 0030-0950/79/0002-0084$2.00/0

ECOLOGICAL ANALYSIS OF THE FISH DISTRIBUTION IN GREEN CREEK, A SPRING-FED STREAM IN NORTHERN OHIO[1]

JAY E. SWAIDNER and TIM M. BERRA, Department of Zoology, The Ohio State University, Mansfield, OH 44906

Abstract. The distribution of fishes in Green Creek, a spring-fed tributary of Sandusky Bay in northern Ohio, was studied from June 1976 through June 1977. A total of 31 species representing 22 genera and 10 families was taken at 8 stations along the length of the creek. Two cold water springs interrupt the longitudinal succession of fishes and cause the stream to be divided into 4 divisions, each with its own ecological characteristics and fauna: I. Upland warm water tributaries with *Catostomous commersoni* and cyprinids dominant. II. Cold water trout stream produced by stocking *Salmo gairdneri* near the spring; *Cottus bairdi* is an abundant native species in this division. III. Marl substrate of low gradient with *Catostomous commersoni*, cyprinids, darters, and *Cottus bairdi*. IV. Estuary of Lake Erie with typical lake fishes. The stations with the highest macroinvertebrate biomass also had the highest fish biomass. Various physical and chemical measurements were made, and it was determined that the marl deposits of the springs were not conducive to fish productivity. The distribution of fishes in Green Creek does not follow the classical pattern of longitudinal zonation but is determined by the unusual physical and chemical parameters induced by the springs.

OHIO J. SCI. 79(2): 84, 1979

Green Creek is an unusual, spring-fed stream in Seneca and Sandusky Counties in northern Ohio. Its first and second order, upground tributaries are supplemented by a large volume of cold water from two calcareous, sulfur springs. The fishes of the creek were studied from June 1976 through June 1977 to determine the effect of these springs on distribution, abundance, and fish community structure.

Horton (1945) devised an ordinal system of stream hierarchy. First order streams have no tributaries, but when two first order streams meet they form a second order stream. Two second order streams join to form a third order stream and so on. The order of a stream is not increased by the entrance of another stream of lower order. These stream orders often correlate with the physical changes mentioned previously which occur along a stream. The use of Horton's (1945) stream order designations objectively standardizes stream descriptions without resort to the many variables of individual streams. Recent studies (Kuehne 1962, Harrel *et al* 1967, Sheldon 1968, Harrel and Dorris 1968, Hynes 1970, Whiteside and McNath 1972, Jenkins and Freeman 1972, Cashner and Brown 1977) have clearly demonstrated that diversity increased as stream order increased and the number of individuals may decrease while biomass remains the same or increases. This can be attributed to an increase in available habitat and a decrease in environmental fluctuation (Harrel *et al* 1967, Harrel and Dorris 1968, Whiteside and McNath 1972). A general trend of many of these studies was the addition of species with increasing stream order rather than the replacement of species (Shelford 1911, Harrel *et al* 1967, Sheldon 1968, Whiteside and McNath 1972, Jenkins and Freeman 1972).

Green Creek is a third order stream of the Sandusky River drainage (fig. 1). It

[1]Manuscript received 11 May 1978 and in revised form 18 October 1978 (#78-26).

