A Preliminary Report on the Use of the Sequential Comparison Index to Evaluate Acid Mine Drainage on the Macrobenthos in a Pre-impoundment Basin[1]

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ABSTRACT

A 35.0 mile segment of the North Anna River, Virginia is currently being impounded to provide cooling water for a nuclear reactor. The headwaters of a major tributary of the North Anna River, Contrary Creek, was the site of extensive pyrite mining operations at the turn of the century. Contrary Creek is a source of acid mine drainage, and confluences with the North Anna River approximately midway through the pre-impoundment basin. The sequential comparison method of establishing diversity indices of community structure was used to evaluate the effect of acid mine drainage on the macrobenthos in a 21.5 mile segment of the river. The diversity indices indicated that the North Anna River recovers from acid mine drainage approximately 19.0 miles below the entrance of Contrary Creek or 2.0 miles below the present dam site. However, the molluscan element, which occupied 32% of the macrobenthos at the upstream control station, did not show a reoccurrence within the study area below the discharge of Contrary Creek. The lack of mussel recolonization indicates that the river has only partially recovered from the acid drainage. Even though the Sequential Comparison Technique provides a rapid method of gathering numerical information regarding biological water quality, the technique as currently used does not exhibit sufficient resolution to distinguish between different degrees of biological recovery.

INTRODUCTION

Virginia Electric and Power Company (VEPCO) is building a 13,000 acre reservoir on the North Anna River which will extend through Louisa, Spotsylvania and Orange Counties, Virginia (Fig. 1). The purpose of the impoundment is to serve as a coolant for a 4,000,000 kilowatt nuclear powered electrical generating facility being constructed on the impoundment in Louisa County, Virginia (Fig. 1). The proposed morphometric data of the reservoir is given in Table 1. Engineering features of the proposed impoundment of limnological interest and importance are given in Table 2. The North Anna River has very few municipalities or industries in its drainage basin, and most of the area is farmed for agricultural crops, livestock, or timber.

GEOLOGY AND MINING ACTIVITIES

The North Anna River originates in the upper Piedmont region of Virginia in Albemarle and Orange Counties, approximately 20 miles east of the Blue Ridge Mountains. The drainage basin is located in the north-central part of the Piedmont physiographic province of Virginia. This province is bordered on the east by the Coastal Plain Province and on the west by the Blue Ridge Province. The river flows eastward and eventually contributes to the formation of the York River which drains into the Chesapeake Bay. The drainage basin consists of gently rolling terrain with broad, flat-topped hills and narrow, eastward sloping valleys. The surface of the Piedmont Province exhibits a slight southeastward slope from an altitude of approximately 1000 feet at the western margin to about 200 feet at the eastern margin.

The Piedmont Province contains a greater variety of mineral resources than either of the other two provinces. Many of these minerals are of commercial importance. Pyrite, associated with gold, silver, lead, and zinc is probably more abundant than any of the other minerals and occurs in many places throughout the gold-pyrite belt in the province. The portion of the belt through Louisa and Spotsylvania Counties has been mapped extensively (Cline, *et al.*, 1921).

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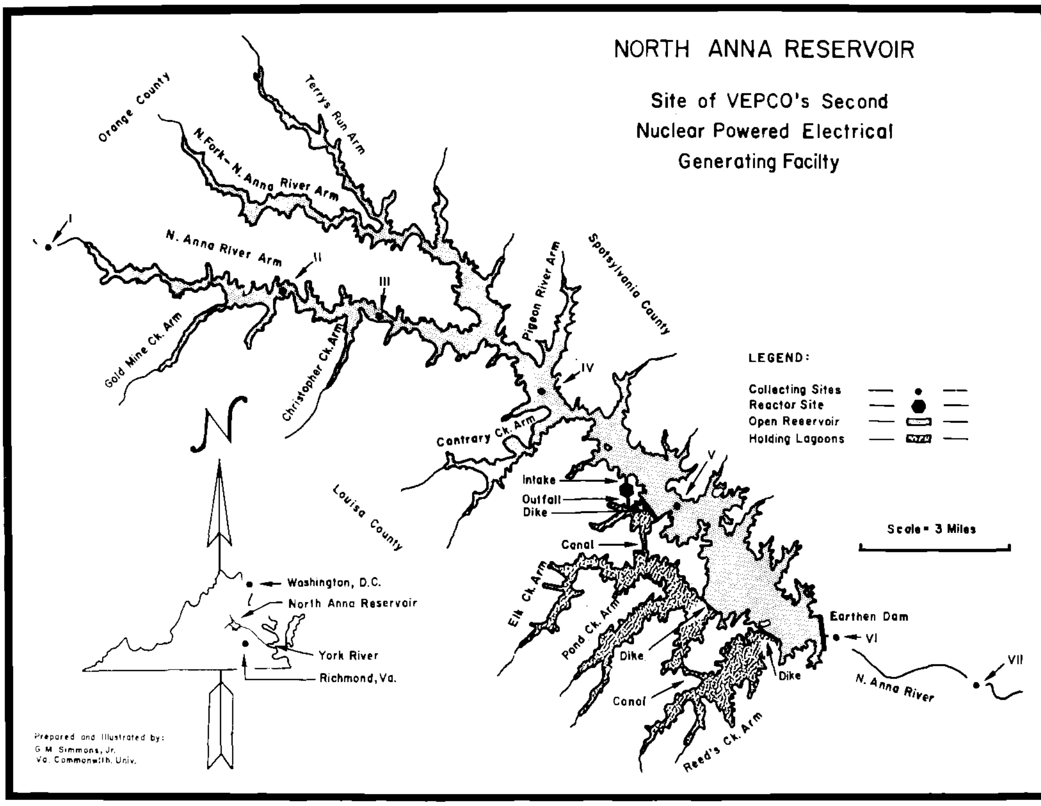

FIGURE 1.—North Anna Reservior.

