ILLINOIS NATURAL HISTORY SURVEY

EFFECTS OF DREDGE MATERIAL PLACEMENT ON MACROINVERTEBRATE COMMUNITIES: PHASE 1

CENTER FOR AQUATIC ECOLOGY

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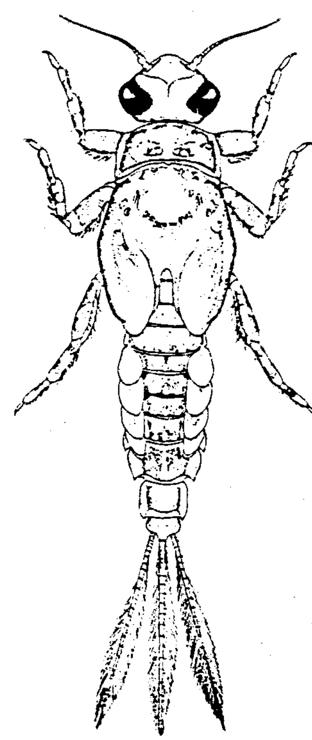
Submitted to the Rock Island District, U.S. Army Corps of Engineers



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Introduction

The U.S. Army Corps of Engineers Rock Island District is responsible for the operation and maintenance of a 9-foot-deep navigation channel on the Illinois River (Rm 80.0-327.0). Maintenance often requires removal of accumulated sediments; hydraulic dredging is often used with bankline placement of dredged material. Impacts of this dredged material on benthic macroinvertebrate communities is not well documented or understood. The major purpose of this study was to determine if there were differences in benthic macroinvertebrate abundances between sites which had received dredged material placement and those which had not.

Methods

Macroinvertebrate collections were made from offshore areas of main channel border habitat in La Grange Reach of the Illinois River during two separate sampling episodes (May/June 1997 and November 1997) (Figure 1). To select sampling sites we first identified 7800 sites at 0.01-mile intervals along each main channel border (right and left) of the 78-mile La Grange Reach (Figure 2). Using records from the Rock Island District, U.S. Army Corps of Engineers and discussions with district personnel, we identified the last date (year) dredged material was placed on each site. In this report, sites never receiving dredged material are referred to as "NP" (No Placement) sites. Sites on which dredged materials were placed are denoted as "P" (Placement) sites. For P sites, an accompanying number refers to the last date the P site received dredged material; therefore a P95 site last received dredged material in 1995. Because of the precision of the boundaries for areas receiving dredged material was poor (sometimes ±0.1 river miles), we designated buffer zones at the transitions between placement (P) and no placement (NP) areas (0.05 mile beyond or 0.10 mile inside the reported outer edge [upriver or downriver] of the dredged material placement site) and between areas receiving placement in different years (Figure 2); sites within these buffer zones were eliminated from the pool of potential sampling sites. Water level fluctuations may influence macroinvertebrate communities and tend to follow a gradient down the reach, therefore we attempted to distribute our sampling effort equally among the upper, middle, and lower thirds (sections) of the reach (Figure 1). For the May/June sampling we classified potential sampling sites into the following six treatments based on when they last received dredged material: never (NP), 1996 (P96), 1995 (P95), 1994 (P94), 1984-1992 (P84-92), and 1941-1969 (P41-69). Ten sample sites were selected randomly from each treatment for each section (third) of the reach (Table 1). We also generated a list of randomly selected alternate sites for each treatment and section. Because of limited dredging in the lower third of the reach in recent years, there we sampled only one P96 site and no P94 sites during the May/June episode (Table 1). Sample sites were located in the field using a hand-held global positioning system (GARMIN-GPS 75) and an Illinois Waterway Chart (U.S. Army Corps of Engineers 1987).

All macroinvertebrate collections were made using a 508-cm^2 Ponar grab sampler. Methods were adapted from those used by the invertebrate component of the Long Term Resource Monitoring Program (Thiel and Sauer 1995). Between 22 May and 4 June 1997, we collected triplicate Ponar grab samples at 161 sites along the main channel border of the La Grange Reach. If the Ponar did not collect a complete sample (i.e., a rock or shell kept the jaws from closing completely), that partial sample was discarded and another was taken. If a site contained large rocks or numerous shells from which a complete set of replicates could not be taken, another site was selected from the alternate sites list. Each sample was characterized by depth, substrate (hard clay, silt/clay, mostly silt/clay with sand, mostly sand with silt/clay, sand, or gravel/rock), and estimated percent shells and detritus (0, 1-20, 21-50, 51-90, or 91-100%). In the field, each sample was washed through a 1-mm-mesh screen. As the sample was washed, macroinvertebrates were picked from the screen and preserved in 10% formalin. The material retained on the screen was stained with Rose Bengal, preserved with 10% formalin, and returned to the laboratory for further processing. In the laboratory, samples were washed through a 600-μm sieve. Material retained on the sieve was examined under a 2x magnifier and macroinvertebrates were picked, sorted into one of six groups (i.e., mayflies, midges, fingernail clams, Asiatic clams, zebra mussels, or other), and enumerated. Mean numbers and densities of these target organisms were calculated.

Because the numbers of organisms collected were very low during our May/June episode, we decided to increase our sample size for the November episode by taking more Ponar grabs at fewer sites. For the November episode, we distributed our sampling effort among the following three treatment groups based on when they last received dredged material: never (NP), 1997 (P97), and 1996 (P96). We did not sample the lower section (third) of the reach during the November episode due to the limited dredging in recent years (Table 3). During the November sampling we sorted our macroinvertebrates into one of nine groups: (mayflies, midges, fingernail clams, Asiatic clams, zebra mussels, dragonflies, Unionid mussels, snails, or other). Between 7 November and 1 December 1997, we collected 15 Ponar grab samples at each of 35 sites for a total of 525 Ponar grab samples (Table 3).

Dredged Material Effect (May/June)

All statistical analyses were conducted utilizing SAS (1989). The numbers of invertebrates collected in all three ponar grabs were pooled for each of the six groups, producing a single sample for each site (site=replicate for treatment). The data collected from the 161 sites during May/June do not approximate a normal distribution and cannot be transformed to do so ($Pr<W$ 0.0001 for all variables). The data also fail the assumption of homogeneity of variance required for most parametric statistical tests, including ANOVA and Duncan's Multiple Comparisons tests (Zar 1984). Statistical procedures utilized were Chi-Square test of independence and Multivariate Analyses of Variance.

