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THE BIOLOGICAL RECOVERY OF THE CLINCH RIVER FOLLOWING A

FLY ASH POND SPILL

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by

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INTRODUCTION

A dike surrounding a fly ash settling lagoon collapsed, dumping highly caustic water into the Clinch River killing over 200,000 fish in 90 miles of river in Virginia and Tennessee. This caustic water was produced at Appalachian Power Company's 700 megawatt steam powered generating plant on the Clinch River at Carbo, Virginia. Native coal is utilized to produce steam which is subsequently used in the production of electric power. The native coal has a high ash content resulting in the production of approximately 960 tons of fly ash daily. To efficiently remove the ash from the furnace hoppers, Clinch River water is mixed with the ash to form a slurry which is pumped to large fly ash settling lagoons. A closed system incorporating recirculation of the supernatant is used to conserve water. Recycling allows free lime (CaO) in the fly ash to react with water forming $Ca(OH)_2$. This eventually raises the pH of the recirculating water and the water in the fly-ash lagoons to extremely high pH values ranging from 12.0 to 12.7 (Anonymous, 1967b).

A Dike Failed

On June 10, 1967, a 50-75 foot section of a dike surrounding a fly ash settling lagoon collapsed. Within less than an hour 400 acre-feet (approximately 130 million gallons) of highly caustic water (pH 12.0) poured into Dump's Creek which joins with the Clinch River one half mile downstream. This slug of caustic water equalled 40% of the daily flow of the Clinch at that time and blocked the normal flow of the river for several minutes while raising the water level several feet forcing some waste upstream approximately 0.5 miles. Thus an essentially undiluted slug of highly caustic water entered the Clinch River. For the next four and one half days the highly basic slug traveled downstream at a rate of approximately 0.85 miles per hour (Anonymous, 1967b).

The exact cause of the dike failure was never determined. One possible reason given by Appalachian Power Company was that a leak developed in a recirculation pipe buried in the dike. Another possible cause was that erosion of foundation material due to the flow of Dump's Creek might have caused part of the dike to settle and collapse (Anonymous, 1967a).

Fish Kill

As the highly basic mass of water moved down the Clinch River, it killed essentially all the fish in its path (Anonymous, 1967a). During this period, 162,000 sport and rough fish were killed in 66 miles of the Clinch River in Virginia. An additional 54,600 sport and rough fish were killed in 24 river miles in Tennessee where the polluted mass was gradually diluted, dispersed, and neutralized in the river by natural physical chemical forces. As the highly caustic mass flowed downstream the lethal effects were neutralized by dilution and by the following chemical reactions:

I) $Ca(OH)_2 + Ca(HCO_3)_2 \longrightarrow 2CaCO_3 + 2H_2O$

In addition CO_2 from the atmosphere reacted with the water to form:

II) $H_2O + CO_2 \rightleftharpoons H_2CO_3$

III) $Ca(OH)_2 + H_2CO_3 \longrightarrow CaCO_3 + 2H_2O$

The lethal agent was reported to be the high pH level of the alkaline water which was composed of 90% hydroxide alkalinity and 10% carbonate alkalinity. A secondary effect of the spill which contributed to the fish kill was a depression of the dissolved oxygen concentration. This may have been caused by the decaying organic matter (Anonymous, 1967b).

Bottom Fauna Are Eliminated

Ten days after the collapse of the dike the Virginia State Water Control Board conducted a bottom fauna survey at selected stations above and below the site of the spill to assess damage to the bottom fauna fish food organisms (Anonymous, 1967a). They observed that:

1) Bottom dwelling fish food organisms appeared to have been completely eliminated for a distance of approximately 3 or 4 miles below the site of the spill (Figures 1, 2).

2) A drastic reduction in the number and kinds of bottom dwelling fish food organisms occurred in the Clinch River for 77 miles below the spill (Figures 1, 2).

3) Snails and mussels were eliminated for 11.5 miles below Carbo, Virginia.

4) The State Water Control Board, based on past experience, predicted that as far as total weight per square foot of stream bottom, the Clinch River would recover to its former productive capacity within three months after the spill.

Both the Virginia and Tennessee Game Commissions were of the consensus that the stream biological organisms would appear in sufficient number for fish restocking of the Clinch River in the fall of 1967 (Anonymous, 1967a).

The major effect of the highly caustic mass of water was to decrease drastically the diversity (number of different kinds of organisms) and the density of the bottom fauna. Station 2, located in the backwash area affected by the spill, showed a drastic reduction in the number of taxons of bottom fauna when compared to Station 1, which was upstream of all damage from the spill (Figures 1, 2). Bottom fauna organisms were completely eliminated at Station 3, located 0.3 miles below the power plant. A recovery pattern was apparent at Stations 4, 5, and 6, indicating that dilution and physical and chemical reactions had probably decreased the toxicity of the caustic mass of water as it passed these points on the river.

At the damaged stations, pollution tolerant midge larvae made up more than 60% of the total population of bottom fauna. At Station 1, which was unaffected by the spill, the midge larvae made up only 8% of the total number of benthic organisms. From Stations 10-12 this percentage decreased to less than 30% indicating a reduction in the severity of the toxic stress.

Biological Recovery Survey - 1969

During the summer and fall of 1969, a bottom fauna and fish survey of the Clinch River was conducted to study the extent of the biological recovery of the river following the 1967 fly ash spill. Particular emphasis was placed on studying the bottom fauna community above and below the spill site because:

1) They are relatively sessile organisms and cannot avoid environmental stress;

2) They have rather long and complex life histories, and therefore, their presence or absence reflects the history of the environment;

3) Since they are members of the food web in an aquatic environment, their presence or absence reflects directly on fish population structure.

4) Sampling techniques for bottom fauna are more reliable than techniques for fish;

5) More biological information can be gained from studying this group of organisms per dollar invested than any other group.

A preliminary fish survey was also conducted to determine if forage fish populations below the site of the 1967 spill were similar to upstream areas unaffected by the spill.

