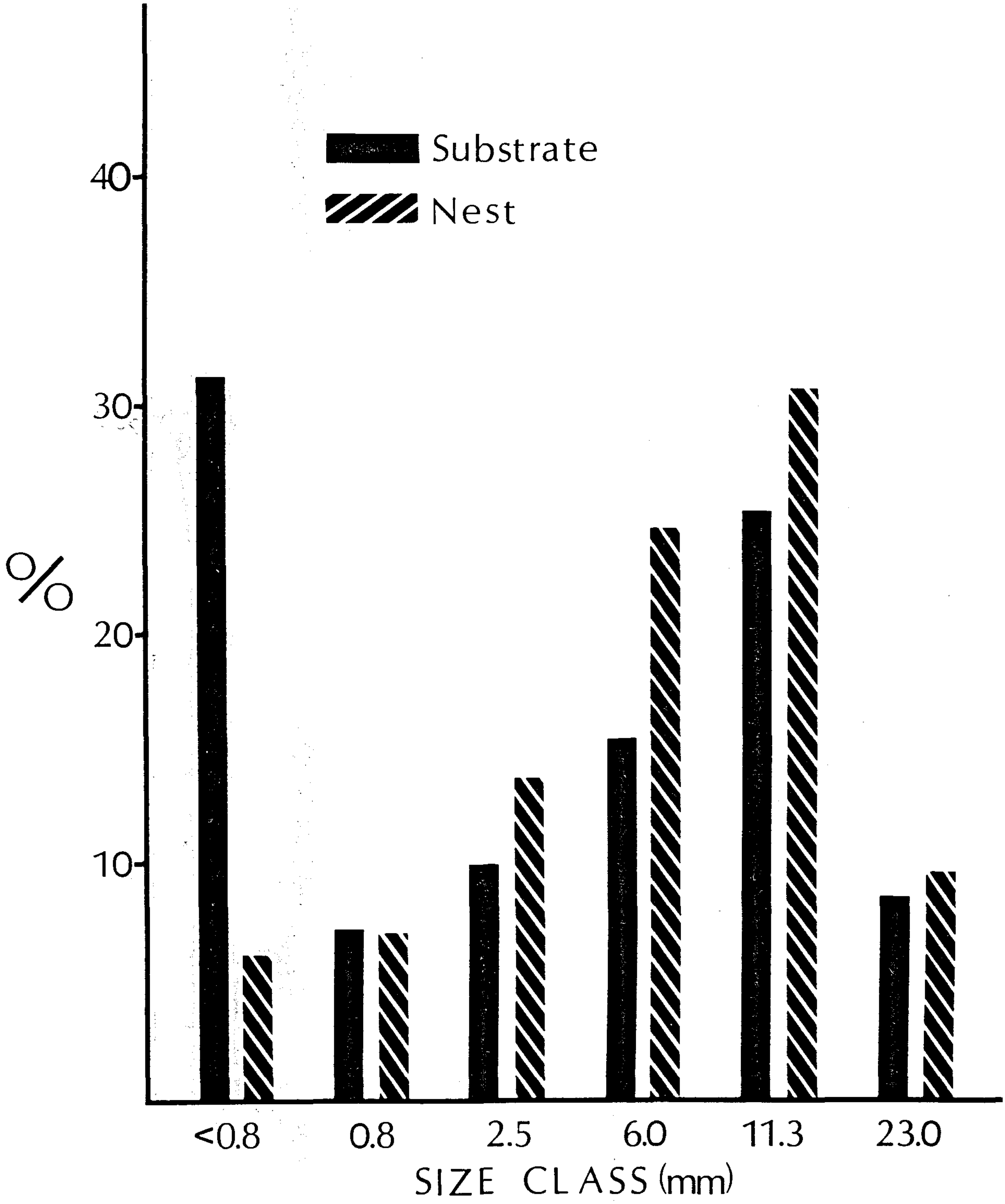

Substrate
Nest
40
30
20
10
%
<0.8
0.8
2.5
6.0
11.3
23.0
SIZE CLASS (mm)

Figure 5. Comparison of average percentages of pebbles by size class among nests of *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*.