Dredged Material Effect (November)

For all eight invertebrate groups used for the November sampling, data for the 15 ponar grabs were combined to constitute a single sample for each of n=35 sites. Each site was classified by when it last received dredged material (year) (P97, P96, or NP) and river section (middle or upper), and frequency distributions of count data for each invertebrate group were analyzed individually for univariate normality using PROC UNIVARIATE. Since the assumptions of normality were rejected for all groups and the count data consisted of small numbers and many zeros, the data were logarithmically transformed by $\log_{10}+1$ (Zar 1984). Even after transformation the tests for normality were rejected ($P<W$ 0.0044 or less).

Effects of dredged material placement year on densities of invertebrates at sites were determined using a series of statistical analyses. For each invertebrate group, we utilized a fixed-effects (Type I) two-way factorial ANOVA with placement year and river section as the main effects (PROC GLM). Additional single-factor parametric as well as nonparametric Kruskal-Wallis ANOVAs (PROC NPAR1WAY) were conducted and provided similar results to the factorial design. Because results of the parametric and nonparametric tests were similar, we used the simpler two-way ANOVA to expedite preliminary analysis, and results as described in this paper are based upon the two-way ANOVA even though the data were not normally distributed. Likewise, Duncan's Multiple Range Tests (α=0.10) were used to determine significant differences among placement year means and among substrate types means for each invertebrate group. Future analyses will utilize nonparametric tests which are arguably more appropriate.

Substrate Effect (November)

Because 1-3 different substrate types often occurred at single sample sites, we calculated densities (mean#/m^2) of each invertebrate group for ponar grabs of equal substrate type at each site. Thirty-five sites provided n=58 site/substrate combinations (samples). Again each sample was classified by substrate type (silt/clay, mostly silt/clay with sand, mostly sand with silt/clay, or sand) and river section (middle or upper); frequency distributions of invertebrate count data (#/m^2) for each group individually were analyzed for univariate normality using PROC UNIVARIATE. As above, the assumptions of normality were rejected for all groups and the data were logarithmically transformed by $\log_{10} +1$ (Zar 1984). Even after transformation the tests for normality were rejected (P<W 0.0392 or less).

Effects of substrate type on densities of invertebrates at sites were determined utilizing a fixed-effects (Type I) two-way factorial ANOVA with substrate type and river section as the main effects (PROC GLM). Additional single-factor parametric as well as nonparametric Kruskal-Wallis ANOVAs (PROC NPAR1WAY) were conducted and provided similar results to the factorial design. Results described in this report are based upon the two-way ANOVA. Duncan's Multiple Range Tests (α=0.10) were used to determine significant differences among substrate type means for each invertebrate group.

Results

From 483 ponar grabs at 161 sites we identified a total of 158 invertebrates in samples collected in May/June 1997. Of these, 77 (48.7%) were midges, 48 (30.0%) were fingernail clams, and the remainder were mayflies, Asiatic clams, zebra mussels, or other taxa (Table 2).

Dredged Material Effect (May/June)

Overall, we observed higher densities of invertebrates at NP sites (0.98/m^2), P41-69 sites (2.29/m^2), and P84-92 sites (1.31/m^2) than P94 sites (0.65/m^2), P95 sites (0.47/m^2), and P96 sites (0.36/m^2), although these differences were not statistically significant. The MANOVA testing failed to identify statistically significant differences among NP, P96, P95, P94, P84-92, and P41-P69 sites (all reach sections combined) (F=1.362, Pr>F 0.117). The MANOVA testing also showed no differences among lower, middle, and upper sections of the La Grange Reach based on invertebrate abundances at sites (n=161) (F=1.556, Pr>F 0.102). Furthermore we detected no differences between NP sites and sites receiving dredged material during recent years (recent years = 1996, 1995, and 1994 combined) (n=101) (F=1.183, Pr>F 0.285).

Dredged Material Effect (November)

From 525 ponar grabs at 35 sites we identified a total of 1222 invertebrates in samples collected in November. Of these, 804 (65.8%) were midges, 73 (6.0%) were mayflies, 43 (3.5%) were fingernail clams, and the remainder were Asiatic clams, zebra mussels, dragonflies, freshwater mussels, snails, or other taxa (Table 4).

Overall, we observed significantly higher densities of invertebrates at NP sites than at P97 and/or P96 sites, although this varied somewhat among invertebrate groups (Table 4). Densities of mayflies, for example, were not significantly different (statistically) among treatments (P=0.2089) but ranged from an average of 5.98/m^2 at NP sites to 0.67/m^2 at P96 sites (Tables 4 and 6, Figure 3). Densities of midges were higher (P=0.0633) at NP and P97 sites (40.39/m^2 and 30.81/m^2, respectively) than at P96 sites. Densities of fingernail clams (P=0.0982) were higher at NP sites (2.84/m^2) than at P97 (0.00/m^2) (Tables 4 and 6, Figure 3). Fingernail clam densities at P96 sites were intermediate (1.35/m^2). Densities of Asiatic clams were higher (P=0.0141) at NP sites (2.25/m^2) than at P96 sites (0.19/m^2) or P97 sites (0.00/m^2). Densities of zebra mussels were higher (P=0.0377) at NP sites (3.04/m^2) than at P96 sites (0.19/m^2) or P97 sites (0.00/m^2)

(Tables 4 and 6, Figure 4). Densities of dragonflies were not significantly different among treatments (P=0.3074) but densities were 0.29/m^2 at NP sites and 0.10/m^2 at P96 sites. No dragonflies were collected at P97 sites. Densities of unionid mussels were higher (P=0.1143) at NP sites (2.06/m^2) than at P97 sites (0.19/m^2) (Tables 4 and 6, Figure 4). Unionid mussels at P96 sites were intermediate (0.77/m^2). Densities of snails were higher (P=0.0041) at NP sites (3.04/m^2) than at P96 sites (0.19/m^2) or P97 sites (0.00/m^2).

