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THE ECOLOGY OF ALGAE GROWING IN THE SALINE RIVER, MICHIGAN, WITH SPECIAL REFERENCE TO WATER POLLUTION

by

John L. Blum

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THE ECOLOGY OF ALGAE GROWING IN THE SALINE RIVER, MICHIGAN, WITH SPECIAL REFERENCE TO WATER POLLUTION

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The algal vegetation of the Saline River was studied throughout a period of twelve months in 1952-53 as to (1) its composition, (2) periodicity of the principal species, (3) succession, and (4) environmental conditions influencing the algae. The upper course of the river is unpolluted and mildly alkaline, has a high bicarbonate content, usually abundant nutrients, and has an algal vegetation which includes Cladophora glomerata in spring, Diatoma vulgare and Gomphonema olivaceum in winter, and a calcified Phormidium-Schizothrix community which is present throughout the year.

The lower course of the river is influenced by industrial wastes and sewage entering the river principally at Saline and Milan. Below the industrial outfall at Saline, the water contains chromium, copper, and cyanide ions, and the flora of the upper course disappears almost completely, being replaced by a luxuriant flora of Stigeoclonium tenue and other species. Below the domestic outfall at Saline, the summer riffle vegetation is dominated by the bacterium Sphaerotilus and the diatom Nitzschia palea; at other seasons Stigeoclonium tenue, Tetraspora cylindrica, and Navicula seminuloides are present on riffles, whereas the pools are dominated by Spirogyra spp.

Analyses for important nutrients were made by colorimetric methods at approximately ten-day intervals. Inorganic phosphates, moderately low to low in the upper course of the stream, increase sharply below the Saline outfalls and remain relatively high for most of the remainder of the stream. They are uniformly low in winter at all stations and are, by contrast, relatively high throughout the other seasons. Nitrates increase markedly in amount in the lower course of the stream. They are more abundant in the cold months than in the warm months. Organic nitrogen is generally plentiful throughout the stream's course. It increases sharply in amount below the Saline outfalls and remains relatively high.

Algal periodicity was investigated by transect studies and by dry weight determinations. Certain evident changes in algal growth were synchronous with certain marked environmental changes. The rise to dominance of the principal algal vegetations of summer, as well as their subsequent disappearance, both occurred when not one but many profound changes were taking place in atmospheric as well as other physico-chemical factors. The presence of more than one variable thus renders inconclusive any generalization expressing a relationship of algal growth to environmental condition.

PREFACE

The present study is an effort to determine and to explain as far as possible the groupings of algae found within a small stream of the temperate humid zone in northeastern United States. The seasonal variations in the characteristic benthal algae are recorded along with concurrent variations in certain physico-chemical factors. In addition, certain supplementary analyses and experiments were carried out in an attempt to account for significant floristic differences between different parts of the stream at a given time. While plankton algae and their ecology have been studied carefully in many American streams, there have apparently been no previous extensive studies on the ecology and periodicity of benthic algae in any stream of the Western Hemisphere.

The author expresses his great indebtedness to the following authorities, each of whom has provided identifications within the designated group specified in parenthesis after his name: Dr. F. Drouet, Chicago Natural History Museum (Myxophyceae); Dr. Mary Gojdics, Barat College (Euglena); Dr. R. J. Lowry, University of Michigan (Musci); Dr. E. Manguin, Muséum d'Histoire Naturelle de Paris (Bacillariophyta); Dr. H. Skuja, University of Upsala (Rhodophyta); Dr. R. D. Wood, Rhode Island State College (Chara).

The writer's sincere thanks are due to the University of Michigan and the Department of Botany for financial assistance in the form of the Emma J. Cole Fellowship in Botany, from which he benefited

throughout the major portion of this study, and without which many phases of the problem could not have been explored.

During his residence at the University, the writer has continuously profited from the phycological knowledge and experience of his professor, Dr. Wm. Randolph Taylor, as well as from the use of his personal library and bibliographic files. Valued technical advice was given on many occasions by Dr. A. S. Sussman. Suggestions and stimulating ideas in connection with various phases of the problem have been contributed by many people, most significantly by Dr. P. Dansereau and Dr. Sussman. Assistance with statistical data was provided generously by Dr. Cecil C. Craig, director of the Statistical Research Laboratory. The members of the writer's graduate committee have given him helpful guidance and plentiful encouragement. To all of these members of the scientific personnel of the University of Michigan, he expresses his profound thanks.

Quantitative data on the effluent of the Universal Die Casting and Manufacturing Company at Saline, Michigan have been kindly provided by Mr. A. Detwiler, chemist on the staff of this firm. Various personnel of the office of the City Clerk at Saline have given the author much pertinent information. Mr. Drew, chief engineer at Ypsilanti State Hospital, has placed at the writer's disposal information concerning the hospital effluent. Data on rate of flow of the river as well as further data on the industrial outfall at Saline have been provided by the Michigan State Water Resources Commission. Numerous landowners have freely granted permission to cross or to work on their property. Without the coöperation of these various people and agencies, to whom the author tenders his appreciation, the preparation of the work in its present form would have been hampered or precluded.

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I. PURPOSE OF THE STUDY

This work was undertaken with the intention of throwing light upon certain subjects virtually or entirely unexplored with reference to an American stream, namely (1) the algal communities present; (2) the seasonal periodicity of important river algae; and (3) differences existing between the algal flora of clean-water and polluted portions of such a river. It was hoped to tabulate the species composing the various algal communities found in the Saline River, to determine the relative importance of the various species within each community, and to determine insofar as possible both the method of, as well as the conditions necessary for, the development of such communities. It was hoped by continued observations, at frequent intervals, of a variety of environmental physico-chemical factors, to adduce evidence that one or another of these factors is limiting at certain seasons or in certain places, and in this way to explain peculiarities of distribution of at least some of the algal species both in time and in space. It was desired, furthermore, to observe the effects upon the algal vegetation in the stream of the introduction at Saline of pollutants in massive amount; and in short to repeat observations as to composition of the vegetation and algal periodicity for the very extensive portion of the stream influenced by these polluting substances.

