

SPECIES DIVERSITY OF STREAM INSECTS ON *FONTINALIS* SPP. COMPARED TO DIVERSITY ON ARTIFICIAL SUBSTRATES¹

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Abstract. Two types of artificial mosses (string and plastic) were compared with *Fontinalis* spp. for their insect inhabitants. These communities were sampled on six dates at eight stream sites and compared by community coefficients, information theory analysis, and rank correlations. These results showed that those insects which were abundant on moss were also abundant on the artificial substrates. Fewer species and fewer individuals were present on the latter.

Little research has been done on the role of bryophytes as a habitat for stream insects. Frost (1942) studied this relationship in an alkaline and an acid stream, and several researchers included them in more general stream studies (Thienemann 1912, Carpenter 1927, Percival and Whitehead 1929, 1930, Illies 1952, Minckley 1963, and Gerson 1969). Percival and Whitehead attempted to show the value of this habitat compared to other stream habitats. Glime (1968a) studied their relationships in 28 mountain streams, and the results of that study suggested that the moss serves only as a substrate, so that any similar substrate might be expected to support similar insect communities. The purpose of the present study was to test this hypothesis by comparing communities of insects on string and plastic artificial mosses with natural communities on mosses.

DESCRIPTION OF STUDY AREA

The inlet of Fox Pond, west of Plymouth, Grafton Co., New Hampshire (Fig. 1), was chosen as the study area because of its availability and its abundant growth of the brook moss, *Fontinalis* spp. The inlet is a tributary of a stream system known locally as Clay Brook. The Fox Pond inlet originates from several small springs about 1.1 km above the study area and has several small, intermittent tributaries. The stream would be considered a first-order stream according to the classification of Leopold (1962). Using the modified stream classification proposed by Knight and Gaufin (1967), the inlet would be classified as a lower, small, stony stream since it is below 2,440 m, is 0.3–5.0 m wide, and has a stony bottom.

According to the bryophyte classification of Glime (1968b), this is a *Fontinalis* stream. Its dominant submerged bryophytes are *F. novae-angliae* Sullivan and *F. dalecarlica* Schimp. ex BSG (Glime 1970).

METHODS

The study was begun in February when a large portion of the stream was frozen. Areas in the stream with open holes that were likely to remain open were

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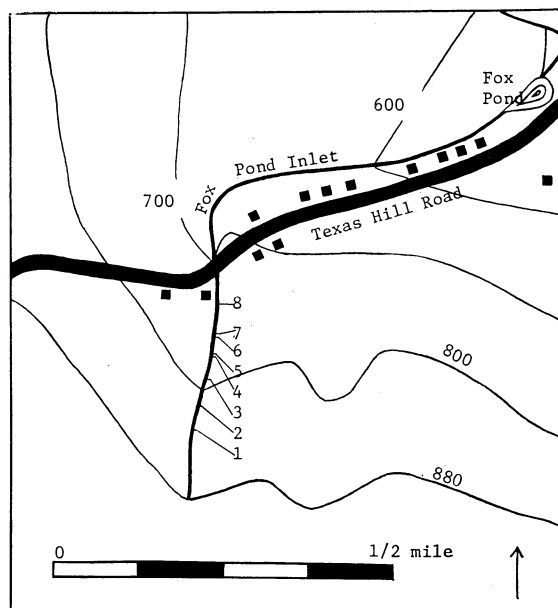


FIG. 1. Map of the western end of Plymouth, New Hampshire, showing location of collecting sites. (Contour intervals in feet are shown.)

chosen. Therefore, we could avoid breaking ice which could disrupt the samples. To achieve random sampling within this biased distribution, the 24 holes available were numbered consecutively and eight of these numbers were drawn from a container. Only eight sites were chosen because of limited time for field work.