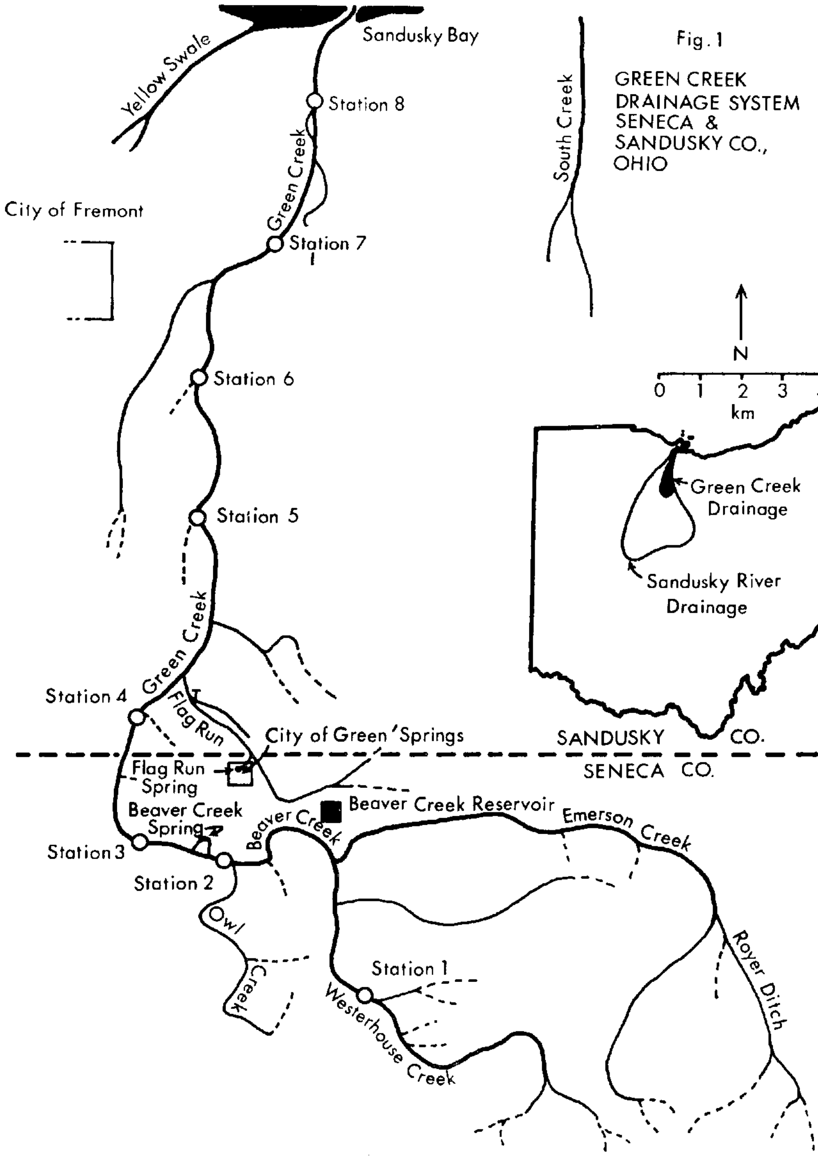

FIGURE 1. Green Creek drainage system Seneca and Sandusky Co., Ohio.

joins the Sandusky River in the southwest corner of Sandusky Bay at an elevation of 175 m (Ohio Dept. of Natural Resources, Div. of Water 1960). It drains a total of 215 km^2, has a total length of 133 km, and has an average volume of flow at the mouth of 1574 ℓ/sec. Emerson and Westerhouse Creeks in northeastern Seneca County are the major headwater tributaries of Green Creek. The elevations at their sources are 252 m and 265 m respectively. Together they drain 114 km^2. The short 5.8 km section between the junction of Emerson and Westerhouse Creeks, elevation 222 m, and the Beaver Creek spring, elevation 208 m, is called Beaver Creek (United States Geological Survey 1974). The remainder of the stream is named Green Creek. This system has an average gradient of 1.3 m/km from the source to the mouth.

There is no industrial discharge into Green Creek. The city of Green Springs, population 1340, is the major source of discharge. The city releases an average of 11 ℓ/sec of water into the stream of which only 3.7 ℓ/sec is treated sewage (United States Geological Survey 1974). The underlying bedrock of the area is Silurian dolomite. Some dolomites of the Tymochtee formation and Silurian group issue a large number of springs charged with H_2S and mineral salts. Monroe series dolomites are of high purity, 94.0–99.5% calcium-magnesium carbonates. Our study will indicate how the presence of a natural feature, a cold water spring, disrupts the well known pattern of longitudinal zonation of fish species.