MATERIALS AND METHODS

From July 1, 1969 to December 1, 1969, twenty-one ecologically similar stations on the Clinch River and related tributaries were located and sampled for bottom fauna organisms (Figure 3). Four stations were located above the site of the spill to serve as control or reference stations with which downstream stations could be compared. Twelve stations were located below the spill site to assess the recovery process and to evaluate any contributing influences arising from industries, municipalities or agricultural areas. Five additional stations were established on tributaries entering the Clinch River.

Sampling sites were carefully selected to insure their uniformity since it is essential that all stations have comparable habitats if a valid comparison is to be made between stations. Comparable sampling of the bottom fauna was carried out at each station using a bottom net and a Surber square foot sampler. Extreme care was taken to see that an equal amount of effort was given to collection at each station. Each station was divided into three substations (left bank, right bank, and midchannel). Samples were taken from each substation with the bottom net and processed separately since it was observed that waste discharges often were restricted to certain areas within each station. Immediately after collection, the bottom material was passed through a series of graded sieves (Tyler mesh Nos. 4, 10, and 35) and all organisms removed and preserved in 70% ethanol.

Fish samples were collected in November 1969 using a 10' by 4' seine of ¼ inch mesh. These collections were obtained at two stations, above the spill site and at four stations below. Only shallow areas and riffles were sampled.

RESULTS AND DISCUSSION

Diversity of Bottom Fauna

Diversity values, consisting of the number of taxons or different species found at each station, were plotted on a histogram, Figure 4, and the following observation was made. A difference existed between upstream control stations and stations immediately below the spill site for a distance of approximately 22 miles. At Control Stations 1-4 the diversity of organisms varied between 48 and 54 taxons while below the spill site there was a decrease in diversity at Station 7 to 43 taxons followed by an even more dramatic decrease at Station 8 to 33 taxons. This low diversity value is followed by a linear increase in the number of different species at the next three stations until Station 11 had 46 taxons, nearly the same number as observed for the control stations. At Station 13 another decrease in taxons was noted followed by increased diversity values, equal to control station values, for the remaining downstream stations.

Density of Bottom Fauna

In Figure 5, a density graph that includes all snail and freshwater mussel species, the difference between the upstream control stations and stations below the spill site was even more pronounced. At the control stations the densities ranged between 145.2 and 24.6 organisms per square foot. In contrast, densities at Stations 8-11 varied between

2.4 and 18.8 organisms per square foot with the highest density being found at Station 11, the furthest downstream station. Station 13 also showed drastic reduction in density, which appeared to be due to a tributary that joined with the Clinch just upstream from this station.

Figure 6, another density graph which excludes snail and freshwater mussel species, showed the same difference between Control Stations 1-4 and Stations 7-11 previously mentioned. However, this graph also showed that:

1) There was a reduction in the densities at Stations 1-4 and 13-21 when compared to the same stations in Figure 4. This decrease was due to the exclusion of the snails and mussels which made up a large percentage of the populations at these stations.

2) Densities were not affected at Stations 7-11 because of the inability of the molluscs to become reestablished after the spill. This inability to recolonize and increase is probably due to longer life cycles than found for most other aquatic invertebrates, the lack of an aerial stage in their life cycles which would increase their reinvasion rates at stations below the plant, and the fact that they are not susceptible to downstream drift.

The diversities and densities found at stations immediately below the spill site indicate a recovery pattern. This pattern involves a combination of interrelated factors that include the initial amount of stream damage at each station after the spill, differing rates of recolonization by different organisms, and the presence of an environmental stress on the aquatic ecosystem. A contributing factor to the recovery pattern was Appalachian Power Company's discharge of an industrial waste above Station 7 which flowed along the right bank for some distance before mixing. Since it was restricted to the right side of the river, the effluent did not affect the overall diversity found at Station 7 but appears to have an adverse effect on the aquatic organisms at downstream stations although the effects gradually decreased due to dilution and naturally occurring chemical reactions in the water. Combined with the fact that the initial stream damage from the alkaline spill was most severe at Stations 7 and 8, a linear increase in the diversity of aquatic organisms the further downstream a station was located may be expected if recovery was not complete. However, Station 7 which had a higher number of taxons than found for Stations 8 and 9 did not follow the typical recovery pattern of a linear increase in diversity. A possible explanation for this deviation is that Station 7 would be the first station to be recolonized with organisms coming downstream and since its overall diversity was not affected by the effluent from the power plant as were Stations 8-11 where a more complicated recovery pattern existed.

Community Structure Analysis of Bottom Fauna

Community structure analyses of the bottom fauna collected at each of the sixteen sampling stations located on the Clinch River indicated that the bottom fauna community structures at stations below the spill site were similar to the control stations upstream (Table I). Interactions between the abiotic environment and biotic components result in a characteristic assemblage of organisms commonly referred to as communities. If stress (pollution) is placed on a natural biotic community, detectable changes in structure occur. Using techniques from information theory, mixed-species populations can be analysed resulting in a diversity index which characterizes the community structure. In this study diversity per individual ($\bar{d}$) was calculated for the left bank, right bank and midchannel substations for all sixteen stations on the Clinch River using the following equation:

$$\bar{d} = -\Sigma (Ni/N) \log_2 (Ni/N)$$

A complete explanation of this technique was given by Wilhm and Dorris, 1968.

Values for $\bar{d}$ exceeded 3.0 at all stations except left bank Stations 1 and 21, right bank Station 7 and midchannel Stations 17 and 20. "Clean water"areas have been found by Wilhm and Dorris, 1968 to have $\bar{d}$ values exceeding 3.0. Border line values for $\bar{d}$ such as were found at the right bank Station 7 (2.92) indicate areas of moderate pollution. Effluents from the power plant entered the Clinch River directly above Station 7 and damaged the right bank substation as indicated by the depressed diversity index ($\bar{d}$) and by the decreased diversity and density of bottom fauna at this substation. However, it appeared that the Clinch River had substantially recovered from the fly ash pond spill when the community structure of the bottom fauna was used as a criterion.

