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A COMPARATIVE STUDY OF FISH POPULATIONS IN THE VICINITY OF A THERMAL DISCHARGE IN THE JAMES RIVER, VIRGINIA

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Abstract

The size, species composition and structure of fish populations in a six mi stretch of the James River in the Piedmont Province of Virginia were analyzed. Twenty collections were made by electrofishing from October 1972 through September 1973 from both the north side of the river, which received a thermal discharge from a power station, and the south side where temperatures were ambient. Parameters investigated were number of species, total number of individuals and the Shannon-Wiener and evenness indices of species diversity. Significant differences in seasonal patterns were found between the communities in the thermal discharge and those on the opposite side of the river for number of species and for the Shannon-Wiener and evenness indices.

Introduction

The effect of temperatures on aquatic organisms has been documented by numerous authors (Hoak, 1961; Odum, 1959; Macan, 1963; Parker and Krenkel, 1969). In recent years it has been recognized that in addition to natural temperature fluctuations, heated effluents discharged from industrial plants may affect the composition and structure of biotic communities that live in the receiving waters (Strund and Douglas, 1968). One such group of organisms is the fishes which are ecologically significant as upper-trophic level organisms in aquatic ecosystems, and are economically important as food and recreational animals for man (Woolcott, 1972). Fishes are often scarce or absent in the warmer seasons below thermal discharges, whereas in the winter they may be attracted to the heated water (Woolcott, 1972; Elser, 1965; Trembley, 1960; Gammon, 1973; Dahlberg, 1972; Parker and Krenkel, 1969).

Natural biotic communities are typically composed of many species represented by few individuals and a few species represented by many individuals (Wilhm and Dorris, 1968). The relationship existing between number of species and number of individuals of each species in a community is thought to be influenced by a number of environmental factors including the variety of available niches, size of those niches, environmental stability, rigorousness of the environment, competition, productivity, length of food chain and body size of individuals (Pianka, 1966; Monk, 1967). Dahlberg and Odum (1970) have shown that the structure of marine fish populations is affected by seasonal factors. Wilhm and Dorris (1968) noted that pollution may cause detectable changes in community structure. Large numbers of individuals and small numbers of species ordinarily are found in streams receiving organic wastes (Wilhm, 1967).

The simplest measure of community diversity is an enumeration of the number of species present, but two drawbacks are encountered (Krebs, 1972). First, the apportionment of individuals among species is not taken into account. A community with maximum distribution of individuals between two species (e.g. 50 and 50) would intuitively be more diverse than a community with a minimal distribution (e.g. 99 and 1). Second, sample size affects the number of species collected. Larger samples would be expected to produce greater numbers of species than smaller samples, thereby making comparisons among communities difficult, unless sample sizes are comparable.

Several authors have dealt with the problem of relative abundance by the use of statistical distributions such as log-normal curves and the logarithmic series (Fisher et al., 1943; Preston, 1948; Kendall, 1948; Odum et al., 1960; Williams, 1944). Another approach to this problem was proposed by Margalef (1958) and involves methods derived from information theory. Diversity is equated with the uncertainty that exists concerning the species of an individual selected at random from a population. The more species present and the more equitable their abundance, the greater the uncertainty and hence the greater the diversity. Ratios between the number of species and number of individuals are termed diversity indices. Although several types of indices have been proposed (Pielou, 1966), the Shannon-Wiener function is considered by many authors to be a reasonable measure of community diversity (Wilhm and Dorris, 1968; Wilhm, 1970; Monk, 1967; Odum, 1971). Its values are that it is a dimensionless equation in which numbers or biomass in any units can be used; it is independent of sample size (e.g., fewer samples are required to obtain a reliable index for the purposes of comparison); it expresses the relative abundance of each species; and it is normally distributed so that routine statistical methods can be used.

The Shannon-Wiener index is a function of three components: (1) total number of individuals, (2) number of species and (3) abundance among the species (equitability). Maximum diversity exists if all individuals belong to a different species and minimum diversity exists if all individuals are of the same species. The equitability component is expressed in the evenness index which may reflect changes in population structure different from that shown by the Shannon-Wiener index (Dalhberg and Odum, 1970). A range of possible values of the Shannon-Wiener and evenness indices exists when a community is composed of more than one species (Monk, 1967). As species are added to a community the range between maximum and minimum diversity possibilities becomes greater because the number of rare species increases and thereby decreases the equitability component.

Mathematically, diversity indices are expressions of community structure which permit summarization of large amounts of information on species-numbers relationships and provide one of the best ways to evaluate and detect pollution (Wilhm, 1967; Wilhm and Dorris, 1968).

Evaluation of the influence of heated discharges on fish populations in earlier studies has been based upon changes in species composition and number of individuals in the region affected (Neill and Magnuson, 1972; Proffit, 1969; Trembley, 1961; Alabaster, 1963). While indices have been applied to describe fish populations under natural conditions in several studies (Dahlberg and Odum, 1970; Harrel et al., 1967) only Gammon (1973) appears to have applied the Shannon-Wiener index in a study of thermal pollution. Wilhm and Dorris (1968) have indicated that much further research is needed to determine how effectively various diversity indices reflect community changes resulting from different kinds of pollution.

The objective of this study was to analyze seasonal changes in the size, species composition and structure (species-numbers relationships) of fish populations in the James River, Virginia and to assess the influence of the heated effluent from an electric power station on these populations. Consideration was given to the relative merits of various criteria used by others to describe community structure. Parameters utilized as criteria were numbers of species, total abundance of individuals, and the Shannon-Wiener and evenness indices of species diversity.

Study Area

The following description of the study area was taken in part from those given by Dahlberg (1972) and Woolcott (1972) in progress reports on a study of the effects of heated discharge from the Bremo Power Station on the water quality in the James River prepared for the Virginia Electric and Power Company. Flora information is from a progress report prepared for the Office of Water Resources Research (Woolcott, 1973).

The study area was a six mi stretch of a piedmont section of the James River near Bremo Bluff, Virginia. Here the river forms the boundary line between Fluvanna county on the north and Buckingham and Cumberland counties on the south (Fig. 1). It is about 250 yd wide at this point and flows in a southeastward direction. Open pasture land and cultivated fields predominate the border of both sides of the river. Two major tributaries between Bremo Bluff and Scottsville (19 mi upstream), the Hardware and Slate Rivers, enter the James at

6.0 and 1.4 mi, respectively, above Bremo Bluff. Neither tributary contributed significant amounts of pollution to the study area. One small creek (mouth 15 ft wide) enters the James on the south side five mi below Bremo Bluff and several smaller streams (mouth less than 2 ft wide) are also present on both sides of the river. The only major industries in the area are the Bremo Power Station and the Solite Corporation on the Slate River.

The Bremo Power Station, located on the north side of the James River at Bremo Bluff, Virginia, is a 210 megawatt coal fueled swingload facility (Fig. 2). Depending on the operation of the plant and river flow, from 2 - 13% of the river water is utilized for cooling. Heated effluent (Δ t 4 - 14 C at outfall) is released into the river and maintains its identity as a narrow plume (approximately 75 ft wide) for about 5 mi downstream.

A survey of the vegetation in the water and along the banks of the river was made on 2 July 1973. The vegetation was similar on both sides except for a greater abundance of *Salix* sp. (willow) on the south side. In order of abundance, *Celtis occidentalis* (hackberry), *Platanus occidentalis* (sycamore) and

Acer *rubrum* (red maple) were the dominant trees. The dominant herbs were *Rhus* *radicans* (poison ivy), *Calystigia* sp. (bindweed), *Impatiens* sp. (waterweed) and *Passiflora* sp. (passion flower vine). *Fraxinus* sp. (ash) were found distributed irregularly. *Betula* *nigra* sp. (river birch) and *Salix* sp. were observed where banks were more sloping. *Justica* *americana* (water willow) was the only rooted vegetation found in the water.

The north and south sides of the river were sampled at five transects established above, at and below the site where the heated effluent from the power station enters the river (Fig. 1). Collecting stations at each transect were paired with regard to most environmental factors aside from those associated with the heated effluent. Paired stations are distinguished by the subscripts n and s (e.g. As and An) which designate the north and south sides of the river, respectively. North side stations B - G were subjected to the direct influence of the heated discharge. Transect A, located three-quarters of a mi above the outfall, provided two control stations to compare fauna on the north and south sides of the river. Transect B was located at the point of discharge of the heated effluent. Transects C, D and G were established approximately one-half, one and five mi, respectively, below the outfall. Two boat landings were utilized for access to the collecting stations; one on the James below a rapids area was used for collections at transects B, C, D and G and the other, on the Slate River, was used for collections at transect A.

The type of bottom substrate at each station varied with river discharge volumes. At low water levels (less than 4000 cfs) riffle areas were exposed at stations An, As and Cs with the bottom consisting mostly of rubble mixed with sand at stations An and Cs and sand mixed with debris at station As. Weed beds of J. americana were found year round at stations An and Cs. All other stations at low later levels were predominately in slow moving pools (approx. 15 cm/sec) with a mixed sand, debris and rubble bottom. Abundant boulders in both pool and riffle areas emerged during low flow periods. At intermediate levels (approx. 4000 to 10000 cfs) all stations were in moderately flowing water (approx. 45 cm/sec) with a combination rubble, sand and debris bottom. During high water levels (over 10000 cfs) the banks were inundated, creating mostly a mud and debris substrate at all stations.

Methods and Materials

Fishes were collected approximately twice every month from October 1972 through September 1973. Due to environmental factors or mechanical difficulties several days were usually required to complete the collections from all stations for one collecting period. Samples were taken at each station from a boat with an electric shocker (220 V, 1-3 amps D. C.). The anode, to which fishes are attracted, was a dip net electrode manipulated by hand; the cathode electrodes were hung over the side of the boat (Fig. 3). Each station was sampled for 20 min, as the boat moved parallel to the bank for a distance of 150-200 yd. The distance from the shore varied from 2-30 ft, depending on the height of the river. Small specimens were put immediately into one gallon jars containing 10% formalin. Fishes too large to fit into the jars were injected with formalin. All specimens were returned to the laboratory where abundance and weight per species were tabulated.