Sites 1, 2, and 3 (Fig. 1) have rocky bottoms with abundant growths of *Fontinalis*. Sites 4–8 have increasingly sandy bottoms and decreasing amounts of *Fontinalis*. The *Fontinalis* found at the lower sites (4–8) is covered with mud and silt and is heavily abraded, while that found at the higher sites is relatively clean and has not been abraded (Conboy and Glime 1971).

On February 14, 1969, six artificial string mosses and six plastic mosses were placed at each site. One of each, along with a sample of *Fontinalis*, was removed from each site at 2-week intervals from

TABLE 1. Species list in order of abundance of families on moss

	Moss		String		Plastic	
	No.	Freq.	No.	Freq.	No.	Freq.
Chironomidae	1095	44/46	285	29/35	190	30/33
Simuliidae						
<i>Prosimulium hirtipes</i> (Fries)	111	20/46	5	4/35	40	8/33
<i>Cnephia mutata</i> (Malloch)	82	20/46	23	11/35	40	9/33
<i>Prosimulium rhizophorum</i> Stone & Jamnback	2	2/46			2	2/33
Nemouridae						
<i>Nemoura</i> sp. 4	84	32/46	67	34/35	10	6/33
<i>Nemoura</i> nr. <i>venosa</i> Banks	4	4/46	7	4/35	1	1/33
Hydroptilidae						
<i>Agraylea</i> sp. 1	34	11/46	2	1/35	2	1/33
Rhyacophilidae						
<i>Rhyacophila</i> nr. <i>invaria</i> (Walker)	23	14/46	10	8/35	4	3/33
Limnephilidae						
<i>Ironoquia punctatissima</i> (Walker)	18	11/46	5	5/35	1	1/33
Capniidae						
<i>Allocapnia</i> spp.	17	10/46	10	8/35	1	1/33
Ephemerellidae						
<i>Ephemerella deficiens</i> Morgan	12	1/46	2	2/35		
<i>Ephemerella funeralis</i> McDunnough	2	1/46				
Perlodidae						
<i>Isoperla bilineata</i> (Say)	12	11/46	1	1/35		
Carabidae sp.	11	6/46	1	1/35		
Veliidae						
<i>Microvelia</i> sp. 3	7	5/46	1	1/35	1	1/33
Lepidostomidae						
<i>Lepidostoma</i> sp. 1	5	5/46	1	1/35		
Leptophlebiidae						
<i>Leptophlebia</i> sp. 1	5	3/46	2	1/35	2	1/33
Odontoceridae						
<i>Psilotreta frontalis</i> Banks	4	4/46				
Hydropsychidae						
<i>Parapsyche apicalis</i> (Banks)	4	4/46	1	1/35	1	1/33
Heleidae						
<i>Bezzia</i> sp. 1	2	2/46				
Hydroptilidae						
<i>Paleagapetus celsus</i> Ross	1	1/46				
Rhyphidae? sp. 1	1	1/46	1	1/35		
Baetidae						
<i>Baetis</i> sp. 5	1	1/46	1	1/35		
Philopotamidae						
<i>Wormaldia</i> sp. 1	1	1/46				
Elmidae						
<i>Promoresia elegans</i> LeConte	1	1/46				
Isotomidae						
<i>Isotomurus</i> sp. 1			2	2/35		
Psychomyiidae						
<i>Polycentropus</i> sp. 1			2	1/35		
Hydrophilidae sp. 2			1	1/35		
Tipulidae						
<i>Limonia</i> sp. 2			1	1/35		
Staphylinidae sp. 1			1	1/35		

March 1 to May 10. The *Fontinalis* was collected by merely pulling a handful from the stream and putting it in a jar. A previous study (Glime 1968a) showed less than 1% loss of insects by this collection method.

The string mosses were made of no. 60 cotton twine, of approximately 0.2-mm diameter. Twenty lengths of twine, each approximately 32 cm long, were tied in the middle with a lighter string. The lighter string was then wrapped around the folded end of the string moss, tied, and a 30-cm length was left to secure the string moss in the stream. The resulting string moss was 16 cm long. Since so many artificial mosses were to be placed at each site, the six were all tied to a string and both ends of this string were tied to rocks.

