BIOTIC CHARACTER AS RELATED TO STREAM MINERAL CONTENT[1]

JOE KENDALL NEEL, SR.
Department of Biology, University of North Dakota, Grand Forks, North Dakota 58201

NEEL, J. K., SR. 1973. Biotic character as related to stream mineral content. *Trans. Amer. Micros. Soc.*, 92: 404–415. Nine montane streams in or near deciduous forests in eastern Kentucky and western Virginia fell into two distinct classes with respect to hardness and alkalinity—five with these values below 30 mgl (Type B streams) and four with them exceeding 50 mgl (Type A streams). B streams contained as much or more phosphorus and nitrogen as the A's, but had no vegetation other than very sparse algal growth, and, with one exception, lacked molluscs. Type A streams had abundant flowering plants and/or algae at all seasons and well-developed mollusc populations. Benthic insects also showed definite A and B characteristics, although the two stream types had a number of forms in common. Neither degree of shading nor stream size seemed primarily involved in scarcity of plants in B streams. Allochthonous debris was more concentrated in B streams. In one stream system the biota changed from B to A in character with downstream mineral increase.

Macrobenthos populations noted in two streams in summer of 1964, led to a general reconnaissance of small streams in the Blue Ridge Mountains of Virginia in early 1965, and this in turn led to study of factors involved in level of autotrophism and benthos composition in streams of the generally mountainous and

[1] Travel was supported in part by Grant No. 65-11 from the Arts and Sciences Research Fund, University of Louisville. Assistance in the field was provided by my wife, Erma Baugh Neel, and son, Joe K. Neel, Jr.

forested area of western Virginia and eastern Kentucky. Eight streams were selected on the bases of environment and accessibility in the upper Tennessee and James River basins, and a small branch of Tygarts Creek, a tributary to the Ohio River in Carter Co., Kentucky, was added after two series of samples were taken in the other streams.

Materials and Methods

The area was visited in summer 1965, winter 1965–66, spring and summer 1966, and summer 1967. Samples of vegetation and macrobenthos were taken each trip and the water was analyzed for oxygen (1965 only), alkalinity, hardness, calcium, magnesium, inorganic phosphorus, and ammonia and nitrite nitrogen. Nitrate was omitted because of long storage required. Algae and other plants were scraped or pulled from the bottom, macrobenthos was taken with a Surber net from movable materials, submerged vegetation, and along bank overhangs, and naiad clams and crayfish were often picked up or caught by hand. All riffle microhabitats were sampled, and any large uniform areas were sampled in a few to several places depending upon size. During low water stages the small streams offered little variety in habitat and limited areas that could be sampled. Bottom materials were invariably too coarse to allow delimitation of an areal unit and debris and organisms taken with the Surber sampler are considered representative only of unit of effort, that is, sampler haul. Number of sampler hauls per collection varied from four in the smallest streams to 32 in the largest. Chemical analyses were according to the usual methods (APHA, 1965). Sensitivities for nutrients were: phosphorus .002, ammonia N.01, and nitrite N.001 mg/l. Vegetation was preserved and stored in 2–4% formaldehyde solutions. Diatoms were later cleaned in acid and mounted in Hyrax. Macrobenthos was fixed in formalin, washed with water, sorted, and stored in alcohol. Parts for microslides were cleared in Euparol essence and mounted in diaphane. Identifications were to species in all groups except turbellarians and *Goniobasis*, which may possibly include three species. Organic debris taken with organisms was washed free of formalin, dried, and weighed. Larger pieces were picked out with forceps and finer grades were floated in a heavy syrup and skimmed. Not all organic matter would float, and it was difficult to exclude algae when present.

Identifications of the various groups were according to Burks (1953), Curry (1958, 1962), Dillon & Dillon (1961), Edmondson (1959), Fasset (1940), Flint (1962), Frison (1935, 1942), Hustedt (1930), Johannsen (1934, 1935, 1937a, b), Malloch (1915), Needham & Westfall (1955), Neel & Allen (1963), Patrick & Reimer (1966), Prescott (1962), Ricker (1952), Ricker & Ross (1968), Ross (1944), Sinclair (1964), G. M. Smith (1950), Stone & Jamnback (1955), Thomsen (1937), and Usinger (1963).

Presentation of Data

Study Areas

Stream names and pertinent features of sampling stations appear in Table I. Rubble is used to designate large broken stones, and shingle indicates smoothly imbricated smaller stones. The Clinch, Holston, and Cow Pasture Rivers were considerably larger than the other six streams, having minimum discharges ranging from 10 to 60 times greater, and were at lower elevations with less forest cover.

The Clinch River was sampled approximately 10 miles below Tazewell, Virginia, the Middle Fork of the Holston near the eastern boundary of Marion, Virginia, and Tygarts Creek just outside Carter Caves State Park near Olive Hill, Kentucky. Dancing, 64.5 Mile, and the two Otter Creeks were reached from the Blue Ridge Parkway a few miles north and south of the James River

