RELATION OF DOMESTIC SEWAGE TO STREAM PRODUCTIVITY[1]

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Food is one of the first requirements of all living things and is often the limiting factor in the establishment and maintenance of a species. Animals depend directly or indirectly upon green plants for their food. A stream may be considered as a nutrient medium, more or less adequately balanced, thus supporting the organisms living in it. The kind and number of organisms supported depends, in addition to food materials, upon factors such as the condition of the water, current, temperatures, pH, suspended solids, dissolved oxygen and carbon dioxide. A body of water well supplied with all the essential mineral elements in proper form and concentration, with optimum conditions of temperature, pH, etc., will naturally support the largest population of organisms. A stream may have optimum conditions for the development of a certain species, resulting in a rapid increase in numbers of that species, with the exclusion of other forms developing the well-known "bloom" of nearly pure culture. This optimum condition may last for only a short time and the bloom quickly disappears. On the other hand, a stream lacking or deficient in one or more of the essential mineral elements will be largely barren of aquatic organisms.

Data from a biological survey of the Ohio River Basin (1939–1940) (1) indicate that in general the barren streams are found south of the Ohio River in regions where the soil is poor in humus, the farms are large and scattered, and few cities or larger towns are located along the streams. It seems probable that these streams may be deficient in some essential mineral or minerals which would account for the low phytoplankton population, and subsequently for the low fish population.

These streams are probably adequately supplied with those salts which can be dissolved from the rocks and soils over which they flow but may be deficient in minerals, possibly nitrates, that could be added by decayed vegetation, domestic sewage and barnyard manure. Owing to the poor soils, the streams in this region, as the soils, are not productive. The streams in the northern sections flow through regions of high soil fertility and dense human population. These streams support a much higher plankton population than the southern streams.

In order to determine the effect of domestic sewage on stream productivity, a study was made on several streams where there is known to be definite sources of pollution and also on streams that are comparatively clean. The Miami, Little Miami, Wabash, and its principal tributary, the White, all flow through industrialized areas and are heavily polluted by domestic sewage from scattered towns and cities in the watershed. The Big Sandy, Guyandot, Licking and Green Rivers are examples of cleaner streams. They flow through a sparsely settled region of poor soils and only a few small cities or towns are located in these areas.

METHOD AND PROCEDURE

The samples for plankton studies were collected in 250 ml. glass stoppered bottles. The samples were studied in the fresh condition or were preserved in 3% formalin. One hundred milliliters of the sample were centrifuged for five minutes at a speed of about 2,500 r. p. m. The organisms in a known amount of the "catch" were counted and the number in one milliliter of the original sample was computed (2). The volume figures, expressed in parts per million (p. p. m.), were obtained

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by multiplying the number of individuals of each species by the average volume of that species and adding the total volume of all species.

RESULTS

The Miami River flows through a densely populated industrialized area in Ohio, and the stretch of the river below Dayton receives domestic sewage and industrial wastes from the following cities: Hamilton (sewered population 54,000), Middletown (pop. 35,000), Franklin (pop. 2,700), and Miamisburg (pop. 5,300). Samples taken at stations above and below these towns, from May to December, 1939, show that the plankton volume is generally high, ranging from 3000 to 8000 p. p. m. The plankton volume near the mouth at Cleves was high (8000 p. p. m.) in May, due mainly to diatoms and large numbers of *Cryptomonas erosa* and *Chlamydomonas*. During the low water period, from July to October, the plankton volume was around 4000 p. p. m., reaching a maximum of 10,000 p. p. m. on August 28; diatoms, Chlorophyceae and Euglenophyceae forming the bulk of the algae. The advent of cold weather (12° or less) after the middle of October reduced the volume to less than 1500 p. p. m.

The sewage from Hamilton tends to increase the volume of river plankton. The total algae below town is usually higher than 4000 p. p. m. with a maximum of 16,000 p. p. m. in August. The plankton population is depressed below Middletown, probably due to the heavy load of industrial waste from the paper mills. Below Franklin the total volume was above 3000 p. p. m. during the summer and reached a peak of 22,000 p. p. m. on August 17. Euglenophyceae, Chlorophyceae and diatoms predominated. The plankton drops immediately below Miamisburg, which may be due to the industrial pollution from paper mills and a tobacco plant, and the smallness of the stream in this region.