The artificial plastic mosses were made from heavy plastic bags cut into 1-cm strips, leaving the folded bottom of the bag to hold the strips together. Two bags were rolled and sewed together and attached to a string in the same manner as the string mosses. A similar method was used by Egglisshaw (1964), who used rubber strips to simulate detritus.

When collections were made, each sample was preserved in 95% ethanol and later sorted with the aid of a dissecting microscope.

RESULTS AND DISCUSSION

Thirty taxa of insects were recognized in this study (Table 1): 25 on *Fontinalis*, 23 on string, and 13 on plastic. Five species occurred on string, but not on the moss, accounting for the 30 species, while no unique species occurred on plastic.

For purposes of comparing the three substrates, data from all collecting dates and all stations for a substrate were combined to form a single list of species and counts for that substrate. A computer program was used to compare the species lists and compute the values of Sorensen's K (Looman and Campbell 1960). The exact probabilities, i.e., $P(X)$ (Mosimann 1968), were figured using logarithms of factorials. While most of the probabilities reached magnitudes of 10^{-7} , the more standard figure of $P < .001$ is used throughout.

Community coefficients

This study and others (Glime and Wilson, unpublished data) have yielded 69 identified insect taxa in the stream, which can be considered as a minimum value of the total number of species in the stream. This value can be used to compute the probability of co-occurrences in any two of the three substrates used, such as measured by Sorensen's K (Looman and Campbell 1960) and Pirlot's Index (Mosimann 1968).

Sorensen's K measures the degree of similarity between two communities: where m = the number of species in community M (or the smaller number

of species), n = the number of species in community N , and x = the number of species common to both. The probability of obtaining such a degree of co-occurrence, as measured by Sorensen's K or any other similarity index, is found by multiplying together the numbers of possible ways each event could occur and dividing by the total possible events.

$$P(X) = \frac{\binom{N}{m} \binom{m}{x} \binom{N-m}{n-x}}{\binom{N}{m} \binom{N}{n}} = \begin{array}{l} \text{the probability} \\ \text{that the two} \\ \text{samples should} \\ \text{be as similar} \\ \text{as they are} \end{array}$$

N = the total species in the system (69 here)

$\binom{N}{m}$ = the number of ways m species could combine

$\binom{m}{x}$ = the number of ways m species (the smaller of the two sets) could be represented in the common set x

$\binom{N-m}{n-x}$ = the number of ways the species which could not be common to both ($n-x$) could be arranged.

To figure this probability, we assume that any species found in the stream is potentially available to the substrates sampled. Therefore, any significant deviations from random arrangement of this total representation might be the result of selectivity of habitat on the part of the insects. Also, if insects inhabit strings and plastic differently from moss, a high correlation should not exist among the represented species.

When the insects of the three substrates were associated by Sorensen's K , a great similarity was revealed. Inhabitants of mosses and strings exhibited $K = .75$ with $P < .001$ ($m = 23$, $n = 25$, $x = 18$), indicating that these two substrata had insect communities more similar than chance alone should account for. Likewise, for moss and plastic $K = .68 < .001$ ($m = 13$, $n = 25$, $x = 13$); for strings and plastic $K = .67 < .001$ ($m = 13$, $n = 23$, $x = 12$). It should be noted that these figures represent the probability of a single event, whereas the probability of that event or any larger intersection occurring is desirable. From these results it appears that species on these three substrates are quite similar. Similar results were obtained by Egglisshaw (1964) in his artificial detritus studies. In both studies, the natural and artificial substrates differ primarily in numbers of organisms.

Species diversity

Recently, aquatic biologists have used information theory as a means of expressing species diversity (Wilhm and Dorris 1966, 1968, Mathis 1968). Thor-

ough explanations of the theory are given by Margalef (1958) and Patten (1962).

