SEASONAL SUCCESSION OF BENTHIC ALGAE AND THEIR MACRO-INVERTEBRATE RESIDENTS IN A HEAD-WATER LIMESTONE STREAM

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Since the early 1900's, a number of attempts have been made to associate biological characteristics with varied stream conditions resulting from man-made pollution. These attempts have been concerned with micro-organisms —Kolkwitz and Marsson (1) (2), Liebmann (3) (4), Lackey (5) (6) (7) (8) (9), Brinley (10), Fjerdingstad (11), and others—and macrobenthos—Forbes and Richardson (12) (13), Gaufin and Tarzwell (14) (15), Ingram (16), Patrick (17) (18), Richardson (19) (20), Beck (21) (22), and several others. The macrobenthos has been studied with respect to long range and/or intermittent conditions, and systems have been proposed by some of the above workers to relate its characteristics to such pollutional influences. None of these approaches has won unqualified approval, and it appears that detailed data from unpolluted streams representative of varied terrains and land usage will shed light on this rather controversial area. To this end, this presentation is made. The information was acquired at weekly intervals in 1949 through 1950 on benthic algae and associated invertebrates dwelling in Boone Creek—a head-water sized stream draining pastures and farmlands near Lexington, Kentucky. A report of physical and chemical interrelationships of this stream was made in 1951 by Neel (23), but work on biological samples was delayed by changes in position and preoccupation with new duties. Analyses of samples were carried on for brief periods at irregular intervals over 14⅔ yr before they were completed. This article relates occurrence of algae to season, bottom materials, degree of exposure to the sun, and stream chemical conditions; and, macrobenthic organisms to season, bottom, and type of algal growth. Number of broods and months of emergence are given for most aquatic insects encountered.

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Study Areas

Boone Creek and the sampling stations located along it were dealt with in detail in the 1951 article (23), and most areas are shown in photographs appearing therein. Most of these collections were made at Station 1, the old mill dam area. Infrequent samples were taken at Stations 2, 3, 4R, 6, 9, and 11. Data from these latter sites often indicated when conditions at Station 1 were and were not duplicated in other stream reaches. Type of situation, bottom, and degree of exposure to the sun were as follows:

Station 1—Riffle; bedrock and broken rock (rubble); fully exposed.

Station 2—Riffle; rubble, shingle (small, flattened stones) and gravel; shaded.

Station 3—Pool; bedrock and sand; partly shaded.

Station 4R—Riffle; rubble on bedrock; partly shaded.

Station 6—Riffle and pool; shingle and gravel mixed; exposed.

Station 9—Riffle; gravel; exposed.

Station 11—Riffle and pool; gravel, sand and silt; shaded.

At the time of these collections Boone Creek received an insignificant amount of human wastes, but was enriched by livestock manure from pastures, and received carbonic acid erosion of calcium diphosphate rock in superficial soil layers. Modern pesticides then were used very sparingly if used at all. Experience with numerous types of pollution and many polluted streams since these studies were made indicates that Boone Creek was in a normal state for a stream draining its type of countryside. It is not believed that seasonal and spatial occurrence of organisms dealt with here were influenced by any factors foreign to this type of drainage area.

Methods

Algae either were scraped or pulled from a bottom area enclosed by a rectangular brass frame that delimited 3 sq in. (approx. 645 sq mm). The frame had sharpened (beveled) lower edges and an accessory bolting cloth bag that fastened to one end and caught most algae scraped from within the frame under water. Rocks, unless too large to lift or too small to fill the frame, were scraped out of water. Scraping was accomplished with a blade that fitted across the shorter dimension of the frame and could be pulled along at an angle corresponding to the beveled interior edge of the frame's leading side. Flat surfaces were required for the frame and blade. A few samples were taken "freehand" where the frame did not fit. It was found practicable to pull green and red filamentous algae under water with the fingers, but the blade was used generally for closely adhering growths of *Phormidium, Stigeoclonium,* and diatoms. Native bottom materials and some introduced materials were sampled.

The desire for quantitative algal samples that hopefully attended design of the frame and blade device was unattained. It seldom was possible to get a clean scrape of the entire frame area on larger rocks and bedrock; and pebbles afforded more attachment area through their raised surfaces than the 645-sq mm frame area. Filamentous algae contained considerable debris and sometimes were longer and sometimes shorter than the frame. It was not resolved whether their samples should represent the area to which they were attached or that covered by their waving fronds. Scraped samples were representative and allowed an accurate estimation of animal density in growths of diatoms and blue-green algae.

Samples were placed in screw-cap French square bottles in which they were stored after the addition of a small quantity of glycerine and sufficient formalin to make a 4-percent formaldehyde solution. Stored samples generally maintained moisture well (they were checked periodically for drying). All organisms, with the exception of certain mayflies that faded and molluscs that lost their shells, remained workable to the end of the long storage period. Organisms were separated with the aid of stereoscopic microscopes. Most animals were identified under these scopes. Hyrax and diaphane mounts were used routinely for identification of diatoms and midge larvae and pupae, respectively. Permanent mounts sometimes were necessary for other animals.

Generic and specific identities were according to the following publications: Desikachary (24), Elmore (25), Husted (26), Prescott (27), and Smith (28)—algae; Burks (29)—mayflies; Frison (30) (31)—stoneflies; Ross

(32) and Flint (33)—caddisflies; Curry (34) (35), Johannsen (36) (37) (38) (39), Malloch (40), and Stone and Jamnback (41)—Diptera; Usinger (42) and Dillon and Dillon (43)—beetles; and Edmondson (44)—crustacea and mollusks.

Samples were collected at weekly intervals with few exceptions over the periods of April through December 1949, and March through April 1950. Collecting was prevented by high water levels in January, February, and May 1950. Individual samples were taken from each type of growth noted on each visit.

Benthic Algae

Algae grew on all bottom types listed for the several stations. Prevalent groups generally were attached to rock in some form—bedrock, rubble, shingle, or gravel. None of the groups (except *Batrachospermum* which was found at only one site) were restricted to a single rocky type. Some of the prevalent algae grew most luxuriantly on one rock substrate but freely occupied others when their "preferred" bottom was absent or overcrowded. Algal growths seldom were homogeneous but consisted of an irregular patchwork of small areas, each occupied by a single group or a rather uniform mixture of two or more groups, or of isolated algal patches on otherwise barren bottom areas. Certain species or associations covered wider areas than their neighbors during some seasons and were absent or more restricted during others. The species or association covering the greatest bottom area was considered the dominant growth for each date of observation, although at times the most abundant group occupied less than one-half the total area taken over by algae. Completely homogeneous growths were observed only on bedrock bottoms in shallow pools during summer months. Those examined consisted of *Phormidium incrustatum* or a mixture of *Phormidium* and diatoms. The growths provided a popular food for stonerollers (*Campostoma anomalum*), whose grazing activities kept the bottoms free of silt and seemingly encouraged greater algal development. These growths often were inhabited by midge larvae.

Qualitative Features

The bulk of every observed algal growth was made up of one or more of the 13 groups shown in Table I.

Diatoms and non-filamentous green algae grew epiphytically on *Cladophora* and *Lemanea* from time to time. The following genera and species of these green algae were noted: *Closterium* sp.; *Cosmarium* sp.; *Scenedesmus bijuga* (Turp.) Lagerh. 1893; *S. armatus* (Chod.) G. M. Smith 1916; *S. quadricauda* (Turp.) de Breb. 1835; *Pediastrum boryanum* (Turp.) Meneg. 1840; and *Ankistrodesmus* sp. Short filaments of *Chaetophora* sp. once were found attached to *Cladophora.*

Seasonal Occurrence

Table II indicates the weeks when the 13 algal groups grew singly and mixed with each other, and when individual groups were absent. Seven groups (listed first in Table II) occurred alone at times, and four groups, *Stigeoclonium lubricum, Melosira varians, Lyngbya major,* and *Calothrix breviarticulata,* were found only in mixtures. It was not decided whether associations were fortuitous or determined by seasonal factors and stream conditions. *Cladophora* and *Lemanea* mixtures appeared due to chance, but the *Phormidium*-diatom association occurred too frequently, and seemingly was too proscribed by certain seasons to result from chance alone. *Phormidium* was present almost constantly, and many of its associations were observed to come about through its invasion by other groups.