The Saline River (Figures 1, 2) lends itself well to such an investigation. Its headwaters region, a course of some six miles (9.6 km.) receives no appreciable pollutants except for drainage

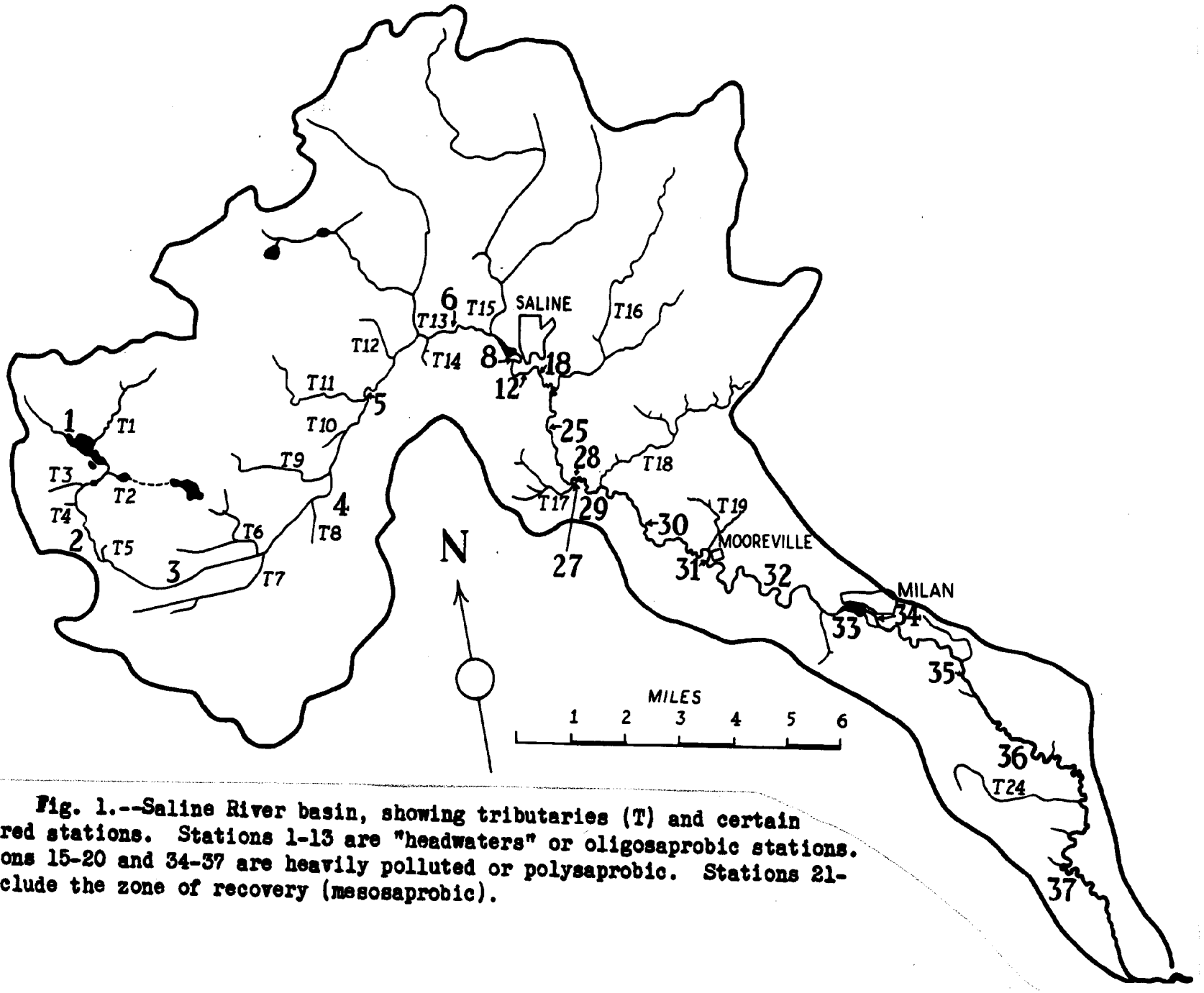

Fig. 1.--Saline River basin, showing tributaries (T) and certain numbered stations. Stations 1-13 are "headwaters" or oligosaprobic stations. Stations 15-20 and 34-37 are heavily polluted or polysaprobic. Stations 21-32 include the zone of recovery (mesosaprobic).