Temperatures(C) at each station were measured with a mercury thermometer. Ambient water temperatures recorded at each south side stations were averaged for each collecting period. River discharge data (cfs) were determined from information received from the U. S. Geological Survey Charlottesville, Virginia on measurements taken at gauging stations on the James River at Scottsville, The Hardware River below Briery Run and the Slate River near Arvonia. Discharge data were averaged for collecting periods when several days were used to complete the sampling.

Two indices of diversity (Odum, 1971) were calculated for collections from each collecting site. The first, the Shannon-Wiener function (hereafter called diversity index) is:

$$\bar{H} = -\sum_{1}^{s}\left(\frac{Ni}{N}\right)\log_e\left(\frac{Ni}{N}\right)$$

where S is number of species, Ni is number of individuals per species and N is total number of individuals. Diversity is zero if one species (or none) is collected. The index increases as the number of species and the equitability of the abundance among species increases. The second, the evenness index is:

$$E = \frac{\bar{H}}{H\ max.} = \frac{\bar{H}}{\log_e S}$$

where S is number of species. Values range from 0 (one or no species) to 1 (all species with equal abundance).

The year was divided into four periods based on ambient water temperature which generally corresponded to the calendar seasons (Table 1). Total abundance per species was determined systematically by season and station. Indices of diversity and evenness, total abundance and number of species were averaged from combined south side stations for each collecting period. North side stations were treated individually for these parameters. Duncan's multiple range test (Steel and Torrie, 1960 and Kramer, 1956) was used to test for significant differences among seasons and among stations for each side of the river. The two factor analysis of variance test (Steel and Torrie, 1960) was employed to determine whether significant differences occurred between averaged south side stations and each north side station. For additional analysis, the unpaired t-test (Lewis, 1966) was applied. In all statistical tests differences were considered to be significant at the .95 confidence level. The terms average and mean were used interchangeably throughout this thesis.

Results

Forty-four species of fishes representing nine familes were collected in the study area (Table 2). The family Cyprinidae (minnow) formed the largest group with fifteen species. The Centrarchidae (sunfish and bass), which contain the most popular sport fishes, had seven species. Among all families, Notropis analostanus (satinfin shiner), Notropis ardens (rosefin shiner), Lepomis auritus (redbreast sunfish), Lepomis macrochirus (bluegill) and Micropterus dolomieu (smallmouth bass) were the most abundant and widespread species. Total abundance of the various species collected at each station and temperature range (C) per season are shown in Tables 3 - 7.

The results of Duncan's multiple range test indicated that there were no significant differences among south side stations for the means of the diversity and evenness indices, number of species and total abundance within each of the four seasons (Tables 8 - 11), therefore the values for each of the four parameters from all south side stations (A - G) were averaged for each collecting period. South side data were then treated as a single station.

Ambient water temperatures on the south side of the river ranged from 2 C in February 1973 to 26 C in July 1973 (Table 12). River discharge on collecting dates ranged approximately from 1400 cfs (gauge ht. 1.0 ft) in September 1973 to 13800 cfs (gauge ht. 5.8 ft) in December 1972 (Table 12).

Results of Duncan's tests on seasonal differences in the four parameters on the south side are shown in Table 13. The average number of species was highest in the fall ($\bar{x}$ 10.2) and summer ($\bar{x}$ 9.6) and differed significantly from those of spring ($\bar{x}$ 4.6) and winter ($\bar{x}$ 2.8). At all south side stations the families Catostomidae (sucker), Ictaluridae (catfish), Percidae (perch) and Centrachidae exhibited a seasonal trend in number of species, declining in the winter and increasing in the summer and fall. A seasonal trend in number of species of Cyprinidae was not as apparent.

Average total abundance on the south side was highest in the fall ($\bar{x}$ 97.8) but differed significantly only from the lowest value of winter ($\bar{x}$ 31.0). Fewer catostomids, centrarchids, ictalurids and percids were collected in the winter than in the fall. The satinfin shiner was collected in abundance at all south side stations in all seasons; however *Notropis hudsonius* (spottail shiner), not as widespread as the satinfin shiner, was particularly abundant only in the fall at As (251), Cs (464) and Ds (169) (Tables 3, 5 and 6).

The average diversity index on the south side was highest in summer ($\bar{x}$ 1.73) and differed significantly from all seasons except fall ($\bar{x}$ 1.41). In winter it was lowest ($\bar{x}$ 0.64) and differed significantly from all seasons except spring ($\bar{x}$ 0.95). The spring and fall values of the diversity index ($\bar{x}$ 0.95 and $\bar{x}$ 1.41, respectively) did not differ significantly, but these two seasons were significantly different for number of species ($\bar{x}$ 4.6 and $\bar{x}$ 10.2, respectively).

The average evenness index for all combined south side stations was highest in summer ($\bar{x}$ 0.81) but differed significantly only from the lowest value in winter ($\bar{x}$ 0.61). Minnows dominated the collections in winter whereas the number of individuals in summer was more evenly distributed among species. Average values for each parameter from combined south side stations per collection period are shown in Table 12 and reflect the results of Duncan's test on seasonal changes.

Results from Duncan's tests indicated that significant differences existed among the north side stations (B - G) only in the winter and summer (Tables 14 - 17). In general the average number of species and average diversity index increased downstream from Bn to Gn in the summer and in both cases the values at Bn ($\bar{x}$ 3.0 and $\bar{x}$ 0.51, respectively) were significantly lower than the values at Gn ($\bar{x}$ 7.8 and $\bar{x}$ 1.43, respectively). In winter these parameters were highest at Bn ($\bar{x}$ 5.6 and $\bar{x}$ 1.40, respectively), but only the average diversity index differed significantly from Gn ($\bar{x}$ 0.86). The average total abundance at Gn was highest in the summer ($\bar{x}$ 35.6) and winter ($\bar{x}$ 35.2) and both values differed significantly from the lowest values which were those found at Cn (summer $\bar{x}$ 8.4 and winter $\bar{x}$ 12.6). The average evenness index at Bn ($\bar{x}$ 0.41) in the summer was lowest and differed significantly from the highest value at Dn ($\bar{x}$ 0.89). In winter the average evenness index did not differ significantly among north side stations B - G. Considering these results and temperature differences, each north side station was treated individually for further statistical analysis.

Temperatures recorded at each north side station A - G is shown in Tables 18 - 22. Outfall temperatures at Bn (Table 19) ranged from 9 C on January 18, 1973 (Δ t 5 C) to 39 C on July 10, 1973 (Δ t 13 C). The highest Δ t, 14 C, was measured on December 8, 1972 when ambient temperature was 8 C and the outfall temperature was 22 C. The lowest Δ t, 4 C, was measured on October 13, 1972 (ambient, 14 C and outfall, 18 C). The Δ t decreased downstream from north side stations B - G. Only slight changes in temperature (0.5 - 1.0 C) existed in the vertical temperature distribution of the heated plume.

Seasonal differences in the four parameters were tested at each north side station B - G (Tables 23 - 26). The average number of species at north side station B - D showed no significant seasonal differences, however the mean number of species at Gn in winter ($\bar{x}$ 4.0) was lowest and differed significantly from all other seasons (Table 26). No species of catfish were collected at Gn in the winter and L. macrochirus, Catostomus commersoni (white sucker) and Notropis procne (swallowtail shiner) occurred only once in the collections. The total number of species collected at Gn in the winter was not strikingly different from the total collected in the other seasons (Table 7).

No significant seasonal differences were found for the mean total abundance at north side stations B - G, although values were lowest in warmer periods.

The mean diversity and evenness indices at Bn (Table 23) were lowest in summer ($\bar{x}$ 0.51 and $\bar{x}$ 0.41, respectively) and differed significantly from other seasons except spring ($\bar{x}$ 1.13 and $\bar{x}$ 0.64, respectively). No catostomids were collected in the summer at Bn and fewer species of centrachids occurred at Bn in the summer than in the fall and winter. No significant seasonal differences were found for the averages of the diversity and evenness indices at north side stations C - G. Average values for each parameter at each north side station (B - G) per collection date is shown in Tables 19 - 22.

The only fishes collected at north side stations B - D in water temperatures ranging from 30 - 35 C were Lepisosteus osseus (longnose gar), N. analostanus, N. ardens, Notropis amoenus (comely shiner), Notemigonus crysoleucas (golden shiner), Nocomis raneyi (bull chub), Ictalurus punctatus (channel catfish), L. auritus, L. macrochirus, M. dolomieu, Micropterus salmoides (largemouth bass) and P. nigromaculatus. No fishes were collected at Bn on July 10, 1973 when the water temperature was 39 C and only two species, L. auritus and L. macrochirus, were collected at Cn (38 C). In the same period collections at south side stations A - G (ambient temp. 26 C) had a mean of 10.2 species.

Results of a two-factor (season and side) analysis of variance test are shown in Tables 27 - 31. No significant interaction (season x side) was found in the comparison of the south side and An, however the mean number of species at An ($\bar{x}$ 8.5) was significantly greater than that on the south side ($\bar{x}$ 6.6) for the entire year (Table 27). There were more species of suckers at An than at any south side station in the spring and winter. A significant season x side interaction was found in the comparison of Bn and the south side for diversity index, evenness index and number of species (Table 28; Fig. 4 - 6). The t-test indicated that the average diversity index at Bn ($\bar{x}$ 1.40) was significantly greater than that on the south side ($\bar{x}$ 0.64) in the winter, whereas the reverse was true for the summer (Bn, $\bar{x}$ 0.51 and south side, $\bar{x}$ 1.73). The same was evident for average number of species with $\bar{x}$ 5.6 and $\bar{x}$ 2.8 in the winter and $\bar{x}$ 3.0 and $\bar{x}$ 9.6 in the summer for Bn and the south side, respectively. More species of Centrachidae and Catostomidae were collected at Bn than on the south side in the winter, whereas the reverse occurred in the summer.