Substrate Effect (November)

Overall, we observed significantly higher densities of invertebrates in silt/clay substrate than in mostly silt/clay with sand, mostly sand with silt/clay, and/or sand substrates (Table 5). Densities of mayflies were higher (P=0.0302) in silt/clay (9.65/m^2) than in all other substrate types (range 0.48/m^2 - 0.78/m^2) (Tables 5 and 6, Figure 5). Densities of midges were significantly higher (P=0.0645) in silt/clay (54.15/m^2) but were also relatively high in mostly silt/clay with sand (27.96/m^2), mostly sand with silt/clay (17.54/m^2), and sand (25.49/m^2). Densities of fingernail clams were higher (P=0.0176) in silt/clay (4.51/m^2) than in all other types (range 0.00/m^2-1.55/m^2) (Tables 5 and 6, Figure 5). No fingernail clams were collected in sand. Densities of Asiatic clams were higher (P=0.2331) in silt/clay (1.87/m^2) than in sand (0.00/m^2). Asiatic clams were intermediate in density in mostly silt/clay with sand (1.36/m^2) and mostly sand with silt/clay (0.96/m^2). Densities of zebra mussels were higher (P=0.0020) in silt/clay (4.05/m^2) than in all other substrate types (range 0.00/m^2-0.58/m^2) (Tables 5 and 6, Figure 6). No zebra mussels were collected in sand. Densities of dragonflies were not significantly different among substrate types (P=0.2642) but ranged from an average of 0.47/m^2 in silt/clay to 0.00/m^2 in mostly silt/clay with sand and sand. Densities of unionid mussels were not significantly different among substrate types (P=0.3492) but ranged from an average of 1.87/m^2 in silt/clay to 0.52/m^2 in sand (Tables 5 and 6, Figure 6). Densities of snails were higher (P=0.1159) in silt/clay (3.11/m^2) than in mostly sand with silt/clay (0.80/m^2) and sand (0.13/m^2). Snails in mostly silt/clay with sand were intermediate in density (1.36/m^2).

Discussion

The May/June sampling resulted in very few invertebrates as compared to the November episode, probably due in part to the life cycles of our target organisms. Our May/June sampling occurred when many organisms were emerging from their larval and pupae stages and new recruitment had not yet taken place; this resulted in low numbers of organisms in our samples. Sampling in November occurred after reproduction and numbers for most groups were higher; therefore we focused our attention on the November samples.

Dredged Material Effect (November)

The NP sites contained higher numbers of the target organisms than either of the dredged material sites. Several factors may account for the lower densities in the P sites. The most obvious is direct burial of organisms by the dredged material. Many organisms are killed outright while others are unable to reach the surface before they suffocate. Another effect of dredged material placement is severe habitat alteration resulting from the change in the physical and chemical characters of the bottom sediments, loss of cover, or change in circulation patterns at the disposal site (Morton 1977).

Substrate Effect (November)

Substrate type seemed to be related to the year the site had received dredged material. Sites that had not received dredged material (NP sites) usually had substrates composed mainly of silt/clay (55%) and mostly silt/clay with sand (31%). Sites which received dredged material in 1996 (P96 sites) had substrates of mostly sand with silt/clay (47%), sand (25%), and mostly silt/clay with sand (18%). Sand was the dominate substrate at 93% of the sites that received dredged material in 1997 (P97 sites). Many organisms found in the main channel border habitat such as mayflies, fingernail clams, and dragonflies require harder more stable substrates which they can burrow into or cling to in the faster current (Nuttall 1972; Ali and Mulla 1976). Our results showed that the silt/clay substrate generally supported a higher density of all target organisms, whereas sand substrates supported very low numbers of organisms except in the case of small-bodied midges. Midges have short life cycles, rapid colonization, and high turnover rates and can adapt to different substrate types (Benke 1984). Reduced species richness and abundance are commonly associated with areas of shifting sand, although certain species of mayflies and midge larva apparently prefer this substrate (Nuttall 1972; Ali and Mulla 1976).

References

Ali, A., and Mulla, M. S. 1976. Substrate type as a factor influencing spatial distribution of chironomid midges in an urban flood control channel system. Pages 362-372 in V. H. Resh and D. M. Rosenberg, editors. The ecology of aquatic insects. Praeger Publishers, New York, New York, USA.

Benke, A. C., T. C. Van Arsdall, Jr., D. M. Gillespie, and F. K. Parrish 1984. Invertebrate productivity in a subtropical blackwater river: The importance of habitat and life history. Ecological Monographs 54:25-63.

Morton, J. W. 1977. Ecological effects of dredging and dredge spoil disposal: A literature review. Technical paper of the U.S. Fish and Wildlife Service, U.S. Department of the Interior, Washington, D. C.

Nuttall, P. M. 1972. The effects of sand deposition upon the macroinvertebrate fauna of the River Camel, Cornwall. Pages 372-377 in V. H. Resh and D. M. Rosenberg, editors. The ecology of aquatic insects. Praeger Publishers, New York, New, York, USA.

Thiel, P. A., and J. S. Sauer. 1995. Long Term Resource Monitoring Program Procedures: Macroinvertebrate monitoring. National Biological Service, Environmental Management Technical Center, Onalaska, Wisconsin, August 1995. LTRMP 95-P002-2. 9pp. + Appendixes A-G.

United States Army Engineer District. 1974. Charts of the Illinois waterway. Corps of Engineers, Chicago, Illinois, USA.

Zar, J. H. 1984. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA.