Samples taken above Dayton, at Tippecanoe City, Troy, Piqua and Sidney, show a variable plankton population which may be due to the various sewage treatment plants, heavy industrial loads and the small size of the stream. However, only one series of samples was taken in September. The total plankton volume of the stream showed a slight rise from 4800 to 6500 p. p. m. below Tippecanoe City, and a slight drop, from 4800 to 2800 p. p. m. below Troy.

The Little Miami River and its tributaries are polluted locally by several small cities in the watershed. The total volume of plankton was somewhat less (2000—6000 p. p. m.) than in the Miami River, except during the low water period in late summer. The plankton usually dropped below South Lebanon, followed by a gradual rise to the mouth at Beechmont, due to the fertilizing effects of the sewage from Kings Mills, Loveland and Milford. During the week of September 22, a bloom of *Pandorina* and *Chlamydomonas* occurred below the mouth of Yellow Springs Creek, which may be due to the heavy pollution load from Yellow Springs and optimum conditions of temperature and stream flow.

Batavia and Williamsburg discharge a small amount of untreated sewage into the East Fork, which is insufficient to cause any marked effect on the plankton.

The Wabash Basin lies largely in the State of Indiana and a small portion of Illinois. The river is locally heavily polluted by several large cities. The plankton population is large, and consists of many species. Below Peru a heavy growth of algae appear along the banks of the river, and the plankton volume is generally high, varying from 14,000 p. p. m. on August 1 to 3000 p. p. m. on September 3. Below Logansport there is found a region of intense pollution which extends downstream for a considerable distance. The bottom and sides of the channel are covered with a growth of attached protozoa and fungus common to extremely polluted regions. The plankton volume is low, less than 2000 p. p. m. The fish are relatively scarce—suckers, shiners and a few carp constituted the catch. The peak of the plankton, due to the fertilizing effect of the Logansport pollution, occurs in

the region of Delphi, some twenty miles downstream, where the volume reached 58,000 p. p. m. on September 6. Here the fish were plentiful and varied. Smallmouth and white bass, common and redhorse suckers, mooneyes, yellow and channel catfish, longeared sunfish, darters and shiners were caught. From Delphi, the plankton population drops off until the influence of the Lafayette effluent is felt in the vicinity of Independence. Above Lafayette smallmouth bass were common, while sunfish, shiners and darters were quite plentiful. Below Lafayette bass were absent but gar pike, channel catfish, mudcats, shiners, darters and sunfish were common. Fish were plentiful along the stream to Terre Haute.

Terre Haute is another source of heavy pollution. In addition to the untreated sewage there are numerous commercial plants that pour their wastes into the river. At this point the current is swift so the pollutants are distributed for many miles downstream. Owing to the strong current and wide distribution of the wastes, the fertilization effect on the plants is not localized to the point of producing a prominent peak in the plankton volume, as is often the case. The total plankton volume is about 2000 p. p. m. From Meron Ferry downstream, the plankton gradually decreases to the mouth, with slight rises at Parton and below the junction of the White and Patoka Rivers. In contrast to upstream conditions, no fish at all were taken below Terre Haute. Ten miles below Terre Haute the natives reported that suckers were common; sunfish, shiners and mooneyes were also present. From here to the mouth of the Wabash, the fish were plentiful and varied.

The White River is subject to heavy pollution for almost its entire course. The pollution immediately below Muncie, Indiana, is so intense that the phytoplankton population is almost entirely destroyed. It is likely that some ciliates exist in these conditions, but as the samples from this location had been preserved in formalin, and the protozoa do not preserve well, they did not show up in the plankton samples. Recovery is rapid but the plankton volume reached its peak above Nobleville (total volume 36,000 p. p. m.). The plankton volume fell below Nobleville and decreased greatly (total volume less than 2000 p. p. m.) above Indianapolis, until Martinsville was reached. Below Martinsville conditions were favorable for the proliferation in large numbers of diatoms, especially *Stephanodiscus* and *Synedra*. This diatom population continued on downstream past the mouth of the Eel River to Newberry where, possibly due to the diluting effect of this tributary, the total volume fell off. At Washington most of the diatoms had vanished, green flagellates appeared under the influence of fresh pollution. From this point downstream the total plankton fell off to approximately 1500 p. p. m. above the mouth.