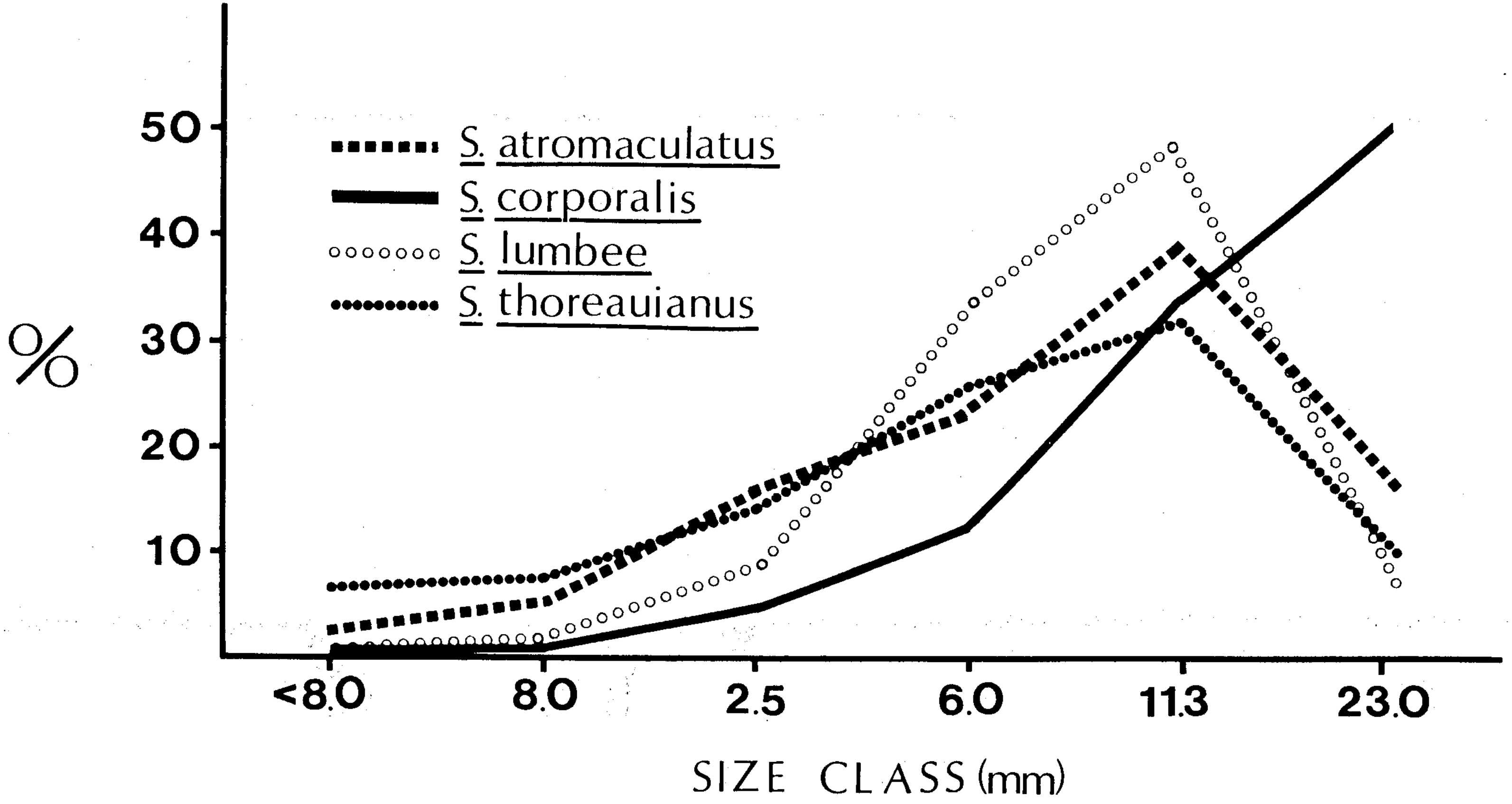