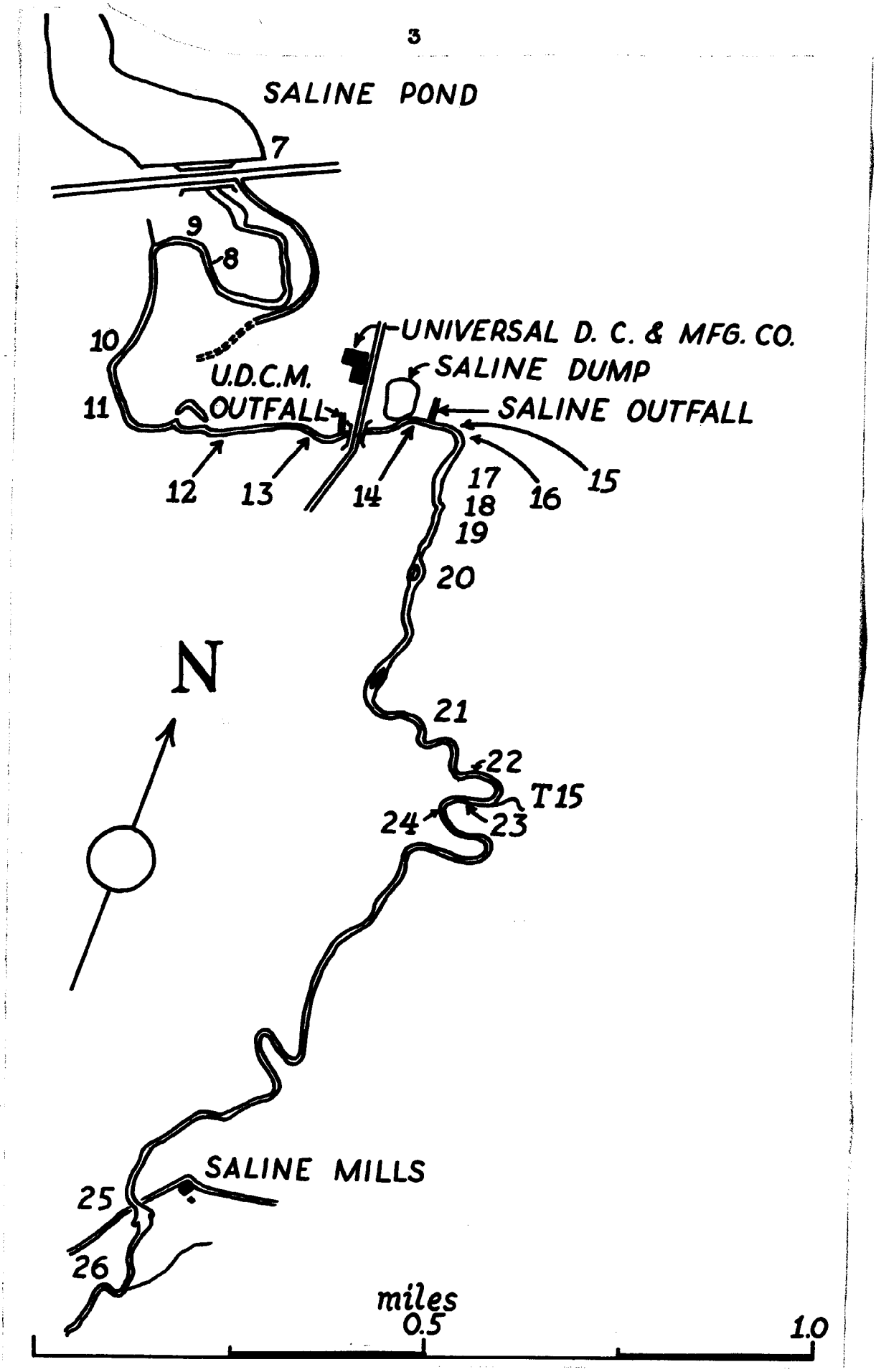

Fig. 2.--Detailed map of Saline River below Saline Pond. Stations 15-20 are polysaprobic; 21-24 are α-mesosaprobic; 25-26 et seq. are β-mesosaprobic. T, tributary.

from cropped soils, and it may be supposed that the stream above the city of Saline is essentially unpolluted. At Saline, the first source of pollution is from a constant-flow industrial outfall of considerable magnitude. For some distance the river receives no other pollutants excepting, probably, minor amounts of seepage from the city dump, and it is thus possible to observe the effects of the industrial pollutants unmixed with large amounts of sewage. At a point about two hundred meters downstream from the industrial outfall is located a second major outfall which introduces raw sewage from the city itself. Beyond this point the river is highly polluted, and develops, at least in summer, a polysaprobic[1] flora of Sphaerotilus, other bacteria, and filamentous fungi. Much further downstream it is possible to observe the effects on the algae of increasing dilution of the pollutants, as the organic particles settle out and undergo chemical change, and tributaries introduce clean water. Just above the city of Milan, a distance of about nine miles downstream from Saline, the river has become approximately oligosaprobic once again, in spite of certain intermediate outfalls of lesser importance. At Milan the river receives further excessive amounts of domestic sewage and becomes heavily polluted for much or all of the remainder of its course. It is thus possible to observe, as one advances downstream from the headwaters, (1) an unpolluted portion, (2) a polluted portion bearing industrial wastes, (3) a polluted portion bearing both domestic sewage and industrial wastes, (4) a zone of recovery which gradually replaces zone (3), and (5) a highly polluted portion.

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1. A discussion of special hydrobiological terms is given in Appendix I.

II. SURVEY OF PREVIOUS INVESTIGATIONS OF STREAM ALGAE

In Appendix II are listed the important works on streams which particularly consider the algae of the stream. Papers which concern only springs and their algae are not included, but studies which concern the estuarial, brackish portions of coastal rivers are included. Studies which are essentially taxonomic or morphological in nature are, in general, omitted, as are such floras as cite collections of river algae in series which include collections from other kinds of habitats. Papers relevant to physico-chemical conditions within streams, but which do not make reference to algae, are not included. Thus, many important papers on stream pollution and self-purification of streams are omitted from the list.

It will be noted that the algae of flowing water have been a subject of investigation in many countries. However, the various problems of stream botany have been attacked from a limited number of directions. The great majority of ecological workers have been interested primarily in stream plankton, with the result that the benthic algae of streams have remained by comparison poorly known. Nearly all of the studies mention at least short term or isolated records of some physical variables, such as water temperature, turbidity, rate of flow, etc., but there are relatively few which record chemical conditions in the water. Although many studies represent observations made throughout a period of one to several months, it

will be noted that few studies of a year-round nature have been made of the seasonal changes in any of the variables, biological or otherwise, and fewer still have been made in which there is an attempt to correlate physico-chemical variables with algal periodicity.

The earliest knowledge of river algae was based on collections made by phycologists interested especially in naming and classification, such as Kuetzing, A. Braun, Hantzsch, and Rabenhorst in Germany, Lyngbye and Wille in Denmark, C. A. Agardh in Sweden, de Brébisson, Thuret, Sirodot, and Gomont in France, Hassall in England, H. C. Wood and Wolle in the United States. Throughout all but the last few years of the Nineteenth Century the study of river algae did not advance much beyond the knowledge of what species were likely to be found in flowing fresh water.

The stream plankton.---Although many early reports contain remarks on certain environmental or sociological relationships of the algae, studies of a truly ecological nature are lacking prior to the discovery of potamoplankton, i.e., the plankton found in flowing water. (Zacharias, 1898.) With the knowledge that large rivers could possess such a community in their lower reaches, workers in many parts of the world were stimulated to explore this community, to catalogue its component species, and, for certain rivers, to determine qualitatively and quantitatively its seasonal changes.

