

Effects of Periodically Disturbing a Small Area of Substratum in a Brown-water Stream of Alberta, Canada¹

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Abstract. A small substratum area of a brown-water stream was thoroughly disrupted at about 15-day intervals for 2.5 months. The disruptions resulted in a more homogeneous substratum, with relatively more gravel and less fine sand in the experimental area. Twenty of the 24 taxa had a smaller mean density in the experimental area by the end of the study. Of these taxa, 11 exhibited significantly ($P < 0.05$) smaller numbers in the experimental area. Nevertheless, considering how frequent and thorough the disturbances were, the overall effect could not be described as severe. Due to life cycle features of various species, many taxa increased in absolute abundances throughout the study in both the experimental and control areas. Unavoidable disturbances of substrata must be common in most streams where the fauna is studied intensively over long periods. Results of this study would indicate that routine sampling of the benthos in the Bigoray River would not have a pronounced effect, probably not even a discernible effect, on the structure of the stream community. Data of the Bigoray River study, and most other studies pertaining to recolonization, deal only with structure of the stream's community. The disturbances undoubtedly had a much greater impact on the underlying functional organization of the community.

Since 1965, several studies have been carried out on a small area of a brown-water stream, the Bigoray River, of west-central Alberta, Canada (Clifford 1978). In all studies there was unavoidable disturbance of the substratum. Often these disturbances appeared minor, e.g., simply walking in the stream to collect water samples, positioning drift nets, or collecting quantitative bottom fauna samples. Other activities, where large areas of the stream bed were sampled, such as qualitatively collecting organisms with a dip net for life cycle studies, appeared to have a much more disruptive effect on the substratum. For several of the Bigoray River studies, these qualitative collections were repeated at about 15-day intervals throughout the ice-free season. Falk (1974) discusses potential impact by the experimenter on aquatic systems where studying a particular environment might be disturbing that environment. By considering the experimenter as a consumer, Falk concludes that experimenter-induced bias can be significant.

Unavoidable disturbances of substrata must be common in most streams when the fauna is studied intensively over long periods. It would be instructive to know how these unnatural disturbances affect the natural assemblages of organisms. Workers (e.g., Waters 1964; Coleman & Hynes 1970; Allan 1975; Reice 1980) have studied the rate that organisms recolonize small areas of denuded natural substrata. The consensus is that stream invertebrates rapidly recolonize, presumably mainly via drift, the denuded areas. In some cases the areas appear to be substantially recolonized in one or two days or by a month at most. Minshall and Minshall (1977) altered the substratum of an Idaho stream by plowing the stream bed; they found the disruption made flow more uniform, and most aquatic invertebrates increased in abundance. Results of dredging studies (e.g., Rees 1959; Meehan 1971; Pearson & Jones 1975) also indicate only short-term (but usually measured in months instead of days) effects on stream invertebrates. Ward (1975) found few changes in fauna-substratum relationships over a long period (1945 & 1974) in a stream where the

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substratum apparently remained relatively undisturbed.

I report here the result of thoroughly disrupting the substratum in a small area of the Bigoray River at about 15-day intervals for 2.5 months. The objective was to assess how these periodic catastrophic disturbances might affect numbers, kinds, and distribution of stream invertebrates over a long period.

STUDY AREA

A detailed limnological description of the Bigoray River is given by Clifford (1978). The brown-water stream, part of the Arctic Ocean Drainage, is a third order stream at the sampling site (53°31'N, 115°26'W). It is a meandering, slow-moving stream draining extensive muskeg terrain, which imparts a dark color to the water, especially in late summer. At the sampling site the stream is small, average summer base flow being 0.80 m³/sec. Maximum water temperatures seldom exceed 18° C. Chironomidae (35%), Ephemeroptera (17%), Ostracoda (13%), and Trichoptera (8%) account for 73% of the total yearly bottom fauna by numbers when averaged over several years. In Cushing's et al. (1980) multivariate analysis of 34 streams, the Bigoray River's physical and chemical variables were in a stream cluster characterized by high solar radiation, large drainage basins, low-channel length to watershed area ratios and, when related to allied clusters, greater winter and summer base flows, precipitation regimes, and lower phosphorus content.