Lemanea sp. was predominantly an alga of spring, beginning development in early March, attaining maximum

TABLE I.—Biological Groups Comprising the Bulk of Observed Algal Growths

Group	Organism	Group	Organism
1	*Stigeoclonium lubricum* (Dillw.) Kuetzing 1845		*Gomphonema lanceolatum* var. *insignis* (Greg.) Cleve
2	*Cladophora glomerata* (L.) Kuetzing 1845 var. ? ? ?		*Gomphonema parvulum* var. *micropus* (Kuetz.) Cleve
3	*Spirogyra* sp. (Vegetative cells only observed; chloroplast very dense and tightly wound, usually completely filling the short cells).		*Gomphonema longiceps* Ehr.
			Nitzschia amphibia Grunow
			N. capitellata Hustedt
4	*Melosira varians* C. A. Ag.		*N. recta* Hantzsch
5	Diatoms* other than *Melosira varians* This group included the following:		*N. vermicularis* (Kuetz.) Grunow
	Melosira granulata var. *angustissima* Müller		*Cumatopleura solea* (Brebisson) W. Smith
	Fragilaria capucina Desmazieres		*Surirella linearis* var. *helvetica* (Brun.) Meister
	Cocconeis pediculus Ehr.		*Surirella ovata* Brebisson
	Cocconeis placentula var. *euglypta* (Ehr.) Cleve	6	*Phormidium incrustatum* (Nag.) Gomont in Bornet and Flahault 1889 (Appears identical to this species but is not purplish; may have faded; has deposits of marl around and under trichomes; may possibly be *P. inundatum* Kuetz, 1849).
	Rhoicosphenia curvata (Kuetz.) Grunow		
	Achnanthes lanceolata Brebisson		
	Gyrosigma sp. (not seen in prepared mounts)	7	*Phormidium Retzii* (C. A. Ag.) Gomont 1892
	Navicula anglica Ralfs		
	Navicula lanceolata (Ag.) Kuetz.	8	*Phormidium subfuscum* Kuetz. ex. Gomont
	Navicula gracilis Ehr.		
	Navicula tuscula (Ehr.) Grunow	9	*Lyngbya major* Meneghini
	Navicula sp.	10	*Calothrix breviarticulata* West & West 1897
	Cymbella prostrata (Berkeley) Cleve	11	*Batrachospermum* sp.
	Cymbella tumida (Brebisson) Van Heurck	12	*Lemanea* sp.
		13	*Vaucheria* sp.
	Gomphonema acuminatum var. *turris* (Ehr.) Cleve		

* Note: These diatoms were not all present on any sampling date.

abundance in mid-April, and then declining to a general disappearance in late June. The term "general" is used because isolated sprigs endured into July in deeply shaded situations. These filaments were deep brown in color whereas spring growths were yellowish green. *Lemanea* once invaded a *Phormidium* area but otherwise was associated only with *Cladophora,* usually being in residence before *Cladophora* appeared. The red alga (*Lemanea*) seemingly grew best when within a few cm of the water surface. The most extensive crops seen were on large pieces of rubble. Station 4R had very luxuriant growths in April 1949 and 1950.

Cladophora was observed in early spring, summer, and autumn. It disappeared before June 1, returned in late July, endured through August, again disappeared, and then returned for two weeks in October. It occurred alone and mixed with *Lemanea, Spirogyra,* and *Stigeoclonium-Pleurocapsa-Phormidium.* It reached its greatest development in early spring and seemed to grow well equally on shingle, rubble, and bedrock. Summer growths were restricted to shaded situations, and generally were thinner and shorter than spring crops.

Phormidium incrustatum (or *P. inundatum*) was the most widespread and frequent alga, and the one most

TABLE II.—Seasonal Distribution of Benthic Algae

(Columns under each month indicate 1st, 2nd, 3rd, and 4th weeks)

Group No.	Algal Group or Association	April	May	June	July	Aug.	Sept.	Oct.	Nov.	1949 Dec.	1950 Mar.	April
1	*Lemanea* alone	++++	++++	+++	+†+†						++++	++++
2	*Cladophora* alone		++++		+	++++		++			++++	++
3	*Phormidium* alone	+	++++	++++	+	+++	++++	++++	++++	++++	++++	++++
4	*Batrachospermum* alone		+									
5	*Spirogyra* alone					++	+					
6	*Diatoms* (other than *M. varians*)		+						++	+ +	+++	
7	*Vaucheria*	++										
8	*Lemanea* and *Cladophora*	++++	++++									+
9	*Lemanea* and *Phormidium*											+
10	*Phormidium* and *diatoms*	++++	++++	++++	++++	+++					++++	++++
11	*Phormidium* and *Stigeoclonium*	+										+
12	*Phormidium-Stigeoclonium*-diatoms		+++									+
13	*Melosira** and other diatoms		+									
14	*Phormidium-Spirogyra*-diatoms			+								
15	*Spirogyra* and *Melosira* varians			+		+						
16	*Phormidium* and *Melosira* varians				+++	+						
17	*Phormidium-Melosira*-Spirogyra*				+							
18	*Cladophora* and *Spirogyra*				+							
19	*Phormidium* and *Spirogyra*				+							
20	*Phormidium-Lyngbya*-diatoms				+							
21	*Phormidium* and *Calothrix*					+	++++	++				
22	*Phormidium-Calothrix-Spirogyra*						+					
23	*Cladophora-Stigeo.*	+										+
24	*Cladophora* and *Phormidium*							+				

* *Melosira varians.*
† A few sprigs only.
Note: Most records from Station 1, but some from Stas. 2, 3, 4R, 6, 9, 11.

often occurring in association with others. It usually was present on bedrock under shallow water in both pools and riffles, and had its most extensive development in early and late summer on bedrock areas fully exposed to the sun. Except in those areas grazed by *Campostoma,* it invariably grew atop a layer of silt. It was covered with oxygen bubbles on many days and at times was responsible solely for photosynthetically induced chemical changes noted at Station 1. It is assumed that many shallow areas in the creek were affected similarly. *Melosira varians* formed networks of varying thicknesses in the upper layers of *Phormidium* mats when they were associated. *Stigeoclonium, Spirogyra, Calothrix,* and *Lemanea* appeared in established *Phormidium* growths. *Phormidium* mats varied from light blue-green to greenish brown in color. Blackish blotches often marked the presence of *Melosira* and *Calothrix.*

Phormidium subfuscum formed small, dense blue-green patches on the ruins of the mill dam and on rubble and mixtures of rubble and shingle. It often grew partly in and partly out of the water, and sometimes when wet by spray was out of the water completely. This *Phormidium* was noted only in late summer and early fall of 1949, when it harbored a midge larva that was not found elsewhere. These mats gave an impression of thickness when collected, but later were found to consist of tough, thin layers that held silt and other detritus beneath them. No sheaths were found on trichomes teased from these layers, but their existence was implied by the toughness of the mat. No species of *Oscillatoria,* described by Desikachary (24) and other references, had similar trichomes.

Phormidium Retzii covered wide areas of bedrock on the shallow riffle below Station 1 in September 1949. It was associated in spots with *Calothrix* and, along its margins, with *P. incrustatum. Lyngbya major* was mixed with *P. incrustatum* and diatoms at Station 1 on July 8, 1949. *Calothrix* occurred only in association with *P. incrustatum, P. Retzii,* and *Phormidium-Spirogyra* on bedrock in late summer and early fall. *Batrachospermum* was found in a small bedrock area below the junction of the mill dam and left bank in May 1949. Filaments were short and pinkish-brown in color. Diatoms other than *Melosira varians* occurred in association with other algae as indicated in Table II. The diatoms also produced extensive bottom covering films of their own in fall, winter, and early spring. Dominance at those times alternated between small species of Nitzchia (*N. amphibia* and *N. capitellata*) and *Gomphonema.* These growths, which had a gelatinous nature and varied from yellowish brown to deep brown in color, were widespread on shingle.