As used by the above authors, species diversity is a measure of both kind and number of species, whereas the term richness can be applied to expression of the number of species alone. The theory uses the concept that a species is either present or absent, and that its presence constitutes a positive binary choice, providing information. Base 2 was also chosen here because the abundance of individuals appears to be distributed in a geometric progression by powers of 2 (Preston 1948). In the present study, the small number of species makes it difficult to demonstrate this relationship, but Fig. 2 shows this approximate distribution for the moss inhabitants.

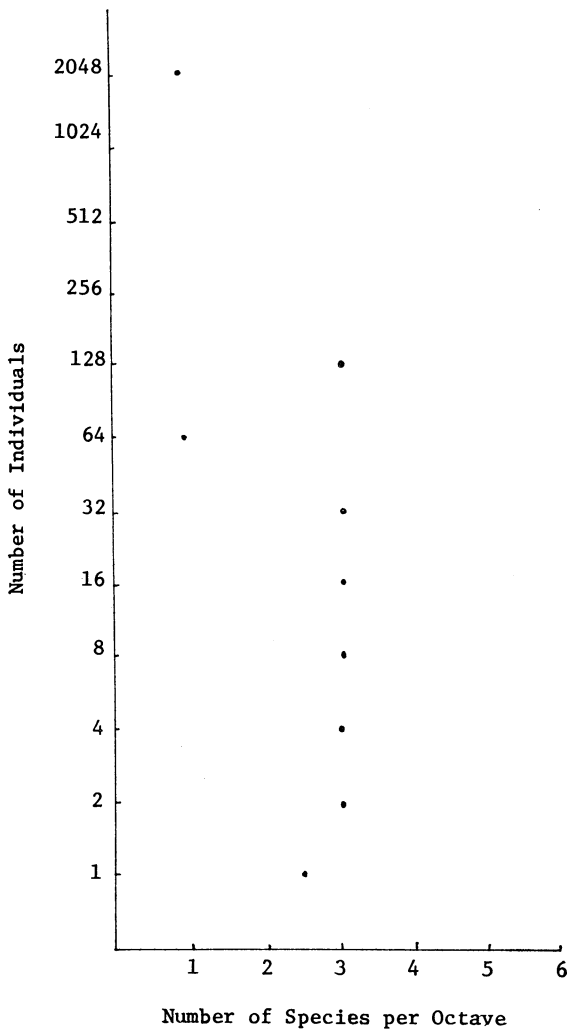


FIG. 2. The number of species of insects to individuals per species in the moss habitat based on the Preston curve of commonness and rarity (1948). The number of species in the first octave is divided by 2 so that octave is half the size of the next one and follows the geometric pattern of doubling.

Species diversity values were calculated by computer using the following formula:

$$\bar{d} = -\sum_i^m \frac{n_i}{N} \log_2 \frac{n_i}{N}$$

where m = the number of species

n_i = the number of individuals of a particular species

N = the total number of individuals of all species

$\frac{n_i}{N}$ = the probability of encountering that particular species in a sample.

Wilhm & Dorris (1968) reported that diversity stabilized by the fourth sample in Skeleton Creek, Oklahoma, so that the 48 samples included here should have reached the asymptotic index of diversity.

The values of diversity obtained were 1.8 on moss, 1.9 on string, and 1.7 on plastic. These values appear similar enough to be within chance variation.

Individual \bar{d} was computed for each collection of moss, string, and plastic. The averages per collection were 1.2, 1.1, and 0.5 respectively.

A comparison of the diversity of the three collections is desirable, since the strings and plastic have fewer individuals and the plastic has fewer species than the moss. To compare the means of the diversity we used a Student's t -test and obtained the following results:

Substrates	t	df	Probability
moss & string	1.3691	80	.1 < P < .2
moss & plastic	4.664	76	P < .001
string & plastic	3.1449	64	.001 < P < .01

It is obvious that while the pooled data have similar diversity indices, the individual collections differ widely, and only the moss and string are not significantly different. Mean diversity is greatest on moss and least on plastic. Since comparison of values of diversity does not mathematically require a constant sample size among different values, we might regard these comparisons as valid.