METHODS

Stream invertebrates were collected with a modified Neil-type box sampler that enclosed an area of 844 cm² and sampled to a depth of 7 cm (Clifford 1972). The attached net had a pore size of 150 μm. Substratum samples were collected with a cannister, 10 cm in diameter, that sampled to a depth of 12 cm. In the laboratory, the substratum was separated into particle size classes by dry sieving (Cummins 1962), using a Pascall Engineering mechanical shaker and a series of sieves. No attempt was made to determine the silt and clay component by settling velocity methods. The silt and clay (particle size < 0.06 mm) component recorded in the analysis was determined by the dry sieving technique only.

I selected two areas with seemingly similar substrata, current (average mid-summer water velocity was 20 cm/sec), and depth. The downstream area was the experimental area, approximately 4 m wide and 3 m in length. The upstream control area was longer, in order that the bottom fauna could be sampled progressively upstream at each sampling interval. This ensured there was no experimenter-induced bias in collecting organisms from the control area. On 26 June 1979, four bottom fauna samples each were taken from the experimental and control sites. We then simulated a small-scale catastrophic disturbance by vigorously disrupting the substratum of the entire experimental area. Rakes and hoes were used but the most effective method appeared to be simply walking in the substratum and plowing down to the hardpan with boots on. The disruption, accomplished by three people for ca. 25 min, extended to the substratum's hardpan to ensure that hyporheic areas could not serve as refugia. There was no attempt at physically removing substratum particles, but many of the finer particles were washed downstream.

Two bottom fauna samples were taken immediately after the disturbance of 26 June (and again after the disturbance of 10 July) to test the effectiveness of the disruption. The total fauna was reduced by 80%. For the abundant taxa the reduction ranged from 97% for Baetidae to 63% for *Zapada cinctipes* (Plecoptera). These data might be somewhat misleading because most of the organisms recovered immediately after the disturbance appeared to be badly damaged; most had probably been killed but had not washed out of the area. Nevertheless, the disturbance, as thorough as we attempted to make it, was obviously not 100% effective in removing all organisms. The same sequence of events (i.e.,

four bottom samples from experimental and control areas prior to the disturbance, then disturbing the experimental area) were repeated on 10 July, 25 July, 10 August, and 27 August.

RESULTS

Substratum

The substratum of the experimental site consists mainly of fine particles. Average particle size for the three sampling dates combined (eight samples) was 1.70 mm and average particle size heterogeneity, the 60/10 quotient (quotient between particle size at 60 weight percent and 10 weight percent, see Schwoerbel 1970), was 21.5. The periodic disruptions did not result in a large change of the substratum's cumulative percent weight profile, although this assessment is based on a small sample size (Fig. 1). The periodic disruptions resulted in relatively more gravel and less fine sand in the experimental area. This suggests that vigorously disturbing the substratum accounted for a loss of fine sand and the finer silts and clays to the water column and hence downstream. The current was probably not strong enough to move much of the coarser sand or gravel downstream. Between disturbances, the fine silt and clay component could have been replenished from upstream, since these materials are normally carried in the water column; whereas at average flow there was probably less of the relatively heavier sands being moved downstream. The disturbance resulted in a more homogeneous substratum. The average 60/10 quotient of the three samples prior to the first disturbance (26 June) was 23.7, whereas for the one sample of 27 August, the quotient was 7.09.

Fauna

To facilitate analysis, the 60 taxa identified during the study were grouped into 24 easily recognizable taxonomic units (Table 1). Chironomid larvae were the most abundant taxon, making up about a third of the total fauna in both the control and experimental areas. Chironomids were not separated into more definitive categories for this study. Tanytarsini (55%) and Tanypodinae (20%) accounted for 75% of the total chironomids emerging from the Bigoray River in July and August, 1973 (Boerger 1978). Five taxa, Chironomidae, Baetidae (mainly *Baetis tricaudatus* but some *Centroptilum* spp.), other Ephemeroptera (mainly *Leptophlebia cupida*), Oligochaeta (mainly Naididae) and Ostracoda, accounted for three-fourths the total numbers in both the control and experimental areas.

Many taxa increased in abundance throughout the study in both the experimental and control areas (Fig. 2). This was due to life cycle features of the various species, July and August being months when large numbers of individuals of the new generations first appear in the stream (Clifford 1978). The disturbances resulted in a relative decrease in abundance for most taxa in the experimental area (Table 1). Twenty taxa had a smaller mean density in the experimental area than in the control area. *Dicranota*, *Paraleptophlebia*, *Ephemera simulans* and Nematoda had a larger mean density in the experimental area; but the sample sizes of *E. simulans* and *Dicranota* were very small, and an adequate assessment of nematode abundance was hampered by the relatively large mesh size (150 μm) used to collect these minute organisms.