Melosira varians was abundant in the associations listed in Table II during late spring and summer. It was not observed to be attached directly to rocks, but instead grew profusely into other algae, usually forming dense networks near their upper surfaces. *M. varians* commonly occurs as a plankter. In Boone Creek, however, it grew luxuriantly in the benthos.

Stigeoclonium lubricum also occurred only in association with other algae, although it fastened directly to rock. It was common on shingle and shingle-rubble mixtures. *Spirogyra* sp. seemed more affected by season than by other factors, since it grew alone freely and among all other algae that were present in summer and early fall. *Pleurocapsa* was a rare form, found only in the association listed in Table II in April 1950. *Vaucheria* occurred in pure stands in brooks at Station 9.

Introduced Substrates

When it became evident in late summer 1949 that the frame and blade device seldom would deliver quantitative samples from uneven rocks naturally occurring in the creek, bricks and limestone pieces with one smooth surface were placed at random in the area below the mill dam at Station 1 with the hope that they would attract characteristic algal growths. Observations of these materials indicated that their utility in providing a better scraping surface was offset to a large degree by their frequent failure to attract all of the prevalent groups present on a given date. When they were placed selectively into areas that previously had been occupied by certain algae at certain seasons, the introduced limestone pieces often but not always were host to the species that later grew there. Previous records did not indicate always just what areas would be taken over by certain species the following year. *Lemanea* was rare on the mill dam ruins in 1949, but grew there profusely in 1950. Bricks had a strong attraction for *Phormidium*-diatoms (and sometimes *Stigeoclonium*) and often formed small clumps of these groups in carpets of *Lemanea* or *Cladophora*.

Since the experiment covered only the period October 1949 through April 1950, results are considered inconclusive. Observations suggest that the most successful materials were smoothed pieces of stones native to the stream, and that introduced rocks could not be relied on to deliver all representative algae, even when selectively placed into areas previously known to be inhabited by definite groups. The use of prepared materials, such as brick or limestone, to determine algal characteristics of an unknown stream appears inadvisable unless the material is used in large numbers and is accompanied by observations of growths on natural surfaces. Introduced stones appear to require a "seasoning" period of at least a few weeks for attraction of algae native to the site into which they are put.

Algae and Water Chemistry

Changes in water chemistry induced by algal activities were discussed in the 1951 article (23). It seems desirable to indicate here, however, the duration and extent of their effects (an item not mentioned previously in any detail). Figure 1 shows variation in pH and oxygen saturation at Station 1 over the 17 month period from December 1948 through early May 1950, and dominant algal growths over the period April 1949 through April 1950. All records except stage are lacking for January 1950. No algal records are on hand for January and February of

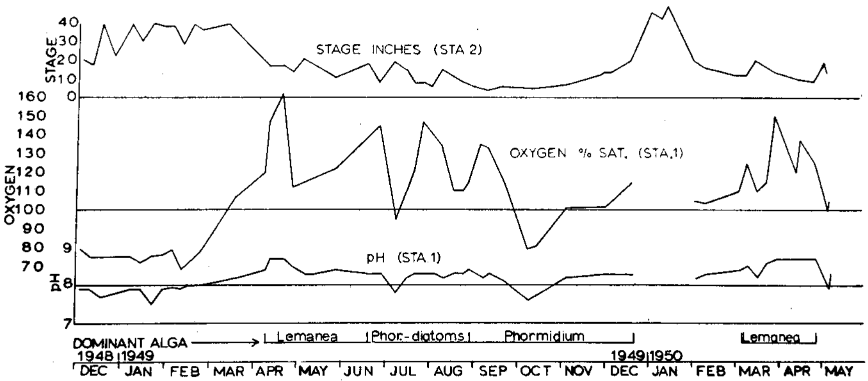

FIGURE 1.—Seasonal variation in pH, oxygen, and dominant algae at Station 1 associated with stage changes at Station 2. Diatoms (not shown) were dominant on March 5, 1960.

that year. During 12 of the 16 months of record, algal photosynthesis maintained carbonate in solution (pH > 8.0) and supersaturated oxygen concentrations. Since time of records varied from 9:00 AM to 2:30 PM, minima and maxima seldom were encountered at this site; but pH readings up to 9.0 and oxygen saturation up to 217 percent were observed in small, upland tributary brooks near Stations 6 and 9. Time for night observations was limited. Three after-dark visits to Station 1 showed a minimum pH of 7.8 and a minimum oxygen saturation of 71 percent. On one occasion in April 1950 oxygen fell to slightly less than 100 percent of saturation while pH declined only to 8.4. Temperature was 9°C and it was assumed that oxygen largely was lost by diffusion to the air, and that rate of decomposition-respiration was too slow or spring inflow too limited to provide sufficient CO_2 to combine with all carbonate present. Oxygen was 157 percent of saturation and pH 8.7 at 1:30 PM the preceding day.

Oxygen decline to below 100-percent saturation and pH drop to 8.0 (Figure 1) and below during daylight hours were occasioned by stage elevations that brought in fresh precipitation, and, in October 1949, by decomposition of fallen leaves that choked most riffles and covered the majority of pools. Algae grew in large numbers at that time, but their photosynthesis was unable to overcome the CO_2-producing, oxygen-utilizing effects of decomposition. No night observations were possible then, but it appeared that annual pH and oxygen minima could be expected at night during the falling leaf period. Algae played a considerable role in supply of oxygen to Boone Creek, and their production of carbonate during daylight hours served to retrieve much of the CO_2 produced at night and entering in ground waters.

During the period of these records, Station 1 rarely if ever was free from algal influences of some sort. It was routine for the creek to have carbonate in solution and supersaturated oxygen levels during daylight hours. This condition was observed to be disrupted only by entrance of rainwater and choking accumulations of fallen leaves. Disappearance of one type of prevalent algal growth always was accompanied by increase of another form or association. There were no discernible periods at weekly intervals when the stream was without algae. Benthic algae evidently were a normal part of Boone Creek riffles and other shallows.

Domination of water chemistry was achieved by only 13 groups of algae, of which only 3 groups attained the defined "dominant" status. Algal species and associations that did not cover the largest area of bottom were not without influence, since two or more non-dominant groups had combined growth areas at times that exceeded those of the most abundant species or association. However, the two groups at times individually did not cover as much territory, and their individual influences probably were less marked.

Algal growths that carried on photosynthesis at a discernible rate were not conspicuous always. They were difficult to observe at times until a certain familiarity with their habits was acquired. *Phormidium* on sand sometimes was inconspicuous and often detectable only by sampling or through its chemical influences. This obscurity was brought about by partial cover of sand grains atop the algae. On several occasions partially hidden *Phormidium* produced a velvety layer of gas bubbles atop the sand. Brown *Phormidium* and diatoms, and diatoms alone often could have been overlooked by a casual observer.

Macroinvertebrates

Sixty-six groups, species, or complexes, of macroscopic animals were

TABLE III.—Seasonal Occurrence of Individual Macroinvertebrate Groups

(Columns under each month indicate 1st, 2nd, 3rd, and 4th weeks)