One of the main tributaries of the North Anna River is Contrary Creek (Fig. 2). Land adjacent to the headwaters of this stream was the site of extensive mining operations during the period 1882–1920. Although many minerals were mined, the primary elements sought were iron and sulfur in the form of iron pyrite (FeS_2). During this time (commercial operation: 1885–1920), three different mines were in operation, and these mines produced

TABLE 1.—*Morphometric data of proposed reservoir on the North Anna River*[1]

Type of dam	Compacted earth
Length of dam	3000 feet
Drainage area	343 Square Miles
Approximate total area	13,000 acres
Approximate area available for recreational use	9,400 acres
Approximate area used to hold thermal effluent	3,600 acres
Approximate length of reservoir	15 miles
Normal Pool Elevation	250 MSL
Depth of Water at dam	80 feet
Length of shoreline	105 miles
Maximum recorded flow of river	24,300 c.f.s. (21 August 1969)
Minimum recorded flow of river	1 cfs (September–October 1932)

[1] Condensed from brochure submitted by VEPCO to the Virginia State Water Control Board for certification of project.

TABLE 2.—*Engineering features of proposed impoundment of limnological interest and importance*[2]

Type of electrical generating facility	Nuclear powered
Potential number of generating units	4
Potential kilowatt capability	4,000,000
Proposed beginning of commercial operation of first unit	1974
Amount of water needed for cooling unit No. 1	1600 cfs
Amount of water needed for cooling at maximum operating capacity	4% of reservoir volume per day
Minimum flow guaranteed regardless of reservoir level	40 cfs
Maximum temperature of discharge into treatment lagoon at maximum operating capacity	38 C
Projected maximum temperature in lake at maximum operating capacity	32 C

[2] *Ibid*, p. 12.

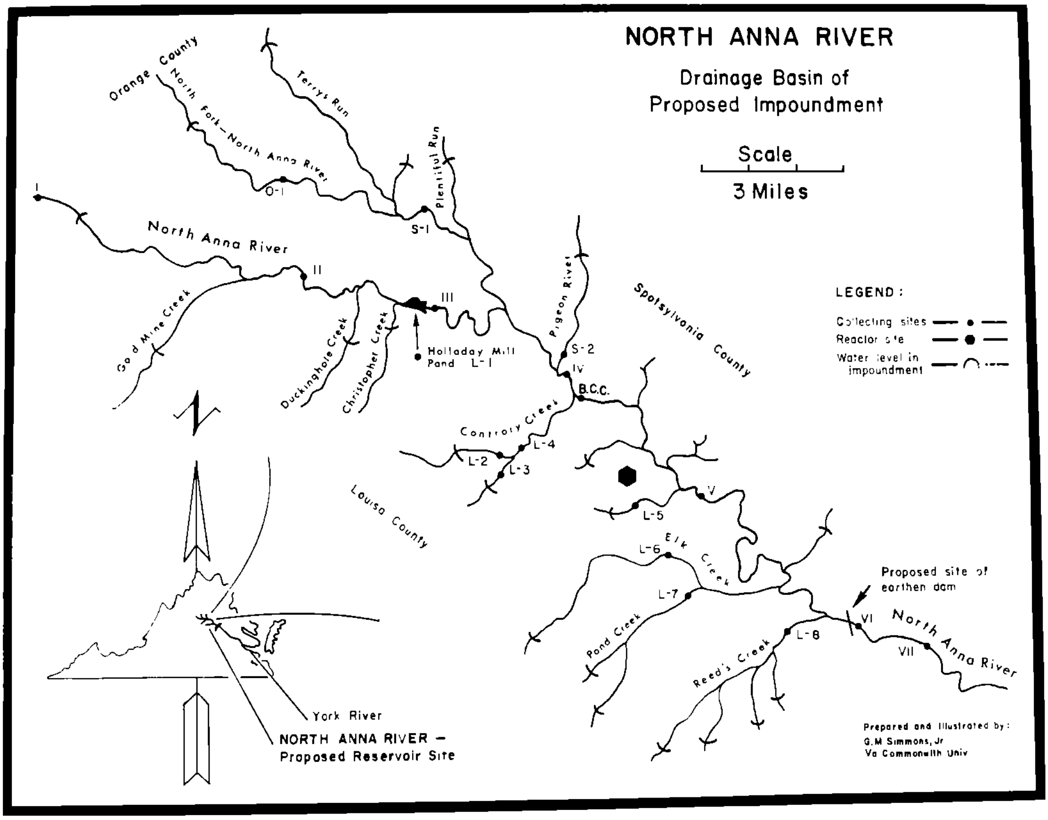

FIGURE 2.—Drainage basin of the proposed North Anna Reservior.

nearly 6,883,000 tons of pyrite constituting approximately 13.2% of the national output. A comprehensive history of the ownership of the properties has been discussed in detail by several writers (Katz, 1961; Painter, 1905a; Painter, 1905b; Watson, 1907).

The ore was mined, milled, and washed at the mine sites, and the tailings were deposited along the stream bank (Painter, 1905a; Painter, 1905b). It has been shown that sulfuric acid is produced when the sulfide is exposed to air and water (Parsons, 1968). As a result, sulfuric acid has been introduced into Contrary Creek, not only from the washings of the mining, but also from subsequent drainage of the tailings along the stream bank. In summary, Contrary Creek and the area of the North Anna River below the entrance of Contrary Creek has suffered from acid drainage for nearly 100 years. Figure 3 is an aerial photograph of a portion of the

FIGURE 3.—Aerial view of upper portion of Contrary Creek Basin. State Route 652 and bridge are in foreground.