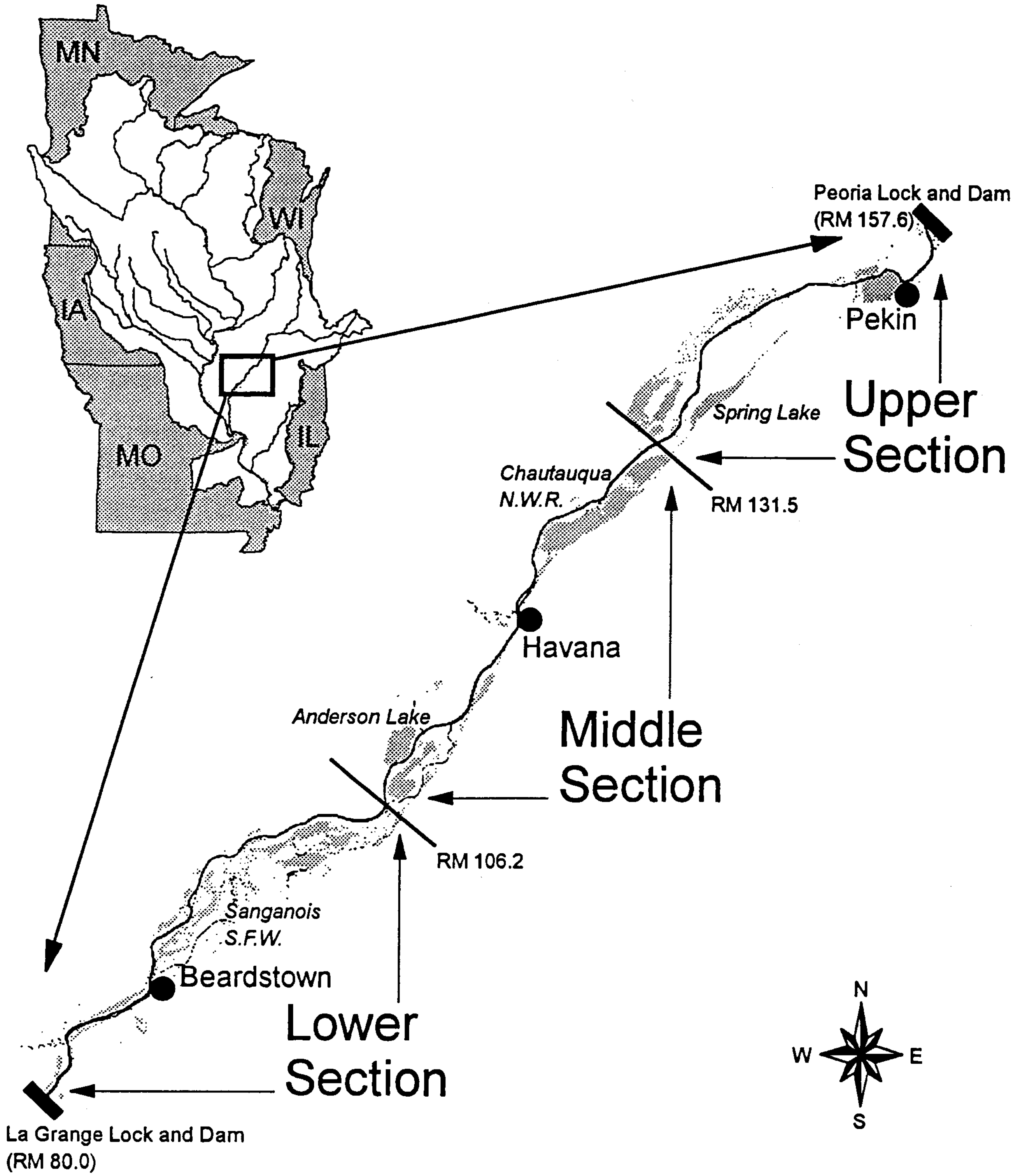
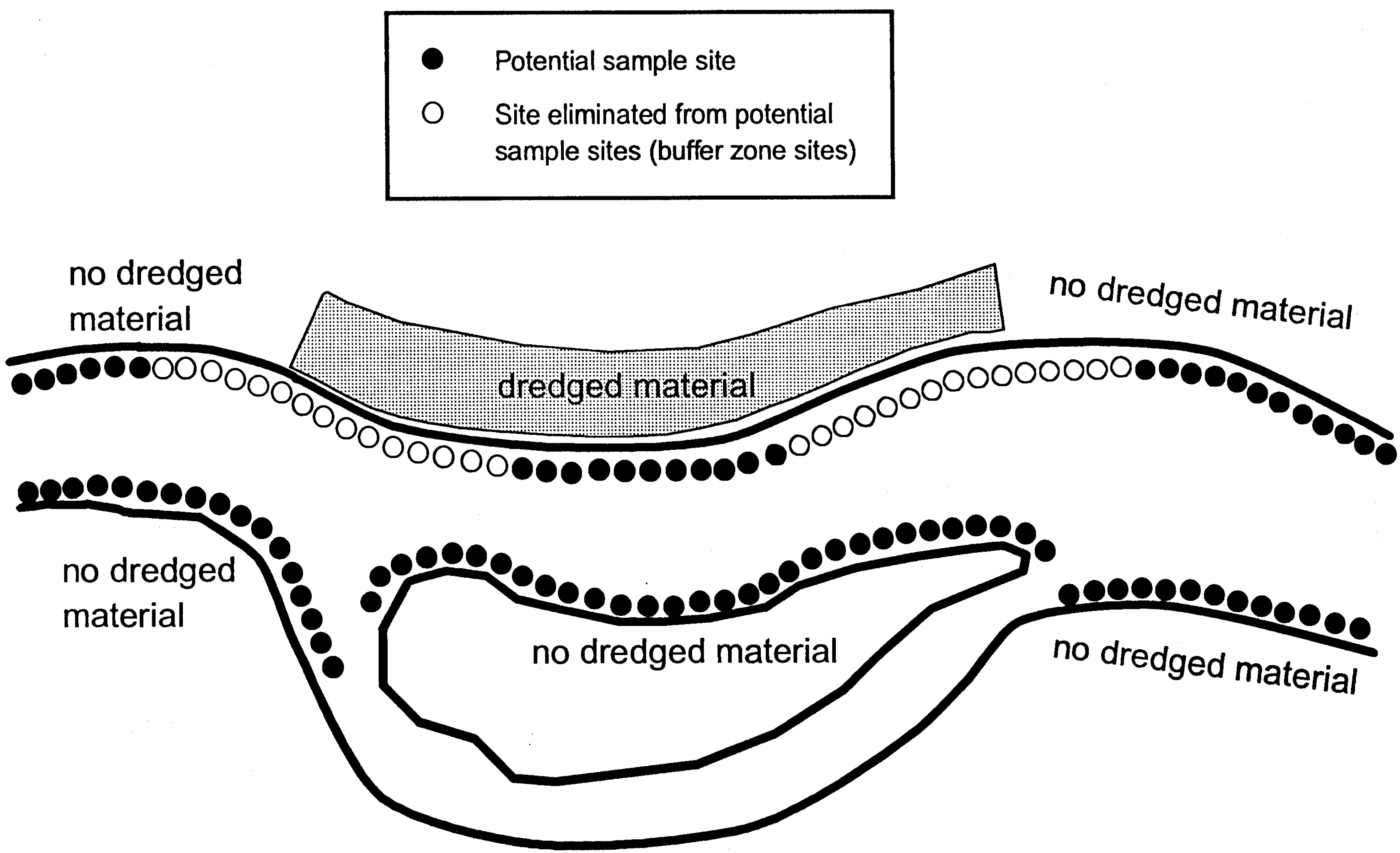


Figure 1. Upper, middle, and lower sections of the La Grange Reach (RM 80.0-157.6) of the Illinois River sampled for invertebrates during May/June and November, 1997.

Figure 2. Example of potential sampling sites and sites eliminated from potential sampling sites (buffer zones).



Last received dredged material (year)	Upper	Middle	Lower	Total
1996	10	10	1	21
1995	10	10	10	30
1994	10	10	0	20
1984-1992	10	10	10	30
1941-1969	10	10	10	30
Never	10	10	10	30
Total	60	60	41	161

Section (third) of reach

Table 1. Sites sampled in May/June 1997 (3 ponar samples/site).