The fish population above Indianapolis at Perkinsville, Strawtown, Noblesville and Nora is varied and quite plentiful, consisting of basses, buffalo, carp, bluegills and crappies. Below Indianapolis some sunfish and buffalo were caught and local fishermen reported that carp and catfish were also present. At Martinsville common and quillback suckers, hogmollies, sunfish and numbers of minnows were taken in the seine. From Spencer to the mouth fishing was generally good, the catch consisting of a mixed population.

In comparison with the above streams, the Licking, Big Sandy, Kanawha, Guyandot and Green are clean rivers. For the most part they flow through sparsely populated territory and the soils are poor in organic matter. The plankton population as a whole is low, maintaining a level of less than 2000 p. p. m. for the entire watershed during the summer. In a few cases, such as below Paris and Cynthiana, the volume rose to slightly higher figures.

DISCUSSION

Raw sewage which enters streams from city sewers or organic industrial wastes affects aquatic organisms in a variety of ways. The waste may have an immediate

toxic effect, or it may induce rapid multiplication of aerobic bacteria which sharply lower the dissolved oxygen concentration, frequently to the asphyxial level for fishes, and sometimes to depletion. This latter is probably the most frequent cause of mass death of fishes in the streams of the Ohio Basin. This toxic zone is evident for a variable distance below the sources of pollution, depending upon temperature, rate of flow and type of stream. This region has a low plankton population. The fish are few and principally of the rough species, such as carp and buffalo. Fungi and stalked ciliates may be attached to solid surfaces.

Further down, the polluted stream is characterized by a large variety and volume of photosynthetic algae. The large population of plankton furnish fish food and in this region is usually found a large mixed fish population. This increase in aquatic organisms is probably due to the addition of available plant food materials (nitrates and phosphates) derived, by bacterial action, from the raw sewage introduced upstream. This is the region that shows to a marked degree the beneficial effects of the fertilizing value of the upstream sewage. Further downstream the phytoplankton population rapidly decreases.

Observations made below towns with various sewage treatment plants indicate that when the sewage receives secondary treatment so that the reduction of the complex compounds to available plant food materials by bacterial action takes place before the waste enters the stream, the early obnoxious conditions may never occur. Thus, the stream may be benefitted for much of its course and organic wastes become an asset to a stream instead of a liability.

Streams that do not receive organic material from some source, either natural, such as decayed leaves, dead organisms, or washings from rich (humus) soil or from sewage, are low in plankton population and, therefore, do not support a large fish population. Leaves and other vegetation are composed largely of cellulose and decompose slowly, while domestic sewage, which has been subjected to enzymes and bacterial action in the human body, is quickly converted into available salts after entering the stream.

SUMMARY AND CONCLUSIONS

A study of the relation of domestic sewage to stream productivity was made by comparing the aquatic population of heavily polluted and clean streams in the Ohio River Basin. The Miami, Little Miami, Wabash and White Rivers were selected as examples of heavily polluted streams, and the Licking, Big Sandy, Guyandot and Green Rivers are comparatively free from polllution.

Raw domestic sewage in high concentrations is decidedly detrimental to phytoplankton and most species of fish, either by direct toxicity or to a reduction in the dissolved oxygen by bacterial action. Further downstream, where the sewage has been reduced to available minerals by bacterial and chemical action, the phytoplankton responds to the fertilizing effect of the sewage by a tremendous increase in numbers and species. The phytoplankton furnishes food for the zooplankton which, in turn, is reflected in the increase in the population of mixed fishes. This is the region where the stream clearly shows the beneficial effect of upstream organic pollution. Further downstream the plankton volume decreases, and a comparative few genera persist. This region is characterized by a reduction of the forage and rough fishes and a relative increase in the game fish. As further purification occurs, there is a disappearance of plankton and a corresponding reduction in fish numbers and species.

Proper sewage treatment plants will largely eliminate the early toxic region and the stream will be made more productive by the fertilizing effect of domestic sewage.

REFERENCE

(1) **Floyd J. Brinley** and **L. I. Katzin,** U. S. Public Health Service Bulletin, in press.