FIGURE 4.—Contrary Creek, upstream view-left of center, as seen from State Route 652. Note the extent of erosion around old tree roots.

Contrary Creek basin approximately 3 miles below the mine sites in Louisa County. State Route 652 and the bridge across Contrary Creek are in the foreground. Figures 4 and 5 taken from the bridge seen in Figure 3 show the erosional effects caused by the acid mine drainage.

THE PRE-IMPOUNDMENT STUDY

As part of a more detailed pre-impoundment study, an investigation was undertaken to evaluate the response of the macrobenthic communities in the pre-impoundment basin to the acid mine drainage. The concepts of a community diversity index and histograms of community structure were employed to measure this response.

Although there are several methods of establishing diversity indices available to the aquatic biologist (Margalef, 1951; King, *et al.*, 1964; Burlington, 1962; Wilhm, *et al.*, 1968; Cairns, *et al.*, 1968)., the Sequential Comparison Index (Cairns, *et al.*, 1968) was used in the present study. The original technique, however, has undergone revision and refinement (Cairns and Dickson, 1971). Cairns, *et al.*, 1970a, have shown that the Sequential Comparison Index compared favorably with other methods commonly used to assess water pollution. Because of the recent proposal of this index in the literature, it has not been widely utilized and the present study records the first attempt to use the technique in relation to acid mine pollution.

FIGURE 5.—Contrary Creek, upstream view, right of center, as seen from State Route 652. Note the extent of erosion.

METHODS AND MATERIALS

Physical

Temperature was taken with a calibrated long stem thermometer by immersing the thermometer until equilibration was established. Flow rate data was obtained from a calibrated discharge station approximately 20 miles below the proposed dam site at Doswell, Virginia, which is maintained by the Virginia Department of Conservation and Economic Development, Division of Water Resources. The flow rate at Doswell was corrected to approximate the flow through the impoundment basin at the dam site.

Chemical

Oxygen samples were collected with a sewage sampler and analyzed by the Alsterberg (Azide) Modification of the Winkler Method (American Public Health Association, *et al.*, 1960).

Alkalinity samples were also collected with a sewage sampler and analyzed by the potentiometric method after establishing a differential titration curve (American Public Health Assoc., *et al.*, 1960).

The hydrogen ion concentration was determined electronically with a Corning pH Meter (Model No. 5).

Biological

Samples for the diversity index and histograms of community structure were collected with a D-frame aquatic dip net. Collections were taken from all habitats at the sampling station and were made for specified periods

TABLE 3.—*Related water quality data collected with macrobenthic samples*

Station	Collection Date 1969	Discharge ft^3/sec	Temperature Celcius	Oxygen mg/l	Oxygen %Saturation	Alkalinity mg/l $CaCO_3$	pH	Coliforms MPN/ 100 ml
State Route 208 (Station IV)	25 June	72	28.0	7.0	89%	30.0	7.4	1720
0.3 mile below Contrary Creek Entrance	1 July	45	31.0	6.8	91%	15.0	6.7	2780
State Route 601 (Station VI)	19 June	291	20.0	7.6	86%	14.0	7.7	5420
State Route 658 (Station VII)	3 July	42	25.0	6.8	85%	33.0	7.2	5420
Contrary Creek at State Route 652 (Station L-4)	24 June	—	27.0	6.6	83%	0	3.5	1
Tributary on Contrary Creek (Station L-3)	24 June	—	19.0	7.6	84%	15.0	7.8	2

of time with an equal amount of effort being expended at each collection site. All of the material collected was immediately preserved in formalin without sorting in the field, returned to the laboratory, and subsequently separated with the aid of a magnified illuminator.

Bacteriological samples were collected in sterilized bottles and carried through the presumptive test of the Multiple Tube Fermentation Technique (American Public Health Association, *et al.*, 1960). The density of the coliform group was expressed as the Most Probable Number/100 ml of water (MPN/ 100 ml).

RESULTS

Related Water Quality Information

Water samples for related water quality factors were collected along with the macrobenthic samples. Table 3 lists the station sites as well as the associated physical, chemical and bacteriological data. No attempt is presented here to evaluate the effect of acid discharge on water quality on the basis of these associated data since all stations were not sampled simultaneously. Rather these data are intended to show the existing water quality at the respective stations at the time of macrobenthic collections.

As Table 3 shows there was an initial high discharge of 291 ft^3/sec on the first collecting trip, 19 June 1969. Within a 5 day period, the discharge decreased 73%. The discharge continued to decrease to 42 ft^3/sec on 3 July 1969 which marked the lowest discharge during the period of study.

The highest temperature recorded was 31.0 C at the station immediately below the Contrary Creek discharge and the lowest temperature recorded was 19.0 C on a woodland tributary of Contrary Creek. The North Anna River temperatures showed a mean of 26.0 C for the period of study.

Oxygen concentrations and percent saturation levels showed similar variations. The highest recorded values were 7.6 mg/l at State Route 601 and the Contrary Creek tributary, while the lowest level recorded was 6.6 mg/l on Contrary Creek. The highest saturation value recorded was 91.0% immediately downstream from the Contrary Creek entrance into the North Anna River.

Alkalinity and pH values showed even greater variations than temperature and oxygen values. The lowest recorded alkalinity and pH values were on Contrary Creek. Although the pH values of the Contrary Creek water quickly returned to neutral levels once introduced into the North Anna River, the alkalinity was in some cases reduced as much as 50%.