Last received dredged material (year)		Mayfly	Midge	Fingernail clam	Asiatic clam	Zebra mussel	Other	Overall
1996								
	Total organisms	3	3	1	0	0	0	7
	Ponar grabs	63	63	63	63	63	63	63
	Mean density (#/m²)	0.93	0.93	0.31	0	0	0	0.36
	Standard error	0.53	0.69	0.31	0	0	0	0.38
1995								
	Total organisms	1	8	2	0	0	2	13
	Ponar grabs	90	90	90	90	90	90	90
	Mean density (#/m²)	0.22	1.74	0.44	0	0	0.44	0.47
	Standard error	0.22	1.1	0.31	0	0	0.31	0.49
1994								
	Total organisms	1	6	2	0	3	0	12
	Ponar grabs	60	60	60	60	60	60	60
	Mean density (#/m²)	0.33	1.96	0.65	0	0.98	0	0.65
	Standard error	0.33	1.01	0.65	0	0.56	0	0.56
1984-1992								
	Total organisms	0	21	10	0	1	4	36
	Ponar grabs	90	90	90	90	90	90	90
	Mean density (#/m²)	0	4.58	2.18	0	0.22	0.87	1.31
	Standard error	0	1.52	0.72	0	0.22	0.53	0.74
1941-1969								
	Total organisms	6	23	28	1	1	4	63
	Ponar grabs	90	90	90	90	90	90	90
	Mean density (#/m²)	1.31	5.01	6.1	0.22	0.22	0.87	2.29
	Standard error	0.81	1.4	2.47	0.22	0.22	0.61	1.26
Never								
	Total organisms	6	16	5	0	0	0	27
	Ponar grabs	90	90	90	90	90	90	90
	Mean density (#/m²)	1.31	3.49	1.09	0	0	0	0.98
	Standard error	0.75	1.05	0.48	0	0	0	0.57
Overall								
	Total organisms	17	77	48	1	5	10	158
	Ponar grabs	483	483	483	483	483	483	483
	Mean density (#/m²)	0.69	3.13	1.95	0.04	0.2	0.41	1.07
	Standard error	0.22	0.51	0.51	0.04	0.09	0.16	0.32

Table 2. Total organisms, mean density, and standard error from each placement year during May/June 1997 sampling.

Section (third) of reach

Last received dredged material (year)	Upper	Middle	Lower	Total
1997	7	0	0	7
1996	7	7	0	14
Never	7	7	0	14
Total	21	14	0	35

Table 3. Sites sampled in November 1997 (15 ponar samples/site).

Last received dredged material (year)		Mayfly	Midge	Fingernail clam	Asiatic clam	Zebra mussel	Dragonfly	Unionid mussel	Snail	Other	Overall
1997	Total organisms	5	165	0	0	0	0	1	0	5	176
	Ponar grabs	105	105	105	105	105	105	105	105	105	105
	Mean density (#/m ^{2})	0.93	30.81	0	0	0	0	0.19	0	0.93	3.65
	Standard error	0.41	4.57	0	0	0	0	0.19	0	0.41	0.6
1996	Total organisms	7	227	14	2	2	1	8	2	50	313
	Ponar grabs	210	210	210	210	210	210	210	210	210	210
	Mean density (#/m ^{2})	0.67	21.82	1.35	0.19	0.19	0.1	0.77	0.19	4.8	3.33
	Standard error	0.25	2.57	0.52	0.19	0.14	0.1	0.3	0.14	1.5	0.37
Never	Total organisms	61	412	29	23	31	3	21	31	122	733
	Ponar grabs	210	210	210	210	210	210	210	210	210	210
	Mean density (#/m ^{2})	5.98	40.39	2.84	2.25	3.04	0.29	2.06	3.04	11.84	7.94
	Standard error	1.38	4.86	0.75	0.54	1.01	0.17	0.51	0.64	2.9	0.72
Overall	Total organisms	73	804	43	25	33	4	30	33	177	1222
	Ponar grabs	525	525	525	525	525	525	525	525	525	525
	Mean density (#/m ^{2})	2.81	30.97	1.66	0.96	1.27	0.15	1.15	1.27	6.81	5.21
	Standard error	0.57	2.39	0.36	0.23	0.41	0.08	0.24	0.26	1.31	0.35

Table 4. Total organisms, mean density, and standard error from each placement year during November 1997 sampling.

Substrate		Mayfly	Midge	Fingernail clam	Asiatic clam	Zebra mussel	Dragonfly	Unionid mussel	Snail	Other	Overall
1	Total organisms	0	7	0	0	2	0	0	0	0	9
	Ponar grabs	9	9	9	9	9	9	9	9	9	9
	Mean density (#/m ^{2})	0	15.25	0	0	4.36	0	0	0	0	2.18
	Standard error	0	5.45	0	0	2.88	0	0	0	0	0.84
2	Total organisms	62	348	29	12	26	3	12	20	92	604
	Ponar grabs	136	136	136	136	136	136	136	136	136	136
	Mean density (#/m ^{2})	9.65	54.15	4.51	1.87	4.05	0.47	1.87	3.11	14.32	10.44
	Standard error	2.05	6.57	1.24	0.5	1.51	0.26	0.62	0.81	3.11	1.02
3	Total organisms	4	144	8	7	3	0	8	7	56	237
	Ponar grabs	104	104	104	104	104	104	104	104	104	104
	Mean density (#/m ^{2})	0.78	27.96	1.55	1.36	0.58	0	1.55	1.36	10.87	5.11
	Standard error	0.38	4.95	0.59	0.73	0.33	0	0.59	0.49	4.43	0.81
4	Total organisms	3	110	6	6	2	1	6	5	17	156
	Ponar grabs	126	126	126	126	126	126	126	126	126	126
	Mean density (#/m ^{2})	0.48	17.54	0.96	0.96	0.32	0.16	0.96	0.8	2.71	2.76
	Standard error	0.27	2.27	0.44	0.49	0.22	0.16	0.44	0.47	1.93	0.39
5	Total organisms	4	195	0	0	0	0	4	1	12	216
	Ponar grabs	150	150	150	150	150	150	150	150	150	150
	Mean density (#/m ^{2})	0.52	25.49	0	0	0	0	0.52	0.13	1.57	3.14
	Standard error	0.26	3.72	0	0	0	0	0.26	0.13	0.57	0.47
Overall	Total organisms	73	804	43	25	33	4	30	33	177	1222
	Ponar grabs	525	525	525	525	525	525	525	525	525	525
	Mean density (#/m ^{2})	2.81	30.97	1.66	0.96	1.27	0.15	1.15	1.27	6.81	5.21
	Standard error	0.57	2.39	0.36	0.23	0.41	0.08	0.24	0.26	1.31	0.35

Substrate
1 Hard Clay
2 Silt/Clay
3 Mostly Silt/Clay with Sand
4 Mostly Sand with Silt/Clay
5 Sand

Table 5. Total organisms, mean density, and standard error from each substrate during November 1997 sampling.