Group No.	Invertebrate group	April	May	June	July	Aug.	Sept.	Oct.	Nov.	1949 Dec.	1950 Mar.	April	Stations where found
	Isopoda												
1	*Lirceus fontinalis* Rafinesque	+	++ +	+				+				++	1, 6, 9
	Amphipoda												
2	*Hyalella azteca* (Saussure)	+											9
	Ephemeroptera												
3	*Ephemerella frisoni* McDunnough		++++										1, 2
4	*Pseudocloeon myrsum* Burks	+	+								+	+	1, 6
5	*Pseudocloeon punctiventris* (McDunnough)		+ +		+		+				++	+	1, 2, 6
6	*Pseudocloeon* sp.		+								+	+	1, 2, 9
7	*Centroptilum* spp.	+	+ +	+	+ +	++++	+	++				+	1, 2
8	*Baetis* sp.			+									1
9	*Heterocloen* sp.	+											6
10	*Isonychia* sp.†						+						1
11	*Heptagenia* sp.					+							1
12	*Stenonema tripunctatum* gr.										+		1
13	*Stenonema* sp.					+	+						1, 3
	Plecoptera												
14	*Perlesta placida* Hagen		+										2
15	*Isoperla* sp.											+++	2, 6
	Trichoptera												
16	*Rhyacophila lobifera* Betten	+									++	+	1, 4R
17	*Rhyacophila fenestrata* Ross											++	6
18	*Agapetus* sp.	+											1
19	*Ochrotrichia unio* gr.	+	++ +			+	+				+	+++	1, 2, 4R, 6
20	*Hydroptila spatulata* Morton	+									+	+	1
21	*Hydroptila* sp.		+								+		1
22	*Neotrichia* sp.					+							1
23	*Cheumatopsyche* sp.		+	++									1, 2
	Lepidoptera												
24	*Cataclystra* sp.										+		6, 9
	Coleoptera												
25	*Peltodytes duodecimpunctatus* Say		+										1
26	*Stenelmis* sp.		+		+								1
27	*Dubiraphia* sp. A			+									1
28	*Dubiraphia* sp. B			+									1
29	*Psephenus* sp.					+	++						1, 2
30	*Helocharis* sp.						+						1
	Diptera-Stratiomyiidae												
31	*Euparyphus* sp.		+										1
	Simuliidae												
32	*Prosimulium* (magnum Dyar & Shannon?)	++									++++		1, 2, 4R
33	*Simulium (Neosimulium) vittatum* Zetterstedt				+ +								1, 2
34	*Simulium (Simulium) tuberosum* gr.		++ +			+ +						+++	1, 2, 6
	Chironomidae												
35	*Pentaneura flavifrons* gr.		+									+	1, 9

* Apparently undescribed forms.
† Considered a "stray."

TABLE III.—*Continued*

Group No.	Invertebrate group	April	May	June	July	Aug.	Sept.	Oct.	Nov.	1949 Dec.	1950 Mar.	April	Stations where found
	Chironomidea												
36	*Pentaneura monilis* gr.		++										1
37	*Procladius* sp.		+										2
38	*Diamesia nivoriunda* (Fitch)	+											2
39	*Metriocnemus lundbecki* Johannsen	+	+++	+							++	+	1, 2, 4R, 11
40	*Metriocnemus* sp. 1*					+					+	+	1
41	*Metriocnemus* sp. 2*	+++											1, 2, 6
42	*Cricotopus exilis* Johannsen		+										1
43	*Cricotopus fugax* (Johannsen)	+	+			+				+			1, 2
44	*Cricotopus trifasciatus* (Panzer)	+	+										1, 2
45	*Cricotopus* sp.*					+							1
46	*Corynoneura* (*Thienemanniella*) sp.					++	+						1, 2
47	*Spaniotoma* (*Euk.*) *longicalcar* gr. Kieffer	+	+									+++	1, 4R
48	*Spaniotoma* (*Euk.*) *coronata* Edwards		++										1
49	*Spaniotoma* (*Euk.*) sp.		++			+						+	1, 2
50	*Spaniotoma* (*O.*) *obumbrata* Johannsen	+	++			+	+			+	++		1, 2, 3, 9, 11
51	*Spaniotoma* (*O.*) *sordidella* Johannsen	+											1
52	*Spaniotoma* (*O.*) *nivoriunda-tatrica* gr.		+			+							1
53	*Spaniotoma* sp. 2*		+										2
54	*Spaniotoma* sp. 3*			++	++++	++++	++++	++					1
55	*Spaniotoma* sp. 4*				+								1
56	*Spaniotoma* sp. 5*					+							2
57	*Polypedilum* sp.		+	++	++	++++	+						1, 2
58	*Calopsectra.* sp.*					+							1
59	*Cryptochironomus digitatus* (Malloch)					+							3
60	*Glyptotendipes senilis* (Johannsen)		+			+							1
61	*Chironomus* (*Limnochironomus*) sp.*						+						1
	Ceratopogonidae												
62	*Dasyhelea oppressa* Thomsen					+	+						1
63	*Forcipomyia* sp.						+						1
64	*Bezzia* sp.											++	6
	Gastropoda												
65	*Physa* sp.						+					+	1, 6, 9
	Pelecypoda												
66	*Pisidium* sp.											+	9
Total No. of groups per month		18	29	9	7	21	15	3	0	2	13	19	

TABLE IV.—Algal Groups and Bottom Types Inhabited by Each Invertebrate Group

Number	Invertebrate Group	Algae Inhabited																								Bottom Types Inhabited						Notes
		Lemanea	*Lemanea-Cladophora*	*Lemanea-Phormidium*	*Cladophora*	*Cladophora-Spirogyra*	*Cladophora-Phormidium*	*Cladophora-Stigeoclonium*	*Phormidium*	*Phormidium-*Diatoms	*Phormidium-Stigeoclonium*	*Phormidium-Stigeo.*-Diatoms	*Phormidium-Spiro.*-Diatoms	*Phormidium-Melosira*	*Phormidium-Melo.-Spiro.*	*Phormidium-Spirogyra*	*Phormidium-Lyngbya*-Diatoms	*Phormidium-Calothrix*	*Phormidium-Calo.-Spiro*	*Melosira*-Diatoms	*Spirogyra*	*Spirogyra-Melosira*	*Batrachospermum*	Diatoms	Vaucheria	Bedrock	Rubble	Shingle	Gravel	Sand	Other	
1	*Lirceus fontinalis*	+	+		+					+	+							+					+		+	+	+	+	+			
2	*Hyalella azteca*																								+				+		+	Silt
3	*Ephemerella frisoni*	+			+																					+	+	+				
4	*Pseudocloeon myrsum*										+													+		+	+	+				
5	*P. punctiventris*	+			+				+	+														+		+	+	+				
6	*Pseudocloeon* sp.	+	+		+			+																+		+	+	+				
7	*Centroptilum* sp.	+	+		+	+			+	+						+		+			+	+				+	+	+	+			
8	*Baetis* sp.																					+				+						
9	*Heterocloeon* sp.									+																		+	+			
10	*Isonychia* sp.								+																		+					
11	*Heptagenia* sp.									+																	+					
12	*Stenonema tripunctatum* gr.																							+			+					
13	*Stenonema* sp.								+	+																+				+		
14	*Perlesta placida*	+																										+				
15	*Isoperla* sp.	+						+		+																		+	+			
16	*Rhyacophila lobifera*	+			+					+																	+					
17	*Rhyacophila fenestrata*	+								+																		+	+			
18	*Agapetus* sp.											+															+					
19	*Ochrotrichia unio* gr.	+	+		+			+		+											+					+	+	+	+			
20	*Hydroptila spatulata*	+																													+	Masonry
21	*Hydroptila* sp.				+																					+	+					
22	*Neotrichia* sp.																				+						+					
23	*Cheumatopsyche* sp.	+							+																		+	+				
24	*Cataclystra* sp.																							+				+	+			
25	*Peltodytes duodecimpunctatus*	+																								+	+					
26	*Stenelmis* sp.	+														+										+	+					
27	*Dubiraphia* sp. A	+																								+						
28	*Dubiraphia* sp. B	+																								+						
29	*Psephenus* sp.								+									+									+					
30	*Helocharis* sp.																				+					+						
31	*Euparyphus* sp.	+																								+						
32	*Prosimulium (magnum?)*	+	+	+	+																			+		+	+					Also on bare rocks
33	*Simulium (S.) tuberosum* gr.	+	+		+			+																		+	+	+	+			
34	*Simulium (N.) vittatum*				+					+																+	+					
35	*Pentaneura flavifrons* gr.	+			+																				+	+	+	+	+			
36	*Pentaneura monilis* gr.	+	+																							+	+					
37	*Procladius* sp.									+																		+				
38	*Diamesia nivoriunda*			+																											+	Masonry