No taxon was eliminated from the experimental area. The cumulative adverse effects appeared to act most strongly on the oligochaetes, ostracods, and elmid larvae (Fig. 2). Species diversities (the Shannon-Weaver function, mean diversity, \bar{d} , being calculated by the machine formula of Lloyd, Zar and Karr (1968) of the control (\bar{d} of the four dates = 2.88) and experimental (\bar{d} = 2.72) areas were not significantly different ($P < 0.05$), but the taxonomic units in most cases were much broader than desirable for diversity calculations.

Transformational and Statistical Tests

Prior to performing parametric statistical tests, the count for each taxon of each 844

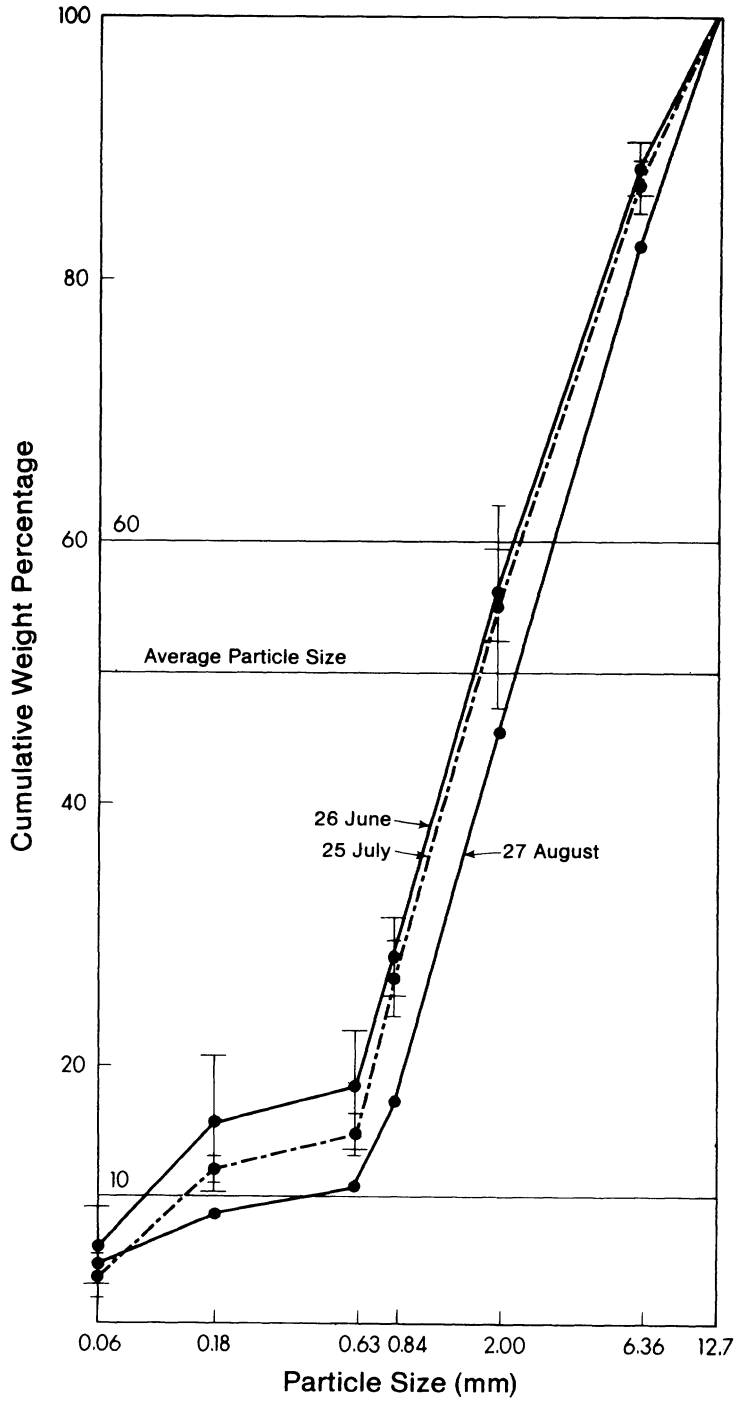


Fig. 1. Cumulative-weight percentages, ± 2 S.E., for substratum particle size classes of the experimental area, 26 June (prior to first disturbance), 25 July, and 27 August 1979. The 0.06 mm size class also includes particles (silt and clay) < 0.06 mm.