Density and Diversity of Fish

Taxonomic results for the fish collections are shown in Figures 7 and 8. Figure 7 shows the number of taxons or different fish species, made up of mostly minnows and darters, found at each station. Control Stations 1 and 2 had 19 and 17 different species respectively, while Station 7 below the spill site had 11 species. This difference indicated recovery was not complete and may be correlated with the decreased availability of fish food organisms and/or the power plant's waste discharge. Further downstream at Station 9 the number of taxons had increased to the same level as observed at the upstream control stations but a drop at Station 11 to 2 taxons was found. Field observations made at the time of collection showed a large amount of silting at Station 11 which may have caused a reduction in diversity.

Fish densities for each station, Figure 8, show the same variations as were noted for the bottom fauna where there was a reduction in density of individuals immediately below the spill site -- the density of individuals increased the further downstream the samples were taken. Combined with the results from Figure 7 this indicated there were nearly the same number of fish species below the spill site as found upstream. However, the fish did not have comparable densities to those found at the upstream control stations. Station 11 was an exception because of the previously mentioned problem of siltation.

CONCLUSIONS

From this preliminary survey, conducted in the summer and fall of 1969, involving sampling for bottom fauna and fish, the following tentative conclusions seem justified:

1) Aquatic communities of "bottom fauna" that were completely eliminated below the power plant at Station 7 had recovered to a point where the number of different kinds of organisms found at this station were approximately the same as in upstream control stations unaffected by the spill. However, the densities of individuals of these species were still less than the control stations indicating that full recovery had not occured.

2) Populations of benthic fish food organisms at Stations 8-11 showed a linear recovery pattern. Station 8 had the lowest density and number of taxons, and there was an increase in both population parameters at downstream stations.

3) Large portions of the populations at control stations and at stations 30 miles or further downstream consisted of molluscs. However, these aquatic invertebrates had not recovered at Stations 7-11 below

the site of the spill. This failure to recover was probably due to their inability to reinvade and recolonize areas below the spill site as fast as aquatic insects.

4) Community structure analyses indicated that the bottom fauna below the site of the spill were similar in structure to that of stations above the spill site and were characteristic of "clean water" situations.

5) Different species of minnows and darters apparently had recolonized stations below the plant but did not have the density levels found at the upstream control stations.

6) Two years after the spill, the Clinch River had not fully recovered. However, fish food organisms such as mayflies, stoneflies, hellgramites, and midge larvae were present at all the "spill" areas and should support a productive sport fishery.

ACKNOWLEDGMENTS

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TABLE I

DIVERSITY VALUES OBTAINED WITH THE INDEX $\bar{d}=-\Sigma(Ni/N)\log_2(Ni/N)$ FOR BOTTOM FAUNA COLLECTED AT SIXTEEN STATIONS ON THE CLINCH RIVER

Substations	Stations															
	Above Spill				Below Spill											
	1	2	3	4	7	8	9	10	11	13	15	16	17	19	20	21
Left Bank	2.97	3.65	3.75	3.79	4.21	4.35	3.76	3.29	3.61	3.81	3.95	3.85	3.67	4.19	4.19	2.98
Midchannel	3.22	3.33	3.27	3.93	3.28	3.64	2.88	3.19	4.17	3.64	3.26	3.30	2.48	3.41	2.26	3.37
Right Bank	3.32	3.86	3.94	4.03	2.92	4.06	4.01	4.06	3.87	4.01	3.86	3.31	3.79	3.54	4.03	3.27

FIGURE CAPTIONS

Fig. 1. Number of taxons found at each station for June, 1967 bottom fauna survey.

Fig. 2. Density of organisms found at each station for June, 1967 bottom fauna survey.

Fig. 3. Diagram of sampling locations on Clinch River and related tributaries.

Fig. 4. Number of taxons found at each station for 1969 bottom fauna survey.

Fig. 5. Density of organisms, including molluscs, at each station for 1969 survey.

Fig. 6. Density of organisms, excluding molluscs, at each station for 1969 survey.

Fig. 7. Number of fish taxons found at sampling stations for November, 1969 survey.

Fig. 8. Density of fish at each sampling station for November, 1969 survey.