Source of variation	Mean square	*F*	df	*P*
	Mayfly			
Dredged material effect				
Year dredged*	0.1898	1.65	2	0.2089
Section	0.5184	4.51	1	0.0421
Year dredged* x section	0.2425	2.11	1	0.1568
Substrate effect				
Substrate type	0.0214	3.23	3	0.0302
Section	0.0032	0.49	1	0.4881
Substrate type x section	0.0165	2.49	3	0.0710
	Midge			
Dredged material effect				
Year dredged*	0.6629	3.03	2	0.0633
Section	0.3127	1.43	1	0.2413
Year dredged* x section	0.1282	0.59	1	0.4499
Substrate effect				
Substrate type	0.1168	2.57	3	0.0645
Section	0.0006	0.01	1	0.9088
Substrate type x section	0.0252	0.55	3	0.6472
	Fingernail clam			
Dredged material effect				
Year dredged*	0.2506	2.51	2	0.0982
Section	0.0533	0.53	1	0.4706
Year dredged* x section	0.1691	1.69	1	0.2030
Substrate effect				
Substrate type	0.0090	3.70	3	0.0176
Section	0.0013	0.57	1	0.4548
Substrate type x section	0.0087	3.56	3	0.0206
	Asiatic clam			
Dredged material effect				
Year dredged*	0.2641	4.93	2	0.0141
Section	0.1869	3.49	1	0.0716
Year dredged* x section	0.0635	1.19	1	0.2848
Substrate effect				
Substrate type	0.0026	1.47	3	0.2331
Section	0.0034	1.89	1	0.1755
Substrate type x section	0.0012	0.70	3	0.5567
	Zebra mussel			
Dredged material effect				
Year dredged*	0.2827	3.66	2	0.0377
Section	0.1512	1.96	1	0.1717
Year dredged* x section	0.0435	0.56	1	0.4584
Substrate effect				
Substrate type	0.0136	5.68	3	0.0020
Section	0.0023	0.97	1	0.3283
Substrate type x section	0.0021	0.88	3	0.4555
	Dragonfly			
Dredged material effect				
Year dredged*	0.0116	1.23	2	0.3074
Section	0.0129	1.36	1	0.2521
Year dredged* x section	0.0000	0.00	1	1.0000
Substrate effect				
Substrate type	0.0001	1.36	3	0.2642
Section	0.0002	2.01	1	0.1628
Substrate type x section	0.0000	0.63	3	0.6012
	Unionid mussel			
Dredged material effect				
Year dredged*	0.1526	2.33	2	0.1143
Section	0.0174	0.27	1	0.6093
Year dredged* x section	0.2079	3.18	1	0.0847
Substrate effect				
Substrate type	0.0037	1.12	3	0.3492
Section	0.0000	0.02	1	0.8908
Substrate type x section	0.0027	0.82	3	0.4903
	Snail			
Dredged material effect				
Year dredged*	0.4414	6.64	2	0.0041
Section	0.0044	0.07	1	0.7982
Year dredged* x section	0.0864	1.30	1	0.2633
Substrate effect				
Substrate type	0.0038	2.07	3	0.1159
Section	0.0005	0.31	1	0.5774
Substrate type x section	0.0020	1.09	3	0.3629

* Year of last dredged material placement

Table 6. Analysis of variance (ANOVA) for year dredged and substrate type using 2-way factorial design for each of the eight invertebrate groups.