Some of the differences in diversity values may be the result of successional or invasional pattern on the artificial substrates, a difference that would not influence the pooled results so strongly. The first sampling of plastic revealed no insects, while on later dates at least some stations had insects on the plastic. Furthermore, the loss of 13 artificial substrates near the end of the experiment narrowed the spectrum of comparison and placed undue weight on early samples. But even on the sixth collection date, some plastic samples had no insects and only 13 total samples of plastic had insects. For the strings, the first four dates had mean diversities of 0.8, 1.2, 1.2,

and 1.2, respectively. It appears that the species diversity had stabilized by the second collecting date.

Several studies have been done comparing diversity on artificial substrates to that on natural substrates, emphasizing similarities and colonization rates. Periphyton literature abounds with studies on glass or plastic slides (Newcombe 1949, 1960, Sladeckova 1962, King and Ball 1966, Cairns et al. 1969). Cooke (1956) and Hohn (1966) review literature on the various artificial substrates used for periphyton studies. There is disagreement among authors as to the usefulness and validity of such studies. For example, bacteria tend to aggregate on such surfaces and may become more concentrated than they would on some natural surfaces where inhibitors are present (Brock 1966). Some organisms will not attach to the glass slides (Cooke 1956), and plants provide nutrients not present on slides (Brock 1966). This is relevant to the discussion of the plastic moss, which provides a smooth surface and causes greater attachment difficulty for insects than a moss. Since we know little of the community structure on a moss (Percival and Whitehead 1929, Frost 1942, Glime 1968a) and why certain organisms live there or what they derive from living there, it is difficult to say what role the moss periphyton might play in establishing the macrofauna of the moss. Nevertheless, one must consider the possibility that a plastic or string moss might limit the species of periphyton, and this in turn might limit the kinds of macrofauna.

In his study using rubber to simulate leaf detritus, Egglisshaw (1964) showed the same species in trays with plant detritus or with rubber, but the number of individuals was significantly higher in trays with plant detritus. Using his mean data, species diversity on his rubber detritus is 2.2 and on real detritus 1.7. These are much more widely separated than the real and artificial moss figures, but are probably caused in part by the greater dominance of Chironomidae in the plant detritus compared to the same number of total species as in the artificial detritus. Egglisshaw feels that animals aggregate in plant detritus for food. This could well be the reason for their aggregation among mosses. Jones (1949) stated that the mayfly *Ephemerella* had eaten mosses, that the stonefly *Dinocras* had *Fontinalis* in its crop, and that the mayfly *Baetis* appeared to eat moss. On the other hand, Glime has observed that a Diptera larva ingests detritus-covered moss fragments and egests clean, undigested moss fragments. Slack (1936) reported that the caddisfly *Limnophilus rhombicus* L. used *Fontinalis* as a food source and that epiphytic diatoms would be taken in with the fragments.

Thus, colonization by periphyton may be an important consideration in the rate of macrofauna invasion. Gause (1936) cites the experiments of Duplakov in which the composition of algal species on

glass slides stabilized in 9 days. Cairns et al. (1969) found the point of stabilization to be 42–43 days when they considered bacteria, plants, and animals on glass slides.

Probably the most important feature of mosses in altering stream colonization is substrate area. Sprules (1947) compared insects emerging from areas with stones embedded in gravel to rocks piled upon one another. Six times as many insects emerged from the latter, more chambered habitat. Similar results were obtained by Wene and Wickliff (1940) when they introduced rubble into a sandy area. Likewise, in the present study the more intricate, surface-rich moss housed more insects than the plastic or string. That the chambered *Fontinalis* plant can provide a different habitat from the stream in general is evidenced in a South African waterway where it was introduced (Richards 1946). Here the moss rapidly increased, blocking the waterway, but the existing rock-clinging insects were unable to inhabit the moss and were crowded out by the moss. These notes support the assumption of Thorup (1966) that stream mosses constitute a biotope, a well-defined habitat supporting an animal community which has characteristic species.