The coliform count of the river proved to be rather high and was not always associated with a high discharge. Since there are few municipalities in the river, the major source of these coliforms is probably from drainage of livestock areas. The lowest recorded values were on Contrary Creek and one of its tributaries. Although a single observation does not characterize the river with regard to a

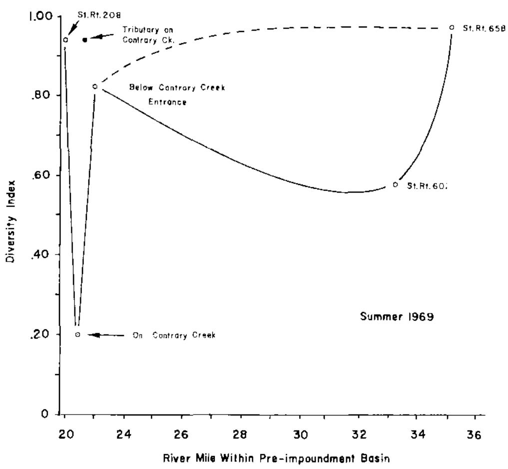

FIGURE 6.—The response of community diversity in the North Anna River to acid drainage from Contrary Creek.

particular factor, previous bacteriological data indicate that these high levels are not infrequent.

Macrobenthic Studies

Macrobenthic samples were collected at six stations in the pre-impoundment basin on the North Anna River during June–July 1969, to establish diversity indices and histograms of community structure. Table 4 lists the station sites as well as the results of the collections.

The range of diversity in the Sequential Comparison Index is 0.00–1.00 with the least diversity approaching 0.00 and the greatest diversity approaching 1.00. When the diversity indices from Table 3 are graphed as in Figure 6, the effects of the acid drainage from Contrary Creek are unmistakable. The acid pollution has drastically lowered the community diversity not only on Contrary Creek, but also in the North Anna River to the station at State Route 601 (Station VI), approximately 9.0 river miles downstream.

During the time of collection at State Route 601, the river was unusually high and samples could not be taken from the riffle areas due to the swift current. As a result, collections could only be taken in the emergent vegetation at the river margin and the sample was biased due to the large number of hemipteran and coleopteran species. The diversity of the corixid element of the collection exceeded the original expectation. What was thought to be only one species of corixid, turned out to be six.

The index at State Route 601 is probably underestimated not only as a result of high water conditions, but also due to my inability to distinguish the corixid species at the time of sample evaluation. It is estimated that subsequent samples taken at this station in which riffle areas are included will show a higher diversity index (dotted line).

The diversity indices in Table 3 indicate that the river has completely recovered from the acid pollution at State Route 658, approximately 11 river miles below the Contrary Creek entrance, and is in a recovery phase at the first riffle-pool area, approximately one-fifth mile below the Contrary Creek entrance. Thus, the only true polluted zone as indicated by the indices is that of Contrary Creek itself. Contrary Creek showed the most disturbed habitat of those included in the study. The stream bottom consisted of a crusty deposition of iron and silt as a result of oxidation and subsequent precipitation of the iron (Parsons, 1968). The pH of the water was 3.5 at the time of collection and other readings indicate that this is the normal pH for Contrary Creek. Although the water was not turbid at the time of collection, subsequent collections show that the silt load can reach 1690.0 mg/l. Temperature and oxygen values were not abnormal in comparison to other readings in the pre-impoundment basin. Few forms of vegetation were found in Contrary Creek and there was very little protection for macrobenthic organisms. Observations indicated that most of the organisms collected on Contrary Creek occurred in marginal zones of standing pools slightly off the main flow of the creek. When one considers that Contrary Creek was a small woodland stream before the mining activities, the diversity probably approached that found on one of its own woodland tributaries (collection site L – 3 = .92).

In the original proposal of the Sequential Comparison Index (Cairns, *et al.*, 1968), it was estimated that approximately 200 animals were

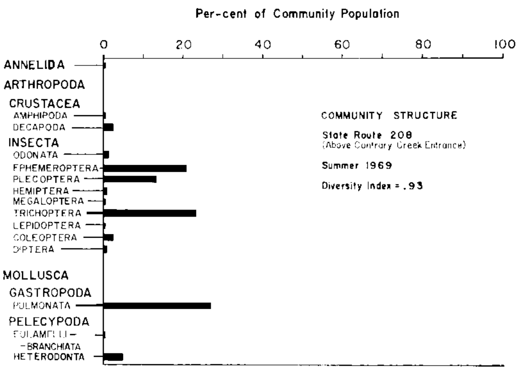

FIGURE 7.—Community structure of the macrobenthic community above Contrary Creek at State Route 208.

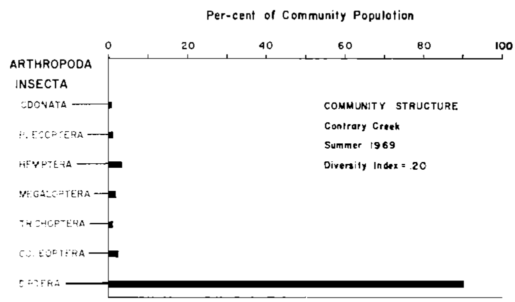

FIGURE 8.—Community structure of the macrobenthic community on Contrary Creek.

needed in order to obtain a satisfactory index. However, since the organisms were not sorted in the field at the time of collection, it could not be determined exactly how many animals were present in the sample. The results of the collections made during this period showing the number of animals collected and the resulting number of tests are also tabulated in Table 3. From this table it is apparent that the standing crop of animals at the station immediately below Contrary Creek entrance was low and additional effort should be expended in order to collect the suggested number of animals. The index at this station is probably overestimated due to the insufficient number of animals.