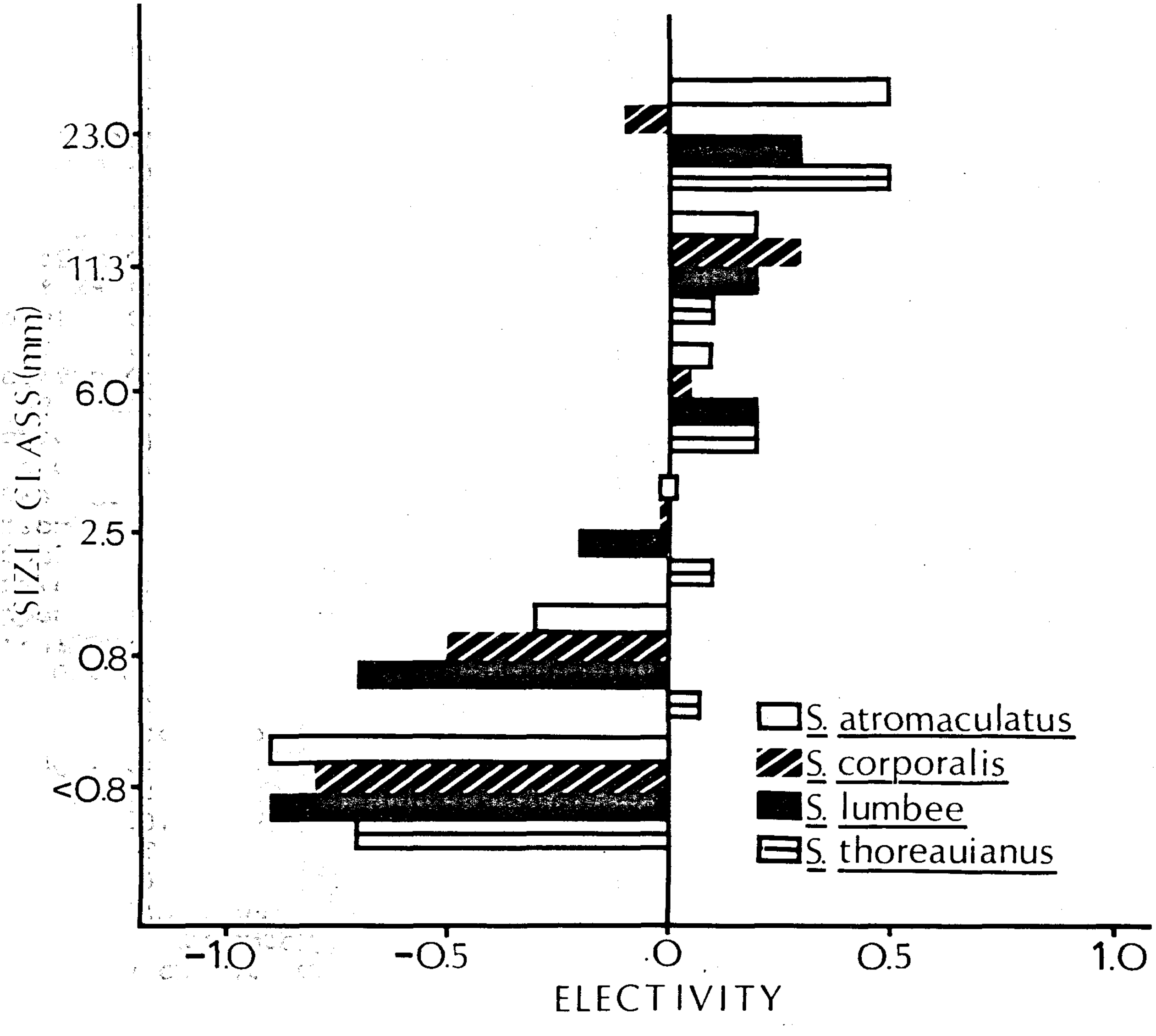