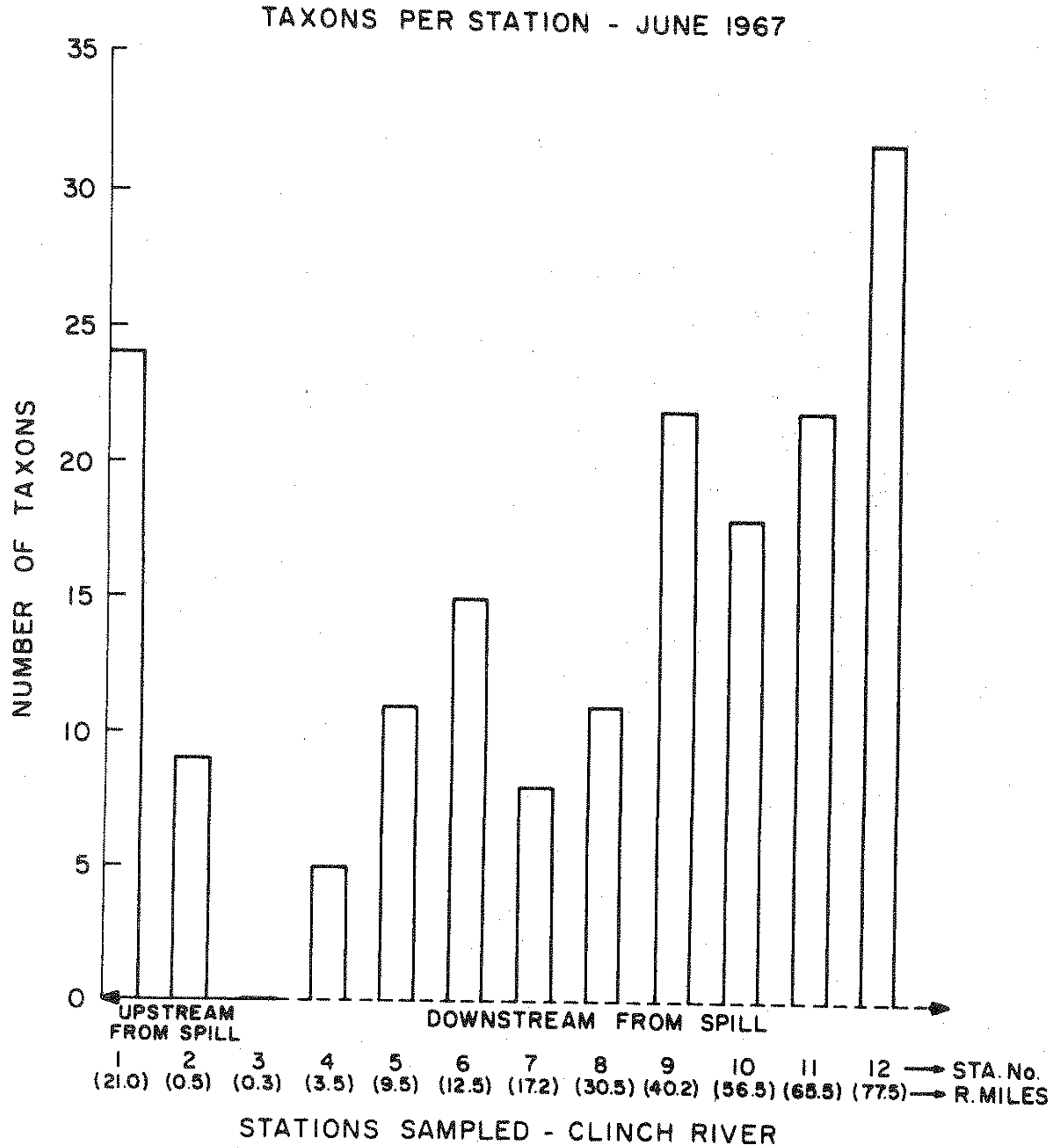

Fig. 1 Number of taxons found at each station for June, 1967 bottom fauna survey.

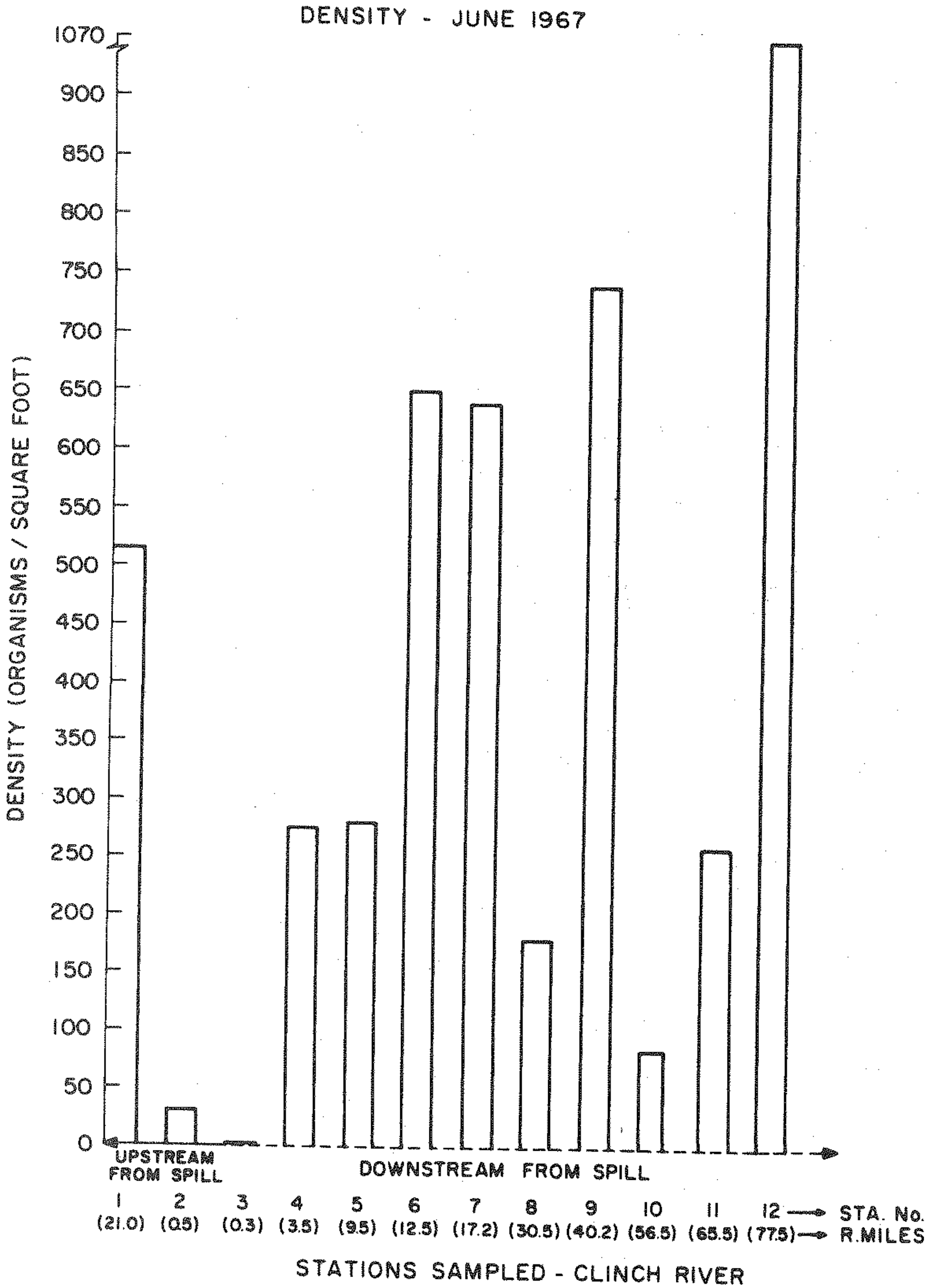

Fig. 2 Density of organisms found at each station for June, 1967 bottom fauna survey.