Although the existence of such planktonic organisms in rivers has been known for more than a half century, the existence of a plankton peculiar to rivers has not yet been demonstrated beyond

question.[2] Steuer (1910, cited by Fjerdingstad, 1950) believes the potamoplankton to be distinctive and bases this belief upon the quite general presence of certain diatom species. Butcher (1932a, 1940) regards the plankton of shallow streams as representing only a "pale image" of the benthic algae, thus as having its origin in the benthos and as lacking distinction per se. Manguin (1949) in a report on the Seine phytoplankton states an opinion that a true river plankton does not exist. Although information on the planktonic organisms of at least sixty rivers is available, a truly distinctive stream plankton is yet to be found. In defense of the individuality of river plankton, however, it should be acknowledged that the periodicity of the plankton in a stream of a given region does not necessarily parallel that of lakes and ponds in the same region (Kofoid, 1903, Brunnthaler, 1900, 1907, Bethge, 1915), and that the temporary assumption of the planktonic habit may be essential to the success and the distribution of essentially benthic species in streams (see below).

Among the most significant contributions to limnology by studies of the potamoplankton may be cited the following facts, more or less well established: that the major plankton pulse occurs usually in spring (Fritsch, 1903, Kofoid, 1903, 1908, Meyer, 1928, Pearsall, 1930, Rice, 1938); this pulse has been correlated with decline in

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2. A peculiar or distinctive potamoplankton may be defined as one which is (a) qualitatively or quantitatively different for at least part of the year from the plankton of lenitic habitats in similar edaphic and climatic regions, and (b) possesses certain elements which are common to a number of rivers of similar type and are not present in comparable amount in lenitic habitats. It is conceivable that a distinctive potamoplankton might differ from the plankton of nearby lakes and ponds only in seasonal composition or in relative numbers of the component organisms, but it seems clear that condition (b), the existence of comparable and peculiar conditions in a series of streams, must be met before the distinctiveness of river plankton can be recognized.

water level following floods (Kofoid, 1903, 1908, Pearsall, 1930, Rice, 1938), but some rivers either do not show a single major plankton pulse, or exhibit a pulse at other times of the year; both Butcher (1924) working on the Wharfe (Yorkshire), and Rice (1938) working on the Thames have observed a plankton pulse to be synchronous with relatively high concentration of nitrates in the water. Kofoid (1903) has described a tendency in the Illinois River for diminished plankton production following winter floods, but for an increased plankton production following spring floods. Water blooms of magnitude have been observed on a few rivers, among them the Mayenne (France, Denis, 1921, cited by Batard, 1932), the Weser (Germany, E. Budde, 1927), and the Potomac (U. S. A., Conger, 1941).

Origin of the potamoplankton.--The origin of the stream plankton has received careful investigation in relatively few streams. For the Illinois River, it was found (Kofoid, 1903) that the plankton was largely autonomous, being derived in large part from the channel backwaters and from the benthos. Seepage and tributary creek waters were largely diluents. The reservoir backwaters were of great importance both as a source of the channel plankton and in its maintenance. Krieger (1927) states as a result of his work on the Havel (Germany) that river plankton is derived largely from lakes within the basin. Inasmuch as the Havel is peculiar in possessing numerous lakes along its course, this conclusion, while undoubtedly valid for this river, is not of general application. What validity it has has been rightly circumscribed in this connection by Butcher (1932).

Budde (1930) has shown that certain species characteristic of the plankton of the polluted Ruhr are derived from the relatively

unpolluted tributary Moehne. These species survive in the Ruhr only because of numerous impoundments. The other species of the Ruhr plankton originate within the Ruhr itself, particularily in the same (or higher) impoundments. Butcher (1932a) states that in smaller streams, the potamoplankton is derived largely from the sessile flora. Rice (1938) succeeded in tracing certain plankters of the Thames to one or another of its tributaries, but the commoner plankton organisms seem to come from the stream itself, and to multiply in their passage downstream.

Phytoplankton components.--The Eder (Budde, 1935) is remarkable for its desmids, numerous both in species and individuals. Most other rivers have a phytoplankton dominated by diatoms to the virtual exclusion of desmids. A summary of the results of many prior investigations by himself and other workers was made by Butcher (1932a) who concluded that phytoplankton components of streams are mostly either (a) diatoms, the commonest of which are Fragilaria and Synedra, or (b) small green and blue-green algae, including especially Scenedesmus and Pediastrum. As the river becomes larger, group (b) becomes more important.

Benthic algae.--These have recently received particular attention from a small number of European workers including Budde (1928, 1929, 1930, 1932), Fritsch (1929, 1949, 1950), Butcher (1932, 1932a, 1940, 1946), Jaag (1938), and Raabe (1951). In these reports, a beginning has been made in cataloguing the algal communities of European streams. Much of the work has been based upon purely qualitative collections and observations, but methods have been devised in recent years (Butcher, 1932, Margalef, 1949, Aleem, 1949) which permit the

quantitative determination of certain types of algal growth on river bottoms. Butcher and his co-workers particularily have employed a method involving submersed microscope slides and present abundant data based upon this method. These papers on British streams represent almost the only investigations sustained on a month-to-month basis of the annual variations in the benthic algae of rivers; the papers of Budde (1928, 1930, and others) and those of Juergensen (1935) and Brown (1908) qualify in this respect, but for the most part are not based on such a long series of observations spaced at regular intervals throughout the year.

Correlations between algal growth and environmental factors.-- One of the most striking phenomena in nature and very possibly the one factor which has been most influential of all in stimulating phycologists to undertake research of this nature, is the frequently abrupt changes which occur from month to month in the algal flora of streams. Visits to a stream spaced at frequent intervals will often reveal the complete disappearance within a period of only six to ten days of an erstwhile conspicuous and abundant alga. Floristic changes from month to month render the benthic vegetation of one season completely distinctive and visibly different from that of the other seasons. Success, however, has not been generally attendant upon efforts to correlate such obvious biological results with environmental causes. It has likewise become clear with the appearance of successive papers describing the benthic vegetation of different European rivers, that certain streams which might be expected to have vegetations similar to each other, occasionally have quite different ones. Among the few correlations that have been tentatively or conclusively drawn are:

that an extended period of relatively low water with little change in hydrographic conditions is conducive to the full development of benthic organisms (Budde, 1930); that progressive eutrophication of a stream will bring about progressive increase in total numbers of algae present (Butcher, 1949). Various workers have observed seasonal variations in certain algal species. In general, and for most species, these variations may be summarized broadly as maximum development in warm months, followed by minimum development in cold months, but many algae behave in quite different ways. Whether these seasonal changes are due to differences in light or in length of day, or to temperature, or to chemical changes in the water, or to some other factor, has not been established.