TABLE 1

*Physical Description of Each Station on Green Creek System.**

Sta. No.	Trans-parency (cm)	Width (m)	Dominant Substrate	Mean Depth (cm)	Max. Depth (cm)	Min. Flow (ℓ/sec)	Max. Flow (ℓ/sec)	Undercut %	Shade %	Riffle %	Pool %	Gradient (m/km)
1	30	3	sand	40	80	0	290	50	50	1	99	2.27
2	36	5	sand	50	125	0	950	20	50	5	95	2.40
3	100	6	rock and clay	50	200	220	1150	80	90	20	80	2.37
4	74	6	gravel and clay	50	125	320	1230	40	50	20	80	1.50
5	63	7	clay	70	200	590	1530	10	90	5	95	1.20
6	41	8	clay	50	150	590	1800	5	90	10	90	1.20
7	28	7	clay	60	120	600	1850	1	95	5	95	1.20
8	—	15	mud	150	300	—	—	70	80	0	100	0.00

*Yearly average of all data; consult Swaidner (1977) for seasonal data.

METHODS AND MATERIALS

From June 1976 through June 1977 Stations 1 through 6 were sampled every 2 to 3 weeks during ice free months. These 6 regularly tested stations, plus occasional Stations 7 and 8, were selected on the basis of accessibility, equal distribution along the stream, and suitability for seining (Fig. 1). Station 3 was chosen because of the stocking of trout at this point, while Station 8 was picked because of its estuary level.

Fish were sampled with a 1.22 m x 3.05 m nylon seine with 5 mm ace mesh. Sampling was limited to 30 minutes per station. Station 7 was sampled only 8 times while Stations 1–6 were sampled 16 times each. A 30.48 m experimental gill net (mesh 1 cm to 10 cm) was used at Station 8 in April and May. The gill net was checked after each of two 45 minute periods in the evening. All fish specimens were preserved in a 10% formalin solution. Samples were rinsed after 1 week, sorted, [identified according to Trautman (1957)] labeled, and stored in 40% isopropyl alcohol. Species from each collection were counted; total weights and minimum and maximum weights and lengths were recorded. Specimens have been deposited in the Ohio State University Museum of Zoology, Columbus, Ohio.

Macro-invertebrates were quantitatively sampled 7 times at each station using a Surber sampler that covered a 929 cm^2 area. Insects were preserved in 40% isopropyl alcohol, identified, at least to family, and then counted and weighed.

A physical description of each station is presented in Table 1. Relative levels of the stream were measured by a calibrated line hung from the bridges to the surfaces of the water. When depth of water permitted, secchi disc readings were taken from bridges. Air and water temperature and dissolved oxygen content were measured by a Precision Scientific Galvanic Cell Oxygen and Temperature Analyzer. The velocity of the stream was measured by timing a float for 5 m. Then the rate of flow was calculated by using the formula: Rate = Width x Depth x the constant .9 x Length divided by the Time (Needham and Needham 1962).

Total alkalinity was measured by the methyl orange indicator method and free CO_2 was measured by the Phenolphthalein indicator solution (American Public Health Association 1971). H_2S was measured with a Hach Kit HS-7. The following chemical tests were done at the Heidleberg College Sandusky River Laboratory. pH was measured by an Orion Model 710 digital pH meter standardized at 7.0 and 9.18 for temperature compensation. All samples were tested at 25°C and conductivity in micromhos/cm was measured by a Barnsted conductivity meter (American Public Health Association 1971). Suspended solids and metals were measured and details of results may be found in Swaidner (1977). The fish species diversity at each station was determined by means of the Shannon-Weaver formula:

$$\bar{H} = \frac{C}{N} (N \log_{10} N - \Sigma N_i \log_{10} N_i)$$

where C=3.321928, N=total number of individuals, and N_i=total number of individuals in i_{th} species (Shannon and Weaver 1949, Lloyd *et al* 1968).

RESULTS

The results of the chemical analysis clearly showed the effect of the springs on the stream (Table 2). The geometric pH

TABLE 2

Minimum, Maximum and Yearly Mean pH, Conductivity, Dissolved Oxygen and Temperature at each Station.