The Sequential Comparison Index provides a numerical evaluation of community structure. However, in ecological evaluations of macrobenthic responses it is also important to know the composition of the communities in question (Hynes, 1960). In order to complete the evaluation of the effect of acid drainage on the macrobenthic fauna, histograms of four communities under consideration were established. The community structure at State Route 208 (Station IV) above Contrary Creek entrance for this period is illustrated in Figure 7. At this station 15 orders of macrobenthic organisms were represented, consisting of 49 genera. The Plecoptera, Ephemeroptera and Trichoptera elements, generally regarded to contain the more sensitive organisms to pollution (Gaufin, *et al.*, 1952; Gaufin, *et al.*, 1956) constituted 58.2% of the total community. Moreover, note that the Mollusca, with 7 genera represented at this station, made up approximately 33% of the population. The species list of organisms occurring at this station is given in Table 4.

The community changed drastically on Contrary Creek as the diversity index indicated. Here the total macrobenthic orders represented dropped to 7 with *Chironomus attenuatus* representing 90% of all animals collected (Fig. 8). The remaining fauna could also be found in upstream tributaries. The immature insects collected on Contrary Creek were in the latter instar stages and their presence was probably the result of drift from these tributaries. The species list of organisms occurring at this station at the time of collection is also given in Table 4.

At the station immediately below the Contrary Creek entrance, the major components

TABLE 4.—*Diversity index*

Location of Collections	Number of tests/ Number of animals	Index (Summer)
State Route No. 658 (Collection Site VII)	490/495	.99
State Route No. 601 (Collection Site VI)	423/729	.58
Below Entrance on Contrary Creek (B.C.C.)	64/77	.83
On Contrary Creek (Collection Site L-4)	42/208	.20
Tributary of Contrary Creek (Collection Site L-3)	149/162	.92
State Route No. 208 (Collection Site IV)	1071/1152	.93

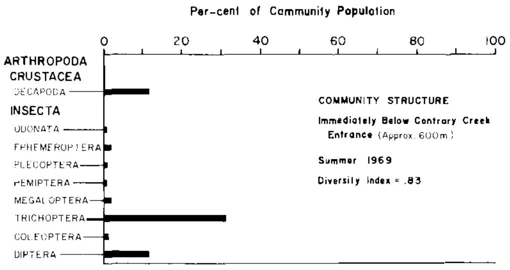

FIGURE 9.—Community structure of the macrobenthic community immediately below the entrance of Contrary Creek.

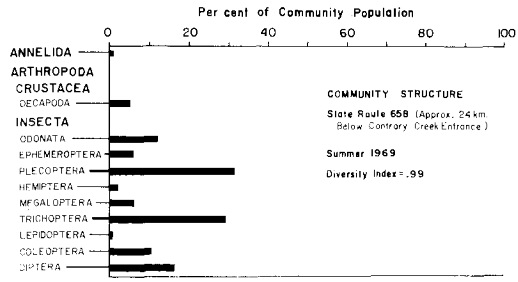

FIGURE 10.—Community structure of the macrobenthic community at the farthest downstream station.

of the population were crayfish, Trichoptera, and as yet an undetermined species of *Chironomus* (11.6%, 31.1%, and 11.6% respectively). Nearly all of the crayfish encountered were females. Only one male was present and represented the genus *Orconectes*. The other components of the population were also represented upstream at the State Route 208 station and it is proposed that the station below the entrance of Contrary Creek is colonized mainly by drift. Although 7 of the 9 orders found at State Route 208 are represented at the station below Contrary Creek entrance, the composition of the community is drastically altered as seen in Figure 9. The most noticeable alterations were the complete lack of the Mollusca, the drastic reduction of Ephemeroptera and Plecoptera, and a decrease in the number of species of Trichoptera represented.

The diversity index at State Route 658 (Station VII) indicated that the river had fully recovered at this point. The same number of insect orders were present, but the composition of the community was still altered (Fig. 10). Note that there is still a complete absence of Mollusca at State Route 658. Examination of the tributaries below the entrance of Contrary Creek into the North Anna River revealed that the molluscan fauna found at State Route 208 is distributed through these tributaries (Fig. 2, river basin map). However, the results of the analysis of the community structure at State Route 658 showed that these components of the community are failing to become established after reintroduction from the tributaries.

The technique used to collect these samples is similar to, but less quantitative than, the technique described by Macan (1958) in which the standing crop of animals is approximated by expressing the parameter as organisms collected per unit period of time. Keup (1966) described the four basic responses of bottom animals to pollution. According to his discussion, toxic materials, if not in high concentrations, tend not only to decrease the number of species in the habitat, but also the standing crop. A consideration of the histograms (Fig. 7–10) and Table 3 supports Keup's description of this type of response. Note again that the entire molluscan element is absent at the farthest downstream station and the standing crop of the remaining benthic community was reduced by approximately 50%.