Gar were collected at Bn but not on the south side in winter. Percids were absent at Bn in the summer. Fewer species of Cyprindae occurred at this station in summer than were present on the south side. The evenness index at Bn was significantly greater than that on the south side in the fall ($\bar{x}$ 0.93 and $\bar{x}$ 0.66, respectively) and in the winter ($\bar{x}$ 0.83 and $\bar{x}$ 0.61, respectively). A significant season x side interaction occurred in the comparison of Cn and the south side for diversity index and number of species (Table 29). These two parameters were significantly greater on the south side ($\bar{H}$, $\bar{x}$ 1.73 and species, $\bar{x}$ 9.6) than at Cn ($\bar{H}$, $\bar{x}$ 0.77 and species, $\bar{x}$ 3.0) in the summer. No species of Catostomidae, Ictaluridae and Percidae were collected at Cn in the summer. Average total abundance per collection period on the south side ($\bar{x}$ 54.4) was significantly greater than at Bn ($\bar{x}$ 17.3) and Cn ($\bar{x}$ 17.3) for the entire year (Tables 28 - 29). In the comparison of differences in the diversity index between Dn and the south side, a significant season x side interaction occurred (Table 30). The index was significantly higher at Dn ($\bar{x}$ 1.09) than on the south side ($\bar{x}$ 0.64) in the winter. Species occurrence at Dn was similar to that at Bn in the winter. Average evenness index was significantly higher at Dn ($\bar{x}$ 0.80) than on the south side ($\bar{x}$ 0.64) for the year (Table 30). A significant interaction also occurred at Gn and the south side for number of species (Table 31), however when Gn was tested against the south side with a t-test no significant difference was found between the sides for each season. This implied that the significant interaction was between season for each side and not between the sides (Table 26). The main effect of season was not analyzed as it included both sides.

Discussion

Gammon (1973) states that direct current electrofishing probably is the best single approach to sampling fish populations near the shore of rivers. Although it is known that changes in water temperature, depth and turbidity may influence the effectiveness of electrofishing (Lewis and Charles, 1957; Lewis, 1955) it is doubtful that these factors appreciably affected the sampling technique used in this study because 44 species of fishes were collected in the six mi study area. This represents over one-half of the 87 species known from the entire freshwater system of the James River (Jenkins et al., 1972). Of these 87 species many are known only from headwater and coastal plain habitats and normally would not be expected in the piedmont reaches of the river.

Seasonal changes in the fish populations were apparent on the south side of the river. All parameters were lowest in the winter and increased during warmer periods. Although overwintering in deep water is less common among fishes which inhabit rivers (Nikolsky, 1963), most fishes probably move out from the banks in the winter and thereby avoid the fluctuating temperatures in the shallow water near shore. Such a response would reduce the size of winter collections. In warmer weather the fishes are attracted to the banks for feeding and reproductive activities (Breder and Rosen, 1966; Nikolsky, 1963). Wickliff (1941) and Larimore (1954) have indicated that seasonal changes in abundance occur in freshwater fish populations in that they are high in summer and fall, and low in the winter. Other authors, however, have indicated that certain species do not show this trend. Smith (1963) found that Pimephales notatus (bluntnose minnow) in the Kaskaskia River, Illinois was most abundant in the winter and Proffit (1969) noted that Notropis spilopterus (spotfin shiner) in the White River, Indiana was abundant throughout the year. In the present study N. analostanus, which is a close relative of the spotfin shiner, reacted similarly to that species and was abundant at all south side stations in all seasons.

Since stations were paired at each transect for similarity of habitat and because no significant differences were found between the south side stations in any season, the significant differences that occurred between north side stations (B - G) in the summer and winter may be largely attributed to the thermal discharge.

The elevated temperatures at north side stations (B - G) dampened seasonal influences and only at the outfall station Bn and five mi downstream at Gn were there significant differences among seasons. In contrast to the south side, the summer values for the indices of diversity were significantly lowest at Bn. Station Gn, on the other hand, showed seasonal characteristics for average number of species, which was similar to those on the south side.

When the individual north side stations were compared with the combined south side stations, significant differences between sides were found to exist primarily in the summer and winter seasons. In general most fishes avoided the high temperatures at Bn in the summer and were attracted to higher temperatures at this station in the winter. Elser (1965) also noted this phenomenon and reported that fish tended to congregate in the heated effluent of a power station on the Potomac River in cooler months. Woolcott (1972) and Trembley (1960) recorded this observation for the James and Delaware Rivers, respectively.

Only certain fishes were collected at relatively high temperatures. Trembley (1961) indicated, as observed in this study, that the golden shiner, satinfin shiner, channel catfish, smallmouth bass, largemouth bass, black crappie, bluegill and redbreast sunfish were found in water temperatures between 30 - 35 C in the Delaware River. Most cyprinids can tolerate upper lethal temperatures exceeding 30 C through acclimation (Brett, 1956). In this study the redbreast sunfish and bluegill appreared to have the highest tolerance limit as they were the only fishes taken in a water temperature of 38 C. Dahlberg (1972) collected these species in 37 C water. The catostomids, percids and some species of Centrarchidae, e.g., *Lepomis gibbosus* (pumpkinseed) and *Lepomis gulosus* (warmouth) and Cyprinidae e.g., *N. hudsonius* and *Notropis rubellus* (rosyface shiner) appeared to avoid 30 - 35 C water as none were collected at these temperatures. No thermal fish kills were observed during this study nor were they expected as only a small area of the river was affected by the thermal discharge. In addition fishes are highly mobile and ordinarily are able to escape undesirable temperatures such as those in heated effluents (Parker and Krenkel, 1969).

Each parameter utilized in this study contributed to the analysis of seasonal effects on the fish populations but not always at the same magnitude. Diversity index probably offered the best single approach to understanding the fluctuation in community structure that results from environmental changes in natural and thermally influenced systems as it incorporates the information available from the other parameters. This is in general agreement with others (Wilhm, 1970; Monk, 1967) who have reached similar conclusions under circumstances differing from those of the present study.

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Table 1. Time period selected for each season with range of mean ambient water temperatures (C) in the study area of the James River, Virginia.

Season	Time Period	Temperature Range
Fall	October 1972 and September 1973	14.0 - 20.0
Winter	November 1972 - February 1973	2.0 - 8.0
Spring	March 1973 - May 1973	10.5 - 17.5
Summer	June 1973 - August 1973	20.5 - 26.0

Table 2. List of freshwater fishes collected with an electric shocker in the James River near Bremo Bluff, Virginia from October 1972 to September 1973.

Lepisosteidae - gars
Lepisosteus osseus - longnose gar

Anguillidae - freshwater eels
Anguilla rostrata - American eel

Esocidae - pikes
Esox niger - chain pickerel

Cyprinidae - minnows and carps
Cyprinus carpio - carp
Exoglossum maxillingua - cutlips minnow
Nocomis leptocephalus - bluehead chub
Nocomis raneyi - bull chub
Notemigonus crysoleucas - golden shiner
Notropis amoenus - comely shiner
Notropis analostanus - satinfin shiner
Notropis ardens - rosefin shiner
Notropis cornutus - common shiner
Notropis hudsonius - spottail shiner
Notropis procne - swallowtail shiner
Notropis rubellus - rosyface shiner
Pimephales notatus - bluntnose minnow
Rhinichthys atratulus - blacknose dace
Semotilus corporalis - fallfish

Catostomidae - suckers
Carpiodes cyprinus - quillback
Catostomus commersoni - white sucker
Hypentelium nigricans - hog sucker
Moxostoma cervinum - black jumprock
Moxostoma erythrurum - golden redhorse
Moxostoma macrolepidotum - shorthead redhorse
Moxostoma rhothoecum - torrent sucker

Table 2. Continued

Ictaluridae - freshwater catfishes
Ictalurus natalis - yellow bullhead
Ictalurus nebulosus - brown bullhead
Ictalurus punctatus - channel catfish
Noturus insignis - margined madtom
Poeciliidae - livebearers
Gambusia affinis - mosquito fish
Centrarchidae - sunfishes
Lepomis auritus - redbreast sunfish
Lepomis gibbosus - pumpkinseed
Lepomis gulosus - warmouth
Lepomis macrochirus - bluegill
Micropterus dolomieu - smallmouth bass
Micropterus salmoides - largemouth bass
Pomoxis nigromaculatus - black crappie
Percidae - perches
Etheostoma flabellare - fantail darter
Etheostoma nigrum - Johnny darter
Etheostoma olmstedi - tessellated darter
Etheostoma vitreum - glassy darter
Percina crassa - Piedmont darter
Percina notogramma - stripeback darter
Percina peltata - shield darter

Table 3. Total number of individuals per species collected with an electric shocker and temperature range (C) on the north (N) and south (S) sides of the river at transect A for each season from October 1972 through September 1973.

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	12.0-20.0	13.0-21.0	2.0-6.0	2.5-7.0	11.0-17.0	11.0-18.0	20.0-25.0	21.0-26.0
Lepisosteus osseus						2	1	5
Anguilla rostrata	3	8			4	4	7	6
Cyprinus carpio						1		
Exoglossum maxillingua	1							
Nocomis raneyi	15	8		3	2	6	7	7
Notemigonus crysoleucas			1					
Notropis amoenus		8	20	2		2		
Notropis analostanus	175	259	111	216	288	510	48	55
Notropis ardens	7	15	157	20	213	30	2	4
Notropis cornutus	2	1					1	2
Notropis hudsonius	251	7					30	2
Notropis procne	12	2	1	1		4	1	1
Notropis rubellus		8	5	18	20	12	1	2
Pimephales notatus	1							
Rhinichthys atratulus							1	
Carpiodes cyprinus								1
Catostomus commersoni		2		2		2	8	2
Moxostoma cervinum	1							
Moxostoma erythrurum	13							2

Table 3. Continued

Species	Fall S 12.0-20.0	Fall N 13.0-21.0	Winter S 2.0-6.0	Winter N 2.5-7.0	Spring S 11.0-17.0	Spring N 11.0-18.0	Summer S 20.0-25.0	Summer N 21.0-26.0
Moxostoma macrolepidotum	17	5		1	1	2	3	1
Moxostoma rhothoecum						1	1	
Hypentelium nigricans	10	13		1			4	8
Ictalurus natalis	1						2	3
Ictalurus nebulosus		1						
Ictalurus punctatus	9	2				1	3	2
Noturus insignis	3	2	1		1		2	3
Gambusia affinis	1							1
Lepomis auritus	25	51		4	30	16	53	39
Lepomis gibbosus	2	9					6	
Lepomis macrochirus	3	18			4	4	12	23
Micropterus dolomieu	8	40			1	2	6	6
Micropterus salmoides	4	4			2		2	
Percina crassa	2							
Percina notogramma		4					1	
Percina peltata	9	2					3	2
Etheostoma nigrum	1	1						1
Etheostoma olmstedi					1			
Etheostoma vitreum	1			1			1	

Table 4. Total number of individuals per species collected with an electric shocker and temperature range (C) on the north (N) and south (S) sides of the river at transect B for each season from October 1972 through September 1973.