Community structure

Since the communities appear similar in kinds of taxa and in overall diversity, we should ask if the taxa possess the same relative abundance in the three communities. To test this relationship, taxa were ranked in order of abundance and compared by Spearman's rank correlation coefficient (Siegel 1956), a nonparametric test:

$$r_s = \frac{1 - 6 \sum d_i^2}{N(N^2 - 1)}$$

d = difference in rank of paired observations (rank of abundance of a taxon of insect)

N = number of paired observations.

To correct for ties in ranks, the formula is modified:

$$r_s = \frac{\sum X^2 + \sum Y^2 - \sum d^2}{2 \sum X^2 Y^2}$$

$$\sum X^2 = \frac{N^3 - N}{12} - \sum \frac{tX^3 - tX}{12}$$

$$\sum Y^2 = \frac{N^3 - N}{12} - \sum \frac{tY^3 - tY}{12}$$

t = number of ties; $df = n - 2$.

The results were as follows:

Substrates	r_s	df	Probability
moss & string	.705	28	$P < .01$
moss & plastic	.697	22	$P < .01$
string & plastic	.629	21	$P < .01$

These results suggest a significantly high correlation in the relative abundance positions of the insects.

DISCUSSION AND CONCLUSIONS

The structure of insect communities and the overall species diversity among moss (*Fontinalis* spp.), strings, and plastic is similar, suggesting that insects recognize little difference among the three substrates. Nevertheless, when comparing individual samples the species diversity is significantly different on plastic. Furthermore, since the strings occupied a stream areas approximately similar to that of the moss, we can conclude, based on total counts and frequencies (number of occurrences divided by the number of collections) of insects shown in Table 1, that the number of individuals per area of streambed would be much lower on the artificial substrates.

It seems to be generally true that mosses themselves are seldom the source of insect food, but rather that they provide a substrate both for the insects and for numerous food organisms, including diatoms, desmids, and protozoa (Glime, unpublished data). For those insects that feed on periphyton of the moss, the rate of establishment of food organisms would probably influence the insects' rate of colonization and cause a typical time lag in the population curve. If periphyton had not been sufficient, those individuals which feed on it may have been on the artificial substrates temporarily while in search of new substrates.

Other insects on the mosses feed on particulate organic matter in the water. Blackflies (Simuliidae) filter particles, especially bacteria (Fredeen 1964, Hynes 1970), as they drift by the larvae's large head fans. These larvae need a place of attachment where circulating water carries a continuous food supply. Such a substrate is provided by both string and plastic, and it is noteworthy that the Simuliidae were the second most abundant insects on plastic and third on the string. Hynes (1970) points out experimental evidence of their need for flowing, but not turbulent, water.

The Chironomidae were the most abundant insects on all three substrates. These larvae probably feed on detritus that would collect on all three substrates. The stonefly *Nemoura* sp. was abundant on all three substrates and ranked second among the insects on the string. This concurs with the observations of Frost (1942), who found nemourids abundant on moss. Wu (1923) reports that *Nemoura* eats leaf fragments, diatoms, and desmids. The latter two foods are abundant among *Fontinalis* and could be a reason for the abundance of *Nemoura*. Abundant fine detritus might have provided an additional source of food (Chapman and Demory 1963), and Hynes (1970) reports that some nemourids eat mosses.

In summary, because of the relatively small numbers of individuals on the artificial substrates compared with *Fontinalis*, we conclude that these sub-

strates provide a poor substitute for *Fontinalis*. On the other hand, the high degree of correlation of insect species among the three substrates suggests that the moss may in fact be only a physical surface for the insects and that its living properties, such as food production, may be inconsequential. It is probably true that the additional surface area and chambering effected by the presence of leaves largely account for the difference in numbers of individuals.

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