Station		pH	Conductiv. (mhos/cm)	Dissolved O_2 (mg/ℓ)	Temp. (°C)
	Min.	7.47	301	2.5	0.2
1	Max.	8.58	1157	15.5	22.0
	Mean	8.07	664	9.02	12.9
	Min.	7.70	442	6.9	0.2
2	Max.	8.34	1157	16.7	22.0
	Mean	8.11	718	9.81	12.9
	Min.	7.68	680	6.9	6.5
3	Max.	8.05	2694	14.0	15.5
	Mean	7.86	2127	10.52	11.6
	Min.	7.77	707	8.8	0.2
4	Max.	8.14	2640	13.5	18.5
	Mean	7.96	2023	11.15	11.9
	Min.	7.80	814	8.1	0.3
5	Max.	8.17	2594	11.5	18.7
	Mean	8.04	2044	9.93	11.5
	Min.	7.79	759	7.2	0.1
6	Max.	8.19	2600	11.7	19.5
	Mean	8.09	2000	9.56	11.9
	Min.	8.06	1154	6.7	0.1
7	Max.	8.12	2390	12.0	18.0
	Mean	8.13	1927	9.44	11.9

average dropped from an annual mean of 8.09 at Stations 1 and 2 to 7.86 at Station 3. From Stations 4 through 7, it gradually returned to a yearly geometric mean of 8.13. A high free CO_2 concentration of 14 mg/ℓ corresponded to the low pH values at Station 3. Free CO_2 gradually dropped at 2.0 mg/ℓ at Station 6 as the pH rose. Alkalinity varied very little with a maximum mean of 285 mg/ℓ at Station 1 to a low mean of 250 mg/ℓ at Station 4 (Swaidner 1977).

The conductivity at Stations 1 and 2 had a yearly mean of 692 micromhos/cm. Conductivity was extremely high at Station 3 as a result of the spring water charged with $CaCO_2$ (Table 2). The conductivity gradually decreased from a yearly mean of 2127 micromhos/cm at Station 3 to a mean of 1927 at Station 7. The effect of dilution by ground water from Emerson and Westerhouse Creeks was obvious during the high water levels. Conductivity dropped to a low reading of 680 micromhos/cm at Station 3.

Dissolved oxygen was fairly consistent over the length of the stream ranging from a yearly mean of 9.0 mg/ℓ at Station 1 to 11.2 at Station 4 (Table 2). Stations 3 and 4 had higher concentrations than Stations 1 and 2 because of lower water temperatures and higher saturation points. The low water levels and high transparencies helped to produce high dissolved oxygen concentrations through photosynthesis by algae at Stations 1 and 2. Supersaturated dissolved oxygen readings were recorded at high temperatures and low flow periods at Stations 1 and 2. The dissolved oxygen during the winter months remained relatively constant even with heavy snow and ice cover (Swaidner 1977).

Hydrogen sulfide concentrations were too low to be detected at any of the stations. Turbulence due to currents tend to diffuse and eliminate H_2S gas (Reid 1962). H_2S at the Beaver Creek Spring was 3.2 mg/ℓ. At the Flag Run Spring it was in excess of 5.0 mg/ℓ and 2 km downstream on Flag Run it was 2.0 mg/ℓ (Fig. 1).

The mean yearly water temperatures ranged from 12.9°C at Station 1 to 11.5°C at Station 5 (Table 2). The temperature extremes at Station 1 and 2 varied 21.8°C, while at Station 3 there was only a 9.0°C variance. The water never froze at Station 3 even in the long periods of the extremely cold winter weather of 1977. Ice cover was very thick at the other stations, up to 60 cm at Station 2 and 40 cm at Station 6. Snow cover ranged from 10 cm to 1 m drifts for most of December and January. The water temperatures at Stations 4 to 7 remained below 15°C for 8 months.

Suspended solids data indicated that

the water was most transparent at Station 3. During high flow periods, the ground run-off above the spring created high readings along the whole stream. In the fall and winter the suspended solids at Stations 4 to 7 were uniform and lower than average while the transparencies were higher than average. As the water warmed in the spring, the suspended solids increased progressively from Station 3 to 7. The level of water did not vary extremely during the year and the minimum and maximum levels at all stations occurred only one month apart in April and May. In general, high water levels correlated with low transparency and high suspended solids (table 1).

Macro-invertebrates. Qualitative macro-invertebrate samples made by dipnet showed 13 genera or families of macro-invertebrates present at Stations 1 and/or 2 that were not collected at Station 3. There were 7 macro-invertebrates found at Station 3 that were not found at either Station 1 or 2. The number of types of macro-invertebrates steadily declined from Stations 3 to 7. The quantitative results of the Surber sampler showed a decrease in biomass and numbers of macro-invertebrates per 929 cm^2 from Stations 3 to 7 (Table 3).