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-20.0	18.0-29.0	2.0-7.5	9.0-22.0	11.0-16.0	17.5-25.0	21.0-26.5	30.0-39.0
Lepisosteus osseus	1	2		4		7	3	9
Anguilla rostrata	10	1	1		2		4	
Esox niger				1				
Cyprinus carpio		5				13	1	
Nocomis raneyi	8				1	2	11	
Notemigonus crysoleucas								1
Notropis amoenus		1						2
Notropis analostanus	82	5	164	35	11	52	68	55
Notropis ardens	2	1	3	7			2	2
Notropis cornutus	3							
Notropis hudsonius	29				80		33	
Notropis procne	2						3	
Notropis rubellus			1	6				
Semotilus corporalis				1				
Carpiodes cyprinus	2	2				1	3	
Catostomus commersoni	4		1	6			5	
Moxostoma cervinum	1						1	
Moxostoma erythrurum	1						8	
Moxostoma macrolepidotum	12	3		1		2	7	
Moxostoma rhothoecum	1							

Table 4. Continued

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-20.0	18.0-29.0	2.0-7.5	9.0-22.0	11.0-16.0	17.5-25.0	21.0-26.5	30.0-39.0
Hypentelium nigricans	16	1					17	
Ictalurus punctatus	5	2		1				4
Noturus insignis	2						1	
Lepomis auritus	20	8		2	8	2	14	2
Lepomis gibbosus	5						1	
Lepomis macrochirus	4	6		2	1	4	10	4
Micropterus dolomieu	11	5		2		1	7	
Micropterus salmoides		1					1	
Pomoxis nigromaculatus		1		2				
Percina notogramma	3						3	
Percina peltata	1						1	
Etheostoma nigrum	1						1	

Table 5. Total number of individuals per species collected with an electric shocker and temperature range (C) on the north (N) and south (S) sides of the river at transect C for each season from October 1972 through September 1973.

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-19.5	17.0-28.0	2.0-7.5	5.0-9.0	10.5-16.0	14.0-18.0	20.5-26.0	25.0-38.0
Lepisosteus osseus		1				1	4	3
Anguilla rostrata	20	2			1	1	13	
Esox niger					1			
Cyprinus carpio						5		
Nocomis leptocephalus	1							
Nocomis raneyi	22	2			1		11	
Notropis amoenus				2				
Notropis analostanus	51	74	63	31	2	32	58	25
Notropis ardens	3	10	4	20	3	2	1	4
Notropis cornutus	3							
Notropis hudsonius	464						144	
Notropis procne		1	1					
Notropis rubellus		2	1	6				
Rhinichthys atratulus	1							
Semotilus corporalis	1						1	
Carpiodes cyprinus					1	3	1	
Catostomus commersoni	1	2	1	3			2	
Moxostoma erythrurum	1	1					1	
Moxostoma macrolepidotum	42	1					5	
Hypentelium nigricans	27	1			1		16	

Table 5. Continued

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-19.5	17.0-28.0	2.0-7.5	5.0-9.0	10.5-16.0	14.0-18.0	20.5-26.0	25.0-38.0
<u>Ictalurus punctatus</u>	3	1				1	6	
<u>Noturus insignis</u>	2							
<u>Lepomis auritus</u>	41	7	1	1	2	6	27	3
<u>Lepomis gibbosus</u>	1	1					1	
<u>Lepomis macrochirus</u>	6	7	1		1	1	5	4
<u>Micropterus dolomieu</u>	7	4				1	7	1
<u>Micropterus salmoides</u>							1	2
<u>Pomoxis nigromaculatus</u>					1	1	1	
<u>Percina notogramma</u>	1						2	
<u>Percina peltata</u>	15						11	
<u>Etheostoma flabellare</u>	1							
<u>Etheostoma nigrum</u>	3							
<u>Etheostoma vitreum</u>		1						

Table 6. Total number of individuals per species collected with an electric shocker and temperature range (C) on the north (N) and south (S) sides of the river at transect D for each season from October 1972 through September 1973.

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-20.0	17.0-28.0	2.0-8.0	4.0-8.0	10.5-16.0	12.0-18.0	20.5-26.0	23.0-35.0
Lepisosteus osseus		5		10		14	2	3
Anguilla rostrata	7	2			2		9	
Cyprinus carpio		1				3	1	
Nocomis raneyi	1						6	1
Notropis amoenus			6	1			1	2
Notropis analostanus	98	163	72	40	15	8	22	33
Notropis ardens	13	25	38	53	2			1
Notropis cornutus	3					1		
Notropis hudsonius	169	2	1				24	
Notropis procne	2	1						
Notropis rubellus	13	8	9	9			2	
Semotilus corporalis	1						3	
Carpiodes cyprinus		1						
Catostomus commersoni			1	1	1			
Moxostoma erythrurum	8						2	
Moxostoma macrolepidotum	9			1			2	
Hypentelium nigricans	2						4	
Ictalurus natalis		1						
Ictalurus punctatus	1	3				1	1	3

Table 6. Continued

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-20.0	17.0-28.0	2.0-8.0	4.0-8.0	10.5-16.0	12.0-18.0	20.5-26.0	23.0-35.0
Noturus insignis	1		1					
Gambusia affinis		2						
Lepomis auritus	12	28	2	2	4	4	21	6
Lepomis gulosus		1						
Lepomis macrochirus	2	2	1	3	2		5	18
Micropterus dolomieu	3	4		2	1	1	4	1
Micropterus salmoides		1			1			3
Pomoxis nigromaculatus						1	3	1
Percina notogramma	1							
Etheostoma nigrum	1							

Table 7. Total number of individuals per species collected with an electric shocker and temperature range (C) on the north (N) and south (S) sides of the river at transect G for each season from October 1972 through September 1973.

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-19.5	16.0-23.0	3.0-8.0	4.0-8.0	9.5-15.5	10.5-16.5	20.0-26.0	21.0-29.0
Lepisosteus osseus		2		1	3	5	6	3
Anguilla rostrata	5	3				1	5	3
Esox niger			1					
Cyprinus carpio	1							
Nocomis raneyi	1					1	6	
Notropis amoenus			76	3		1	1	1
Notropis analostanus	36	61	83	107	31	67	78	92
Notropis ardens	1	7	8	45	2			2
Notropis cornutus							2	
Notropis hudsonius	3	3			1	1	117	17
Notropis procne	1			2		1	2	
Notropis rubellus	1		2	11		1	2	3
Semotilus corporalis							1	1
Catostomus commersoni	1			1	1	1	1	
Moxostoma erythrurum	5						9	1
Moxostoma macrolepidotum	5						4	
Moxostoma rhothoecum							1	
Hypentelium nigricans	1	1					2	
Ictalurus natalis	1							1

Table 7. Continued

Species	Fall		Winter		Spring		Summer	
	S	N	S	N	S	N	S	N
	14.0-19.5	16.0-23.0	3.0-8.0	4.0-8.0	9.5-15.5	10.5-16.5	20.0-26.0	21.0-29.0
Ictalurus punctatus	4	2				2	3	4
Noturus insignis	1					1	2	1
Lepomis auritus	9	26	4	3	9	4	25	26
Lepomis gibbosus	1	4					3	1
Lepomis gulosus							1	
Lepomis macrochirus	6	13		1	5	1	22	14
Micropterus dolomieu	5	11	1	2		3	6	6
Micropterus salmoides		4					1	1
Pomoxis nigromaculatus							3	
Etheostoma nigrum	1						1	
Etheostoma olmstedi	1							

Table 8. Results of Duncan's multiple range test for mean number of species ($\overline{X}$) at each south side station (A-G) in the study area of the James River per season. Means underscored by the same line were not significantly different (.95 level).

Fall

Station	Ds	Gs	Bs	Cs	As
$\overline{X}$	7.2	8.2	11.2	11.8	12.2

Winter

Station	Bs	Cs	Gs	As	Ds
$\overline{X}$	1.7	2.7	3.0	3.0	3.8

Spring

Station	Bs	Cs	Gs	Ds	As
$\overline{X}$	3.7	4.0	4.3	4.7	5.6

Summer

Station	Ds	Bs	Cs	As	Gs
$\overline{X}$	7.0	10.0	10.0	10.2	10.8

Table 9. Results of Duncan's multiple range test for mean total abundance ($\bar{X}$) at each south side station (A-G) in the study area of the James River per season. Means underscored by the same line were not significantly different (.95 level).

Fall

Station	Gs	Bs	Ds	As	Cs
$\bar{X}$	22.5	56.5	86.8	144.2	179.2

Winter

Station	Cs	Ds	Bs	Gs	As
$\bar{X}$	15.2	27.0	28.8	32.5	59.6

Spring

Station	Cs	Ds	Bs	Gs	As
$\bar{X}$	5.7	15.0	37.3	51.3	113.4

Summer

Station	Ds	Bs	As	Gs	Cs
$\bar{X}$	22.4	41.0	41.2	60.8	63.6

Table 10. Results of Duncan's multiple range test for mean diversity indices ($\overline{X}$) at each south side station (A-G) in the study area of the James River per season. Means underscored by the same line were not significantly different (.95 level).