Pollution.--Most of the studies which relate in any way to the ecology of river algae have been made upon streams which are at least in part polluted by man. An abundant literature exists relating to the effects of pollution upon the stream biota and upon the various "indicator" organisms. It is claimed by many workers that the latter indicate within certain limits the degree of pollution locally characteristic of the habitat. Many of these organisms are algae, particularly plankton algae, and many observations have been made as to their tolerance to poisons and unfavorable conditions existing within polluted streams. Uspenski (1927) showed the importance of iron in determining the presence or absence of certain algae in rivers. Vaucheria is resistant to high quantities of iron, whereas Cladophora and certain other benthic algae are extremely sensitive to it and are never found alive in high concentrations of iron. Lackey (1938) showed that certain benthic algae (Ulothrix zonata, Stigeoclonium

sp.) are capable of growing at unusually low hydrogen-ion concentrations.

Summaries of the biological changes brought about as a consequence of pollution are to be found in Butcher (1940), Fjerdingstad (1950), Huet (1949), Jaernefelt (1952), and Seeler (1935). Discussions and tabulations of indicator organisms are given by Budde (1930), Fjerdingstad (1950), Jørgensen (1952), Lackey (1941), Liebmann (1942), Nowak (1940), and Seeler (1935).

In 1932 Kolbe made the statement that:

> Das Studium der durch die Industrien hervorgerufenen Periodizitaet bzw. der einzelnen jahreszeitlichen Phasen von der Industrie beeinflusster Gewaesser bietet besonders dankbare Aufgaben fuer den Algologen. (p. 325)

At the present time precise knowledge of seasonal variations of algae of polluted streams is still in an elementary state, in spite of the work of Budde and of Butcher and his co-workers.

Succession.--Virtually no work has been published on colonization by algae and succession within algal communities of streams. Eddy (1925) describes, largely on empirical evidence, the probable sequence of hydrologic events leading to "middle age" of a stream, at which algal development is supposed to be at its maximum. Shelford and Eddy (1929) pose a series of questions which are intended to guide future research on stream communities. The existence of climax communities in streams is claimed by Butcher (1946). He describes two climax communities as characteristic of British rivers, the Achnanthes-Chaetopeltis community (oligotrophic) and the Cocconeis-Chamaesiphon community (eutrophic). It is to be supposed that certain of the numerous algal communities which have been named by other European workers are actually climax communities; but the majority of them,

consisting, it would appear, of more or less haphazard combinations of species, are so only in a restricted sense, or not at all.

Studies of American streams.--Throughout the period of greatest activity of European workers on stream self-purification and indicator organisms (1900-1910), and the period characterized by the most widespread interest in stream vegetation (1920-1940), the algal vegetation of American rivers remained relatively unexplored. Following the classical work of Kofoid on the plankton of the Illinois River, which extended over a period of six years, no work even approximately comparable was undertaken on other rivers for over fifteen years. Purdy (1916) presented extensive plankton data for the Potomac watershed, and later for the Ohio (1922) and the Illinois (1930). Allen (1920), in a study of the plankton of the San Joaquin River (California), concluded for that stream that currents above a very moderate speed are inimical to plankton development. Eddy in 1932 described the summer plankton of the Sangamon River (Illinois), and other workers have reported on the plankton of the Mississippi River (Wiebs, 1928, Reinhard, 1931), and the Hocking River (Ohio, Roach, 1932). The plankton of the Huron River (Michigan) has been the subject of experimental work (Chandler, 1937).

In 1937 the United States Congress authorized, under the Rivers and Harbors Act, a stream pollution survey of the streams of the entire Ohio River basin. This unit, functioning under the Public Health Service, has since made numerous studies of stream pollution, its effects and its abatement, as well as of related bacteriological, epidemiological, and chemical problems. While there has been no apparent emphasis in this work on the algae of the rivers studied, much

information on the plankton of the streams has been published (Ohio River Pollution Control, 1944). For any one stream, this information is often scanty, representing plankton counts made from only few samplings of a stream on few occasions; however, the pertinent work on the Ohio, the Wabash, and the Scioto (Ohio, Kehr et al., 1941, Lackey, 1941) Rivers is well documented.

Several states as well as the federal government have undertaken river surveys, principally in fisheries and pollution investigations. Among the most consequential may be mentioned the complete survey of drainage in New York State, extending from 1929 through 1939. In general, these works show little preoccupation with stream algae, planktonic or otherwise.

In 1948 the State of Pennsylvania and the Philadelphia Academy of Natural Sciences undertook a survey of the Conestoga and the Brandywine River basins (Patrick, 1949), and subsequently the Philadelphia Academy has surveyed other streams in Pennsylvania as well as in other states. These surveys have obtained extensive chemical data simultaneously with data on an unusually large number of groups of animals and plants within the stream, and represent probably the most ambitious attempt to date to explore the stream habitat with its entire biota. It is regrettable that this work has remained largely unpublished. While the algae have been investigated with care in these studies, quantitative work on this group has not been done, and for certain months of the year the data have remained in large part fragmentary so that it has not been possible to obtain a clear picture of the periodicity of the various algae.

Ecological work specifically on benthic algae of streams has been carried out in America by only a handful of workers. H. Brown (1908) observed a small stream on the campus of Indiana University throughout an entire twelve-month period. His paper remains, so far as can be ascertained, the only description of the relative abundance of benthic algae of different species in an American stream throughout an entire year. In this study, comparison was made briefly between the algae of a polluted stream and the algae of a "pure" spring, and in addition some experimental work was done on the tolerance of certain species to polluted (and to unpolluted) water.