TABLE I

Mean density /m² for taxa of the control and experimental area (10, 25 July; 10, 27 August 1979), and values of the power function constants a and $b \pm 95\%$ CL (above four dates plus 26 June); control and experimental areas combined. There were 10 values for each taxon's regression analysis and 180 values (omitting Chironomidae pupae and Simuliidae pupae) for the overall regression analysis; r^2 is the coefficient of determination.

Taxon	Control \bar{x}/m^2	Experiment \bar{x}/m^2	a	b \pm 95% CL	r^2
Chironomidae larva	8989	6379	0.99	1.74 \pm 0.16	0.99
Chironomidae pupae	127	90	3.00	1.42 \pm 0.48	0.77
Simuliidae larvae	866	406	2.69	1.53 \pm 0.44	0.89
Simuliidae pupae	30	19	1.87	1.61 \pm 0.72	0.77
<i>Dicranota</i> sp.	37	41	3.43	0.88 \pm 0.76	0.47
Baetidae	2498	2061	1.60	1.48 \pm 1.08	0.56
<i>Ephemera simulans</i>	30	44	2.41	1.35 \pm 1.27	0.43
<i>Paraleptophlebia</i> spp.	249	474	1.80	1.73 \pm 0.35	0.94
Other Ephemeroptera	3679	2061	3.22	1.49 \pm 0.16	0.98
<i>Zapada cinctipes</i>	847	345	0.85	1.85 \pm 0.58	0.88
Other Plecoptera	145	71	0.60	2.17 \pm 0.99	0.76
Hydropsychidae	1288	763	1.29	1.79 \pm 0.25	0.98
Other Trichoptera	133	57	2.68	1.61 \pm 0.33	0.94
Elmidae larvae	421	88	3.25	1.36 \pm 0.41	0.88
Hydracarina	126	59	10.65	0.67 \pm 0.42	0.64
Ostracoda	1593	607	0.23	2.36 \pm 0.59	0.91
Copepoda	703	674	0.57	2.01 \pm 0.69	0.85
Cladocera	539	206	2.68	1.45 \pm 0.37	0.94
Oligochaeta	3540	1037	0.15	2.31 \pm 0.80	0.85
Nematoda	312	331	4.75	1.28 \pm 0.97	0.53
Others	127	88	--	--	--
Total Fauna	26276	15900	0.31	1.98 \pm 1.04	0.71
Total Aquatic Insects	19336	12898	0.35	1.94 \pm 1.36	0.57
Total Entomostracans	2846	1487	0.65	1.94 \pm 0.85	0.78
Overall	--	--	1.95	1.59 \pm 0.08	0.91

cm² sample was transformed. The power function was used to determine the amount of aggregation of each taxon. In the equation:

$$s^2 = a \bar{x}^b$$

(where s^2 is the variance, \bar{x} the mean density, and a is a sampling factor constant) the exponent b is an index of aggregation (Taylor 1961; Elliott 1971). The appropriate transformation is then x^p , where $p = 1-b/2$. If $a = b = 1$, the population is randomly distributed. The constants of each taxon and the overall constants were calculated separately for the experimental and control areas, excluding the 26 June samples. With the exception of other Trichoptera, there were no significant differences ($P < 0.05$) between the b values of the experimental and control areas for a given taxon nor for the overall b values of the two areas. For example, the overall b value of the experimental area was 1.58 ± 0.12 (95% CL) where $r^2 = 0.91$ and $n = 72$ (the number of values for the regression); for the control area $b = 1.40 \pm 0.16$, $r^2 = 0.83$, and $n = 72$. Therefore, I calculated single