TABLE I
General stream characters at collecting stations

Stream	Bottom materials	Approx.[1] discharge range m³/sec.	Tributary to:	Surroundings	Shading[2]	Depth range cm
Middle Fork Holston River	Bedrock overlaid with gravel and shingle	1.5 –6.0	Tennessee River	Pastures and deciduous forest	Partial	20–90
Clinch River	As above plus rubble	3.0 –9.0	Tennessee River	Pastures and deciduous forest	Partial	30–100
Cow Pasture River	Bedrock overlaid with cobble, shingle, and rubble	1.5 –4.5	James River	Pastures, trees on margins	Nearly complete	38–85
Tygarts Creek	Bedrock with rubble deposit	.05– .29	Ohio River	Deciduous forest	Complete[3]	10–47
Bob Downey Creek	Bedrock and shale, overlaid with rubble	.05– .24	Cow Pasture River	Dense deciduous forest	Complete	5–50
Dancing Creek	Bedrock overlaid with rubble	.05– .30	James River	As above	Complete	5–40
Upper Otter Creek	As above	.11– .44	As above	As above	Complete	10–55
Lower Otter Creek	As above	.15– .75	As above	Deciduous forest	Nearly complete	10–65
64.5 Mile Creek	As above	.05– .30	As above	Dense deciduous forest	Complete	5–28

[1] At times visited only.
[2] During verdant months.
[3] Trees extending over stream from both banks.

crossing, and Bob Downey Creek and Cow Pasture River study sites were near U. S. Highway 60 in Allegheny County, Virginia. With the exception of the Cow Pasture River, all James River tributaries were in national forests.

Physical and Chemical Features

Water temperature usually ranged 2–6 C lower than that of the air, but the Clinch and Holston Rivers were slightly warmer than the air in summer of 1966. Recorded stream temperatures ranged from 2–32 C. All streams were clear (turbidity < 25 units) when visited.

Mineral content as indicated by alkalinity and hardness varied from stream to stream, but the first four streams listed in Table II were noticeably and consistently higher in these respects than the remaining five. Differences in level of mineralization will be mentioned in later sections, and, to simplify matters, those with higher mineral content (Clinch, Holston, and Cow Pasture Rivers and Tygarts Creek) will be designated Type A streams, and those with low mineral level (Bob Downey, Dancing, Upper and Lower Otter, and 64.5 Mile Creeks) Type B streams. Carbonate alkalinity was found only in Type A streams, and only in them did oxygen attain supersaturation in 1965 (it was not measured in Tygarts Creek).

Phosphorus became rather heavily concentrated at times in all streams, achieving peaks in each during summer months and declining, usually to < 0.002 mg/l, in winter. Its level in Type A streams, although high in summer, was not greater than could be expected at times from fertilized fields, municipal and,

TABLE II
Range of chemical conditions (mg/l)

	O_2 % Sat. 1965	CO_3- ALK.	HCO_3- ALK.	Total hardness	Calcium hardness	Magnesium hardness	Inorganic Phosphorus	Ammonia Nitrogen	Nitrite Nitrogen	
Clinch River	143	4–12	122–136	152–214	104–160	48–54	0–2	0.4–0.5	0–0.015	Type A Streams
Middle Holston River	127	8–12	84–86	135–144	77–84	58–60	1.5–3	0.35–0.45	0	
Cow Pasture River	102	0–2	52–71	74–102	60–86	12–18	0–3	0.35–0.6	0	
Tygarts Creek	–	2–12	76–113	140	114–117	23–26	0.5–2.6	0.4–0.7	0.0–0.04	
Bob Downey Creek	72	0	6–14	8–14	8–14	0–6	0–3.2	0.3–0.6	0	Type B Streams
Dancing Creek	83	0	4–12	8–12	2–6	4–8	0–3	0.25–0.55	0	
Upper Otter Creek	76	0	6–8	8–12	6	2–6	0–2.6	0.3–0.35	0	
Lower Otter Creek	81	0	8–16	8–16	4–8	4–8	0–8	0.25–0.5	0	
64.5 Mile Creek	87	0	8–10	8–14	6–8	0–8	0–9	0.25–0.6	0	

for Tygarts Creek, sanitary wastes, but it was unexpectedly high in Type B streams, which were situated in dense forests and received no wastes nor drainage from fertilized fields. The absence (< .002 mg/l) of phosphorus from all five in winter suggests that tourist or forest management activities were involved in high summer concentrations.

Ammonia nitrogen was found at all times in all streams, but nitrite was detected only in summer in Clinch River and Tygarts Creek. It seemingly owed its presence in the latter to sanitary facilities in a state park and could have been contributed by fertilized fields or Tazewell, Virginia, in the former.

Organic Debris

In spring and summer, Type B streams contained parts of mountain laurel, *Rhododendron*, flowering dogwood, and tulip tree (*Liriodendron*) blossoms, green leaves, and remnants of autumn leaves, acorns, and nuts, which were the only materials seen in winter. Debris in Type A streams was mainly leaves, but magnolia blossoms occurred in summer in Tygarts Creek. Type B streams contained considerably more organic debris than the three Type A rivers, but Tygarts Creek differed but little in this respect from Type B streams. Average dry weights per sampler haul were 2.7g for the 3 Type A rivers, 8.5g for Tygarts Creek, and 9.9g for the 5 Type B streams. Greatest amounts of debris occurred in winter in all streams.

Vegetation

Composition and extent of plant growth in each stream at each visit is shown in Table III. Type A streams contained widespread growths of aquatic flowering plants and/or algae in summer and algae alone in winter, whereas Type B streams, with one exception, usually had extremely sparse plant growth except for limited algae in summer and spring. The exceptional Type B stream, Lower Otter Creek, had widely scattered patches or sprigs of algae whenever visited.

Blue-green algae in Tygarts, Bob Downey, and Upper Otter Creeks consisted of *Phormidium* sp., *Calothrix breviarticulata* West, and *Lyngbya major* Meneghini.