Fall

Station	Ds	As	Cs	Bs	Gs
$\overline{X}$	1.02	1.28	1.46	1.63	1.64

Winter

Station	Bs	As	Cs	Gs	Ds
$\overline{X}$	0.42	0.51	0.71	0.71	0.84

Spring

Station	Bs	Gs	Ds	As	Cs
$\overline{X}$	0.67	0.71	1.10	1.12	1.22

Summer

Station	Ds	Cs	As	Gs	Bs
$\overline{X}$	1.61	1.67	1.76	1.77	1.83

(In each season, a single line underscores all five means.)

Table 11. Results of Duncan's multiple range test for mean evenness indices ($\overline{X}$) at each south side station (A-G) in the study area of the James River per season. Means underscored by the same line were not significantly different (.95 level).

Fall

Station	As	Cs	Ds	Bs	Gs
$\overline{X}$	0.54	0.62	0.70	0.76	0.82

Winter

Station	As	Bs	Ds	Gs	Cs
$\overline{X}$	0.44	0.60	0.61	0.62	0.74

Spring

Station	Gs	Bs	As	Ds	Cs
$\overline{X}$	0.50	0.65	0.70	0.73	0.94

Summer

Station	Cs	Gs	As	Bs	Ds
$\overline{X}$	0.76	0.77	0.80	0.83	0.87

Table 12. Physical factors: average values of river discharge (cfs) and temperature (C); and study parameters: average indices of diversity ($\bar{H}$) and evenness (E), and average values of number of species and total abundance per collection (October 1972 - September 1973) on the south side in the James River near Bremo Bluff, Virginia.

Collection Date	Physical Factors: Discharge	Physical Factors: Temp.	Study Parameters: $\bar{H}$	Study Parameters: E	Study Parameters: No. Species	Study Parameters: Total Abundance
Oct. 13, 1972	5192	14.0	1.16	0.53	8.8	65.0
Oct. 25,27	3300	14.0	0.91	0.72	4.2	14.4
Nov. 24[1]	12385	6.0	0.64	0.54	2.6	11.8
Dec. 8[2]	13831	8.0	0.66	0.72	2.8	11.8
Dec. 20,21,28	11342	6.5	0.54	0.50	2.2	39.6
Jan. 3,4, 1973	9418	7.0	0.33	0.45	2.0	52.0
Jan. 17,18	5738	4.0	0.79	0.73	3.2	10.4
Feb. 14,15,20	10855	2.0	0.91	0.73	4.2	60.4
Mar. 13,14[1]	10000	12.0	0.73	0.63	4.2	103.8
Apr. 16,17	12114	10.5	0.75	0.63	3.8	38.2
Apr. 25[3]	8855	16.5	1.33	0.74	6.0	20.0
May 8,10	8153	16.0	1.38	0.80	5.8	31.4
May 24[3]	5056	17.0	1.08	0.98	3.0	8.0
June 4,5	8100	20.5	1.55	0.80	7.0	24.0
June 19,21	5750	23.0	1.60	0.83	7.4	21.2
July 10,11	2998	26.0	1.56	0.71	10.2	82.2
July 31, Aug. 3,6	2360	23.5	1.84	0.89	9.4	31.0
Aug. 16,17	3222	23.5	2.10	0.81	13.8	70.6
Sept. 10,11	1478	20.0	1.80	0.75	11.6	118.8
Sept. 26,28	1514	18.5	1.77	0.64	16.0	193.2

[1]Power station not operating.

[2]An and As not sampled.

[3]Only An and As sampled.

Table 13. Results of Duncan's multipe range test of mean values ($\overline{X}$) for each season per parameter on the south side of the James River study area. Means underscored by the same line were not significantly different (.95 level).

Diversity Index

Season	Winter	Spring	Fall	Summer
$\overline{X}$	0.64	0.95	1.41	1.73

Evenness Index

Season	Winter	Fall	Spring	Summer
$\overline{X}$	0.61	0.66	0.69	0.81

No. of Species

Season	Winter	Spring	Summer	Fall
$\overline{X}$	2.8	4.6	9.6	10.2

Total Abundance

Season	Winter	Summer	Spring	Fall
$\overline{X}$	31.0	45.8	57.8	97.8

Table 14. Results of Duncan's multiple range test for mean number of species ($\overline{X}$) at each north side station (B-G) in the study area of the James River per season. Means underscored by the same line were not significantly different (.95 level).

Fall

Station	Bn	Cn	Gn	Dn
$\overline{X}$	6.5	6.8	7.0	7.5

Winter

Station	Cn	Gn	Dn	Bn
$\overline{X}$	3.2	4.0	4.4	5.6

Spring

Station	Dn	Bn	Cn	Gn
$\overline{X}$	5.5	6.5	7.0	8.5

Summer

Station	Bn	Cn	Dn	Gn
$\overline{X}$	3.0	3.0	4.2	7.8

Table 15. Results of Duncan's multiple range test for mean total abundance ($\bar{X}$) at each north side station (B-G) in the study area of the James River per season. Means underscored by the same line were not significant different (.95 level).

Fall

Station	Bn	Cn	Gn	Dn
$\bar{X}$	11.0	29.5	34.2	62.5

Winter

Station	Cn	Bn	Dn	Gn
$\bar{X}$	12.6	14.0	24.4	35.2

Spring

Station	Dn	Cn	Bn	Gn
$\bar{X}$	16.5	27.0	42.0	45.0

Summer

Station	Cn	Dn	Bn	Gn
$\bar{X}$	8.4	14.4	15.8	35.6

Table 16. Results of Duncan's multiple range test for mean diversity indices ($\overline{X}$) at each north side station (B-G) in the study area of the James River per season. Means underscored by the same line were not significantly different (.95 level).

Fall

Station	Cn	Dn	Gn	Bn
$\overline{X}$	1.22	1.22	1.52	1.56

Winter

Station	Gn	Cn	Dn	Bn
$\overline{X}$	0.86	0.87	1.09	1.40

Spring

Station	Bn	Dn	Gn	Cn
$\overline{X}$	1.13	1.28	1.28	1.45

Summer

Station	Bn	Cn	Dn	Gn
$\overline{X}$	0.51	0.74	1.13	1.43

Table 17. Results of Duncan's multiple range test for mean evenness indices ($\overline{X}$) at each north side station (B-G) in the study area of the James River per season. Means underscored by the same line were not significantly different (.95 level).

Fall

Station	Dn	Cn	Gn	Bn
$\overline{X}$	0.70	0.72	0.82	0.93

Winter

Station	Gn	Dn	Bn	Cn
$\overline{X}$	0.64	0.80	0.83	0.83

Spring

Station	Gn	Bn	Cn	Dn
$\overline{X}$	0.58	0.64	0.74	0.77

Summer

Station	Bn	Cn	Gn	Dn
$\overline{X}$	0.41	0.64	0.70	0.89

Table 18. Physical factors: river discharge (cfs) and temperature (C); and study parameters: indices of diversity ($\bar{H}$) and evenness (E), number of species and total abundance per collection (October 1972 - September 1973) at station An in the James River near Bremo Bluff, Virginia.

Collection Date	Physical Factors		Study Parameters			
	Discharge	Temp.	$\bar{H}$	E	No. Species	Total Abundance
Oct. 13, 1972	5192	14.0	0.80	0.33	11	217
Oct. 27	3296	13.0	1.29	0.54	11	93
Nov. 24	12385	7.0	1.16	0.72	5	16
Dec. 20	11669	5.0	0.89	0.64	4	21
Jan. 4, 1973	10525	6.0	0.78	0.48	5	123
Jan. 17	5915	3.0	1.17	0.65	6	15
Feb. 20	10867	2.5	0.30	0.22	4	94
Mar. 14	9555	12.0	0.58	0.32	6	220
Apr. 17	11595	11.0	0.21	0.12	6	223
Apr. 25	8855	17.0	1.87	0.90	8	16
May 10	8345	15.5	0.85	0.35	11	109
May 24	5056	18.0	1.70	0.74	10	32
June 5	8155	21.0	1.97	0.82	11	32
June 19	5715	21.5	1.74	0.68	13	79
July 11	2953	26.0	1.95	0.89	9	17
July 31	2107	24.5	1.74	0.90	7	24
Aug. 16	3614	22.5	1.88	0.85	9	26
Sept. 10	1473	21.0	2.06	0.80	13	75
Sept. 28	1491	20.0	1.98	0.77	13	85

Table 19. Physical factors: river discharge (cfs) and temperature (C); and study parameters: indices of diversity ($\bar{H}$) and evenness (E), number of species and total abundance per collection (October 1972 - September 1973) at station Bn in the James River near Bremo Bluff, Virginia.

Collection Date	Physical Factors		Study Parameters			
	Discharge	Temp.	$\bar{H}$	E	No. Species	Total Abundance
Oct. 13, 1972	5192	18.0	2.37	0.96	12	18
Oct. 25	3304	19.0	2.02	0.97	8	11
Dec. 8	13831	22.0	1.16	0.83	4	13
Dec. 21	10649	19.0	1.16	0.72	5	18
Jan 3, 1973	8312	17.0	1.34	0.69	7	20
Jan. 18	5562	9.0	1.61	1.00	5	5
Feb. 14	9961	10.0	1.75	0.90	7	14
Apr. 16	12632	17.5	0.93	0.45	8	67
May 8	7961	25.0	1.33	0.83	5	17
June 4	8045	30.0	0.87	0.54	5	40
June 21	5785	33.0	0.98	0.50	7	35
July 10	3043	39.0	0.00	0.00	0	0
Aug. 3	2450	35.0	0.00	0.00	1	2
Aug. 17	2830	34.5	0.69	1.00	2	2
Sept. 11	1483	25.5	1.20	0.86	4	12
Sept. 26	1537	29.0	0.64	0.93	2	3

Table 20. Physical factors: river discharge (cfs) and temperature (C); and study parameters: indices of diversity ($\overline{H}$) and evenness (E), number of species and total abundance per collection (October 1972 - September 1973) at station Cn in the James River near Bremo Bluff, Virginia.