Studies by Cairns, *et al.* (1970b) on the Clinch River in Virginia following a fly ash spill showed a low standing crop of molluscs immediately below the spill point, even after a sufficient time for partial recolonization by other segments of the bottom fauna community. The authors explain that the inability to recolonize was probably due to: 1) longer life cycles than found for most other aquatic invertebrates, 2) the lack of an aerial stage in their life cycle which would increase their reinvasion rates, and 3) the fact that they are not as susceptible to downstream drift as other macrobenthic species. Two additional factors involving lack of recolonization by mussels on the North Anna River below Contrary Creek appear to be the effect of siltation on the mussels and associated fish populations. If the species and standing crop of fishes in the river fauna is reduced or eliminated, the chances for reintroduction and exploitation of the area below Contrary Creek by the mussels would be greatly diminished since parasitism by the glochidia is a vital stage in the mussel's life cycle (Coker, *et al.*, 1921). Ellis (1931, 1936) documented the damaging effects of siltation on mussel populations. Scruggs (1960) presented data which indicated that the decline of the pigtoe mussel, *Pleurobema cordatum*, in the Tennessee River appeared to be due to the failure of the glochidia to find the proper host-fish. Simmons and Reed (in press) reported as many as 17 species of fish above the confluence of the North Anna River and Contrary Creek while only 10–11 species of fish were collected at the farthest downstream stations (State Route 601 and 658). Particularly noticeable at the downstream stations was the lack of the larger species (bass, sunfish, and pickerel). Whether or not one or more of these larger fish species are glochidia host fish for *Elliptio complanata* remains to be investigated. However, not only mussels but also snails are absent from the area below Contrary Creek. The explanation for lack of recolonization is probably due to the interaction of several factors rather than the result of a single factor.

A comparison of the taxa present at State Route 208 (immediately above the entrance of Contrary Creek) and State Route 658 (farthest station downstream considered in the pre-impoundment study) shows some interesting qualitative changes in community structure (Table 5). At State Route 658 there is a 62.5% reduction in the number of Ephemeropteran taxa represented. Moreover, the dominant genus at State Route 658 was *Ephemerella* rather than *Stenonema*, as seen at State Route 208. Since both of these genera frequent predominantly turbulent water, it is presently unclear why there would be a shift in generic dominance unless *Ephemerella* is more tolerant to silt than *Stenonema*.

There was also a shift in the dominant genus of Trichoptera between the two stations. At State Route 208 *Cheumatopsyche* was the dominant genus with *Hydropsyche* the second most abundant. However, at State Route 658, *Macronenum* became dominant (both *M. zeratum* and *M. carolina* have been collected on the North Anna River in the vicinity of State Route 658). *Cheumatopsyche* and *Hydropsyche* were evenly represented at State Route 658. Specimens of *Wormaldia* and *Phylocentropus* were also collected at the lower station.

All of the plecopteran taxa represented at State Route 208 were also collected at State Route 658. In addition, *Neoperla* was among the most abundant at the latter station while *Pteronarcys*, which was strongly represented at State Route 208, had drastically decreased at State Route 658.

A comparison of taxa in Table 4 shows that there were shifts in representation of other taxa. These shifts were not of the same magnitude as those discussed concerning the preceding forms, and their significance is not known at this time. Further studies will hopefully elucidate the reasons for the lack of recolonization of the molluscan fauna at State Route 658.

AN EVALUATION OF THE SEQUENTIAL COMPARISON INDEX

For a non-biologist, a community diversity index based upon the Sequential Comparison Technique provides a simple, rapid process by which the effects of water quality on macrobenthic communities can be evaluated. The technique is particularly advantageous to the non-biologist in that it alleviates the detailed expertise of taxonomic recognition. Personnel in private industry also have a useable technique by which preliminary inference of water quality can be established. Teachers, who are introducing students with little or no formal training in taxonomy to the "water quality-macrobenthos response" phase of aquatic ecology, will also find this technique very useful.

For the professional aquatic ecologist, this study reinforces the fact that there is no substitute for knowing the exact composition of the community and species which one is studying. In most macrobenthic collections, different genera or species are found together which exhibit a close similarity: *Cheumatopsyche–Hydropsyche*; *Cambarus–Orconectes*; *Ni-*

TABLE 5.—*Location of sampling sites*

	ORGANISMS	IV State Route 208	Tributary on Contrary Creek	L-4 Contrary Creek	Immediately Below Contrary Creek Entrance	VI State Route 601	VII State Route 658
PHYLUM:	ANNELIDA						
CLASS:	Oligochaeta	7	20			24	4
CLASS:	Hirudinea					2	
PHYLUM:	MOLLUSCA						
CLASS:	Gastropoda						
ORDER:	Pulmonata						
FAMILY:	Planorbidae						
	Helisoma trivalis Say	53					
FAMILY:	Physidae						
	Physa sp.	16					
FAMILY:	Lymnaeidae						
	Lymnaea sp.	1					
ORDER:	Prosobranchiata						
FAMILY:	Pleuroceridae						
	Goniobasis virginica Say	193					
FAMILY:	Viviparidae						
	Campeloma sp.	48					
CLASS:	Pelecypoda						
ORDER:	Eulamellibranchiata						
FAMILY:	Unionidae						
	Elliptio complanata Dillwyn	3					
FAMILY:	Sphaeriidae						
	Sphaerium striatum Lamarck	58	3				
PHYLUM:	ARTHROPODA						24
CLASS:	Crustacea						
CLASS:	Decapoda						
FAMILY:	Astacidae				8[3]		
	Orconectes limosus (Rafinesque)		1		1		
	Cambarus montanus acuminatus Faxon	29					44
ORDER:	Amphipoda						
FAMILY:	Gammaridae	1					
	Gammarus sp.						
CLASS:	Insecta						
ORDER:	Odonata						
SUBORDER:	Zygoptera						
FAMILY:	Agrionidae						
	Agrion maculatum Burmeister		3				4
FAMILY:	Coenagrionidae						
	Argia sp.	1					
	Nehalennia sp.	2					
SUBORDER:	Anisoptera						
FAMILY:	Aeschnidae						
	Boyeria vinosa Say	3		1	1	1	
	Aschnea sp.						4
FAMILY:	Cordulegastridae						
	Cordulegaster maculatus Selys		4				
FAMILY:	Gomphidae						
	Hagenius brevistylus Selys	1	2		3		1
	Progomphus obscurus (Rambur)	1			1	16	40
	Dromogomphus spinosus Selys	1					
FAMILY:	Libellulidae						
	Leucorrhina frigida Hagen					1	
	Macromica magnifica McLachlan	8				2	10
ORDER:	Ephemeroptera						
FAMILY:	Baetidae						
	Neocloeon alamance Traver		3				
	Isonychia sp.	79			1	2	1
	Centroptilum sp.	23				23	
	Caenis sp.	4				1	
	Ephemerella deficiens Morgan	1					27
	Brachycercus sp.	2					
FAMILY:	Ephemeridae						
	Leptophlebia, sp.		1				
	Ephoron luekon Williamson	4					
FAMILY:	*Heptageniidae*						
	Stenonema sp.	136	2		6		1
	Epeorus (Iron) sp.	1	1				
ORDER:	Plecoptera						
FAMILY:	Perlidae						
	Acroneuria sp.	17	6	2	2		18
	Perlesta placida (Hagen)	83			1	18	47
	Neoperla sp.				1	13	59
FAMILY:	Pteronarcidae						
	Pteronarcys dorsata Say	51			1		8
ORDER:	Hemiptera						
FAMILY:	Corixidae	8[1]	2[1]		1[1]	471[1]	1[1]
	Sigara depressa Hungerford						
	Sigara alternata Say						
	Sigara sp.						
	Palmocorixa buenoi Abbott						