TABLE III
Aquatic Vegetation/Stream/Season

	Clinch River	Middle Holston River	Cow Pasture River	Tygarts Creek	Bob Downey Creek	Dancing Creek	Upper Otter Creek	Lower Otter Creek	64.5 Mile Creek
Summer 1965	Widespread *Heteranthera* *Potamogeton* *Cladophora*	Scattered *Heteranthera* *Potamogeton*	*Cladophora* *Potamogeton*	Not visited	None found	None found	None found	Sparse blue-green algae	None found
Winter 1965 1966	Widespread diatoms+ *Phormidium*	Widespread diatoms	Scattered *Cladophora*	Diatoms wide-spread	None found	None found	None found	Sparse blue-green algae	None found
Spring 1966	High water	High water	High water	Diatoms wide-spread	None found	Sparse *Stigeoclonium*	Not visited	Sparse diatoms blue-green algae	Sparse diatoms+ *Stigeoclonium*
Summer 1966	Widespread *Heteranthera* *Cladophora*	Widespread diatoms *Potamogeton*	*Potamogeton* *Cladophora*	Not visited	Sparse blue-green algae	None found	None found	Sparse diatoms blue-green algae *Tuomeya*	Sparse *Stigeoclonium*
Summer 1967	Widespread *Heteranthera* *Cladophora* *Phormidium*	Not approachable	Scattered *Potamogeton* *Cladophora*	Wide-spread blue-green algae	Sparse *Stigeoclonium*	None found	Sparse blue-green algae	Sparse *Stigeoclonium*	None found
	Type A Streams				Type B Streams				

In Lower Otter Creek *Phormidium* sp. was invaded by varying numbers of diatom species. *Stigeoclonium lubricum* (Dill.) Kütz. and *Cladophora glomerata* Kütz. were the only green algae observed. *Tuomeya fluviatilis* Harvey was widely scattered in Lower Otter Creek in summer 1966. Diatoms found in the Clinch River, Tygarts, and Lower Otter Creeks are listed below. Aquatic flowering plants were *Heteranthera dubia* (Jacq.) McM. and *Potamogeton pectinatus* L.

Macrobenthos

Qualitative features. Number of collections, sampler hauls (= approximate area covered in square feet), and species found in each stream are shown in Table IV. The 27 collections from about 340 square feet of riffle bottoms yielded 203 species. Number of sampler hauls depended upon the coverage each situation appeared to merit, and it may be noted that number of species was not dependent upon number of hauls. Twenty hauls in Bob Downey Creek gave fewer species than 16 in 64.5 Mile Creek, and 72 hauls in the Cow Pasture River resulted in fewer species than 28 hauls in Tygarts Creek, or 48 in the Holston River, or 16 in 64.5 Mile Creek, etc. Every type of riffle subhabitat observed at each station was sampled, and large areas of like habitat were sampled several times. The Clinch River received greater coverage because of its size and habitat variety. The smaller streams generally had more uniform riffle condition, and this, in conjunction with their limited workable areas, resulted in as few as four sampler hauls per collection. More than that number would have usually disturbed an unconscionably large percentage of their total riffle areas.

Whether or not a series of collections accurately depicts the benthos composition of a stream is conjectural, particularly since valid quantitative samples are usually not possible. This endeavor gave numbers per individual station that are comparable to those yielded by some intensive studies elsewhere. A detailed

TABLE IV
Collection data and benthos details

	Number of collections	Total no. sampler hauls	No. species found	Unique forms	Forms shared with A Streams	Forms shared with B Streams	Forms shared with A and B Streams
Clinch River	3	96	86	20	32	5	29
Holston River	2	48	60	6	28	2	24
Cow Pasture River	3	72	50	10	10	6	24
Tygarts Creek	2	28	56	11	14	10	21
Bob Downey Creek	4	20	35	1	3	14	17
Dancing Creek	3	12	57	6	6	18	27
Upper Otter Creek	2	16	48	6	2	17	23
Lower Otter Creek	4	32	51	6	3	17	25
64.5 Mile Creek	4	16	64	8	5	19	32
Totals	27	340	–	74	–	–	–

study of the Meramec River and its tributaries (Missouri Water Pollution Board, 1964), which entailed making 209 collections covering about 2,300 square feet of riffle bottoms at 51 stations over spring, summer, fall, and winter, produced a maximum of 63 forms per station and less than 200 forms overall. An intensive study of algae-dwelling benthos in Boone Creek (Neel, 1968) yielded 66 species in 327 collections.

A and B streams had characteristic macrobenthos populations when collections were viewed in sorting pans, but this distinctiveness has since tended to become lost in lists and tables. The list of species (Tables VI, VII) indicates the number of streams of each type, and of both types, inhabited by each species. Seventy-four (74) species were found in only one stream, and 53 of these occurred but once. A large number of "singletons" often characterizes intensive stream benthos collections. Twenty-six percent (26%) of the species found in these nine streams were found but once, whereas 35% of the 66 species found in Boone Creek occurred but once (Neel, 1968). Thirty-nine of the 87 species limited to A streams occurred in two or more of them, and 32 of the 59 species found only in B streams were present in two or more of them. A and B streams shared 58 species, 49 of which occurred in three or more streams. Table IV also shows the number of unique forms for each stream, and the number each shared with A streams only, B streams only, and A and B streams. Each stream had more forms in common with its own than with the other type, but there was noticeable uniformity in the number shared with both A and B streams. The mean A stream had in common 21 forms with other A streams, 6 with B streams, and 25 with A and B streams, whereas for the mean B stream these figures were 4, 17, and 25, respectively.