Collection Date	Physical Factors		Study Parameters			
	Discharge	Temp.	$\overline{H}$	E	No. Species	Total Abundance
Oct. 13, 1972	5192	17.0	1.52	0.59	13	75
Oct. 25	3304	18.0	0.54	0.34	5	33
Dec. 8	13831	9.0	0.66	0.96	2	8
Dec. 21	10649	7.0	1.24	0.90	4	15
Jan. 3, 1973	8312	9.0	0.64	0.58	3	10
Jan. 18	5562	6.5	1.14	0.71	5	28
Feb. 14	9961	5.0	0.69	1.00	2	2
Apr. 16	12632	14.0	0.76	0.55	4	36
May 8	7961	18.0	2.14	0.93	10	18
June 4	8045	25.0	0.89	0.64	4	11
June 21	5785	28.0	1.10	0.62	6	25
July 10	3043	38.0	0.69	1.00	2	2
Aug. 3	2450	32.0	0.00	0.00	0	0
Aug. 17	2830	33.5	1.04	0.94	3	4
Sept. 11	1483	24.5	1.79	1.00	6	6
Sept. 26	1537	28.0	1.04	0.94	3	4

Table 21. Physical factors: river discharge (cfs) and temperature (C); and study parameters: indices of diversity ($\bar{H}$) and evenness (E), number of species and total abundance per collection (October 1972 - September 1973) at station Dn in the James River near Bremo Bluff, Virginia.

Collection Date	Physical Factors		Study Parameters			
	Discharge	Temp.	$\bar{H}$	E	No. Species	Total Abundance
Oct. 13, 1972	5192	17.0	1.05	0.46	10	198
Oct. 25	3304	17.0	1.51	0.66	10	30
Dec. 8	13831	8.0	1.19	0.66	6	37
Dec. 28	11708	8.0	0.90	0.82	3	10
Jan. 3, 1973	8312	8.0	1.10	1.00	3	3
Jan. 18	5562	6.5	1.36	0.70	7	27
Feb. 14	9961	4.0	0.90	0.82	3	45
Apr. 16	12632	12.0	1.08	0.78	4	12
May 8	7961	18.0	1.47	0.76	7	21
June 4	8045	23.0	0.83	0.60	4	37
June 21	5785	27.0	1.70	0.90	6	10
July 10	3043	35.0	0.67	0.97	2	5
Aug. 3	2450	31.0	0.69	1.00	2	2
Aug. 17	2830	33.0	1.77	0.91	7	18
Sept. 11	1483	24.0	0.56	0.81	2	4
Sept. 26	1537	28.0	1.77	0.85	8	18

Table 22. Physical factors: river discharge (cfs) and temperature (C); and study parameters: indices of diversity ($\bar{H}$) and evenness (E), number of species and total abundance per collection (October 1972 - September 1973) at station Gn in the James River near Bremo Bluff, Virginia.

	Physical Factors		Study Parameters			
Collection Date	Discharge	Temp.	$\bar{H}$	E	No. Species	Total Abundance
Oct. 13, 1972	5192	16.0	1.20	0.62	7	50
Oct. 25	3304	16.0	1.33	0.96	4	5
Dec. 8	13831	8.0	0.48	0.44	3	48
Dec. 28	11708	8.0	1.14	0.64	6	61
Jan. 3, 1973	8312	7.5	1.12	0.70	5	30
Jan. 18	5562	4.5	0.44	0.40	3	34
Feb. 15	11737	4.0	1.10	1.00	3	3
Apr. 16	12632	10.5	0.45	0.23	7	69
May 8	7961	16.5	2.11	0.92	10	21
June 4	8045	21.0	1.25	0.70	6	16
June 21	5785	25.0	1.41	0.73	7	33
July 10	3043	29.0	1.36	0.65	8	35
Aug. 6	2524	27.0	1.84	0.80	10	49
Aug. 17	2830	26.0	1.31	0.63	8	45
Sept. 11	1483	22.0	1.90	0.83	10	56
Sept. 26	1537	23.0	1.66	0.86	7	26

Table 23. Results of Duncan's multiple range test of mean values ($\overline{X}$) for each season per parameter at station Bn in the study area of the James River. Means underscored by the same line were not significantly different (.95 level).

Diversity Index

Season	Summer	Spring	Winter	Fall
$\overline{X}$	0.51	1.13	1.40	1.56

Evenness Index

Season	Summer	Spring	Winter	Fall
$\overline{X}$	0.41	0.64	0.83	0.93

No. of Species

Season	Summer	Winter	Fall	Spring
$\overline{X}$	3.0	5.6	6.5	6.5

Total Abundance

Season	Fall	Winter	Summer	Spring
$\overline{X}$	11.0	14.0	15.8	42.0

Table 24. Results of Duncan's multiple range test of mean values ($\overline{X}$) for each season per parameter at station Cn in the study area of the James River. Means underscored by the same line were not significantly different (.95 level).

Diversity Index

Season	Summer	Winter	Fall	Spring
$\overline{X}$	0.77	0.87	1.22	1.45

Evenness Index

Season	Summer	Fall	Spring	Winter
$\overline{X}$	0.64	0.72	0.74	0.83

No. of Species

Season	Summer	Winter	Fall	Spring
$\overline{X}$	3.0	3.2	6.8	7.0

Total Abundance

Season	Summer	Winter	Spring	Fall
$\overline{X}$	8.4	12.6	27.0	29.5

Table 25. Results of Duncan's multiple range test of mean values ($\overline{X}$) for each season per parameter at station Dn in the study area of the James River. Means underscored by the same line were not significantly different (.95 level).

Diversity Index

Season	Winter	Summer	Fall	Spring
$\overline{X}$	1.09	1.13	1.22	1.28

Evenness Index

Season	Fall	Spring	Winter	Summer
$\overline{X}$	0.70	0.77	0.80	0.89

No. of Species

Season	Summer	Winter	Spring	Fall
$\overline{X}$	4.2	4.4	5.5	7.5

Total Abundance

Season	Summer	Spring	Winter	Fall
$\overline{X}$	14.4	16.5	24.4	62.5

Table 26. Results of Duncan's multiple range test of mean value ($\overline{X}$) for each season per parameter at station Gn in the study area of the James River. Means underscored by the same line were not significantly different (.95 level).

Diversity Index

Season	Winter	Spring	Summer	Fall
$\overline{X}$	0.86	1.28	1.43	1.52

Evenness Index

Season	Spring	Winter	Summer	Fall
$\overline{X}$	0.58	0.64	0.70	0.82

No. of Species

Season	Winter	Fall	Summer	Spring
$\overline{X}$	4.0	7.0	7.8	8.5

Total Abundance

Season	Fall	Winter	Summer	Spring
$\overline{X}$	34.2	35.2	35.6	45.0

Table 27. Two-factor analysis of variance for each of the four parameters on the north (An) and south sides of the James River study area.

Diversity Index

Source	df	SS	MS	F
A (side)	1	0.17	0.17	0.98
B (season)	3	5.82	1.94	11.28*
AB	3	0.02	0.01	0.04
error	29	4.99	0.17	
Total	36	11.00		

*Statistically significant

$F_{.95}(1,29) = 4.18$

$F_{.95}(3,29) = 2.93$

Evenness Index

Source	df	SS	MS	F
A (side)	1	0.05	0.05	1.61
B (season)	3	0.34	0.11	3.60*
AB	3	0.06	0.02	0.61
error	29	0.90	0.03	
Total	36	1.35		

*Statistically significant

$F_{.95}(1,29) = 4.18$

$F_{.95}(3,29) = 2.93$

Table 27. Continued

No. of Species

Source	df	SS	MS	F
A (side)	1	32.57	32.57	6.02*
B (season)	3	285.10	95.03	17.56*
AB	3	12.56	4.19	0.77
error	29	156.98	5.41	
Total	36	487.21		

*Statistically significant

$F_{.95}(1,29) = 4.18$

$F_{.95}(3,29) = 2.93$

Total Abundance

Source	df	SS	MS	F
A (side)	1	4956.00	4956.00	1.56
B (season)	3	30194.13	10064.71	3.17*
AB	3	5885.87	1961.96	0.62
error	29	92088.07	3175.45	
Total	36	133124.07		

*Statistically significant

$F_{.95}(1,29) = 4.18$

$F_{.95}(3,29) = 2.93$

Table 28. Two-factor analysis of variance for each of the four parameters on the north (Bn) and south sides of the James River study area.

Diversity Index

Source	df	SS	MS	F
A (side)	1	0.01	0.01	0.05
B (season)	3	1.00	0.35	2.08
AB	3	4.03	1.34	7.93*
error	26	4.41	0.17	
Total	33	9.45		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Evenness Index

Source	df	SS	MS	F
A (side)	1	< 0.01	< 0.01	0.02
B (season)	3	0.15	0.05	1.26
AB	3	0.54	0.18	4.63*
error	26	1.00	0.04	
Total	33	1.69		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Table 28. Continued

No. of Species

Source	df	SS	MS	F
A (side)	1	14.63	14.63	1.78
B (season)	3	67.29	22.43	2.73
AB	3	114.17	38.06	4.64*
error	26	213.28	8.20	
Total	33	409.37		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Total Abundance

Source	df	SS	MS	F
A (side)	1	10664.34	10664.34	9.36*
B (season)	3	5299.58	1766.53	1.55
AB	3	6443.39	2147.80	1.88
error	26	29633.87	1139.76	
Total	33	52041.18		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Table 29. Two-factor analysis of variance for each of the four parameters on the north (Cn) and south sides of the James River study area.