Roddy (1915) has described briefly the vegetation of blue-green algae in the Conestoga River (Pennsylvania). Norrington (1927) made collections at high altitudes in lakes and streams of the Wasatch and Uinta Ranges in Utah, and listed many unusual species from these habitats, including Enteromorpha intestinalis, E. plumosa, and Monostroma quaternarium, which she regards as possible relicts. Matthews (1932) made a study of Quaker Run, a cold, swift stream in Allegany State Park, New York, and described its vegetation with particular reference to its numerous bryophytes. A few uncommon genera of red algae are reported [subsequent collections by Gordon (1934) and the author (unpublished) in this stream make it appear likely that Lemanea australis Sirod. is erroneously reported in her paper as Tuomeya]. Neel (1951) has described his research on certain physical and chemical factors in streams in relation to algal growth. Thurman and Kuehne (1952) have made ecological observations on Cladophora glomerata in a Texas stream throughout a nine-month period, and concluded that its disappearance in summer indicates lack of tolerance to higher temperatures.

To summarize the state of our knowledge with respect to American streams, it may be said that we possess rather conclusive and definitive information on the plankton of one American river (the Illinois). The summer plankton of approximately ten major rivers has received preliminary study, and isolated records are available for a score or more of other streams. Brief mention may be found in numerous papers, of individual collections of algae in various rivers, but no exhaustive investigation has been made of the algal flora of any American stream with the possible exception of the Scioto River (Lackey, 1941). The benthic vegetation of about 5-6 small streams in the United States has been studied, for the most part only cursorily. As to seasonal variations in benthic algae, only two studies, both of them very limited in scope, have been attempted. In spite of numerous fishery and water-conservation surveys which have been made of American streams, an elucidation of their algal vegetation and its ecology has been scarcely begun.

It will be evident that the present knowledge of algae in the streams of the United States lags well behind the relatively precise and abundant information which is at hand for European streams, particularly for those of Germany and Great Britain. Even in Europe, however, a general overall picture of seasonal changes in plankton or benthos has to date been impossible, due simply to the absence of enough useful observations. While this is true even for unpolluted streams, it is doubly so for polluted ones, where year-round observations are almost entirely wanting, especially for benthic algae.

Gaps in our present knowledge of river algae.--Because of the aforementioned lack of knowledge concerning the environmental factors

which regulate the extensive seasonal changes in algal vegetation, we are not yet in a position to explain seasonal periodicity in any of the benthic algae of streams. Furthermore, it is impossible even in Europe at the present time to correlate the majority of known algal communities with geology, geography, climate, or water chemistry. The method of formation and the related successional stages of none of the algal communities have as yet been worked out. While the biology of the phytoplankton community has received considerable attention, that of the benthic algae has, by comparison, been neglected. We are thus in a position with respect to river algae similar to the position about sixty or seventy years ago with respect to the terrestrial vegetation of temperate western countries, with this difference, that we are not likely to have a well-drawn picture of the cryptogamic vegetation of the rivers of such countries or of the world as a whole, in even so appreciable a time as seventy years more. In making such a guess it is necessary to consider the enormous number of streams on earth and the relatively isolated, individualistic nature of each, for we may suppose that the boundary of each drainage basin represents a barrier to the migration of aquatic organisms and hence to the development of extensive, uniform communities such as are familiar on land and in the sea. Perhaps, indeed, this well-drawn picture will never be achieved, inasmuch as the influence of man and his works upon streams becomes continually more profound. It may prove impossible to complete even the tabulation of natural river communities before such a time as many of them are totally obliterated by human disturbance.

Lastly, we lack at the present time a synthesis of all the various river surveys and investigations. Information about streams

and the various algal species which inhabit them is scattered throughout a polyglot literature. Many published papers concern themselves exclusively with the stream at hand and attempt to draw no parallels or contrasts with other streams studied by earlier workers. It is to be expected that many facts of great ecological interest will become evident once a far-reaching synthesis of this mass of information is available.

III. TECHNIQUES

In general, standard methods of collection, preservation, and qualitative analysis were used, but certain standard chemical and plankton-determination procedures were replaced with more recently developed, and hence not yet standard, methods.

A. Physical Methods

Temperature.--Water temperature was determined by a standard thermometer immersed either in a shaded pail of freshly drawn river water, or in a shaded position just below the surface in the river itself. Air temperature readings were regularly made in the shade at a height of 20 centimeters above the soil on the banks of the stream.

The nature of the work rendered it impossible to take readings at a given point at the same hour of day each time this point on the stream was visited. As a time-saving measure, and because of the somewhat inconclusive nature of readings made at indiscriminate times of day, readings of water and air temperature were made at certain stations, particularily numbers 5, 8, 18, 28, and 45 rather than at all stations.

Light.--Light measurements were made with a number 594 Weston waterproof cell attached by water-tight seal at the end of a bent five-foot pipe which houses the leads from the cell. This apparatus, when used at arm's length, permitted readings on the river bottom at a horizontal distance of about 1.8 meters from the operator and at depths up to nearly 1.2 meters, which was sufficient for purposes of

the present study. The leads from the cell were connected by a four-way switch to micro- and milliammeters of suitable range. These were housed in a container which, during readings, was held by the operator, or, if possible, placed on the bank. Ammeter readings were calibrated against a Weston light meter reading directly in foot-candles.

Water level.--Level of the water was determined by using as base level the highest point of a conspicuous boulder in or immediately adjacent to certain of the riffles visited at ten-day intervals. The water level and the temperature were measured during each visit for the collection of water samples. Variation in height of the adjacent water surface above or below this arbitrarily chosen level was measured in inches. At Station 8, average depth of bottom was determined on November 4, 1952. This average depth of bottom was then used in determining the zero depth with reference to the aforementioned base level at this station.

Turbidity was determined in the laboratory with a Klett-Summerson colorimeter utilizing a blue filter. This instrument was calibrated against a Hellige turbidimeter. A certain amount of error due to water color is to be expected in substituting a colorimeter for a turbidimeter, but as the water seldom showed much color except in the region immediately below the Universal Company outfall at Saline, it is believed that such error was kept at a minimum.

Rate of current was measured by a modified Pitot tube utilizing a manometer (Welch, 1948, p. 144). This instrument was calibrated against a Leupold and Stevens current meter.

B. Chemical Methods

Hydrogen-ion concentration.--This determination was made regularly with a Beckman pH meter within four to twelve hours after collection.

Dissolved oxygen, carbonate, bicarbonate, and salinity were determined by standard methods (Welch, 1948). For all determinations of dissolved oxygen at points on the river above the industrial outfall, the Winkler method (unmodified) was used, and titrations were followed to completion in the field. For determination of dissolved oxygen from all points on the river below the industrial outfall, the Rideal-Stewart modification of the Winkler method, adapted for polluted waters, was employed; the first steps of this analysis were accomplished in the field, and the titration was completed in the laboratory.