TABLE IV.—*Continued*

Number	Invertebrate Group	Algae Inhabited																								Bottom Types Inhabited						Notes
		Lemanea	*Lemanea-Cladophora*	*Lemanea-Phormidium*	*Cladophora*	*Cladophora-Spirogyra*	*Cladophora-Phormidium*	*Cladophora-Stigeoclonium*	*Phormidium*	*Phormidium-*Diatoms	*Phormidium-Stigeoclonium*	*Phormidium-Stigeo.*-Diatoms	*Phormidium-Spiro.*-Diatoms	*Phormidium-Melosira*	*Phormidium-Melo.-Spiro.*	*Phormidium-Spirogyra*	*Phormidium-Lyngbya*-Diatoms	*Phormidium-Calothrix*	*Phormidium-Calo.-Spiro.*	*Melosira*-Diatoms	*Spirogyra*	*Spirogyra-Melosira*	*Batrachospermum*	Diatoms	Vaucheria	Bedrock	Rubble	Shingle	Gravel	Sand	Other	
39	*Metriocnemus lundbecki*	+	+		+																			+		+	+	+				
40	*Metriocnemus* sp. 1									+	+													+		+	+				+	Masonry
41	*Metriocnemus* sp. 2	+						+	+	+																+		+	+			
42	*Cricotopus exilis*	+																								+	+					
43	*Cricotopus fugax*	+							+	+														+		+	+	+				
44	*Cricotopus trifasciatus*				+				+																	+	+	+				
45	*Cricotopus* sp.									+																+						
46	*Corynoneura* (*Thienemanniella*) sp.				+					+											+					+		+				
47	*Spaniotoma* (*Euk.*) *longicalcar* gr.	+	+		+						+															+	+					Also in black flies
48	*Span.* (*Euk.*) *coronata*				+																			+		+	+					
49	*Span.* (*Euk.*) sp.	+			+																					+	+	+				
50	*Span.* (*O.*) *obumbrata*	+	+	+					+	+	+	+						+			+			+		+	+	+	+			
51	*Span.* (*O.*) *sordidella*								+																	+						
52	*Span.* (*O.*) *nivoriunda-tatrica* gr.				+																					+	+					
53	*Spaniotoma* sp. 2				+					+																		+				
54	*Spaniotoma* sp. 3			+		+	+		+	+						+		+			+	+				+	+				+	Masonry
55	*Spaniotoma* sp. 4									+																+						
56	*Spaniotoma* sp. 5				+																							+				
57	*Polypedilum* sp.	+			+	+			+	+											+					+	+	+				
58	*Calopsectra* sp.								+																		+				+	Masonry
59	*Cryptochironomus digitatus*								+																					+		
60	*Glyptotendipes senilis*	+			+																			+		+	+					
61	*Chironomus* (*Limnochironomus*) sp.																				+					+						
62	*Dasyhelea oppressa*								+	+											+					+	+					
63	*Forcipomyia* sp.								+																	+						
64	*Bezzia* sp.											+																+	+			
65	*Physa* sp.	+																			+				+	+		+	+			
66	*Pisidium* sp.																								+				+			
Total No. groups		31	10	4	23	3	1	5	17	23	5	3	0	0	0	3	0	5	0	0	11	3	1	12	5	43	38	28	14	2	6	

found in these algal samples (Table III). The majority appeared to be *bona fide* algal residents at times of capture. It is not assumed, however, that collection methods, which were aimed at algae, did not permit certain forms to escape consistently or that algae were the only homes of a number of groups.

Seasonal Distribution

Times when each invertebrate group inhabited algae are indicated in Table III. Algal inhabitation (number of invertebrate groups) was pronounced in April and May, and in August and September. Spring populations featured the annual maxima of mayflies, caddisflies, blackflies, and stoneflies, whereas variety in late summer was due largely to chironomids. Species unknown (sp.) listings in this table indicate that species identification was not possible due to fading, young instars only, shell dissolution, no known characters for separation, or not known to be described. Forms that appear to be undescribed are indicated by asterisks.

Relations to Algal Group and Bottom Type

The majority of these macroinvertebrates was found in two or more kinds of algal growths and on two or more bottom types (Table IV). Detailed examination of Table IV will disclose that there were 29 groups, each of which was restricted to a single species or association of algae, and 22 groups, each of which was found on only 1 bottom type. Since *Batrachospermum* was the only alga confined to a single bottom type, bottom may appear more influential than algae in distribution of the latter 22 groups. Because 18 of them were found only once, it appears profitless to dwell on their habitat relationships. Of the 4 groups appearing more than once in these collections, 3 (*Hydroptila spatulata, Spaniotoma* sp. 4, and *Calopsectra* sp.) definitely appeared to be restricted to the algae and bottom types listed in Table IV. Two groups (*Hydroptila sp.* and *Spaniotoma (O.) nivoriunda tatrica* gr.) seemingly were confined to *Cladophora* but occurred on all rocky bottom types. It appears that very few of these organisms differentiated between bedrock and rubble, although a tendency to select these two bottom types over shingle and gravel seems established in these records.

Selecting the algal species or association most favored by these invertebrates depends partially on seasonal influences. *Lemanea* was a widespread and dominant growth in April and May, and was inhabited by 31 of the 38 invertebrate groups found at that time. In August and September, *Phormidium* and the *Phormidium*-diatom association were the most widespread algal growths, being inhabited, respectively, by 17 and 23 of the 27 invertebrate groups then present. Caution also should be applied to selection of the bottom type favored by the majority of these invertebrates, since their presence on varied types could have been dictated by the occurrence of algae. It is safe to assume that the majority of them preferred bedrock and rubble. However, Table IV shows that a fair percentage was found on all rocky bottom types.

Larvae and pupae of *Prosimulium* sp. (*magnum* Dyar & Shannon?) were present in April 1949, and March 1950, in numbers that greatly exceeded those of other blackflies that occurred later in spring and summer. This species occurred only in lower regions (Stas. 1, 2, 4R), in algal growths, and attached directly to bare rock. Pure growths of larvae and pupae were inhabited by midge larvae [(*Spaniotoma (Euk.) longicalcar*)] that occurred at the same time in algae. Since they grew well on bare rock, these blackflies are not dependent strictly on benthic algae, although they preferred algae to naked rock.

Larvae and pupae placed in the *Simulium* (*Simulium*) tuberosum group probably are varieties of *S.* (*S.*) *venustum* Say or *S.* (S.) *verecundum* Stone and Jamnback. They appeared shortly after *Prosimulium* left in May 1949, and April 1950; disappeared in late May; and returned again in August. They lived on all rocky bottom types, but were found only in algae.

Spaniotoma sp. 3 was encountered as the most abundant macroinvertebrate. It grew in many algal groups that occurred on bedrock and rubble, but reached greatest concentration in *Phormidium* or *Phormidium*-diatoms on bedrock in September. It was present on every visit from mid-June to mid-October 1949, but was found only at Station 1. However, it probably occurred on other sunny bedrock and rubble areas. On occasion it was found to be the only invertebrate species in *Phormidium* or *Phormidium*-diatom growths. *Calopsectra* sp. larvae were found only in *Phormidium subfuscum* growing on rubble and masonry at Station 1. Larvae were unusual in having an enlarged prothorax into which the head could be retracted almost completely.

General Distribution

The last column in Table III lists stations where each invertebrate group was found. Since Station 1 was visited almost every week and other stations at longer intervals, it is not assumed that all forms listed only for Station 1 did not occur in other areas. On the other hand, it seems likely that forms found only at other stations did not occur at Station 1. Since Station 1 was inhabited by 53 of the 66 invertebrates found in Boone Creek algal growths, the station was representative of the stream reach covered, although its algae did not harbor stoneflies, lepidoptera, fingernail clams, and amphipods. One or more of these four groups may have been excluded by the lack of shingle and gravel on which they dwelt at other stations.

The reach included by Stations 1 through 4 is near the lower end of Boone Creek. This area was noted to differ in several respects from the smaller upper divisions represented by Stations 6, 9, and 11. Photosynthetic intensity was greater in the smaller branches, shading was less by a considerable amount, and the smaller upper divisions exceeded the lower creek in intermittency. Yet algae growing in the smaller branches contained only six invertebrate groups that did not occur in algae of the lower reaches. *Pisidium* densely populated *Vaucheria* over gravel bottom at Station 9, but did not enter algal growths in lower reaches, although it was noted to be present in gravel and sand at Stations 2 and 3; *Rhyacophila fenestrata* of the upper stream was replaced by *Rhyacophila lobifera* in the lower region; *Bezzia* and *Cataclystra* seemingly were restricted to the upper creek; *Heterocloeon* was represented by a single record; and restriction of *Hyalella* to *Vaucheria* at Station 9 was unusual for a species of many known habitats and seasons.