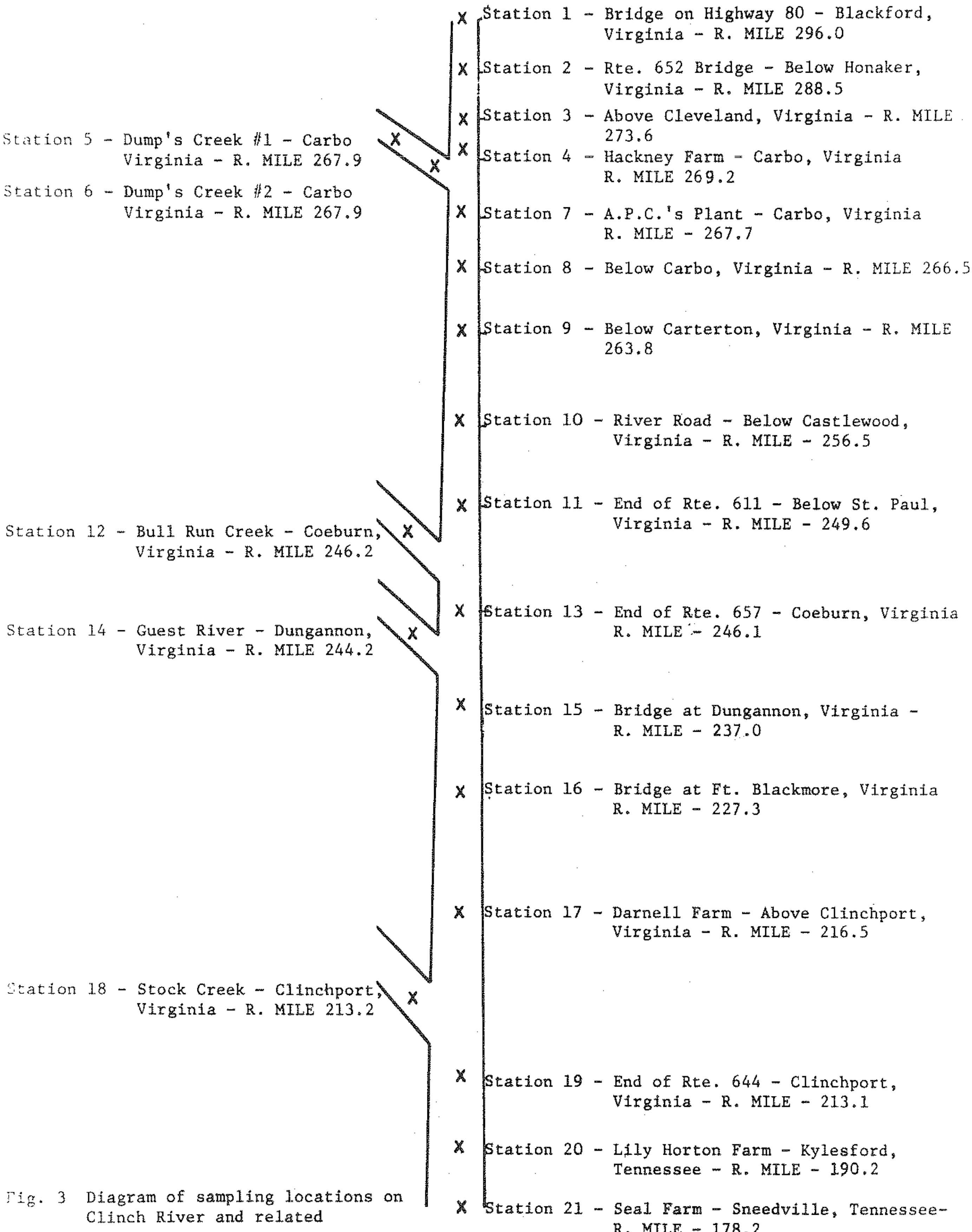

Fig. 3 Diagram of sampling locations on Clinch River and related tributaries

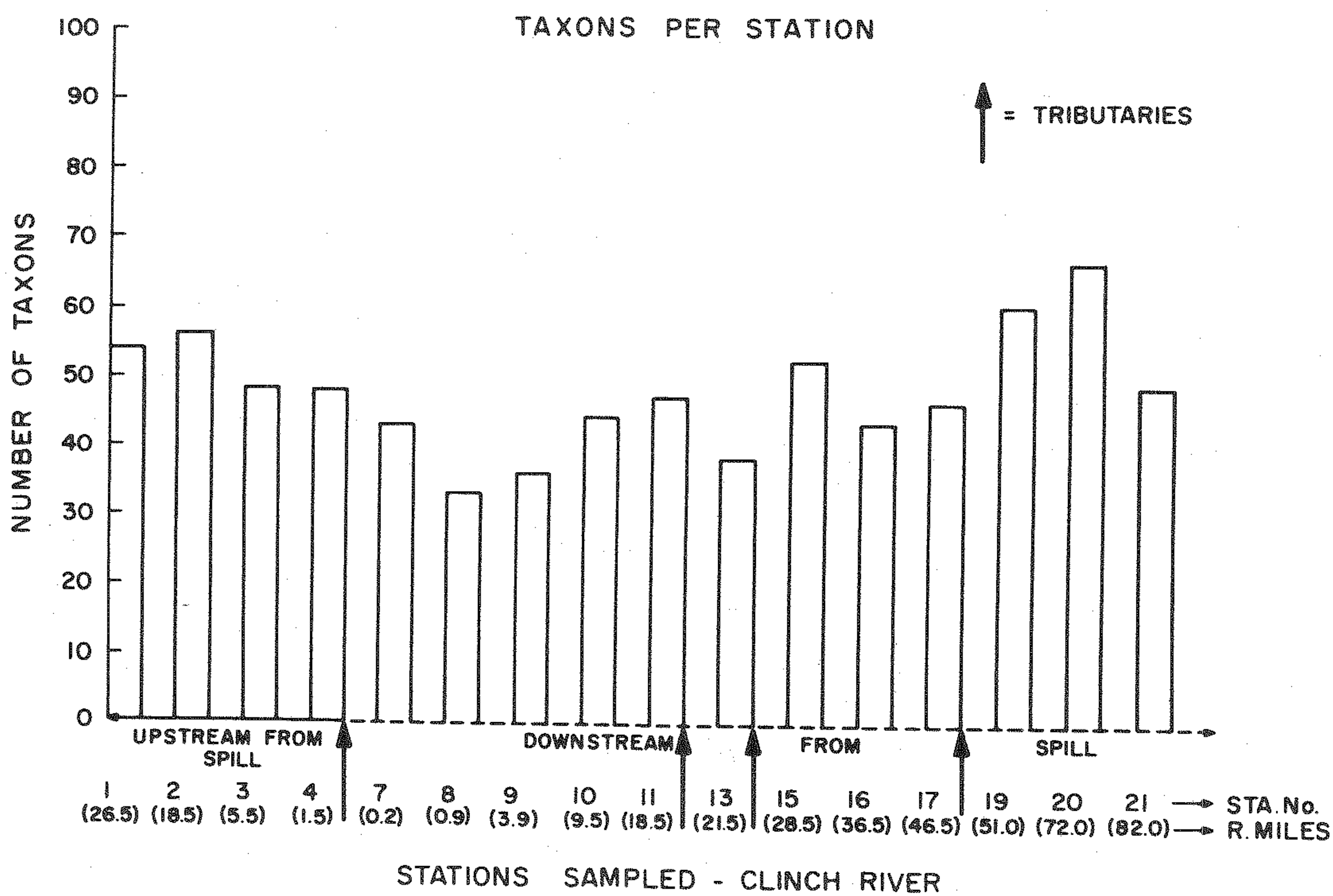