Unless otherwise specified, all water samples, including those for dissolved oxygen, were taken from undisturbed surface water according to methods recommended for the respective tests.

Nutrients.--Samplings and tests for essential nutrients were made from a series of key stations at approximately ten-day intervals throughout an eleven-month period. These 5-7 stations regarded as the most important were all included in the samples taken on virtually every such day, but the number and identity of other stations tested on any one sampling day was variable. With this flexible procedure, it was found possible to keep more satisfactory account of the entire river, and it is believed that much was learned, and that many facts which would otherwise have been missed were brought out by the

occasional samplings from new and relatively unvisited stations on the stream.

Tests for inorganic phosphate were made by the method of Fiske and Subbarow (1929) based upon the reduction of phosphomolybdic acid to blue molybdous compounds. Tests for nitrate were made by the Rietz modification of the Feigl method, which depends upon the oxidation of the colorless diphenyl amine to form a blue dye in the presence of nitrates and in an acid medium (Feigl, 1937). Total organic nitrogen was determined colorimetrically by reaction with Nessler's reagent after digestion according to the method of Koch and McMeekin (1924).

C. Biological Methods

1. Qualitative Work

Observations of the stream and collections of algae were made regularly at approximately ten-day intervals throughout a period of about fourteen months. Prior to that time the stream had been under observation at approximately monthly intervals for six additional months. The algae were examined in the laboratory as soon after returning there as was convenient. If it was necessary to keep the algae more than a few hours, they were kept under refrigeration until it was possible to examine them. After examination and identification of important forms, representative specimens were preserved in formalin for future reference, or else were dried. In general, Cyanophyceae and all larger algae of other groups were dried, whereas desmids, diatoms, and representatives of Chlorococcales were preserved permanently in formalin. Selected collections of preserved diatoms were prepared for study by standard methods and were mounted in Hyrax. Dried

specimens of Cyanophyceae and of all other algae excepting microscopic forms, as well as preserved slides of all important diatoms, have been filed in the Herbarium of the University of Michigan. Specimens of algae preserved in formalin have been filed in the collection of Professor William Randolph Taylor and in that of the author.

In determining the algae, no attempt was made to identify all the species present, largely because it is felt that species lists of fresh water algae in which, after long search, are enumerated faithfully all of the species observed, are ecologically deceptive. A careful search for all species present is bound to yield a great many which are not necessarily reproducing in the habitat from which they are recovered. This is true most particularly and emphatically of river algae, which live surrounded by water in continual motion, and which face constantly the danger (or the opportunity) of being suddenly transported over large distances. It is true for all planktonic algae as well as for any usually benthic algae (cf. Nitzschia palea below) which detach or disengage themselves frequently and rise into the plankton. Thus the algae which are temporarily suspended in stream plankton, which are temporarily trapped in other algae or in bottom sediments, or which are snagged on obstructions in the water, are evidently migrants from points upstream, and quite possibly have no chance whatsoever of survival in their new environment. A list of forms from any one station of a stream which includes such haphazard adventives is not always ecologically significant and may serve only to hinder the derivation of useful knowledge from the data presented. Such lists have been repeatedly published by workers on streams in the past, with no statement or apparent realization of this particular

pitfall. Budde (1930), however, lays emphasis on the fact that the classification of species into one or the other of the saprobic groups of Kolkwitz and Marsson (1908) ought to be made only when a species has been found in great abundance in a specific habitat, as well as in relation to the species found together in the habitat, and states that the mere presence in polluted water of a cell or filament of an alga does not necessarily mean that that organism is deserving of classification as a pollution-tolerant species.

In the present work on the Saline River, those species at each station which were present there in significant numbers were determined. Species, especially microscopic ones, which were represented by only one or two observed specimens, were, in general, ignored unless they were actually attached by some means which showed conclusively that they were not merely adventives in the locality.

No special equipment was used in qualitative sampling except for a three-point grapple adapted from a cultivating tool. This, provided with a wooden handle, was necessary to obtain bottom samples in pools at all times and in riffles at periods of high water. In collecting such microscopic, mostly unicellular forms as inhabit the surface of submerged silt deposits, a simple aspirator bottle was used.

Qualitative collections were commonly made on each day designated for this purpose at stations 5, 8, 12, 13, 14, 17, 18, 25, 28, and 38. Stations 9, 10, and 15 were visited at approximately three-week intervals. In addition, numerous other established stations were visited and sampled at irregular intervals throughout the year, and portions of the stream both above and below Saline and Milan were investigated regularly on foot. It is felt that a general understanding

of the river would have been seriously curtailed if such surveys afoot over considerable horizontal distances had not been made, and if the study had been confined, as many such surveys have apparently been in the past, to the observation from month to month of rather rigidly delimited stations on the stream.

In general and with time it became possible to recognize in the field nearly all the important species of algae and their colonies, except for absolutely microscopic and planktonic forms. Frequently when some doubt as to the identity of an algal mass or layer was felt, the doubt could be resolved by use of a hand lens. Field identification is an absolute prerequisite to quantitative ecological work on fresh water algae, and a macroscopically varied algal vegetation with numerous distinctive species as in the Saline River is a great advantage, if not a necessary condition, to the pursuit of such a project with hope of success.

2. Quantitative Work

In undertaking the quantitative measurement of algal growth in the stream, the possibility of utilizing the submerged slide method of Butcher (1932) was considered. It was felt, however, that the great magnitude of the seasonal changes in the Saline River would not be adequately recorded by the small plants attaching to glass slides, and alternative methods were adopted. These included (1) transects of the stream at monthly intervals, (2) dry weight determinations of the most important algae, (3) placing of sterile rocks within the stream and observation of subsequent colonization on them, and (4) plankton counts.