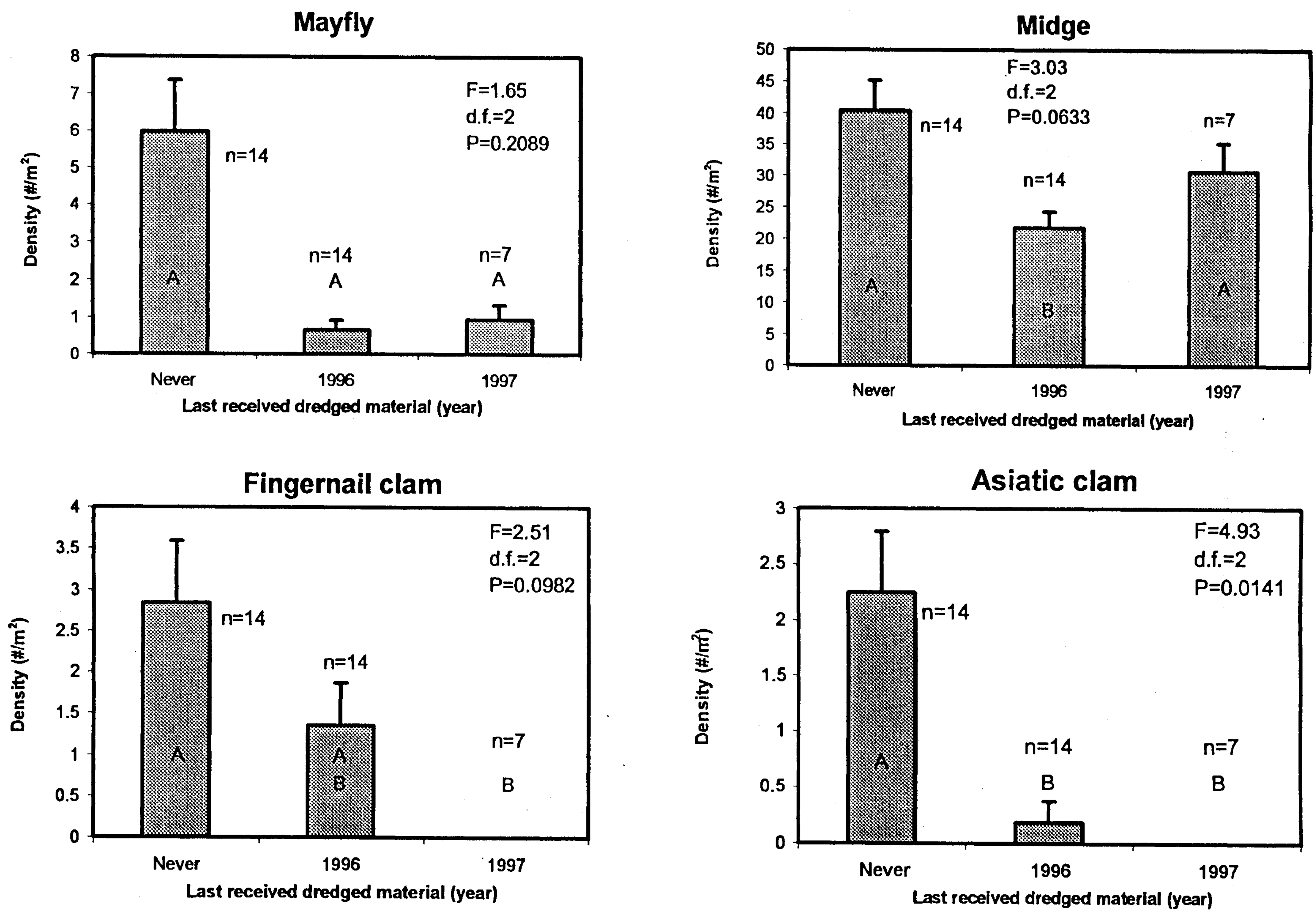


Figure 3. Mean densities of mayflies, midges, fingernail clams, and Asiatic clams during November 1997 sampling. For each taxon, treatments with different letters are significantly different ($P<0.10$).

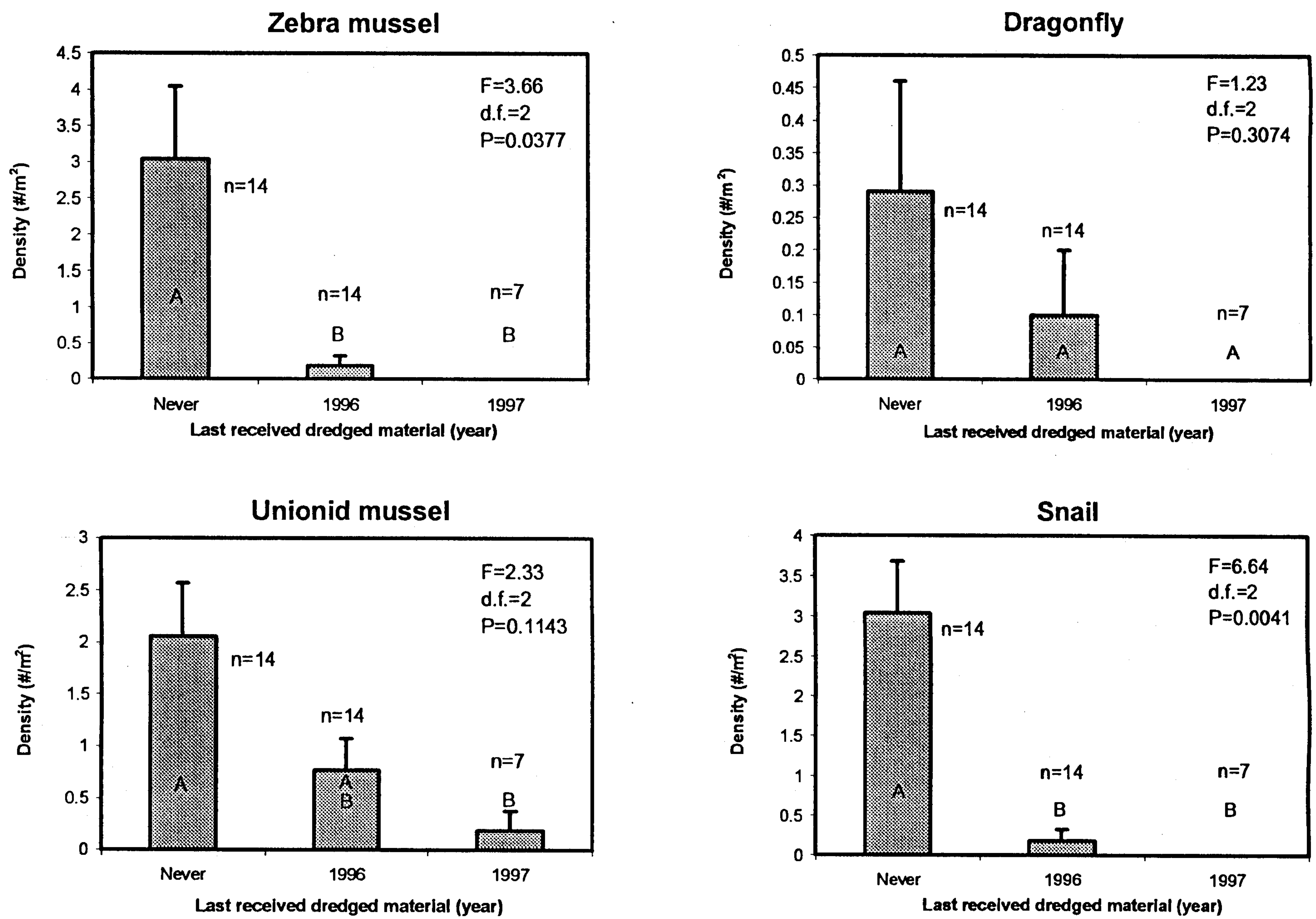


Figure 4. Mean densities of zebra mussels, dragonflies, Unionid mussels, and snails during November 1997 sampling. For each taxon, treatments with different letters are significantly different ($P<0.10$).