Number of species per major taxonomic group per stream (Table V) suggest that Mollusca, Ephemeroptera, Coleoptera, and Diptera favored A streams and that Plecoptera and Trichoptera were better developed in B streams. With the exception of *Ferrissia* in 64.5 Mile Creek, molluscs were not taken in B streams. Number of species showed no consistent relationship to stream type, although means were 63 for A and 51 for B streams. The Clinch River had the largest number, but its closest rival was a B stream (Table IV). Bob Downey Creek yielded the fewest species, but it was well endowed with stoneflies. In sorting pans the B benthos type was recognizable by large numbers of Potamophilidae (largely *Trentonius*), large *Acroneuria* and *Pteronarcys*, *Peltoperla*, *Baetisca*, and, in spring, *Prosimulium*, and the A type by large numbers of small molluscs, beetles, and dipterans. Mayflies were about equally abundant in the two stream

TABLE V
Number of macrobenthic forms found in each stream

	Clinch River	Holston River Middle F	Cow Pasture River	Tygarts Creek	Bob Downey Creek	Dancing Creek	Upper Otter Creek	Lower Otter Creek	64.5 Mile Creek	Mean no. A Streams	Mean no. B Streams
Platyhelminthes	0	0	0	0	0	0	1	0	1	0	.4
Annelida	2	1	2	2	1	1	2	2	3	2	2
Mollusca	11	7	6	3	0	0	0	0	1	7	.2
Crustacea	2	2	1	3	1	1	1	1	1	2	1
Plecoptera	8	7	3	7	12	12	7	6	10	6	9
Ephemeroptera	22	21	16	12	8	17	10	14	20	18	14
Odonata	3	2	4	0	0	2	2	2	1	2	1
Hemiptera	1	1	1	1	0	1	0	1	0	1	.4
Megaloptera	2	1	2	2	2	1	2	2	1	2	2
Trichoptera	10	6	7	6	6	10	9	9	9	7	9
Lepidoptera	0	0	0	0	0	0	1	1	0	0	.4
Coleoptera	9	5	3	2	2	3	4	1	4	5	3
Diptera	16	7	5	18	3	9	9	12	13	12	9
Totals	86	60	50	56	35	57	48	51	64	63	51
	Type A Streams				Type B Streams						

types. Species common to both stream types did not mask these distinctive features.

Only three species occurred in all nine streams, and only one of these in all collections, three B types were found in all five B streams, but only one A type inhabited all four A streams (see Table VII). Leeches and tubificids were not found, but free-living species of the former may not be common to this study area, and the latter may have been excluded by a scarcity of finer bottom materials. The nymph of *Tachopteryx*, which reputedly inhabits seeps, was found in riffle rubble in spring of 1966. This may have been an exceptional occurrence, but adults occurred in that vicinity each summer. Ephemeroptera was the most diverse group with most species belonging to the genera *Stenonema*, *Ephemerella*, and *Paraleptophlebia*. Most mayflies were summer residents. Some trichopterans (e.g., *Trentonius*) were limited to one stream type and others (e.g., *Rhyacophila fuscula*) appeared restricted to a drainage basin. The majority of naiad clams found in the Clinch River were part of the "Cumberlandian" group (Neel & Allen, 1963) that occurs only in the Tennessee and Cumberland Rivers. Two of these species were also taken in the Holston. The moth *Cataclysta* was found only in B streams, but it is known to inhabit algae (Neel, 1968).

Quantitative considerations. In these streams the sampler frame invariably "split" stones whose removal incorporated areas outside and inside it in samples, making number of specimens per sampler haul unrepresentative of any known area. Numbers per unit of effort serve only to indicate relative abundance. Aggregate means per sampler haul were 77 for A streams and 39 for B streams for the total population, but the mean number of insects was 43 for A streams and 38 for B's. Molluscs were chiefly responsible for greater organism mass in A streams. The largest number of all organisms occurred in the Clinch River, but 64.5 Mile Creek had the most insects per haul. Crayfish and larger clams seldom contributed to sampler catches.

Discussion

Streams with alkalinity and hardness below 20 mgl developed no vegetation other than sparse algal growths, and, with one exception, lacked molluscs. Those

TABLE VI
List of diatoms with streams and seasons[1]