Diversity Index

Source	df	SS	MS	F
A (side)	1	0.10	0.10	0.58
B (season)	3	1.44	0.48	2.90
AB	3	2.39	0.80	4.83*
error	26	4.29	0.16	
Total	33	8.22		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Evenness Index

Source	df	SS	MS	F
A (side)	1	0.01	0.01	0.25
B (season)	3	0.01	< 0.01	0.04
AB	3	0.14	0.05	0.98
error	26	1.27	0.05	
Total	33	1.43		

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Table 29. Continued

No. of Species

Source	df	SS	MS	F
A (side)	1	24.64	24.64	3.05
B (season)	3	114.06	38.02	4.70*
AB	3	90.58	30.19	3.74*
error	26	210.12	8.08	
Total	33	439.40		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Total Abundance

Source	df	SS	MS	F
A (side)	1	11433.10	11433.10	9.65*
B (season)	3	8057.93	2685.98	2.27
AB	3	2581.54	860.51	0.73
error	26	30794.47	1184.40	
Total	33	52867.04		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Table 30. Two-factor analysis of variance for each of the four parameters on the north (Dn) and south sides of the James River study area.

Diversity Index

Source	df	SS	MS	F
A (side)	1	< 0.01	< 0.01	< 0.01
B (season)	3	1.40	0.47	3.36*
AB	3	1.32	0.44	3.18*
error	26	3.61	0.14	
Total	33	6.33		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Evenness Index

Source	df	SS	MS	F
A (side)	1	0.07	0.07	4.37*
B (season)	3	0.13	0.04	2.62
AB	3	0.02	0.01	0.50
error	26	0.42	0.02	
Total	33	0.64		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Table 30. Continued

No. of Species

Source	df	SS	MS	F
A (side)	1	14.63	14.63	1.98
B (season)	3	116.60	38.86	5.26*
AB	3	59.68	19.89	2.69
error	26	192.08	7.39	
Total	33	382.99		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Total Abundance

Source	df	SS	MS	F
A (side)	1	6259.34	6259.34	3.04
B (season)	3	13822.95	4607.65	2.24
AB	3	1330.81	443.60	0.22
error	26	53450.97	2055.81	
Total	33	74864.07		

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Table 31. Two-factor analysis of variance for each of the four parameters on the north (Gn) and south sides of the James River study area.

Diversity Index

Source	df	SS	MS	F
A (side)	1	0.06	0.06	0.42
B (season)	3	3.22	1.07	7.50*
AB	3	0.42	0.14	0.98
error	26	3.72	0.14	
Total	33	7.42		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Evenness Index

Source	df	SS	MS	F
A (side)	1	< 0.01	< 0.01	0.02
B (season)	3	0.11	0.04	1.37
AB	3	0.09	0.03	1.16
error	26	0.70	0.03	
Total	33	0.90		

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Table 31. Continued

No. of Species

Source	df	SS	MS	F
A (side)	1	0.01	0.01	< 0.01
B (season)	3	138.62	46.21	8.12*
AB	3	56.35	18.78	3.30*
error	26	147.88	5.69	
Total	33	342.86		

*Statistically significant

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Total Abundance

Source	df	SS	MS	F
A (side)	1	3233.22	3233.22	2.64
B (season)	3	4666.83	1555.61	1.27
AB	3	5015.31	1671.77	1.36
error	26	31901.82	1226.99	
Total	33	44853.18		

$F_{.95}(1,26) = 4.23$

$F_{.95}(3,26) = 2.98$

Figure 1. The James River, Virginia study area. Capital letters denote collecting stations.

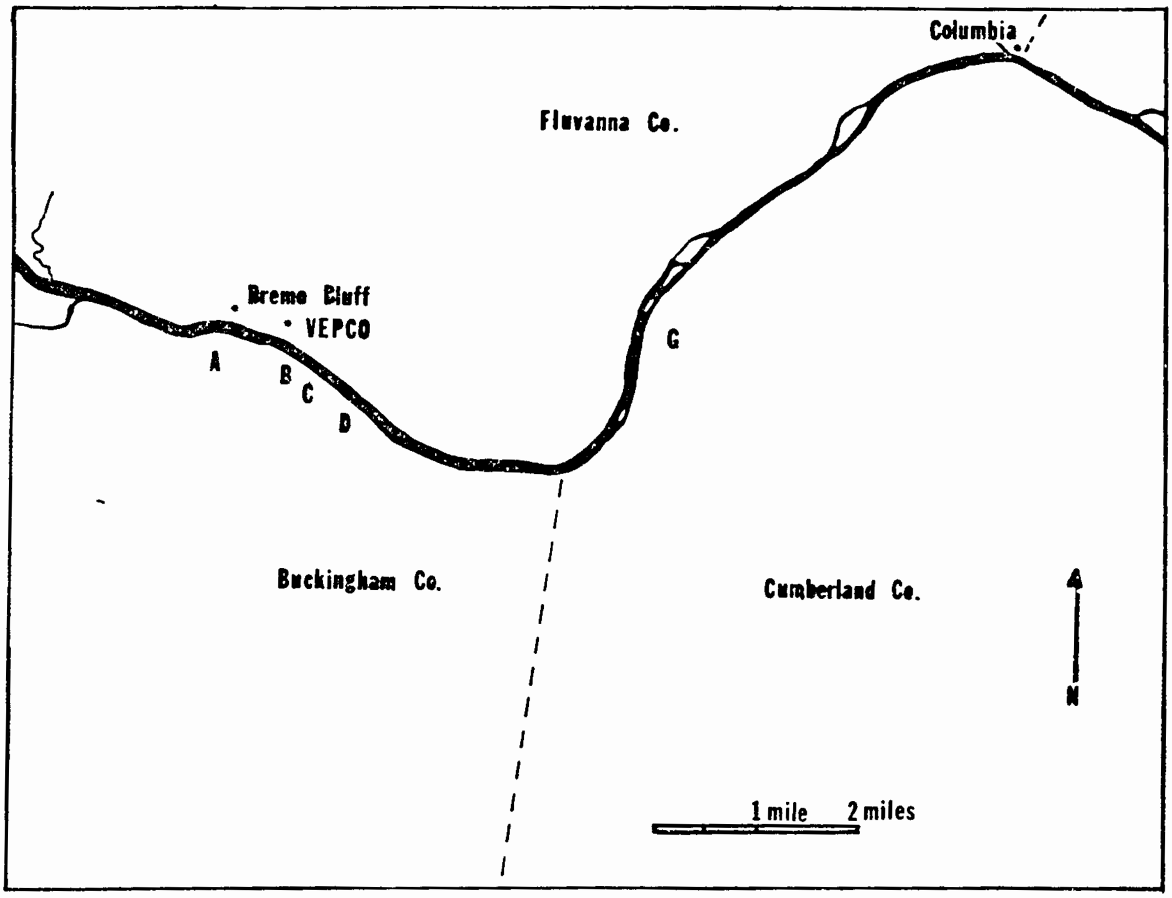
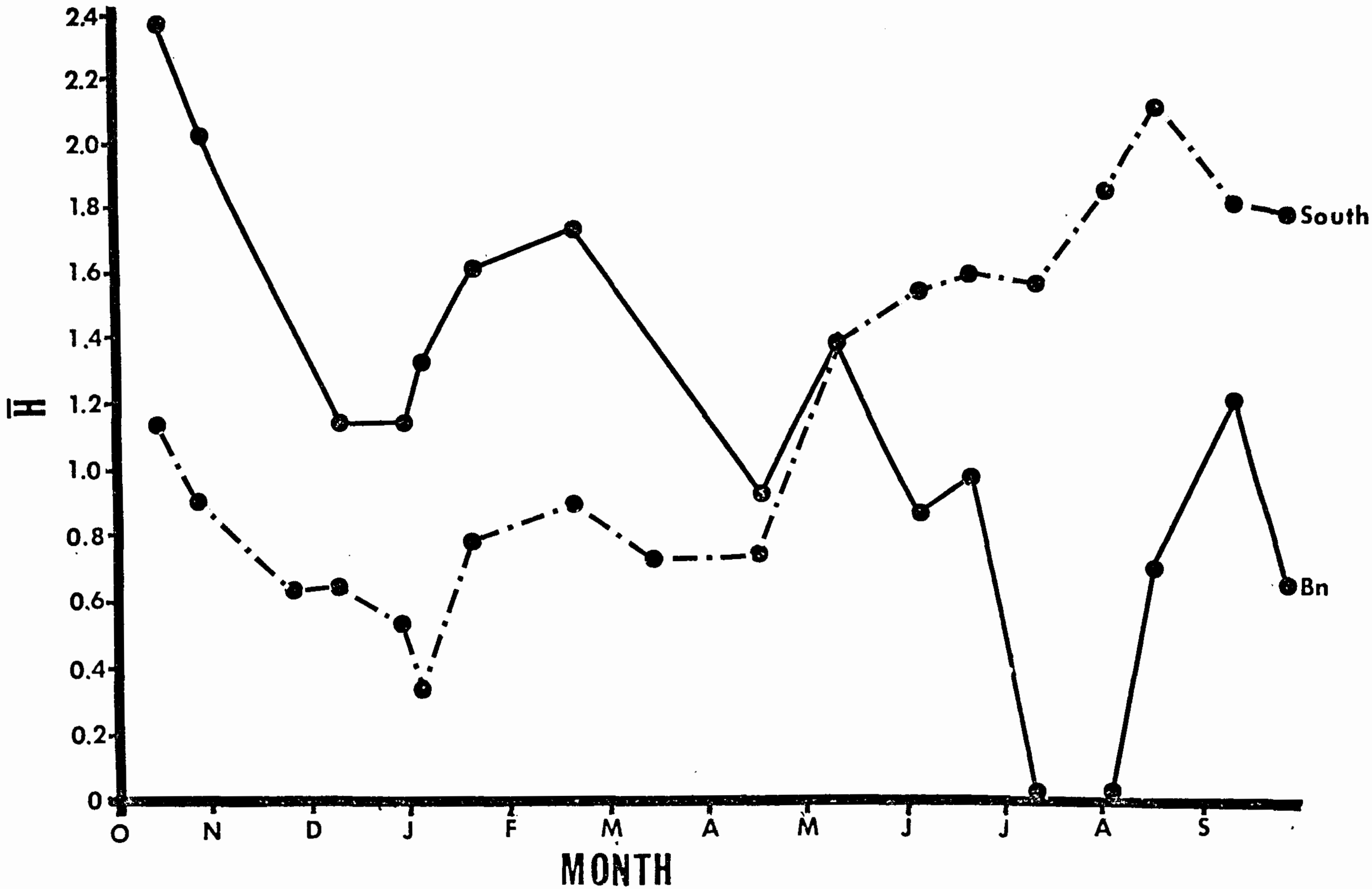

Columbia
Fluvanna Co.
Breme Bluff
VEPCO
A
B
C
D
G
Buckingham Co.
Cumberland Co.
N
1 mile
2 miles

Figure 2. Bremo Power Station at Bremo Bluff, Virginia. Cooling water intake is at left; outfall is at far right.