Stations 1 and 2 had similar macro-invertebrate compositions. Each of the following stations seemed to have their own peculiar fauna. The most abundant family in terms of biomass was heptageniid mayflies. At Stations 3 and 5 hydropsychid caddis flies had the greatest biomass. A large *Hexagenia* sp. mayfly population was noticed at Station 5 in slow pools with soft bottoms although these did not show up in the Surber results. At Station 4 tipulids accounted for the greatest biomass although hydropsychids were very common. Chironomids made up the majority of the biomass at Stations 6 and 7.

Fish. The fish fauna is represented by 10 families, 22 genera, and 31 species. Station 6 had the most species, while Stations 1 and 7 had the fewest (Table 4). Size range of fishes taken at each station can be found in Swaidner (1977). The fish fauna data included Stations 7 and 8, which were occasionally sampled. This should be kept in mind when reviewing the results of these 2 stations compared to Stations 1 through 6. The $\overline{H}$ values for species diversity at each station are given in Table 4. $\overline{H}$ values near one indicate few species having many individuals, while higher values indicate many species having few individuals.

DISCUSSION

The distribution of fishes (Table 4) and the ecological reasons for their distribution can best be discussed by dividing the Green Creek system into 4 divisions. Each division has its own environmental relationships.

Division I (Stations 1 and 2). These stations have very similar chemical and physical characteristics and are comparable to other upland tributaries of the Sandusky River Basin. The sand and mud bottom interspersed with rocky riffles and warm, turbid water are the major factors controlling the species present. The large cyprinid and catostomid populations are typical of tributary streams with these characteristics (Kuehne 1962, Sheldon 1968, Carlander

TABLE 3
Results of Surber Samples of Macro-invertebrates.

	1	2	3	4	5	6	7
Biomass (g)*	0.30	0.41	1.41	1.00	0.13	0.04	0.02
No. Specimens*	29.8	35.2	81.0	61.0	13.5	10.2	5.8
No. families	11	9	10	10	10	10	6

*Sample size=929 cm^2. Average biomass and numbers of macro-inverterbrates taken in 7 samples at each of 7 stations.

TABLE 4

Species of fishes taken from the Green Creek System (June 1976–June 1977).

Species	Station 1	2	3	4	5	6	7	8
Dorosoma cepedianum	—	—	—	—	—	—	—	35/12307
Salmo gairdneri	—	—	944/10348*	5/195	—	—	—	—
Esox lucius	—	—	—	—	2/1114	—	—	—
Catostomus commersoni	1012/3095	665/4008	11/171	330/3825	348/841	141/785	20/102	—
Hypentelium nigricans	—	—	—	—	—	5/446	—	—
Minytrema melanops	—	—	—	—	—	—	1/3	—
Campostoma anomalum	720/861	368/460	71/254	137/429	30/39	11/29	—	—
Carassius auratus	—	1/20	—	—	—	—	—	1/343
Cyprinus carpio	—	10/12180	1/812	2/2	—	—	—	—
Ericymba buccata	—	14/31	—	1/3	—	—	—	—
Notropis atherinoides	—	—	—	1/1	1/1	—	99/176	39/39
Notropis chrysocephalus	439/520	1022/1975	51/216	42/269	54/293	10/45	—	—
Notropis hudsonius	—	—	—	—	—	—	—	22/364
Notropis spilopterus	—	—	—	—	—	—	5/20	5/4
Pimephales notatus	454/549	2066/1689	—	14/26	7/5	1/5	—	—
Pimephales promelas	126/247	633/530	8/13	3/3	7/17	1/2	1/2	—
Rhinichthys atratulus	34/40	171/222	260/476	417/977	94/90	10/63	—	—
Semotilus atromaculatus	545/1827	282/1588	41/281	191/1120	159/210	34/371	—	—
Ictalurus melas	1/13	17/1598	1/7	—	3/585	1/144	—	1/33
Morone crysops	—	—	—	—	—	—	—	1/381
Lepomis cyanellus	32/60	18/69	1/11	12/28	6/108	3/68	1/16	—
Lepomis gibbosus	—	—	—	—	—	1/55	—	—
Lepomis macrochirus	—	—	—	—	—	1/7	—	—
Pomoxis annularis	—	—	1/123	—	—	—	—	8/1707
Etheostoma blennioides	—	—	—	22/24	36/30	88/246	10/31	—
Etheostoma caeruleum	—	—	2/2	170/219	118/74	20/57	7/21	—
Etheostoma nigrum	534/526	546/292	2/4	384/412	124/101	50/65	7/7	—
Perca flavescens	—	—	—	—	—	—	—	1/60
Percina caprodes	—	—	—	—	—	10/117	14/127	—
Percina maculata	5/16	4/2	—	6/10	10/11	3/4	—	—
Cottus bairdi	—	—	424/1177	396/813	59/148	29/191	3/12	—
Total No. specimens	3902	5816	1818	2133	1060	419	168	118
Total Biomass	7754	24624	13895	8356	3667	2700	517	16853
Total No. Species	11	13	14	17	16	18	11	10
Species Diversity ($\bar{H}$)	2.75	2.71	1.96	2.98	2.99	2.94	2.12	—