Melosira varians C. A. Ag. 3
Meridion circulare (Grev.) Ag. 1
M. circulare var. *constricta* (Ralfs) V. H. 2,3
Synedra acus Kütz. 1,2,3,4
Diatoma vulgare Bory var. *vulgare* 1,4
Eunotia solierolii (Kütz.) Rabh. 3
Cocconeis pediculis Ehr. var. *pediculus* 4
C. placentula Ehr. var. *placentula* 3,4
Rhoicosphenia curvata (Kütz.) Grun. ex. Rabh. var. *curvata* 4
Achnanthes exiqua var. *heterovalva* Krasske 3
A. lanceolata (Breb.) Grun. var. *lanceolata* 1,2,3,4
Frustulia rhomboides var. *viridula* (Breb.) Cleve 3
F. rhomboides var. *amphipleuroides* (Grun.) Cleve 3
Stauroneis phoenicentron var. *gracilis* Rabh. 3
S. smithii Grun. 3
Navicula radiosa Kütz. var. *radiosa* 4
N. radiosa Kütz. var. ? 1
N. radiosa var. *parva* Wallace 3
N. rhyncocephala Kütz. var. *rhynocephala* 3
N. rhyncocephala var. *amphiceros* (Kütz.) Grun. 3
N. spicula (Hickie) Cleve var. ? 2,3
N. tripunctate (O. F. Müll.) Bory var. *tripunctata* 4
N. tripunctata var. *schizonemoides* (V.H.) Patr. 1
N. tuscula Ehr. var. *tuscula* 3
Pinnularia hilseana Jan. var. *hilseana* 3
P. braunii var. *amphicephala* (A. Mayer) Hust. 3
Pinnularia sp. 3
Cymbella affinis Kütz. var. *affinis* 4
C. affinis Kütz. var. ? 1
C. prostrata (Berkeley) Cleve var. *prostrata* 4
C. turgida (Greg.) Cleve var. *turgida* 3
C. turgida (Greg.) Cleve var. ? 1
Cymbella sp. 1 2,3
Cymbella sp. 2 3
Gomphonema acuminatum var. *coronata* (Ehr.) W. Sm. 3
G. acuminatum var. *trigonocephala* (Ehr.) Grun. 3
G. spaerophorum Ehr. 3
G. abbreviatum Ag. ? Kütz. var. ? 3
G. olivaceum (Lyngbye) Kütz. var. *olivaceum* 1,3,4
G. olivaceum var. *calcarea* Cleve 1,4
G. parvulum (Kütz.) Grun. var. *parvulum* 3
G. helveticum Grun. var. ? 3
G. lanceolatum Ehr. var. ? 3
Gomphonema sp. (near *G. angustatum* var. *sarcophagus* (Greg.) (Grun.)) 2,3
Nitzschia romana Grun. var. ? 1
N. acuta Hantsch var. *acuta* 1,4
N. dissipata (Kütz.) Grun. var. *dissipata* 1,4
N. ignorata Kraszke var. ? 3
N. linearis W. Sm. var. ? 1,2,3
Surirella ovata Kütz. var. *ovata* 1
S. ovata Kütz. var. ? 4
S. moelleriana Grun. var. ? 3
Rhopalodia gibba (Ehr.) O. Müll. 3
R. gibberula (Ehr.) O. Müll. 3

[1] Legend: 1—Tygarts Creek, Winter 1965–66
2—Lower Otter Creek, Spring 1966
3—Lower Otter Creek, Summer 1966
4—Clinch River, Winter 1965–66

with alkalinity and hardness greater than 50 mgl had extensive growths of algae and/or aquatic flowering plants and well-developed snail and clam populations. A streams first studied were larger and less densely shaded than the B's, and search for a small, well shaded stream with A range mineral content led to study of Tygarts Creek, which resembled B streams in all respects except mineral content. It had abundant algal growths whenever visited and three species of molluscs. Its dense shade was not a deterrent to algal growth, nor did shade appear to be the factor limiting plant growth in B streams. In three of them algae were found only in summer, and in one only in spring, when trees were verdant and shade densest, and the fifth (Lower Otter Creek) had no increased algal growth when leaf shade was gone. Type A streams all contained extensive algal growths in winter. It would thus appear that factors in addition to, or other than, shade determined algal growth in these streams, and the likely suspect is basic mineral content. Significant plant growth evidently required more bicarbonate, or some element associated with it, than was available in B streams. Shading may be overrated as a deterrent to plant growth in streams. *Lemanea* and *Cladophora* were very abundant spring growths in Boone Creek, but occurred only sparsely in the most densely shaded areas in summer (Neel, 1968). *Cladophora* grew very densely during summer of 1952 in the Wind River (= Big Horn River) of Wyoming in the shade of Wind River Canyon, but was absent below there except as floating fronds dislodged in the canyon (Anon., 1954). Light evidently can become too intense for some algal species.

It appears that the species collected depict the true macrobenthos character of these streams in most respects, and differences noted between the A and B types are considered valid. Low mineral content is believed responsible for paucity of molluscs in B streams, and *Ferrissia* in 64.5 Mile Creek scarcely makes this supposition less plausible, since that snail is capable of making thick shells

TABLE VII
Distribution of macrobenthos in streams studied[1]

A. One A Stream
1. *Campeloma* sp. SW
2. *Helisoma* sp. SW
3. *Fusconaia flava* Raf. SpSW
4. *F. cuneolus* (Lea) SpSW
5. *Medionidus conradicus* (Lea) SpSW
6. *Actinonaias carinata gibba* (Simpson) SpSW
7. *A. pecterosa* (Conrad) SpSW
8. *Sphaerium* sp. SW
9. *Orconectes* sp. S
10. *Asellus* sp. (blind) W
11. *Nemoura similis* Hagen SW
12. *Allocapnia vivipara* (Claasen) W
13. *Taeniopteryx maura* (Pictet) W
14. *Paraleptophlebia praepedita* (Eaton) S
15. *Leptophlebia* sp. W
16. *Ephemerella lata* Morgan S
17. *E. needhami* McDunnough S
18. *Pseudocloeon myrsum* Burks S
19. *Callibaetis* sp. S
20. *Heptagenia juno* McDunnough S
21. *Stenonema femoratum* (Say) S
22. *S. pulchellum* (Walsh) gr. S
23. *Stenonema* sp. 2 W
24. *Stenonema* sp. 3 W
25. *Ophiogomphus* sp. SW
26. *Macromia illinoisensis* Walsh SpS
27. *Hydropsyche arinale* Ross S
28. *Chimarra socia* Hagen S
29. *Neophylax autumnus* Vorhies
30. *Psilotreta* sp. SpsW
31. *Helicopsyche* sp. S
32. *Brachycentrus* sp. S
33. *Oecetis* sp. S
34. *Dubiraphia* sp. W
35. *Peltodytes duodecempunctatus* (Say) S
36. *Desmopachria* sp. S
37. *Helichus* sp. S
38. *Berosus* sp. SpSW
39 *Psychoda* sp. S
40. *Spaniotoma* sp. 3 (Neel, 1968) S
41. *Pentapedilum* sp. S
42. *Chironomus decorus* Johannsen S
43. *Chironomus* sp. S
44. *Brillia* sp. S
45. *Dasyhelea* sp. S
46. *Scatella* sp. S
47. *Macronychus glabratus* Müller S