[1] Was unable to differentiate species at time of index evaluation.
[3] Females, undetermined species.

TABLE 5.—*Continued*

ORGANISMS	IV State Route 208	Tributary on Contrary Creek	L-4 Contrary Creek	Immediately Below Contrary Creek Entrance	VI State Route 601	VII State Route 658
Trichocorixa calva Say						
Hesperocorixa, probably *brimleyi* Kirkaldy						
FAMILY: Gerridae						
Metrobates hesperius Uhler	1			1		
Trepobates pictus (Herrich-Schaeffer)			5	2	32	
Gerris conformis Uhler	1	1	2		5	
Rheumatobates rileyi Bergroth					4	5
Mesovelia sp.						1
FAMILY: Veliidae						
Rhagovelia obesa Uhler					8	4
FAMILY: Notonectidae						
Notonecta sp.					5	
ORDER: Megaloptera						
FAMILY: Corydalidae						
Corydalis cornutus (Linn.)	3			3		29
Nigronia serricornis Say	1	11				
FAMILY: Sialidae						
Sialis sp.	1	8	4	4	2	
ORDER: Coleoptera						
FAMILY: Dryopidae						
Helichus sp.	3					
FAMILY: Elmidae						3
Stenelmis sp.	6	8				16
Macronychus sp.	2					
Dubiraphia sp.	3					
FAMILY: Gyrinidae	14[2]			4		3[2]
Dineutes discolor Aulie					8	11
Dineutes vittatus Aulie					3	2
FAMILY: Dytiscidae						
Laccophilus Leach					4	
FAMILY: Haliplidae						
Haliplus					1	6
Peltodytes		1			5	1
Hydroporus undulatus			5		2	
FAMILY: Hydrophilidae: Sphaeridiinae						1
Berosus sp.				2	5	
Tropiotermus sp.				1		
FAMILY: Ptilodactylidae						
Anchytarsus bicolor (Melsh)						3
ORDER: *Trichoptera*						
FAMILY: Brachycentridae						
Brachycentrus numerosus (Banks)	15					1
FAMILY: Calamoceratidae						
Anisocentropus pyraloides		24				
FAMILY: Hydropsychidae						
Hydropsyche sp.	76		1	20		31
Cheumatopsyche sp.	170		1	3		23
Macronenum carolina (Banks)						82
Diplectrona sp.		5				
FAMILY: Leptoceridae						
Leptocella sp.	6					1
Triaenodes sp. McLachlan					7	
FAMILY: Limnephilidae						
Drusinus sp.		9				
FAMILY: Philopotamidae						
Chimarra obscura (Walker)	5					8
Wormaldia sp.						3
FAMILY: Psychomyiidae						
Phylocentropus sp.					3	1
ORDER: Lepidoptera						
Paraponyx sp.	2					2
ORDER: Diptera						
FAMILY: Tipulidae						
Tipula sp.						2
Antocha saxicola Osten Sacken	3					1
Limonia sp.	3	2				
Hexatoma sp.				2	2	
Holorusia sp.					2	
FAMILY: Tendipedidae						
Chironomus attenuatus Walker			187			
Chironomus sp. A	2	23		8	9	4
Chironomid sp. B		8			3	
Chironomid sp. C		2			1	
Procladius sp.		4				
Clinotamypus sp.		7				
FAMILY: Simulidae						
Simulium sp.						1
FAMILY: Culicidae						
Anopheles sp.		1				1
TOTAL	1152	162	208	77	729	495

[2] Larvae

gronia–early instars of *Corydalus*; *Isonychia –Ameletus*; *Trichocorixa–Sigara*; etc. To the untrained eye, many of these forms would not be treated separately, and a lower than normal index would result. For the aquatic biologist, the technique at this time does not provide sufficient resolution which is deemed desirable to differentiate between different degrees of recovery from pollution. This is indicated by a comparison of the diversity indices with histograms of the community structure above and below the inflow of Contrary Creek. The diversity index at the lowest station was higher than that above the entrance of Contrary Creek (.99–.92, respectively) which to a non-biologist would have indicated full recovery. However, a comparison of the histograms shows that this is not the case. Rather, the lowest station is in a stage of partial recovery due to the complete absence of the molluscan fauna.