*Total number over total biomass (g) at each station.

1969). *Semotilus atromaculatus* and *Campostoma anomalum* showed similar distributions as found by Kuehne (1962) in an Eastern Kentucky creek. Low flow and a virtual lack of predators, i.e. *Micropterus*, is conducive to the use of this area as a nursery by the large catostomid and cyprinid populations. Species diversity ($\bar{H}$) at Station 1 was 2.75 and at Station 2 was 2.71. The values and the number of species are lower than Stations 4 through 6 which fits the classical pattern of longitudinal zonation already discussed.

Division II (Station 3). This section of the stream has 2 special factors controlling the habitat and thereby the fauna. The large continuous flow from the Beaver Creek Spring controls temperature, transparency, and the chemistry of the water and the stocking program carried on by the Ohio Division of Wildlife introduced a species of fish that affects the fish fauna.

The Ohio Division of Wildlife has stocked rainbow trout (*Salmo gairdneri*) at an average rate of 5000 fingerlings per year since 1955. In 1977, 5000 rainbow trout were shipped from the federal hatchery in White Sulfur Springs, West Virginia on 29 March. Thirty-three kilograms of rainbow trout at a ratio of

152 fish/kg (6.6 g/fingerling) were stocked the same evening. Brown trout (*Salmo trutta*) have also been stocked several times. The last stocking was in the fall of 1974, when 2500 brown trout, 16 cm average total length, were released. No brown trout were taken in this study.

Salmo gairdneri and *Cottus bairdi* are the overwhelmingly dominant species at Station 3. These 2 species are common inhabitants of cold, clear trout streams of North America (Moyle 1977). Consistantly low temperatures throughout the year, sufficient gradient, substrate type, and an abundance of food items are some of the major natural factors that control the distribution of these fishes (Scott and Crossman 1973, Trautman 1957). The species diversity at Station 3 was 1.96 and was the lowest $\bar{H}$ value for any station. This is at variance with the usual trend for increased species diversity with increasing distance from the headwaters discussed in the introduction. Kuehne (1962) pointed out that spring-fed streams may not fit Horton's (1945) system of stream classification, nor the classical pattern of longitudinal zonation. Stauffer *et al* (1975) showed that species diversity increased at a stream section located in the heated discharge of an electric power plant. Our data show the related but opposite effect of a decrease of species diversity at a cold water spring along a warm water stream.

The introduction of 5000 trout each year at Station 3 undoubtedly effected the low $\bar{H}$ value. Predation by trout on other species of fish was not supported by a food habits study but Dineen (1951) reported that cottids accounted for a major food item for trout. This does not preclude the possibility of competition for other food sources and space.

The unusual chemical conditions did not seem to negatively influence the fish population. For example, H_2S could be smelt but was not measured. The high calcium content of the water may enhance the habitat for trout at Station 3, in that calcareous water tends to produce larger trout (Coker 1954). Dilution by ground water from the spring may reduce the fertility of water at Station 3 and might be considered a reason for the decrease in herbivores, such as the catostomoids and cyprinids which were so abundant above the spring (Coker 1954).