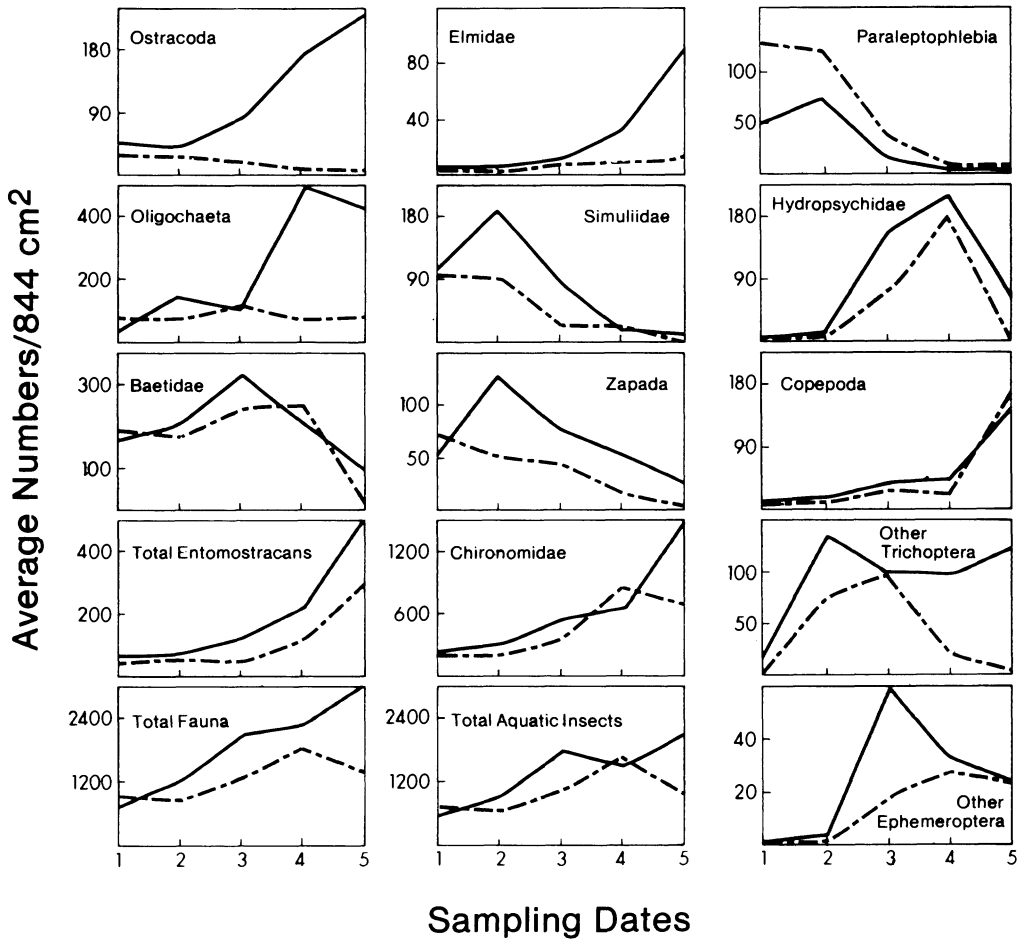


Fig. 2. Average number of animals per 844 cm² from the control (solid line) and experimental (broken line) areas for each of the five sampling dates: 1 = 26 June 1979 (prior to first disturbance), 2 = 10 July, 3 = 25 July, 4 = 10 August, 5 = 27 August 1979.

constants for each taxon for the entire study period by pooling the experimental and control area values including values of the 26 June sample.

The b values ranged from 0.67 to 2.36 (Table 1). Generally, the power function was a good fit and the b values comparable in most cases to those reported by Downing (1979) and Elliott and Drake (1981). However, for Baetidae and *Ephemera simulans*, two taxa prominent in behavioral drift, the 95% CL of b overlapped unity, and the intercept value, $\log a$, was not significantly different from zero ($P < 0.05$). Hence, one cannot be 95% certain that these populations were not randomly distributed ($a = b = 1$).

Downing (1979) collected data from published literature and calculated a and b values for numerous taxa; he concluded that the fourth root transformation ($b = 1.5, x^p = x^{0.25}$) can be applied successfully to most benthic data. For Bigoray River taxa, the overall regression value for b was 1.59 ± 0.08 (95% CL), which, although significantly different from 1.50, is closer to the fourth root value than to $b = 1$ (square root transformation) or $b = 2$ (log transformation).

Various transformations were made on the abundance values of Bigoray River taxa.

The paired variate *t*-test (10 July, 25 July, 10 August, 27 August) was then used to test the hypothesis that there was not a lesser abundance of organisms in the experimental area than in the control area. The results indicated there were significantly ($P < 0.05$) fewer organisms in the experimental area for 11 taxa (Table 2). Total fauna, total entomostracans, and Ostracoda had significantly smaller abundances in the experimental area by all transformations and when no transformation was used. Abundances of *Zapada*, Hydropsychidae, Elmidae larvae, and Other Trichoptera were significantly different by at least three of the five tests. If one could accept a 90% significance level, then the difference in abundance values of all taxa of Table 2, plus Simuliidae and Hydracarina, would be significant for at least four of the five tests.