B. Two A Streams
1. *Anculosa* sp. SpSW
2. *Pleurcera* sp. SpSW
3. *Elliptio dilatatus* (Raf.) SpSW
4. *Micromya vanuxemensis* (Lea) SpSW
5. *M. nebulosa* (Conrad) SpSW
6. *Pisidium* sp. SpSW
7. *Gammarus minus* Say S
8. *Nemoura (A.) delosa* Ricker W
9. *Allocapnia granulata* (Claasen) W
10. *Paracapnia angulata* Ricker W
11. *Taeniopteryx burksi* Ricker & Ross W
12. *Neoperla clymene* (Newman) SW
13. *Ephemera simulans* Walker SW
14. *Ephemerella bicolor* Clemens W
15. *E. minimella* McDunnough S
16. *Heptagenia lucidipennis* (Clemens) gr. S
17. *Stenonema rubrum* (McDunnough) W
18. *S. frontale* (Banks) SW
19. *S. canadense* (Walker) S
20. *Caenis* sp. S
21. *Argia* sp. SW
22. *Calopteryx maculata* Burmeister SpSW
23. *Rhagovelia* sp. S
24. *Dubiraphia vittata* Melsheimer SpS
25. *Optioservus* sp. S
26. *Hydraena* sp. S
27. *Spaniotoma (O.) obumbrata* Johannsen W
28. *Diamesia nivoriunda* (Fitch) W
29. *Pentaneura melanops* (Wiedemann) S
30. *Calopsectra* sp. S
31. *Microtendipes aberrans* (Johannsen) S
32. *Bezzia varicolor* (Coquillet) S
33. *Tabanus* sp. S
34. *Hydrellia* sp. W
35. *Physa* sp. SW

C. Three A Streams
1. *Goniobasis* sp. SpSW
2. *Neophylax* sp. SpSW
3. *Metriocnemus lundbecki* Johannsen SW

D. Four A Streams
1. *Chimarra obscura* (Walker) SW

E. One B Stream
1. *Alloperla* sp. 2 W
2. *Perlinella* sp. S
3. *Paraleptophlebia strigula* (McDunnough) S
4. *Habrophlebiodes* sp. S
5. *Ephemerella rotunda* Morgan Sp
6. *E. simplex* McDunnough S
7. *Ameletus lineatus* Traver Sp
8. *Heptagenia* sp. S
9. *Tachopteryx thoreyi* Hagen Sp
10. *Hydropsyche* sp. 2 S
11. *Rhyacophila glaberrima* Ulmer S
12. *R. nigrita* Banks S
13. *R. carolina* Banks gr. S
14. *Astenophylax* sp. S
15. *Micrasema* sp. Sp
16. *Psychomiidae* Genus A Ross Sp
17. *Polycentropus* sp. S
18. *Ancyronyx* sp. Sp
19. *Anchyteis* sp. S
20. *Dineutes* sp. S
21. *Eriocera spinosa* (Osten Sacken) W
22. *Prosimulium* sp. Sp
23. *Simulium (S.) venustum* Say gr. Sp
24. *Simulium* sp. Sp
25. *Spaniotoma (O.) rivolorum* Kieffer Sp
26. *Chironomus (E.) dimorphus* Malloch S
27. *Hemerodromia* sp. S

F. Two B Streams
1. *Paraleuctra sara* (Claasen) SpW
2. *Paraleuctra* sp. SpSW
3. *Allocapnia* sp. W
4. *Alloperla* sp. 1 W
5. *Paraleptophlebia ontario* (McDunnough) S
6. *Habrophlebia* sp. S
7. *Ephemerella excrucians* Walsh Sp
8. *Baetisca bajkovi* Neave Sp
9. *Siphlonurus* sp. SpW
10. *Hydropsyche* sp. 1 S
11. *Pycnopsyche* sp. SpS
12. *Lepidostoma* sp. SpS
13. *Phyrganeidae* sp. S
14. *Cataclysta* sp. SpS
15. *Pseudolimnophila lateipennis* Hart SW
16. *Dixa* sp. S
17. *Stempellina* sp. S
18. *Blepharocera tenuipes* (Walker) S
19. *Turbellaria* sp. S
20. *Ectopari* sp. S
21. *Anchytarsus* sp. SpS

G. Three B Streams
1. *Ephemerella cornuta* Morgan S
2. *Ephemerella* sp. SpSW
3. *Stenonema pudicum* (Hagen) SpW
4. *Lanthus albistylus* Hagen SW
5. *Prosimulium hirtipes* (Fries) Sp

H. Four B Streams
1. *Leuctra* sp. SpS
2. *Isoperla holochlora* (Klapalek) SW
3. *Tipula abdominalis* (Say) SpSW

I. Five B Streams
1. *Pteronarcys* sp. SpSW
2. *Peltoperla* sp. SpW
3. *Trentonius distinctus* (Walker) S

TABLE VII (Continued)