Division III (Stations 4-7). This area has an obvious pattern of decreasing total numbers and biomass as one goes downstream (Table 4). Macro-invertebrates showed the same pattern (Table 3). The $\bar{H}$ values, as given in Table 4, are misleading, but expected, when compared to the large number of species and few individuals collected at these stations (Table 4). As shown by the biomass data in Table 4, these values do not indicate a productive habitat with a large standing crop which an increased $\bar{H}$ usually shows. This division had the most species collected, but total numbers and biomass decreased rather than increased. Two factors, one chemical and one physical, are at work creating this situation.

Chemically the water from both springs is charged with $CaCO_3$ as it flows up through dolomitic limestone. This water which has been under pressure has a high CO_2 content and low pH. As this very hard water flows out of the ground and downstream, CO_2 is lost to the atmosphere because of reduction in pressure, agitation, and through the photosynthetic activity of aquatic plants thus the pH soon begins to rise. With the loss of CO_2, calcium carbonate precipitates out of solution. This $CaCO_3$ is usually deposited on algae and mosses (Minckley 1963, Hynes 1970). The lack of algae at Stations 6 and 7 allows the $CaCO_3$ to deposit on any object in the stream. At Station 4 the *Fissiden* sp. moss was a main site for deposition as described by Minckley (1963).

A laminated effect is produced by alternate periods of deposition and siltation. Deposition occurs only at temperatures above 14°C (Hynes 1970). During the warm water temperatures of spring and summer, the turbidity at Stations 5, 6 and 7 was caused by insoluble carbonate or "precipitating chalk" as described by Coker (1954). The water was very clear at these stations during the cold water periods of fall and winter.

Deposition is at a minimum at Station

3 because of the low temperatures and low pH while Station 4 had considerable deposition. Due to the addition of more spring water from the Flag Run Spring, the average temperatures dropped slightly at Station 5. The Flag Run Spring does not have the noticeable effect on the stream that the Beaver Creek Spring has. The addition of more spring water delays both the reduction of conductivity and the increase in water temperature. Stations 6 and 7 had the heaviest deposits of $CaCO_3$.

Physically, these carbonate deposits, which are sometimes referred to as marl or travertine, are a very harsh substrate. The only alternative substrate at the lower Stations of 6 and 7 is clay. Both clay and marl have been cited as a detriment to reproduction and distribution of aquatic invertebrates and fishes (Hynes 1970, Minckley 1963). Sheldon (1968) concluded that the structural features of the habitat tend to control the distribution and density of fish.

The upstream portion of Division III, represented by Station 4, had remnant characteristics extending from the cold water spring at Station 3. Although trout were taken at Station 4 on three separate occasions, it could not be considered a trout stream as could Station 3. The species of fishes dominant in this division were similar to Division I. Catostomids, cyprinids, and percids were joined by the cottids and additional darters. Stations 6 and 7 have several species that are characteristic of larger streams (i.e. logperch, northern hog sucker, and spotted sucker). Emerald shiners and spotfin shiners indicate the influence of Lake Erie on the lower reaches of the stream. Some of these species are seasonal inhabitants, and use Green Creek as a spawning ground.

Division IV (Station 8). This division corresponds to what Hesse *et al* (1951) called the carp region. Since this area was included only for background information, little work was done at this estuary level. The fishes collected here are typical of Lake Erie and Sandusky Bay as noted by Trautman (1975).

Acknowledgments. This paper is based, in part, on a M.S. thesis submitted by the first author to the Graduate School of Ohio State University. We would like to thank Dr. David Baker and the Heidelberg College Sandusky River Laboratory for their help with water quality analysis. Special thanks go to Ray-Jean Au for help with seining in the very cold water. Beverly Swaidner typed a rough draft of the manuscript, and Yolanda Allen typed the final draft. Drs. Charles Herdendorf and Bud Griswold critically appraised the material and contributed many helpful suggestions. Dr. Clyde D. Barbour and an anonymous reviewer made many improvements in the content and readability of this paper.

LITERATURE CITED

American Public Health Assoc. 1971 Standard Methods for the Examination of Water and Wastewater. 13th ed. New York. 874 pp.

Carlander, K. D. 1969 Handbook of Freshwater Fishery Biology Vol. 1. Iowa State Univ. Press, Ames. 752 pp.