Quantitative Features

Limitations of the sampling frame with regard to quantitative algal samples have been noted. Truly quantitative samples of macroinvertebrates appear to have been obtained only from short growths, such as *Phormidium,* that were scraped from fairly flat surfaces. Removal of longer filamentous algae enclosed in the frame resulted in loss of active invertebrates; and it never was resolved whether these algae should be traced to their holdfasts or just pulled from within a random area delimited by the frame. Since the frame's shortcomings apparently all resulted in loss of animals, maximum numbers listed per

TABLE V.—Maximum Number of Each Macroinvertebrate Species per Frame
(1 frame = 1/48 sq ft (645 sq mm)

Number	Invertebrate Group	Max No. per Frame	Where Found	
			Alga(e)	Bottom
1	*Lirceus fontinalis*	8	*Lemanea*	Rubble
2	*Hyalella azteca*	11	*Vaucheria*	Gravel
3	*Ephemerella frisoni*	5	*Lemanea*	Rubble
4	*Pseudocloeon myrsum*	9	*Lemanea-Cladophora*	Bedrock
5	*Pseudocloeon punctiventris*	7	*Phormidium*-Diatoms	Rubble
6	*Pseudocloeon* sp.	3	*Lemanea*	Rubble
7	*Centroptilum* sp.	13	*Phormidium*	Rubble
8	*Baetis* sp.	2	*Spirogyra-Melosira*	Bedrock
9	*Heterocloeon* sp.	1	*Phormidium*-Diatoms	Shin-Grav.
10	*Isonychia* sp.	1	*Phormidium*	Rubble
11	*Heptagenia* sp.	1	*Phormidium*-Diatoms	Rubble
12	*Stenonema tripunctatum* gr.	1	Diatoms	Rubble
13	*Stenonema* sp.	5	*Phormidium*	Bedrock
14	*Perlesta placida*	1	*Lemanea*	Shingle
15	*Isoperla* sp.	5	*Lemanea*	Shin.-Grav.
16	*Rhyacophila lobifera*	3	*Lemanea*	Rubble
17	*R. fenestrata*	5	*Lemanea*	Shingle
18	*Agapetus* sp.	1	*Phormidium-Stigeo.*-Diatoms	Rubble
19	*Ochrotrichia unio* gr.	13	*Lemanea-Cladophora*	Rubble
20	*Hydroptila spatulata*	5	*Lemanea*	Masonry
21	*Hydroptila* sp.	3	*Cladophora*	Bedrock
22	*Neotrichia* sp.	1	*Spirogyra*	Rubble
23	*Cheumatopsyche* sp.	2	*Lemanea*	Rubble
24	*Cataclystra* sp.	1	Diatoms	Shingle
25	*Peltodytes duodecimpunctatus*	2	*Lemanea*	Bedrock
26	*Stenelmis* sp.	4	*Phormidium-Spirogyra*	Rubble
27	*Dubiraphia* sp. A	2	*Lemanea*	Bedrock
28	*Dubiraphia* sp. B	1	*Lemanea*	Bedrock
29	*Psephenus* sp.	7	*Phormidium*	Rubble
30	*Helocharis* sp.	1	*Spirogyra*	Bedrock
31	*Euparyphus* sp.	1	*Lemanea*	Bedrock
32	*Prosimulium* sp.	103	*Lemanea*	Rubble
33	*Simulium (N.) vittatum*	11	*Cladophora-Spirogyra*	Rubble
34	*Simulium (S.) tuberosum* gr.	13	*Lemanea-Cladophora*	Rubble
35	*Pentaneura flavifrons* gr.	3	*Cladophora*	Bedrock
36	*Pentaneura monilis* gr.	2	*Lemanea-Cladophora*	Rubble
37	*Procladius* sp.	1	*Phormidium*-Diatoms	Shingle
38	*Diamesia nivoriunda*	3	*Lemanea-Phormidium*	Masonry
39	*Metriocnemus lundbecki*	19	*Lemanea*	Bedrock
40	*Metriocnemus* sp. 1	2*	*Phormidium*-Diatoms	Bedrock
41	*Metriocnemus* sp. 2	4*	*Lemanea*	Bedrock
42	*Cricotopus exilis*	3*	*Lemanea*	Bedrock
43	*Cricotopus fugax*	4*	*Phormidium*	Bedrock
44	*C. trifasciatus*	3*	*Cladophora*	Rubble
45	*Cricotopus* sp.	2*	*Phormidium*-Diatoms	Bedrock
46	*Corynoneura (Thienemanniella)* sp.	7	*Phormidium*-Diatoms	Bedrock
47	*Spaniotoma (Euk.) longicalcar* gr.	41	*Lemanea*	Rubble
48	*Spaniotoma (Euk.) coronata*	10*	*Cladophora*	Bedrock
49	*Spaniotoma (Euk.)* sp.	3*	*Lemanea*	Bedrock
50	*Span. (O.) obumbrata*	17	*Phormidium*	Rubble
51	*Span. (O.) sordidella*	2*	*Phormidium*	Bedrock
52	*Span. (O.) nivoriunda tatrica* gr.	14*	*Cladophora*	Bedrock
53	*Spaniotoma* sp. 2	7*	*Cladophora*	Shingle
54	*Spaniotoma* sp. 3	471	*Phormidium*	Bedrock

* Approximate—not all midges in samples identified

TABLE V.—*Continued*

Number	Invertebrate Group	Max No. per Frame	Where Found	
			Alga(e)	Bottom
55	*Spaniotoma* sp. 4	3*	*Phormidium*-Diatoms	Bedrock
56	*Spaniotoma* sp. 5	4*	*Cladophora*	Shingle
57	*Polypedilum* sp.	23	*Phormidium*	Bedrock
58	*Calopsectra* sp.	7	*Phormidium subfuscum*	Rubble
59	*Cryptochironomus digitatus*	1	*Phormidium*	Sand
60	*Glyptotendipes senilis*	10*	*Cladophora*	Bedrock
61	*Chironomus* (*Limnochironomus*) sp.	15	*Spirogyra*	Bedrock
62	*Dasyhelea oppressa*	5	*Phormidium*	Bedrock
63	*Forcipomyia* sp.	3	*Phormidium*	Bedrock
64	*Bezzia* sp.	17	*Phormidium-Stigeo.*-Diatoms	Shingle
65	*Physa* sp.	3	*Vaucheria*	Gravel
66	*Pisidium* sp.	20	*Vaucheria*	Gravel

frame in Table V generally are conservative. The value for *Spaniotoma* sp. 3 is considered the most accurate.

These quantitative data truly serve to indicate only the macrobenthos productive potential of algae on the different bottom types, since none of the algal-bottom associations were sampled more than once/date/station. For example, a 200- to 300-sq ft (18.6- to 27.9-sq m) *Phormidium* bedrock area would have been represented by 3 sq in. (645 sq mm) at a single location; or, benthos on rubble covered with *Lemanea* would have been known from just 3 sq in. on a single slab. Except for the month of November 1949, samples always contained macrobenthos in some form. It seems likely that the samples depicted benthic forms that generally attained greatest development on specific algae-bottom combinations. Random sampling of each habitat area would be prerequisite to learning its actual carrying capacity. Study of Tables IV and V will disclose a number of facets that will permit the reader to arrive at his own decisions with regard to favored algal growths and other details. For example, *Lemanea* was inhabited by 31 invertebrates, and 19 of these showed maximum development there; 43 species dwelt on bedrock and 28 of them achieved greatest concentration there; *Spaniotoma* sp. 3 lived in several algae but evidently grew best in *Phormidium;* etc.

Entries in Table V indicate that benthic algae supported a weighty as well as varied invertebrate fauna in this creek. Reference also to Table III will show that some of these organisms were present during all months of record except November. The food source they offered for larger invertebrates and fish appeared constant and plentiful, but it is not known to what extent it was utilized. Crayfish and stone rollers were observed feeding on *Phormidium* growths that were known to contain large numbers of midges, and gizzard shad 4 to 6 in. (10.2 to 1.52 cm) long were observed feeding rather selectively in such areas. They may have been picking up midge larvae.