J. Two A and B Streams
1. *Acroneuria* sp. 2 SpS
2. *Acroneuria* sp. 3 SpS
3. *Ephemera guttulata* Pictet SW
4. *Stenonema carolina* (Banks) SW
5. *Dolophilus moestus* (Banks) SW
6. *Sialis* sp. W
7. *Pseudolimnophila* sp. S
8. *Nemoura* sp. SpW
9. *Rhithrogena* sp. S

K. Three A and B Streams
1. *Lumbriculidae* SW
2. *Ferrissia* sp. SW
3. *Isoperla orata* Frison SpW
4. *Paraleptoplebia guttata* (McDunnough) S
5. *Stenonema vicarium* (Walker) gr. SW
6. *S. nepotellum* McDunnough SW
7. *Boyeria vinosa* Say SpS
8. *Lanthus parvulus* Selys SW
9. *Hydropsyche bifida* Banks gr. SpSW
10. *Chimarra aterrima* Hagen SpW
11. *Metriocnemus* sp. Sp

L. Four A and B Streams
1. *Neophasganophora capitata* (Pictet) SW
2. *Baetis* sp. SW
3. *Heptagenia maculipennis* Walsh S
4. *Stenonema ares* Burks SW
5. *Gerris* sp. S
6. *Rhyacophila fuscula* (Walker) SpSW
7. *Eriocera fultonensis* Alexander SpSW
8. *Eriocera* sp. SpSW
9. *Antocha saxicola* Osten Sacken SpS
10. *Simulium (N.) vittatum* Zetterstedt S
11. *Spaniotoma (O.) nivoriunda-tatrica* Johannsen gr. SpS
12. *Pentaneura flavifrons* (Johannsen) gr. S
13. *Polypedilum* sp. S

M. Five A and B Streams
1. *Glossoscolecidae* SpS
2. *Isoperla* sp. SpSW
3. *Stenonema ithaca* (Clemens & Leonard) SpSW
4. *Potamyia flava* (Hagen) SpSW
5. *Rhyacophila carolina* Banks gr. sp 5 SW
6. *Stenelmis* sp. SpSW
7. *Spaniotoma* sp. SW
8. *Atherix variegata* Walker SpSW

N. Six A and B Streams
1. *Acroneuria* sp. 1 SpSW
2. *Ephemerella deficiens* Morgan S
3. *Isonychia* sp. SpSW
4. *Centroptilum* sp. S
5. *Stenonema* sp. 1 SpSW
6. *Corydalis cornutus* Linnaeus SpSW

O. Seven A and B Streams
1. *Acroneuria carolinensis* (Banks) SpSW
2. *Pseudocloeon* sp. SW
3. *Hydropsyche betteni* Ross SpSW
4. *Nigronia* sp. SpSW

P. Eight A and B Streams
1. *Branchiobdellidae* SpSW
2. *Paraleptophlebia mollis* (Eaton) SpSW
3. *Ephemerella dorothea* Needham SpSW
4. *Cheumatopsyche* sp. SpSW

Q. Nine A and B Streams
1. *Cambarus longulus* Girard SpSW
2. *Iron* sp. SpSW
3. *Psephenus lecontei* (LeConte) SpSW

Legend: Sp = Spring S = Summer W = Winter

in soft water (Russell-Hunter, 1970). Laurel Fork of the Rockcastle River, comparable in size to Lower Otter Creek, had many mussels in shingle and gravel riffles (Neel & Allen, 1963).

Mineral content variation is assumed indirectly responsible for some A and B differences in other macrobenthos groups, and the probability exists that it may not have been involved in others. However, its concentration level largely determined the basic character of the stream environment, and many forms may have responded to this. Tygarts Creek, chemically in the A category, had several physical resemblances to B streams, and shared more macrobenthos forms with them than did other A streams. This seems to suggest that mineral content was not all determining.

B streams were all tributary to A streams lying at lower elevations. Bob Downey Creek had hardness and alkalinity about 50 mgl lower than its recipient stream, the Cow Pasture River, and this mineral increase brought about a decided change with respect to plant growth and benthos. Rawson (1951) attributed increasing productivity to growing mineral content with distance down a lake-river system. In these streams nitrogen and phosphorus had no limiting role in plant growth. Photosynthetic intensity in B streams was insufficient to produce CO_3 or supersaturated oxygen, both of which characterized A streams, and both of which are normally indicative of appreciable photosynthesis (Anon., 1959; Neel, 1951, 1953, 1968; Neel & Smith, 1961). Streams in the size range of those dealt with here may be designated as autotrophic if they do and as heterotrophic if they do not contain CO_3, but this system would have shortcomings for larger streams whose chemistry may at times reflect tributary events.

Literature Cited

American Public Health Association. 1965. *Standard Methods for the Examination of Water and Wastewater.* 12th ed. New York. 769 pp.

Anonymous. 1954. Central Missouri River Water Quality Investigation August 1952–December 1953. U. S. Public Health Service, Missouri Drainage Basin. 72 pp.

1959. Shoal Creek—Turkey Creek. Basic data on stream conditions, water quality, and aquatic organisms significant to present utilization and future development. Missouri Water Pollution Board Miscellaneous Report. 29 pp.

Burks, B. D. 1953. The mayflies of Ephemeroptera of Illinois. *Bull. Ill. Nat. Hist. Sur.*, 26: 1–216.