Fig. 4 Number of taxons found at each station for 1969 bottom fauna survey

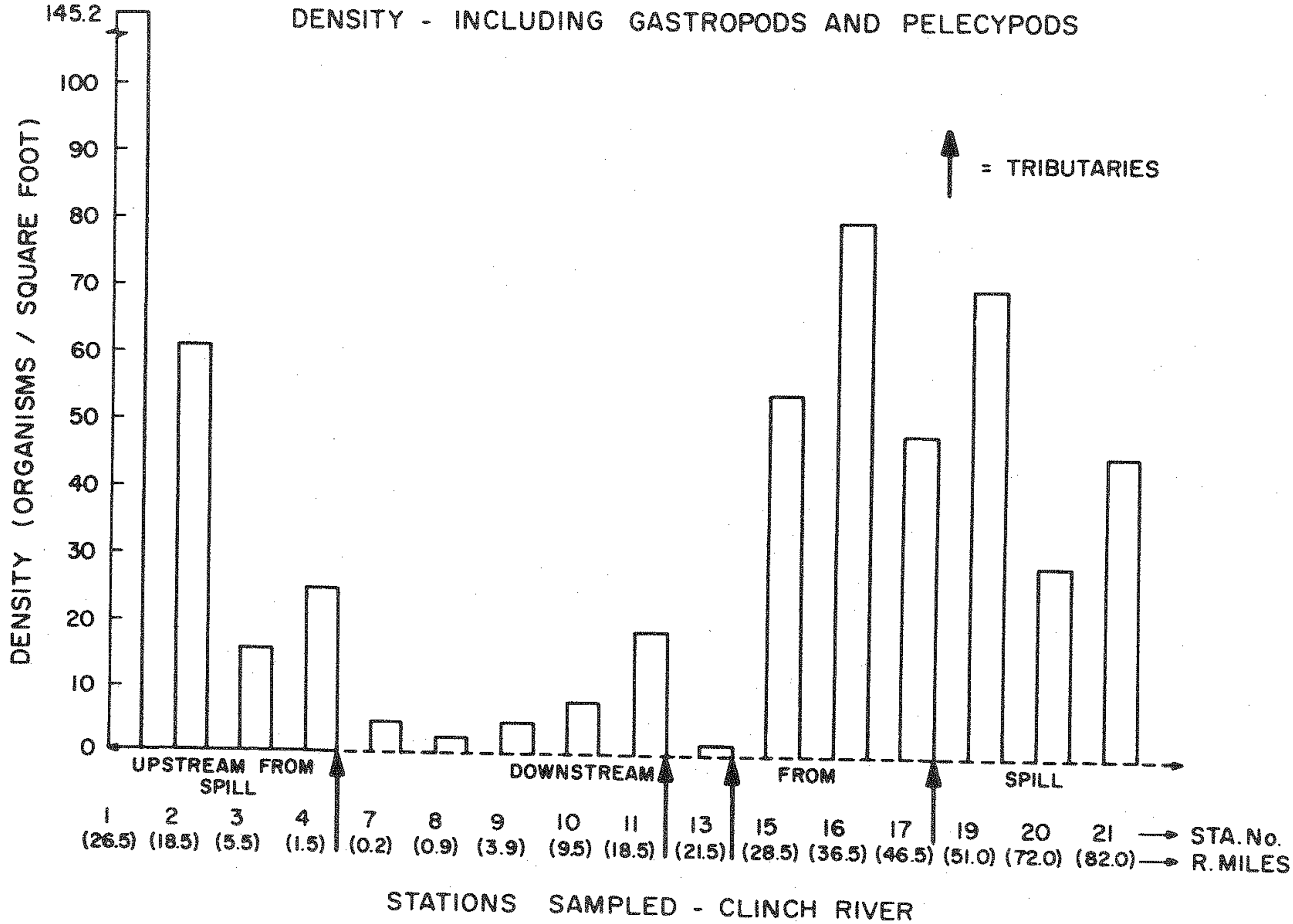

Fig. 5 Density of organisms, including [redacted] molluscs, at each station for 1969 survey.