Different transformations led to slightly different interpretation of significance levels. The greatest disparity was between the square root transformation and the empirically derived transformations, where there was a significance level agreement for only four of the 11 taxa. For the 11 taxa in question, significance levels of the empirically-derived transformation were in agreement with eight for those of the fourth root transformation and seven for those of the $\log(x + 1)$ transformation. See also Resh (1977) for data comparison of several clumped distribution types.

Paraleptophlebia was the only taxon having abundance values significantly greater in the experimental area. No obvious explanation can be offered for this. *Paraleptophlebia* specimens were also more abundant in the experimental area prior to the first disturbance (26 June, see Fig. 2); but after the various transformations of the counts, the *t*-test (two means) did not indicate significantly ($P < 0.05$) greater abundance in the experimental area on this date. Also, the *t*-test did not indicate significant differences in numbers between the experimental and control areas for other taxa prior to the first disturbance on 26 June.

DISCUSSION

The periodic disturbances of the substratum significantly reduced the number of organisms in the experimental area for several taxa relative to their abundance in the control area. Considering how thorough the disruption was, the overall effects could

TABLE II

Student *t*-test for taxa with significantly fewer organisms in the experimental area (except *Paraleptophlebia*, which had significantly greater abundance in the experimental area) as determined by the paired variate *t*-test ($df = 3$) using the following transformations: no transformation (x), fourth root ($x^{0.25}$), square root (\sqrt{x}), $\log(x + 1)$, and empirical for the taxon in question (x^p), i.e. $p = 1-b/2$. Asterisk values are significant at $P < 0.05$.

	x	$x^{0.25}$	\sqrt{x}	$\log(x + 1)$	x^p
Total Fauna	2.691 *	3.382 *	3.123 *	3.362 *	3.578 *
Total Entomostracans	2.398 *	4.318 *	4.080 *	6.342 *	6.386 *
Ostracoda	2.772 *	4.523 *	3.934 *	4.453 *	3.676 *
<i>Zapada cinctipes</i>	3.664 *	3.097 *	7.292 *	2.511 *	1.679
Hydropsychidae	2.062	3.473 *	3.464 *	3.458 *	2.505 *
Elmidae larvae	1.555	2.947 *	2.222	2.790 *	2.748 *
Other Trichoptera	2.630 *	2.100	2.600 *	2.501 *	1.964
Total Aquatic Insects	1.947	2.285	2.164	2.411 *	2.392 *
Oligochaeta	1.981	2.225	2.126	2.355 *	2.487 *
<i>Paraleptophlebia</i> spp.	1.716	2.310	8.446	2.512 *	1.494
Other Ephemeroptera	1.490	2.117	1.805	2.374 *	2.117

certainly not be described as severe. Nevertheless, the effect was statistically detectable for several taxa. Should one be surprised that these disturbances at 15-day intervals resulted in any detectable reduction in the fauna or that the overall reduction in numbers and kinds of organisms was not much more pronounced? Similar series of physical disturbances on land or even marine areas would have resulted in a much greater impact on the community's organisms (Woodin 1978). In this respect, the major difference between these environments and streams is the ability of stream organisms to recolonize rapidly via downstream drift, especially behavioral drift.

Studies (see introduction) show what appears to be complete recolonization of denuded stream substrata taking place in a few days, and this also apparently holds for colonization of artificial substrata (Hart 1978). Given the relatively long interval (15 days) between disturbances, it might seem surprising that significant reductions in abundance could be detected for any of the Bigoray River's taxa. The type of study carried out in the Bigoray River (as is true for most studies pertaining to recolonization in streams) treats data that are only expressive of the stream community's structure (i.e., number and kinds of organisms) and not the underlying functional organization of the community (Peterson 1977). The severe periodic disturbances at short intervals probably had a much greater impact, although unmeasurable by the methods used, on the community's functional organization (e.g., predation, competition, etc.) in the disturbed areas. In fact, the statistically significant changes in density that were detected for certain taxa probably are a reflection of functional reorganization caused by the disturbances.

Pertaining strictly to the structure of the Bigoray River's community, it would appear that intense sampling of the substratum, and hence the possibility of experimenter produced bias, would not have a pronounced long-term effect on the fauna. Routine sampling in most streams probably would have an undetectable effect on structure of the stream community. Falk's (1974) inferences about experimenter-induced bias were mainly concerned with the functional organization of communities, not their structure. Also, Falk drew most of his inferences from data pertaining to a spring, where downstream drift would most likely be less consequential than in a typical stream.

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