Curry, L. L. 1958. Larvae and pupae of the species of *Cryptochironomus* (Diptera) in Michigan. *Limnol. Oceanogr.*, 3: 427–442.

1962. 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. 149 pp.

Dillon, E. S. & Dillon, L. S. 1961. *A Manual of Common Beetles of Eastern North America.* Row, Peterson, Evanston, Illinois. 884 pp.

Edmondson, W. T., ed. 1959. Ward and Whipple's *Freshwater Biology.* J. Wiley and Sons, New York, New York. 1,248 pp.

Fasset, N. C. 1940. *A Manual of Aquatic Plants.* University of Wisconsin Press, Madison, Wisconsin. 405 pp.

Flint, O. S., Jr. 1962. Larvae of the caddis fly genus *Rhyacophila* in Eastern North America (Trichoptera: Rhyacophilidae). *Proc. U. S. Nat. Mus.*, 113: 465–493.

Frison, T. H. 1935. The stoneflies or Plecoptera of Illinois. *Bull. Ill. Nat. Hist. Sur.*, 29: 281–471.

1942. Studies of North American Plecoptera with special reference to the fauna of Illinois. *Bull. Ill. Nat. Hist. Sur.*, 22: 235–355.

Hustedt, F. 1930. *Bacillariophyta (Diatomeae).* Heft 10, Die Süssswasser-Flora Mitteleuropas. G. Fischer, Jena. 466 pp.

Johannsen, O. A. 1934. Aquatic Diptera. Part 1. Nemocera, exclusive of Chironomidae and Ceratopogonidae. Cornell Univ. Agric. Exp. Sta. Mem., No. 164. 71 pp.

1935. Aquatic Diptera. Part 2. Orthorrhapha-Brachycera and Cyclorrhapha. Cornell Univ. Agric. Exp. Sta. Mem., No. 177. 62 pp.

1937a. Aquatic Diptera. Part 3. Chironomidae: subfamilies Tanypodinae, Diamesinae, and Orthocladiinae. Cornell Univ. Agric. Exp. Sta. Mem., No. 205. 84 pp.

1937b. Aquatic Diptera. Part 4. Chironomidae: sub-family Chironominae. Cornell Univ. Agric. Exp. Sta. Mem., No. 210, pp. 1–56.

Malloch, J. R. 1915. The Chironomidae or midges, of Illinois, with particular reference to the species occurring in the Illinois River. *Bull. Ill. State Lab. Nat. Hist.*, 10: 273–543.

Missouri Water Pollution Board. 1964. *Water Quality Big, Bourbeuse, Meramec River Basins.* 65 pp.

Needham, J. G. & Westfall, M. J., Jr. 1955. *A Manual of the Dragonflies of North America.* University California Press, Berkeley. 615 pp.

Neel, J. K., Sr. 1951. Interrelations of certain physical and chemical features in a headwater limestone stream. *Ecology*, 32: 368–391.

1953. Certain limnological features of a polluted irrigation stream. *Trans. Amer. Micros. Soc.*, 72: 119–135.

1968. Seasonal succession of benthic algae and their macroinvertebrate residents in a headwater limestone stream. *J. Water Poll. Cont. Fed.*, 40: R10–R30.

Neel, J. K., Sr. & Allen, W. R. 1963. The mussel fauna of the upper Cumberland Basin before its impoundment. *Malacologia*, 1: 427–459.

Neel, J. K., Sr. & Smith, W. E. 1961. An investigation of phytoplankton growth and relationships in the Cedar River System, Iowa. U. S. Public Health Service Region VI Report. 12 pp.

PATRICK, R. & REIMER, C. W. 1966. The diatoms of the United States exclusive of Alaska and Hawaii. *Acad. Nat. Sci. Philadelphia Monogr.*, No. 13. 688 pp.

PRESCOTT, G. W. 1962. *Algae of the Western Great Lakes Area.* W. C. Brown, Dubuque, Iowa. 977 pp.

RAWSON, D. S. 1951. The total mineral content of lake waters. *Ecology*, 32: 669–672.

RICKER, W. E. 1952. Systematic studies in Plecoptera. Indiana Univ. Pub., Sci. Ser. 18. 200 pp.

RICKER, W. E. & ROSS, H. H. 1968. North American species of *Taeniopteryx* (Plecoptera, Insecta). *J. Fish. Res. Bd. Canad.*, 25: 1423–1439.

ROSS, H. H. 1944. The caddis flies, or Trichoptera, of Illinois. *Bull. Ill. Nat. Hist. Sur.*, 23: 1–326.

RUSSELL-HUNTER, W. D. 1970. *Aquatic Productivity.* MacMillan, Collier MacMillan, London. 306 pp.

SINCLAIR, R. M. 1964. Water quality requirements for elmid beetles with larval and adult keys to the eastern genera. *Tenn. Str. Poll. Con. Bd.*, Tenn. Dept. Pub. Health. 14 pp.

SMITH, G. M. 1950. *The Freshwater Algae of the United States.* McGraw-Hill, New York. 719 pp.

STONE, A. & JAMNBACK, H. A. 1955. The black flies of New York State (Diptera: Simuliidae). *N. Y. St. Mus. Bull.*, No. 349. 144 pp.

THOMSEN, L. C. 1937. Aquatic Diptera. Part 5. Ceratopogonidae. Cornell Univ. Agric. Exp. Sta. Mem., No. 210, pp. 57–80.

USINGER, R. L., ed. 1963. *Aquatic Insects of California, with Keys to North American Genera and California Species.* University California Press, Berkeley. 508 pp.