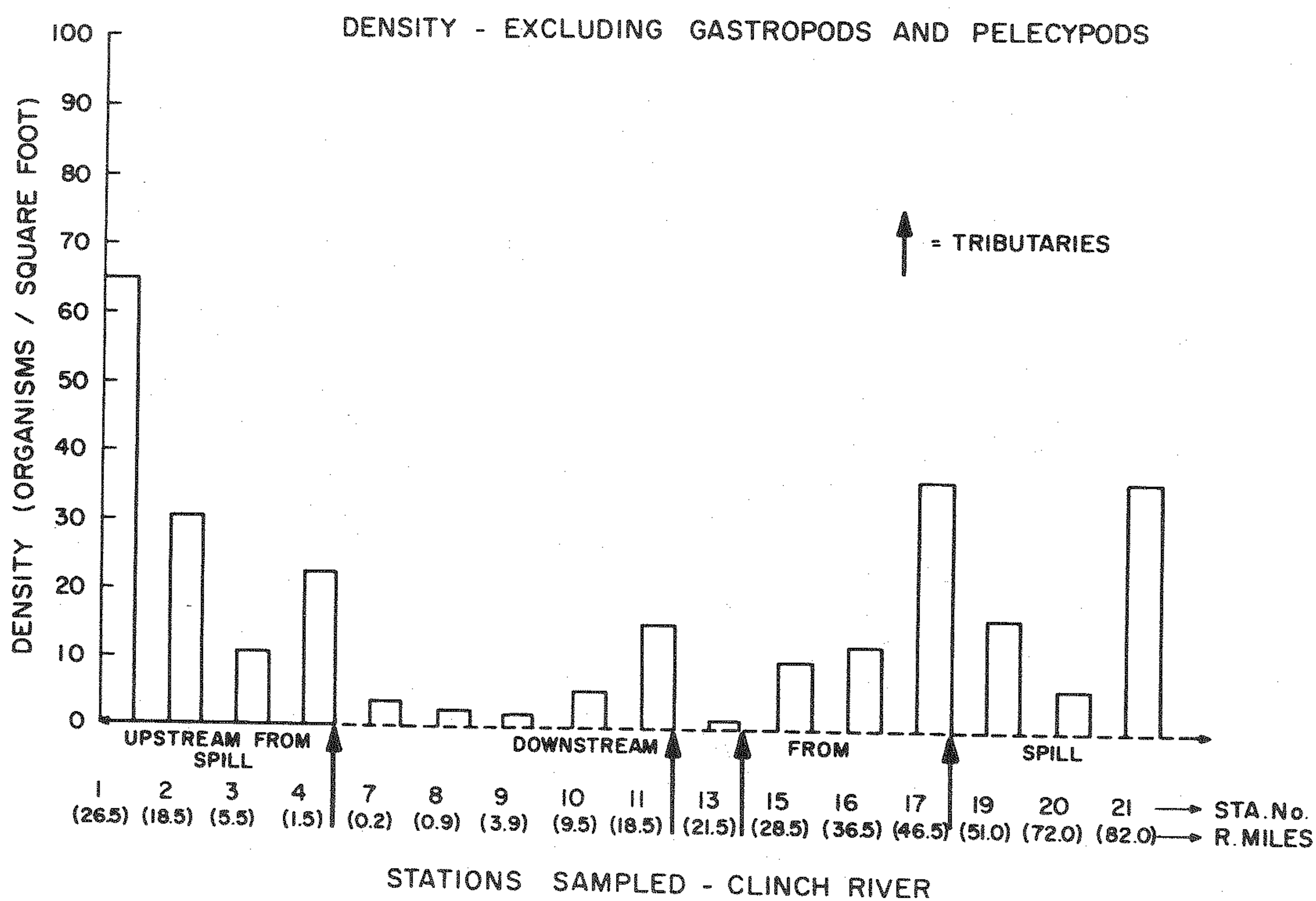

Fig. 6 Density of organisms, excluding [redacted] molluscs, at each station for 1969 survey.