Broods of Aquatic Insects

Sampling and study regimens allowed no time for trapping emerging insects. However, maturation or emergence of broods often could be detected by pupae, black-winged nymphs, and shed pupal and nymphal skins in samples, or nymphal exuviae on rocks. Sampling probably was too infrequent to detect all emergences of poly brooded forms; and numbers of broods indicated probably are less than

TABLE VI.—Broods of Aquatic Insects Observed

Species	No. Broods	Month(s) of Emergence(s)
Ephemerella frisoni	1	May
Pseudocloeon myrsum	2	March, April, May
P. punctiventris	4	2 in March, April, May
		1 in July
		1 in September
Centroptilum sp.	6 (approx.)	1 in April, May
(may be more than one species)		1 in June
		1 in July
		1 in August
		1 in September
		1 in October
		(may be part of Sept. brood)
Rhyacophila lobifera	1	March, April
Rhyacophila fenestrata	1	April
Ochrotrichia unio gr.	4	1 in March, April
(may be more than one species)		1 in May
		1 in August
		1 in September
Hydroptila spatulata	1	March, April
Hydroptila sp.	1	April, May
Cheumatopsyche sp.	1	May, June
Prosimulium (magnum?)	1	March, April
Simulium (S.) tuberosum gr.	3	1 in April
(may be two species)		1 in May
		1 in August
Simulium N. vittatum	1	July
Pentaneura flavifrons gr.	1	April, May
Pentaneura monilis gr.	1	May
Procladius sp.	1	May
Diamesia nivoriunda	1	May
Metriocnemus lundbecki	2	1 in March, April
		1 in May, June
Metriocnemus sp. 1	2	1 in April, May
		1 in August
Metriocnemus sp. 2	1	April
Cricotopus exilis	1	May
Cricotopus fugax	3	1 in April, May
		1 in August
		1 in December
Cricotopus trifasciatus	1	April, May
Corynoneura (Thienemanniella)	1	August, September
Spaniotoma (Euk.) longicalcar	1	April, May
S. (Euk.) coronata	1	April, May
S. (Ortho.) obumbrata	4 (approx.)	1 in March, April
		1 in May
		1 in August
		1 in September
		(possibly 1 brood in December larvae only seen then)
Spaniotoma sp. 3	8 (approx.)	1 in June
		2 in July
		2 in August
		2 in September
		1 in October
S. (Ortho.) niv. tatrica	2	1 in May
		1 in August

TABLE VI.—*Continued*

Species	No. Broods	Month(s) of Emergence(s)
Polypedilum sp.	5	1 in May 1 in June 1 in July 1 in August 1 in September
Calopsectra sp.	1	August
Glyptotendipes senilis	2	1 in May 1 in August
Chironomus (*Limno.*) sp.	1	September
Dasyhelea oppressa	1	August, September
Bezzia sp.	1	April

actually occurred. No data exist for forms not appearing in Table VI.

Discussion

This sampling program initially was planned to gather qualitative and quantitative data on benthic algae. Failure to relate mass of algae accurately to unit area was to a large extent compensated by the unanticipated dividend of qualitative and varyingly accurate quantitative information on macrobenthos that inhabited the algae. Sampling had been under way for a time before inclusion of invertebrates became known. Procedures then were continued unchanged, although the method may have been less than adequate for the more active animals. At first it appeared that data on invertebrates represented mere salvage from an unsuccessful quantitative algal program; but, as facts of their occurrence and distribution were considered, it became apparent that conventional macrobenthos sampling methods would have hidden their relations with algae. Collection in smaller grades of loose rock with a Surber net or tow dredge will include algal residents with those dwelling in other situations. Several Surber collections from gravel and shingle in Boone Creek (Stations 2, 6, 9) netted some groups (*Corydalis, Ephemera, Pteronarcys, Acroneuria, Allocapnia, Hydropsyche, Sphaerium, Chironomus, Tipula, Tabanus, Goniobasis,* tubificids, dytiscids, and others) that were not found in algal samples, and several invertebrates that inhabited algae. It would have been impossible to distinguish between algal and non-algal residents from Surber samples alone, and these collections did not reveal invertebrate populations in algae growing on bedrock and large pieces of rubble.

The apparent preference of many invertebrates for algae growing on large unbroken areas of rock indicates that bedrock and larger grades of rubble should be included in benthos studies of streams of this general type. These areas generally have been ignored, probably because of their barren appearance. They could be worked with a standard Surber sampler with minor modification (foam plastic, etc.) to fit the frame to the unyielding bottom. Scraping would be required for *Phormidium* and similar closely adhering algae. Numbers of organisms found in algae on bedrock in Boone Creek suggest that an areal unit less than 1 sq ft (0.09 sq m) might be desirable to avoid frequent handling of several thousand specimens. Inconspicuous blue-green algae on bedrock and large flat pieces of rubble at times were inhabited by single invertebrate species that developed the greatest benthos concentrations noted. *Spaniotoma* sp. 3 at one time had 22,608 individuals/sq ft (244,166 individuals/sq m) and on several occasions exceeded 5,000/sq ft (54,000/sq m). This midge in "clean" water exhibited a condition that commonly is considered characteristic of polluted waters—that is, large numbers of one or a few species in a small area. Most known species of these algae-inhabiting midges have exhibited less tolerance for pollution than species of Chironominae and Tanypodinae (= Pelopiinae).

The uses to which algae were put by each invertebrate group are speculative to a degree. Many mayflies and midges evidently gained shelter or shelter and food from the algae. Stoneflies may have invaded the algae primarily in search of insect prey. *Cheumatopsyche* sp. apparently used the algae mainly to anchor its pupal cases. *Prosimulium* seemed to prefer algae to barren rock, although occasionally attaching to the latter. The cases of *Ochrotrichia unio* gr. and *Hydroptila spatulata* were fastened to algae (usually to filaments of *Lemanea*). Several midges lived and pupated in flimsy silken cases in short open-ended burrows made in blue-green algae and diatoms. It is not known if the midges fed on these algae or on materials caught in nets. No midge cases were observed in other algae. After preservation, some midge larvae bore a strong resemblance to *Lemanea* filaments. Few of the more active predaceous insects were found, but they may have evaded capture by this collecting method. They hardly could have found better hunting grounds for midges and mayflies.

Seasons of algal occupation by varied invertebrates, algae, and bottoms favored by individual groups, and the importance of each algal habitat as a benthos producer are shown by these data; however, they do not differentiate between obligative and facultative algal inhabitants (or show that such categories exist), and are too poorly representative of widespread growths to denote accurate quantitative relationships. This study indicated that both conspicuous and generally unnoticed algal growths markedly affected water quality and harbored great numbers of invertebrates on bottom types normally considered poorly productive.

Algal bottom preferences and invertebrate algae and bottom preferences are indicated in preceding tables and text, and this matter merits little attention here. *Lemanea, Cladophora, Phormidium*-diatoms, *Phormidium,* diatoms, *Spirogyra,* and *Lemanea-Cladophora* were the only growths harboring 10 or more invertebrate species. *Lemanea* was the most favored alga in spring and early summer, and the *Phormidium*-diatom association was inhabited most in summer and early autumn. Whether a growth was favored or just dwelt in because it was present at the time is a point in question that hardly appears resolvable with these data. Certain mayflies, caddisflies, and midges inhabited a wide variety of algal types. The most numerous species lived in the greatest number of algal associations. Algal type appeared to be limiting for a few invertebrate species. A number of invertebrates found in algae also may live in other environments, and their relative success in each situation is worthy of study by techniques that will secure all organisms and deliver samples from only one habitat at a time. This may not be a simple matter.

References

1. Kolkwitz, R., and Marsson, M., "Ökologie der Pflanzlichen Saprobien." *Berichte Deutschen Botanischen Gesellschaft,* **26a**, 505 (1908).
2. Kolkwitz, R., and Marsson, M., "Ökologie der Tierischen Saprobien." *Intl. Rev. gesamten Hydrobiologie Hydrographie,* **2**, 126 (1909).
3. Liebmann, H., "Die Bedeutung der Mikroskopischen Untersuchung für die Biologische Wasseranalyse." *Vom Wasser,* **15**, 181 (1942).
4. Liebmann, H., "Handbuch der Frischwasser und Abwasser Biologie." Munich (1942).