Cashner, R. C. and J. D. Brown 1977 Longitudinal distribution of fishes of the Buffalo River in Northwestern Arkansas. Tulane Studies Zool. Bot. 19: 37–46.

Coker, R. E 1954 Streams, Lake, Ponds. Univ. N. Carolina Press, Chapel Hill. 327 pp.

Dineen, C. F. 1951 A comparative study of the food habits of the *Cottus bairdi* and associated species of *Salmonidae.* Amer. Midl. Natl. 84: 226–236.

Harrel, R. C., B. J. Davis, and T. C. Dorris 1967 Stream order and species diversity of fishes in an intermittent Oklahoma stream. Amer. Midl. Natl. 78: 428–436.

——— and T. C. Dorris 1968 Stream order, morphometry, physico-chemical conditions and community structure of benthis macroinvertebrates in an intermittent stream system. Amer. Midl. Natl. 80: 220–251.

Hesse, R., W. C. Allee, and K. P. Schmidt 1951 Ecological Animal Geography. John Wiley and Sons, New York. 715 pp.

Horton, R. E. 1945 Erosinal development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Bull. Geol. Soc. Amer. 56: 275–370.

Hynes, H. B. N 1970 The Ecology of Running Waters. Univ. of Toronto Press. 555 pp.

Jenkins, R. E. and C. A. Freeman 1972 Longitudinal distribution and habitat of the fishes of Mason Creek, an Upper Roanoke River drainage tributary, Virginia. Virginia J. Sci. 23: 194–202.

Kuehne, R. A. 1962 Classification of streams illustrated by fish distribution in an Eastern Kentucky creek. Ecology 43: 608–614.

Lloyd, M., J. H. Zar, and J. R. Karr 1968 On the calculation of information—Theoretical measures of diversity. Amer. Mid. Natl. 79: 257–272.

Minckley, W. L. 1963 The ecology of a spring Doe Run, Meade Co., Kentucky. Wildl. Monogr. 11: 1–124.

Moyle, P. B. 1977. In defense of sculpins. Fisheries 2: 20–23.

Needham, J. G. and P. R. Needham 1962 A Guide to the Study of Freshwater Biology. Holden-Day, San Francisco. 107 pp.

Ohio Department of Natural Resources Div. of Water 1960 Gazatier of Ohio Streams No. 12. Columbus. 179 pp.

Reid, G. K. 1962 The Ecology of Inland Waters and Estuaries. Reinhold Pub. Corp. New York. 375 pp.

Scott, W. B. and E. J. Crossman 1973 Freshwater Fishes of Canada. Fish. Res. Board Canada, Ottawa. 966 pp.

Shannon, C. E. and W. Weaver 1949 The Mathematical Theory of Communications. University of Illinois Press, Urbana. 117 pp.

Sheldon, A. L. 1968 Species diversity and longitudinal succession in stream fishes. Ecology 49: 193–198.

Shelford, V. E. 1911 Ecological succession I. Stream fishes and the methods of physiographic analysis. Biol. Bull. 21: 9–35.

Stauffer, J. R. Jr., C. H. Hocutt, M. T. Masnik, and J. E. Reed, Jr. 1975 The longitudinal distribution of the fishes of the East River, West Virginia-Virginia. Virginia J. Sci. 26: 121–125.

Swaidner, J. A. 1977 An Ecological Study of the Distribution of Fishes in the Green Creek System, a Spring-Fed Stream of Seneca and Sandusky Counties, Ohio. Unpubl. M.S. Thesis, Ohio State Univ., Columbus. 101 pp.

Trautman, M. 1957. The Fishes of Ohio. Ohio State Univ. Press, Columbus. 683 pp.

——— 1975 Fishes of the Sandusky River system. International Joint Comm. Proc., Sandusky River Symp. p. 233–242.

United States Geological Survey 1974 Water resource data for Ohio, part 2. Ohio Water Resource Division, Columbus 455 pp.

Whiteside, G. B. and R. M. McNath 1972 Fish species diversity in relation to stream order and physicochemical conditions in the Plum Creek drainage basin. Amer. Midl. Natl. 88: 90–101.