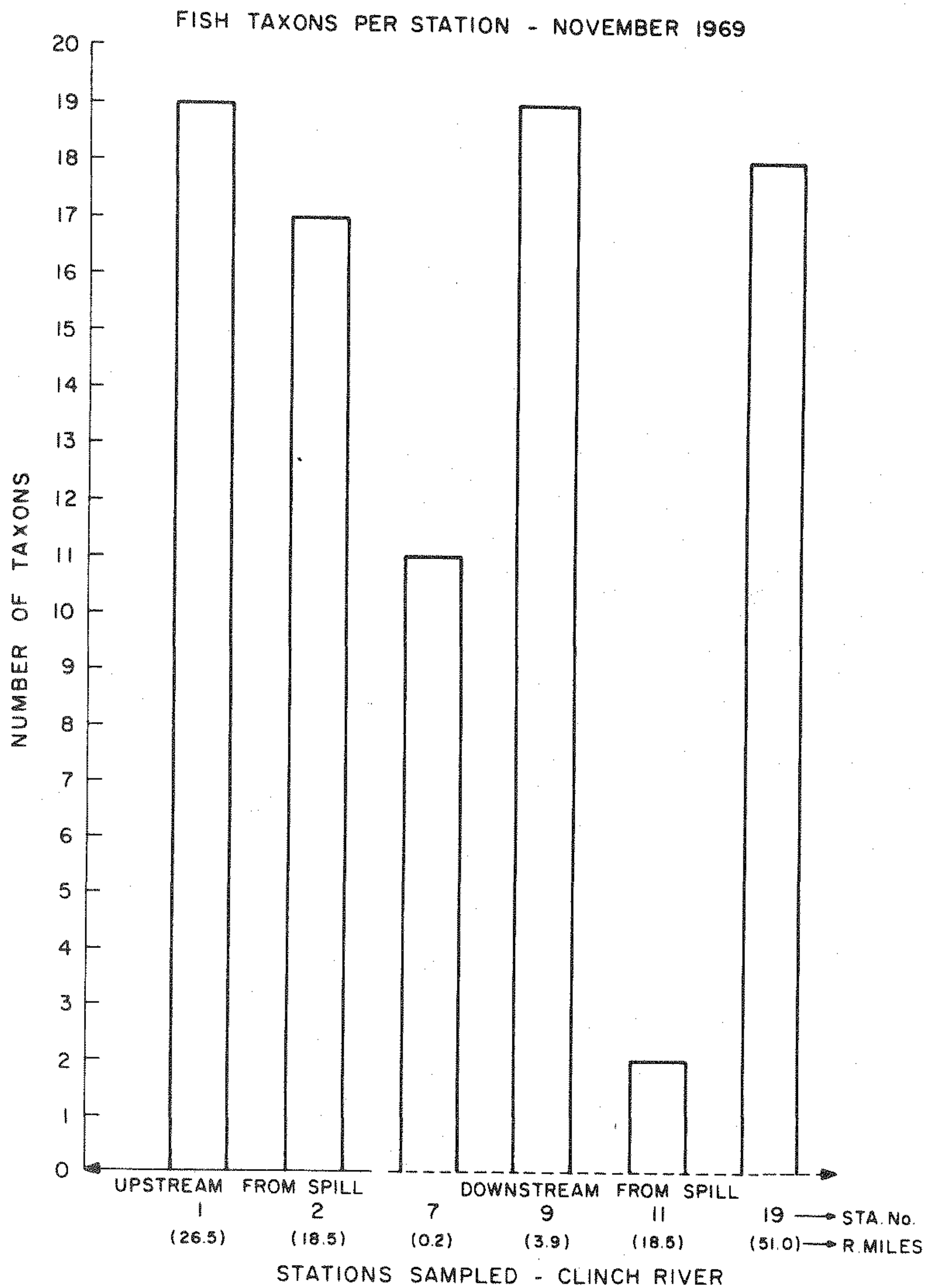

Fig. 7 Number of fish taxons found at sampling stations for November, 1969 survey.

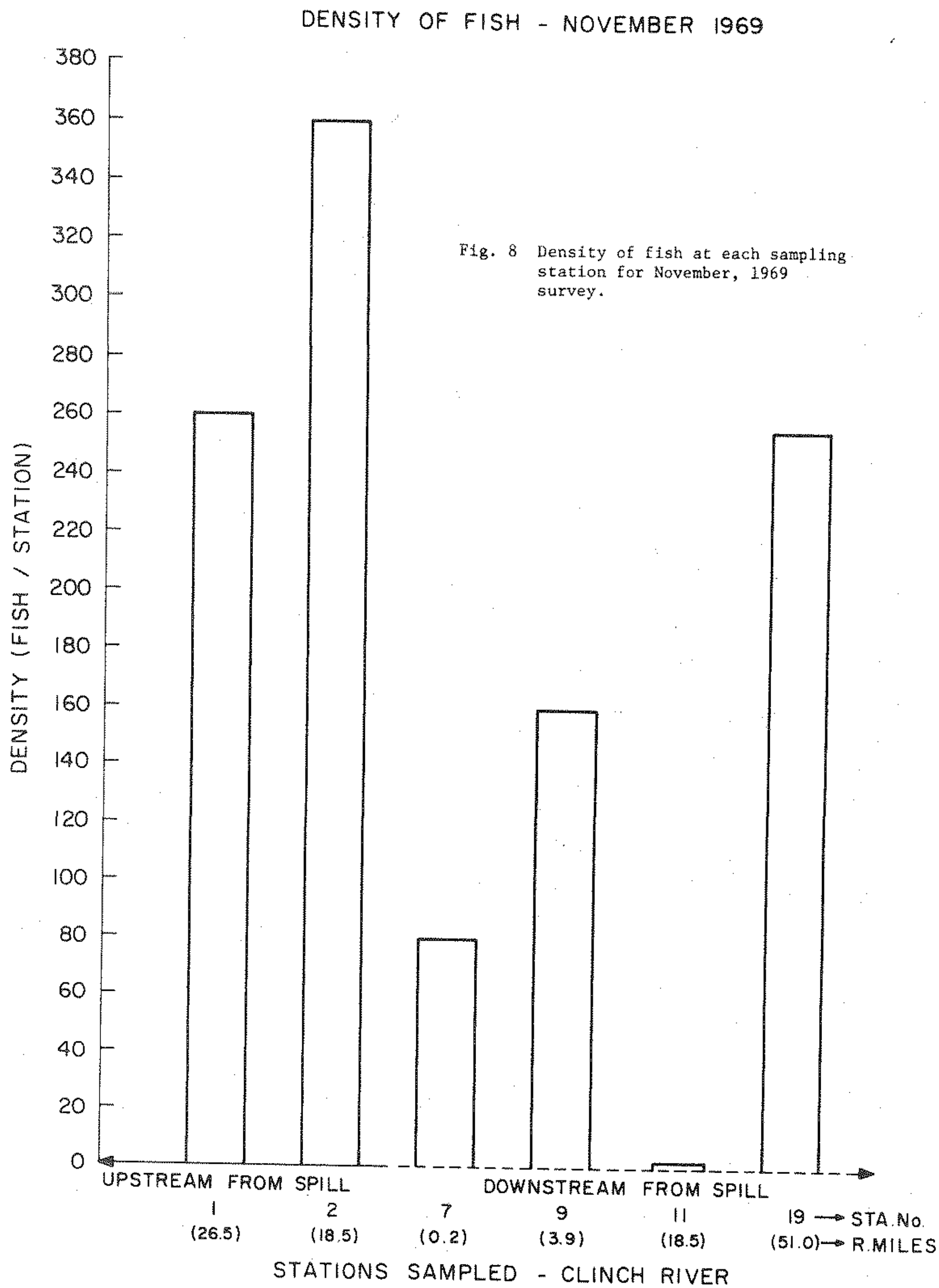

Fig. 8 Density of fish at each sampling station for November, 1969 survey.