S. atromaculatus
S. corporalis
S. lumbee
S. thoreauianus
%
50
40
30
20
10
<8.0
8.0
2.5
6.0
11.3
23.0
SIZE CLASS (mm)

Figure 6. Comparison of average electivity values for pebbles by size class among nests of *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*.


SIZE CLASS (mm)
23.0
11.3
6.0
2.5
0.8
<0.8
-1.0
-0.5
.0
0.5
1.0
ELECTIVITY
S. atromaculatus
S. corporalis
S. lumbee
S. thoreauianus

Appendix I. Collection number, number of nests (in parentheses), locality and date for *Semotilus atromaculatus*, *Semotilus corporalis*, *Semotilus lumbee*, and *Semotilus thoreauianus*.

Semotilus atromaculatus. EGM-VA-106 (1), Virginia: Faquier Co., unnamed tributary of Thumb Run at Co. Rt. 688, 300 yds. upstream from bridge, 7 May 1983. EGM-VA-107 (2), Virginia: Faquier Co., Carter Run at Co. Rt. 688 bridge, 7 May 1983. EGM-VA-115 (1), Virginia: Fairfax Co., Indian Run at bridge on Edsal Rd., 0.75 mi. E of I-395, 21 April 1984. EGM-VA-116 (3), Virginia: Fairfax Co., Indian Run at bridge on Edsal Rd, 0.75 mi. E of I-395, 21 April 1984. EGM-VA-117.1 (1), Virginia: Fairfax Co., Indian Run at bridge on Edsal Rd, 0.75 mi. E of I-395, 21 April 1984. EGM-VA-117.3 (1), Virginia: Fairfax Co., Indian Run at bridge on Edsal Rd, 0.75 mi. E of I-395, 21 April 1984. EGM-MD-121 (1), Maryland: Montgomery Co., unnamed creek of Monocacy R. on Rt. 28, 0.5 mi. from turnoff to PEPCO Dickerson Plant, 13 May 1984. EGM-VA-209 (2), Virginia: Fairfax Co., unnamed tributary of Indian Run, 0.5 mi. E of I-395 jct. with Edsal Rd. WSW-VA-365 (1) Virginia: Appomattox Co., small drainage near jct. St. Rt. 24 and Co. Rt. 627 opposite Appomattox National Park, 15 May 1987. WSW-VA-369 (1), Virginia: Hanover Co., tributary of Falling Cr. at Co. Rt. 667 approximately 2 mi. N of Ashland, 23 May 1987.

Semotilus corporalis. EGM-VA-54 (2), Virginia: Madison/Green Co. line, Conway R. at Rt. 667 and Rt. 613 bridge, 16 May 1982. EGM-VA-108 (2), Virginia: Faquier Co., Great Run at Rt. 211 bridge, 4 mi. W of Warrenton, 7 May 1983. WSW-VA-381 (2), Virginia: Campbell Co., Oppossum Cr. at bridge on Co. Rt. 669, 1 mi. S of Co. Rt. 664, 9 May 1988.

Semotilus lumbee. EGM-NC-104.1 (1), North Carolina: Moore Co., tributary of Drowning Cr., on Co. Rt. 1122, 2.3 mi. W of jct. with Co. Rt. 1004 at Foxfire, 25 April 1982. EGM-NC-105 (1), North Carolina: Moore Co., tributary of Drowning Cr., on Co. Rt. 1122, 2.3 mi. W of jct. with Co. Rt. 1004 at Foxfire, 16 April 1983. EGM-NC-208 (3), North Carolina: Moore Co., tributary of Drowning Cr., on Co. Rt. 1122, 2.3 mi. W of jct. with Co. Rt. 1004 at Foxfire, 16 April 1988.

Semotilus thoreauianus. EGM-GA-199 (1), Georgia: Stephens Co., Gibson Branch on Ray Rice's farm St. Rt. 124, 13 April 1986. EGM-GA-204 (1), Georgia: Barrow Co., tributary of Mulberry Cr. on W. C. Wade's farm on St.

Rt. 211, 3 mi. W of Winder, 11 April 1987. EGM-GA-207 (3), Georgia: Barrow Co., tributary of Mulberry Cr. on W. C. Wade's farm on St. Rt. 211, 3 mi. W of Winder, 10 April 1988. EGM-GA-208 (1), Georgia: Stephens Co., Aebulon Branch, tributary of N. Fork Broad R. on Ray Rice's property, approximately 1.5 mi. from jct. Rt. 124, N of Toccoa, 11 April 1988. EGM-NC-212 (1), North Carolina: Macon Co., tributary of Cullasaga R. at intersection of Horse Cove Rd. and Leonard Rd. in Highlands, 7 June 1988. EGM-NC-213 (1), North Carolina: Macon Co., North Fork , tributary of Little Tennessee R. on Co. Rt. 1115, 0.7 mi. N of jct with Co. Rt. 1112, approximately 1.8 mi. E of US Rt. 441, 8 mi. S of Franklin, 8 June 1988.

Vitae

James Timothy Magee was born on January 25, 1961 in Richmond, Virginia. He attended public schools in Colonial Heights, Virginia and graduated in 1979. In 1981 he entered Old Dominion University in Norfolk, Virginia to study biology and graduated with a Bachelor of Science degree in May 1985. He enrolled in the University of Richmond Graduate School in 1986 and graduated with the degree of Master of Science in Biology in May, 1989.