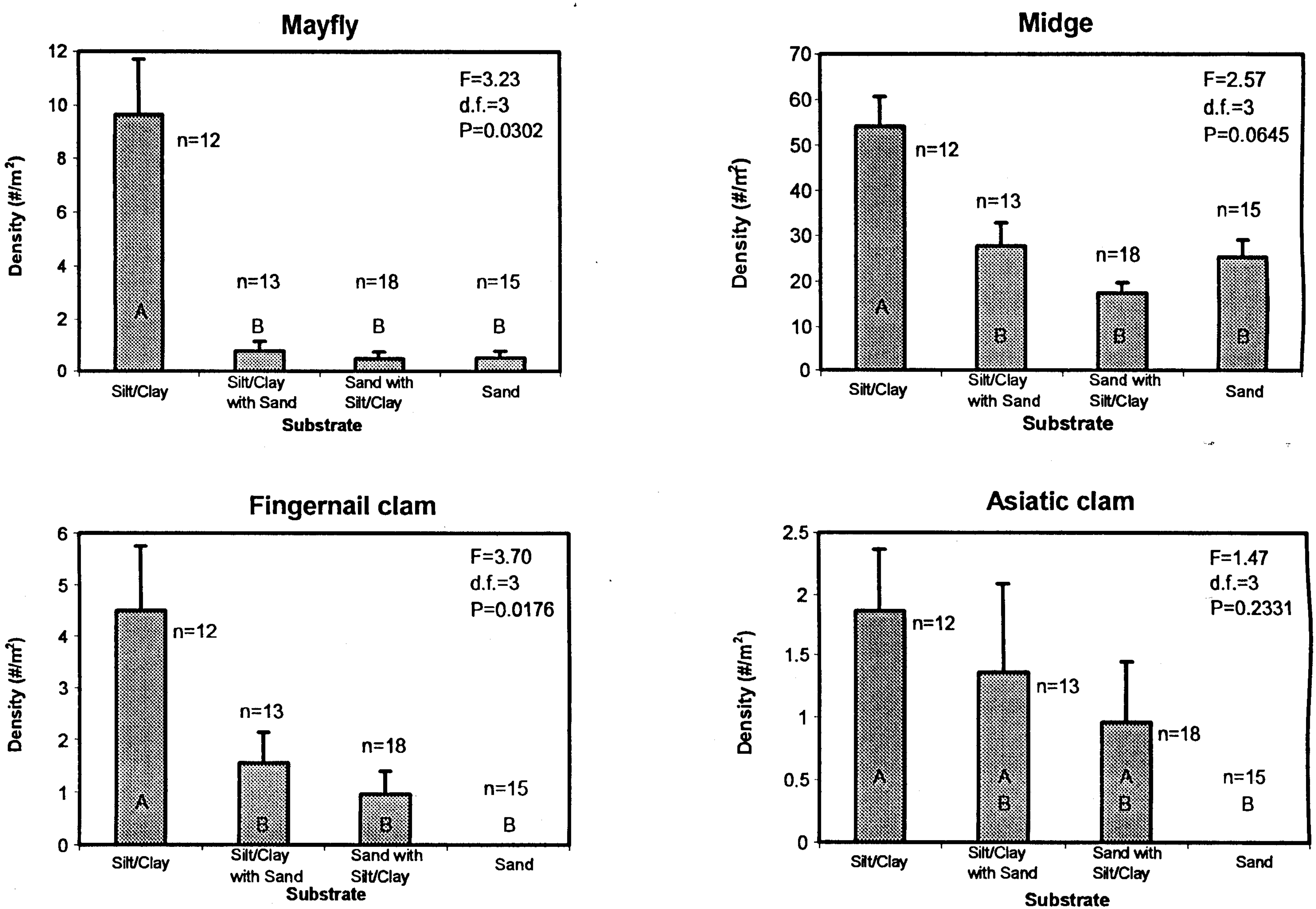


Figure 5. Mean densities of mayflies, midges, fingernail clams, and Asiatic clams during November 1997 sampling. For each taxon, treatments with different letters are significantly different ($P<0.10$).

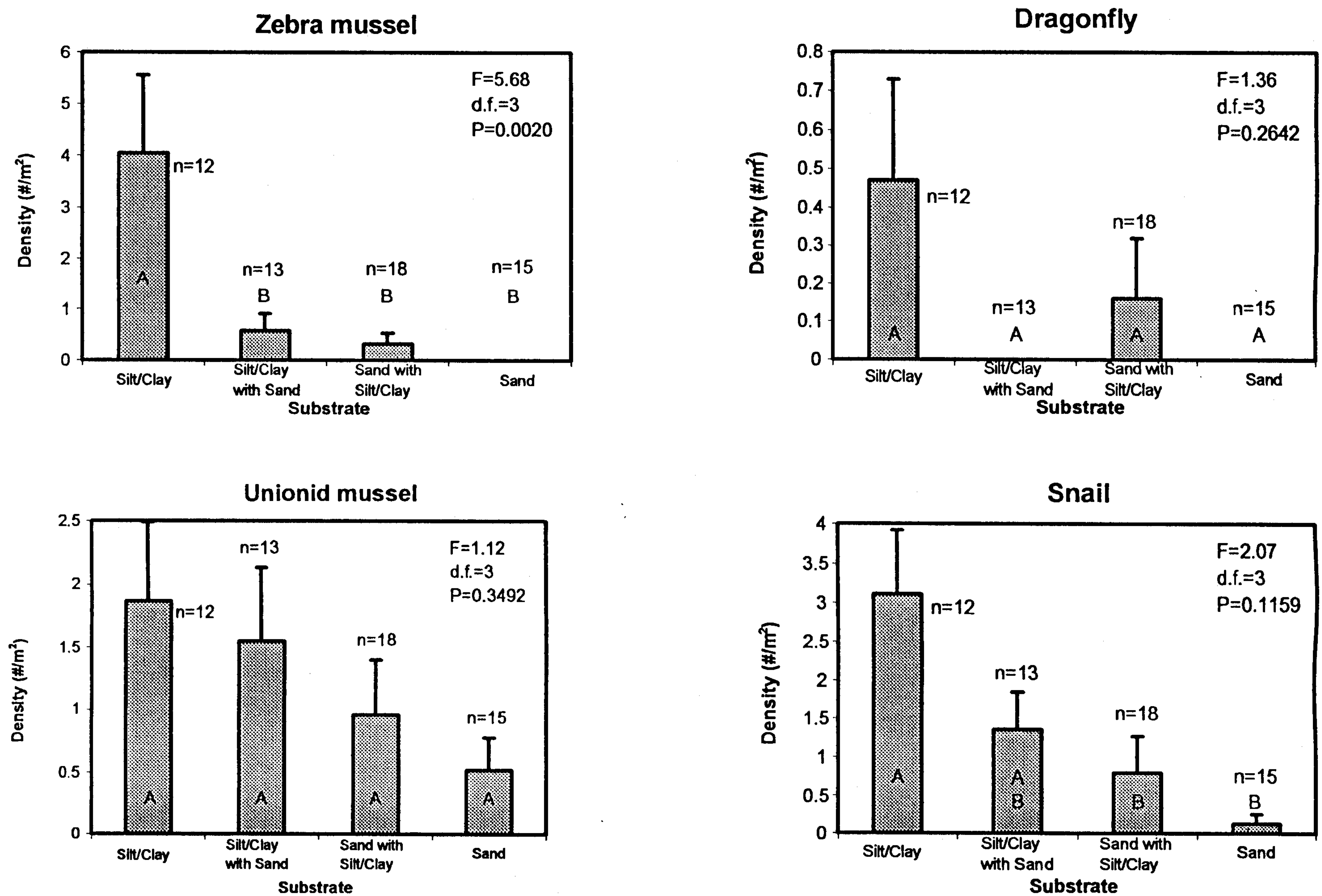


Figure 6. Mean densities of zebra mussels, dragonflies, Unionid mussels, and snails during November 1997 sampling. For each taxon, treatments with different letters are significantly different ($P<0.10$).