5. Lackey, J. B., "Protozoan Plankton as Indicators of Pollution in a Flowing Stream." *Pub. Health Rept.*, **53**, 2037 (1938).
6. Lackey, J. B., "Aquatic Life in Waters Polluted by Acid Mine Wastes." *Pub. Health Rept.*, **54**, 740 (1939).
7. Lackey, J. B., "Two Groups of Flagellated Algae Serving as Indicators of Clean Water." *Jour. Amer. Water Works Assn.*, **33**, 1099 (1941).
8. Lackey, J. B., "The Significance of Plankton in Relation to Sanitary Conditions in Streams. A Symposium on Hydrobiology." Univ. Wisconsin Press, Madison, Wis. (1941).
9. Lackey, J. B., "Plankton as Related to Nuisance Conditions in Surface Water." In "Moulton and Hitzel, Limnological Aspects of Water Supply and Waste Disposal." *Amer. Assn. Advance. Sci.*, XXX, 56 (1949).
10. Brinley, F. J. "Biological Studies, Ohio River Pollution Survey. I. Biological Zones in a Polluted Stream." *Sewage Works Jour.*, **14**, 1, 147 (Jan. 1942).
11. Fjerdingstad, E., "The Microflora of the River Mølleaa with Special Ref. to the Relation of the Benthal Algae to Pollution." *Folia Limnological Scandinavica*, **5**, 123 (1950).
12. Forbes, S. A., and Richardson, R. E., "Studies on the Biology of the Upper Illinois River." Bull. Ill. Nat. Hist. Sur., **9**, 481 (1913).
13. Forbes, S. A., and Richardson, R. E., "Some Recent Changes in Illinois River Biology." Bull. Ill. Nat. Hist. Sur., **13**, 139 (1919).
14. Gaufin, A. R., and Tarzwell, C. M., "Aquatic Invertebrates as Indicators of Stream Pollution." *Pub. Health Rept.*, **76**, 57 (1952).
15. Gaufin, A. R., and Tarzwell, C. M., "Aquatic Macro-Invertebrate Communities as Indicators of Organic Pollution in Lytle Creek." *Sewage and Industrial Wastes*, **28**, 7, 906 (July 1956).
16. Ingram, W. M., "Use and Value of Biological Indicators of Pollution; Freshwater Clams and Snails." In "Biological Problems in Water Pollution—Transactions of the 1956 Seminar." R. A. Taft Sanitary Engineering Center, W57-37 (1957).
17. Patrick, R., "A Proposed Biological Measure of Stream Conditions, Based on a Survey of the Conestoga Basin, Lancaster County, Pennsylvania." Proc. Phila. Acad. Nat. Sci., **101**, 277 (1949).
18. Patrick, R., "Aquatic Organisms as an Aid in Solving Waste Disposal Problems." *Sewage and Industrial Wastes*, **25**, 2, 210 (Feb. 1953).
19. Richardson, R. E., "Changes in the Bottom and Shore Fauna of the Middle Illinois River and its Connecting Lakes Since 1913–15 as a Result of the Increase, Southward, of Sewage Pollution." Bull. Ill. Nat. Hist. Sur., **14**, 33 (1921).
20. Richardson, R. E., "The Bottom Fauna of the Middle Illinois River 1913–1925; its Distribution, Abundance, Valuation and Index Value in the Study of Stream Pollution." Bull. Ill. Nat. Hist. Sur., **17**, 387 (1928).
21. Beck, W. M., Jr., "Studies in Stream Pollution Biology. I. A Simplified Ecological Classification of Organisms." *Quart. Jour. Fla. Acad. Sci.*, **17**, 211 (1954).
22. Beck, W. M., Jr., "Suggested Method for Reporting Biotic Data." *Sewage and Industrial Wastes*, **27**, 10, 1193 (Oct. 1955).
23. Neel, J. K., "Interrelations of Certain Physical and Chemical Features in a Head-water Limestone Stream." *Ecology*, **32**, 368 (1951).
24. Desikachary, T. V., "Cyanophyta, Indian Council of Agricultural Research Monographs on Algae." Academic Press, New York and London (1959).
25. Elmore, C. J., "The Diatoms (Bacillarioideae) of Nebraska." University Studies, Lincoln, Nebraska, **21**, **22** (Nos. 1–4), 214 (1922).
26. Hustedt, F., "Bacillariophyta (Diatomeae) Heft 10 Die Suswasser-Flora Mitteleuropas." Jena (G. Fischer), **8**, 466 (1930).
27. Prescott, G. W., "Algae of the Western Great Lakes Area." W. C. Brown & Co., Dubuque, Iowa (1962).
28. Smith, G. M., "The Fresh-Water Algae of the United States." McGraw-Hill, New York. (1950).
29. Burks, B. D., "The Mayflies, or Ephemeroptera, of Illinois." *Bull. Ill. Nat. Hist. Sur.*, **26**, 1 (1953).
30. Frison, T. H., "The Stoneflies, or Plecoptera, of Illinois." *Bull. Ill. Nat. Hist. Sur.*, **20**, 281 (1935).
31. Frison, T. H., "Studies of North American Plecoptera with Special Ref. to the Fauna of Illinois." *Bull. Ill. Nat. Hist. Sur.*, **22**, 235 (1942).
32. Ross, H. H., "The Caddis Flies, or Trichoptera, of Illinois." *Bull. Ill. Nat. Hist. Sur.*, **23**, 1 (1944).
33. Flint, O. S. Jr., "Larvae of the Caddis Fly Genus *Rhyacophila* in Eastern

North America (Trichoptera: Rhyacophilidae).'' *Proc. U. S. Nat. Mus.*, **113**, 465 (1962).

34. Curry, L. L., ''Larvae and Pupae of the Species of *Cryptochironomus* (Diptera) in Michigan.'' *Limnol. Oceanog.*, **3**, 427 (1958).
35. Curry, L. L., ''A Study of the Ecology and Taxonomy of Freshwater Midges (Diptera: Tendipedidae) of Michigan with Special Reference to their Role in the 'Turnover' of Radioactive Substances in the Hydrosol.'' Progress Report, **2**, 9 (1962).
36. Johannsen, O. A., ''Aquatic Diptera. Part. I. Nemocera Exclusive of Chironomidae and Ceratopogonidae.'' Memoir 164, Cornell Univ. Agr. Exp. Sta., 71 (1934).
37. Johannsen, O. A., ''Aquatic Diptera. Part II. Orthorrhapha-Brachycera and Cyclorrhapha.'' Memoir 177, Cornnell Univ. Agr. Exp. Sta., 61 (1935).
38. Johannsen, O. A., ''Aquatic Diptera. Part III. Chironomidae: Subfamilies Tanypodinae, Diamesinae, and Orthocladiinae.'' Memoir 205, Cornell Univ. Agr. Exp. Sta., 84 (1937a).
39. Johannsen, O. A., ''Aquatic Diptera. Part IV. Chironomidae: Subfamily Chironominae.'' Memoir 210, Cornell Univ. Agr. Exp. Sta., 1 (1937b).
40. Malloch, J. R., ''The Chironomidae or Midges of Illinois, with Particular Reference to the Species Occurring in the Illinois River.'' *Bull. Ill. State Lab. Nat. Hist.*, **10**, 273 (1915).
41. Stone, A. and Jamnback, H. A., ''The Black Flies of New York State.'' N. Y. State Mus. Bull., **349**, 144 (1955).
42. Usinger, R. L. (Editor), ''Aquatic Insects of California.'' Univ. Calif. Press, **9**, Special ref. Leech and Chandler, 293 (1956).
43. Dillon, E. S. and Dillon, L. S., ''A Manual of Common Beetles of Eastern North America.'' Row, Peterson & Co., Evanston, Illinois (1961).
44. Edmondson, W. T. (Editor), ''Ward and Whipple's Fresh-Water Biology.'' John Wiley and Sons, New York (1959).