Figure 3. Direct current electrofishing (220 V, 1-3 amps) on the James River near Bremo Bluff, Virginia. Dipnet at bow is anode; cathodes hang from the boat.

Figure 4. The Shannon-Wiener index ($\overline{H}$) at Bn and the mean $\overline{H}$ from the combined south side stations for collections each month, October 1972 - September 1973, in the James River study area.



2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
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O
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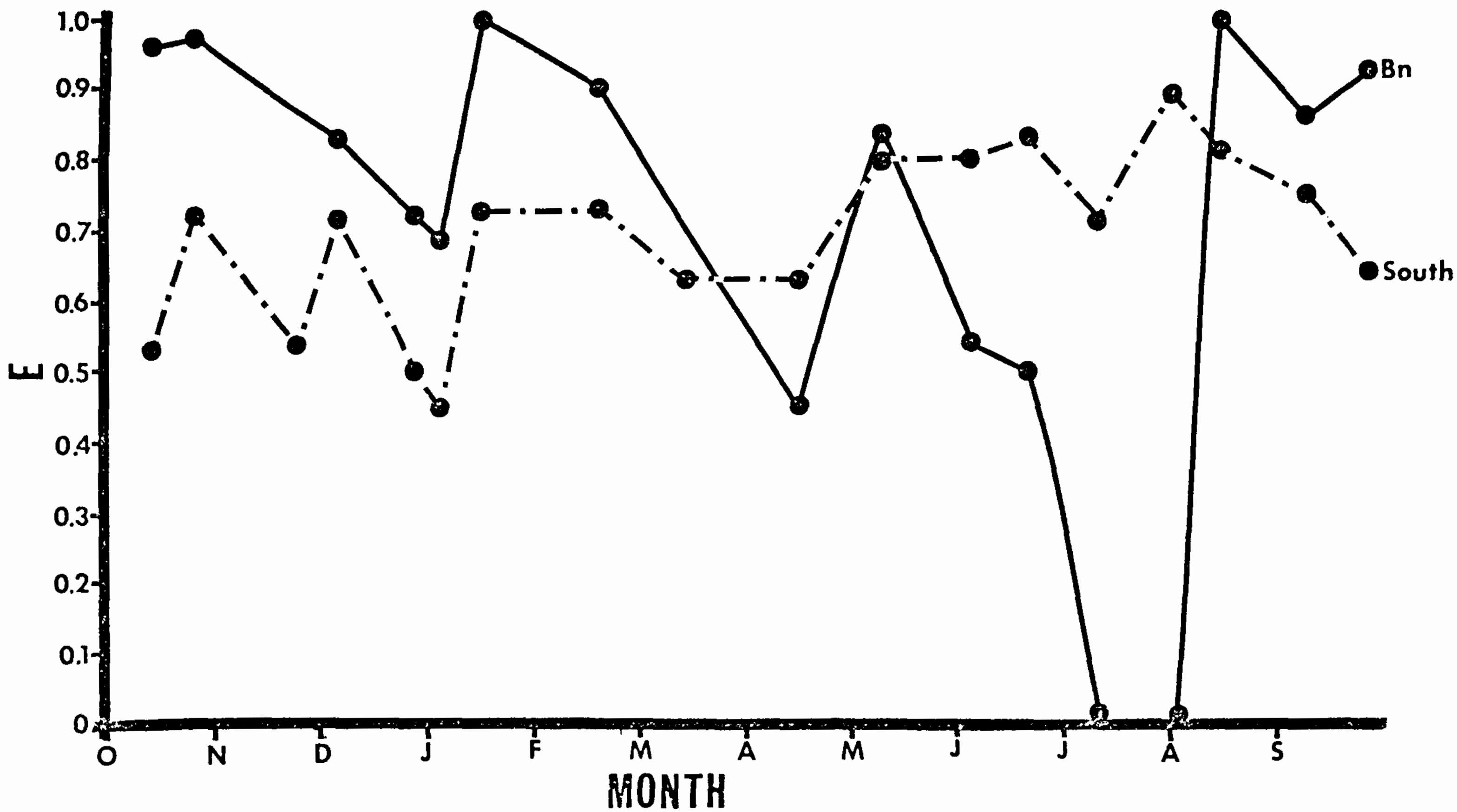
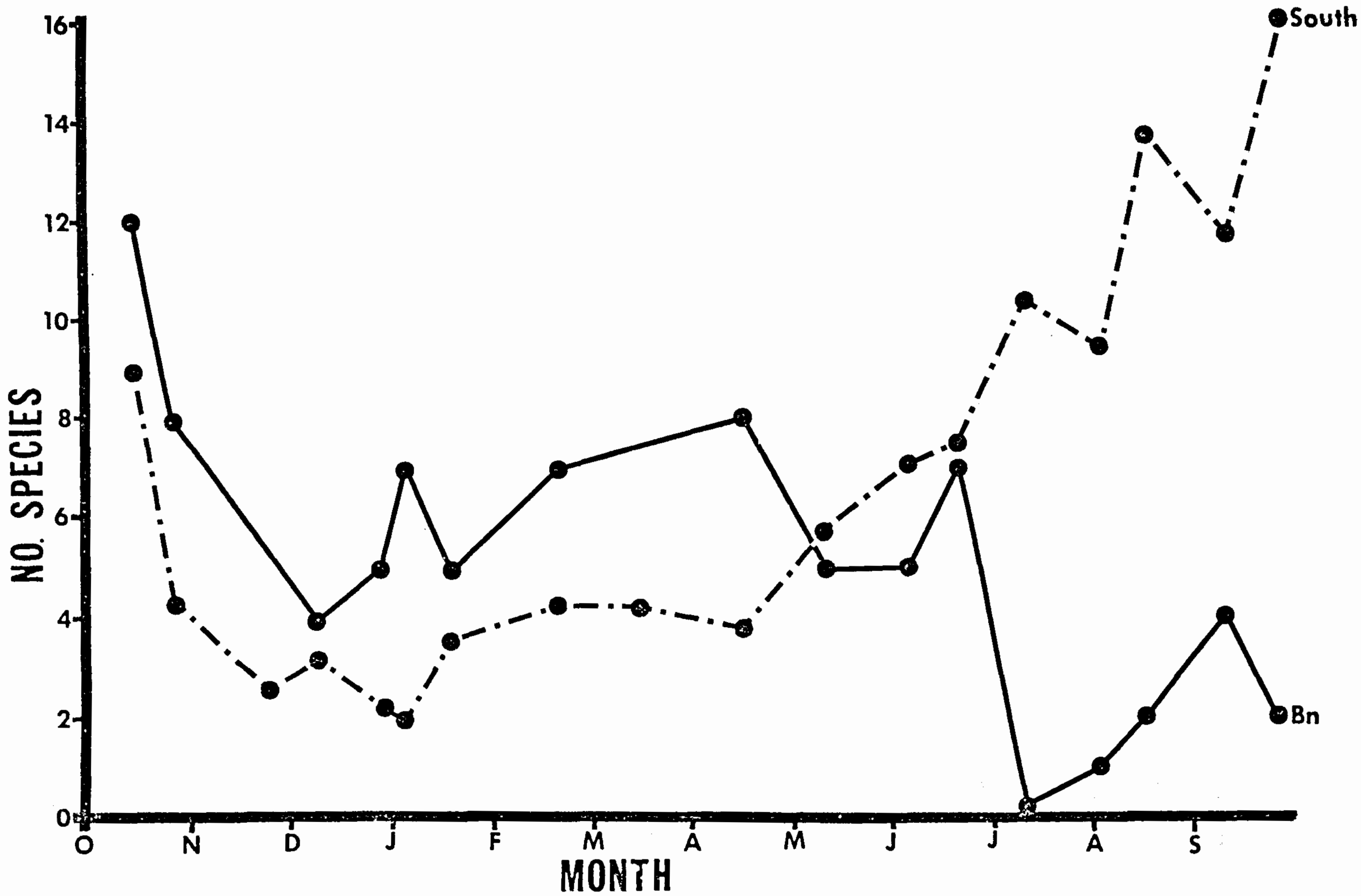
MONTH
South
Bn

Figure 5. The evenness index (E) at Bn and the mean E from the combined south side stations for collections each month, October 1972 - September 1973, in the James River study area.



E
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
O
N
D
J
F
M
A
M
J
J
A
S
MONTH
Bn
South

Figure 6. The number of species at Bn and the mean number of species from the combined south side stations for collections each month, October 1972 - September 1973, in the James River study area.



South
Bn
NO. SPECIES
MONTH
16
14
12
10
8
6
4
2
0
O
N
D
J
F
M
A
M
J
J
A
S

Vita

Judson Wayne White was born on April 29, 1950 in Richmond, Virginia where he attended public elementary school and high school. He received a Bachelor of Science degree from the University of Richmond in June, 1972 with a major in Biology. After graduation he began graduate study at the University of Richmond where he was initiated into the Beta Beta Beta Honorary Biological Society. While fulfilling the graduate program requirements he worked part-time at the Virginia Institute for Scientific Research on a thermal pollution study. He completed the requirements for the Master of Science degree from the University of Richmond in May, 1974.