In the original proposal of the technique (Cairns, 1968) and in subsequent communication (personal communication) the authors have stressed that the Sequential Comparison Index should not be misconstrued to represent or replace other, more accurate, techniques requiring personnel trained in aquatic ecology. The technique is designed to accommodate individuals with little or no formal training in taxonomy and/or aquatic ecology, yet who need rapid inference on a numerical basis regarding water quality. To this end the Sequential Comparison Index makes a valuable contribution.

SUMMARY

This is the first account in which the Sequential Comparison Index has been utilized to measure the response of the macrobenthic community to acid mine drainage.

The technique provides a simple, rapid process by which an indication of water quality can be obtained. This is particularly advantageous to teachers and certain segments of private industry.

The technique does not appear to exhibit the necessary resolution to separate different degrees of recovery from acid pollution which is a necessity for aquatic ecologists.

FURTHER STUDIES

Further studies of the macrobenthos will revolve around utilizing the Sequential Comparison Index to evaluate seasonal changes of community diversity. The manner of establishing the index number will also be refined. Efforts are currently underway to program the data on a computer for randomization and subsequent evaluation. After a seasonal study of the effects of acid mine drainage on the macrobenthic community, the Sequential Comparison Index will be compared with other currently available techniques which are also used to establish diversity indices.

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LITERATURE CITED

American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1960. Standard methods for the examination of water and waste water including bottom sediments and sludges, 11th ed. American Public Health Association, New York. 626 p.

Burlington, R. F. 1962. Quantitative biological assessment of pollution. J. Water Pollution Control Fed. 34(2): 179–183.

Cairns, J., D. W. Albaugh, F. Busey, and M. D. Chanay. 1968. The sequential comparison index—a simplified method for non-biologists to estimate relative differences in biological diversity in stream pollution studies. J. Water Pollution Control Fed. 60: 1607–1613.

Cairns, J., Jr., K. L. Dickson, R. E. Sparks, and W. T. Waller. 1970a. A preliminary report on rapid biological information systems for water pollution control. J. Water Pollution Control Fed. 42(5): 685–703.

Cairns, J., Jr., J. Crossman, and K. L. Dickson. 1970b. The biological recovery of the Clinch River following a fly ash spill. Purdue Univ. Eng. Bull. (In Press).

Cairns, J., Jr., and K. L. Dickson. 1971. A simple method for the biological assessment of the effects of waste discharges on aquatic bottom-dwelling organisms. J. Water Pollution Control Fed. 43(5): 755–772.

Cline, J. H., T. L. Watson, and F. J. Wright. 1921. Map of pyrite-gold belt in Louisa and Spotsylvania Counties, Virginia: Virginia Geological Survey.

COKER, R. E., A. F. SHIRA, H. W. CLARK, AND A. D. HOWARD. 1921. Natural history and propagation of fresh-water mussels. U.S. Bur. Fish, Bull. 893: 71–181.

ELLIS, M. M. 1931. Some factors affecting the replacement of the commercial fresh-water mussels. U.S. Dep. Comm., Bur. Fish Cir. 7: 1–10.

———. 1936. Erosion silt as a factor in aquatic environments. Ecology 17(1): 29–42.

GAUFIN, A. A., AND C. M. TARZWELL. 1952. Aquatic invertebrates as indicators of stream pollution. Public Health Reps. 67(1): 57–64.

GAUFIN, A. A., AND C. M. TARZWELL. 1956. Aquatic macroinvertebrates communities as indicators of organic pollution in Lytle Creek. Sewage Ind. Wastes 28: 906–924.

HYNES, H. B. N. 1960. The biology of polluted waters. Liverpool University Press, Liverpool, England.

KATZ, A. S. 1961. The mineralogy of the sulfur mine, Mineral, Virginia, including a history of the property. M.S. Thesis, University of Virginia, 104 p.

KEUP, L. E. 1966. Stream biology for assessing sewage treatment plant efficiency. Water and Sewage Works 113(11): 411–417.

KING, D. L., AND R. C. BALL. 1964. A quantitative biological measure of stream pollution. J. Water Pollution Control Fed. 36(5): 650–653.

MACAN, T. T. 1958. Methods of sampling the bottom fauna of stony streams. Mitt. Intern. Ver. Limnol. 8: 1–21.

MARGALEF, R. 1951. Diversidad de especies en lao comunidades naturales. Proc. Inst. Biol. Apl., 9: 5–27.

PAINTER, R. H. 1905a. Pyrite mining in Virginia. Eng. Mining J. 80: 148–149.

PAINTER, R. H. 1905b. Pyrite mining and milling in Virginia. Eng. Mining J. 80: 433.

PARSONS, J. D. 1968. The effects of acid stripmine effluents on the ecology of a stream. Arch. Hydrobiol. 65(1): 25–50.

SCRUGGS, G. D., JR. 1960. Status of fresh-water mussel stocks in the Tennessee River. U.S. Dep. Int., Fish Wildl. Serv., Spec. Rep. 370: 1–41.

SIMMONS, G. M., AND J. R. REED, JR. The ecological advantage of locating a nuclear powered electrical generating facility on the North Anna River, Virginia. Manuscript to be published in Proceedings of the Third National Symposium on Radioecology. Symposium held May 10–12, 1971 at Oak Ridge, Tennessee.

WATSON, T. L. 1907. Mineral resources of Virginia: Lynchburg, Virginia. J. P. Bell Co. p. 190–208.

WILHM, J. L., AND T. C. DORRIS. 1968. Biological parameters for water quality criteria. BioScience 18(6): 477–481.