Transects.--The method which was evolved after some trial and error is a modification combining some of the features of both the transect method and the list quadrat, and is especially useful for ecological work in streams. A rope marked off into decimeter and meter units is stretched across the stream at a riffle (Fig. 2a) and as close to the water as possible. Presence is recorded in alternate decimeters of all algal species an individual or colony of which is crossed by the rope. If a tuft or colony of a given species was present in a given decimeter of the vertical plane through which the rope passed, that species was, therefore, counted as present and no further record was made of its importance in that particular decimeter. The importance of a species was thus determined by the relative number of decimeters within which that species was present. Alternate rather than consecutive decimeters were recorded in order to avoid the effect of grouping, the tendency, that is, for the presence of a species in any one decimeter to increase the likelihood of its occurrence in neighboring decimeters. Frequency was obtained for each species present by determining the relative percentage of the total decimeters in which it was found in relation to the total number of decimeters whose composition was recorded. Usually two or more such transects were made at each such visit to a station, until a total of 50-100 decimeters had been recorded for that station on that day. These transects were all oriented at approximately right angles to the direction of water movement, and all were located with the intention of providing a typical cross section of the riffle. This method is not applicable to pools, and is workable only with difficulty even on riffles when the water is eight inches or more in depth and

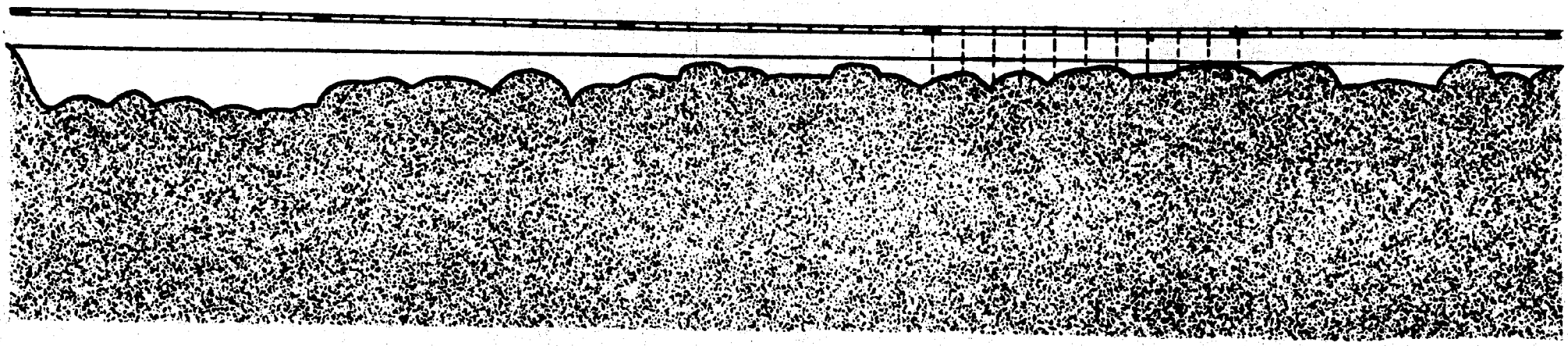


Fig. 2a.--Diagram of Station 8 (riffle) in cross section showing rope marked in decimeters and meters (thickness exaggerated) in position for transect determinations. Scale of depth (1.0 cm. = 1.0 dm.) is twice that of breadth (1.0 cm. = 2.0 dm.). Soundings made October 3, 1952.

when turbidity is high.

In the early portion of the work records were made of the complete transect, from bank to bank. Portions of the stream near the bank, differing in depth or in rate of flow or in both these factors from water across the more central portion of the stream, were recorded separately from mid-stream portions. As work progressed, it was found that the edges of the stream, atypical as they were, involved so many ecological variables that statistical observation of the changes there would be a study in itself. In order to obtain more significant and more comprehensible data from the typical portions which naturally are of greatest interest, statistical records on the edges of the stream were discontinued: only those portions of the transect passing through apparently typical parts of the stream were considered. Qualitative observations of the edges of the stream were, of course, continued as before.

Delimitation of "typical" portions of the transect was based upon average conditions prevailing there. A "typical" portion is an area which is essentially like the greater part of the riffle as regards average depth, apparent total incident light per day, the nature of the bottom, current rate, and composition of the water. The latter factor is probably non-variable throughout the riffle at a given time, except in riffles immediately below the entry of a tributary or other effluent.

All visible species are reduced by this method to the same category, regardless of the level within the stream at which the species is found. Filaments of large algae such as Stigeoclonium or Cladophora recorded on the transect are likely to be attached at some point upstream but to float free within the water current at a vertical distance of some centimeters above other benthic forms which lie in the

plane of the transect. Below the larger algae, the rocky bottom of the riffle may be covered over with an appressed crust of microscopic algae which are nevertheless visible as a colony. Above this hard, part mineral, part organic, crust may be a thin to relatively thick layer of diatoms or a mat of blue-green algae which cover over and completely conceal the crustose forms. If the rocks are thoroughly scrubbed with a brush in a current of water, such superficial layers will be removed, exposing the crustose forms below. After some experience in this work, it is generally possible, however, to recognize the presence or absence of at least certain crustose forms even when they are covered over by a continuous layer of another species. Tabulation of forms present upon a given transect necessitates, therefore, the observation of species present at these different levels within the stream.

In practice, it was found inconvenient to record the presence or absence of certain of the crustose communities which remained present in apparently unchanged amount throughout the year and showed, in such quantitative determinations as were made of them, no significant seasonal variation. The forms recorded as present on a given transect were limited, therefore, to a series of conspicuous and important species or communities, certain or all of which fluctuated widely in frequency from season to season. Species forming colonies so small as to be inconspicuous to the eye, and non-colonial microscopic species, were not recorded, along with the principal crustose forms whose variation, if indeed they experience any, is not mensurable by the present method.

Certain of the diatoms of streams form colonies which are easily distinguishable macroscopically. These were recorded by species on the

transects. Certain other benthic, non-calcified, diatoms grow in wide-spreading layers on the surface of submerged silt banks, and others will be found in fairly cohesive layers on rocks and on bottom gravel, even in areas of swift water. In polluted portions of the Saline River, such growths are likely to be limited to only one or two species, whereas in the non-polluted upper portions of the stream, a mixture of many diatom species is to be expected. In transect records, the presence of such a "diatom layer" was generally recorded as if it were a single species, and its composition was subsequently determined in the laboratory from samples taken at representative places on the transect.

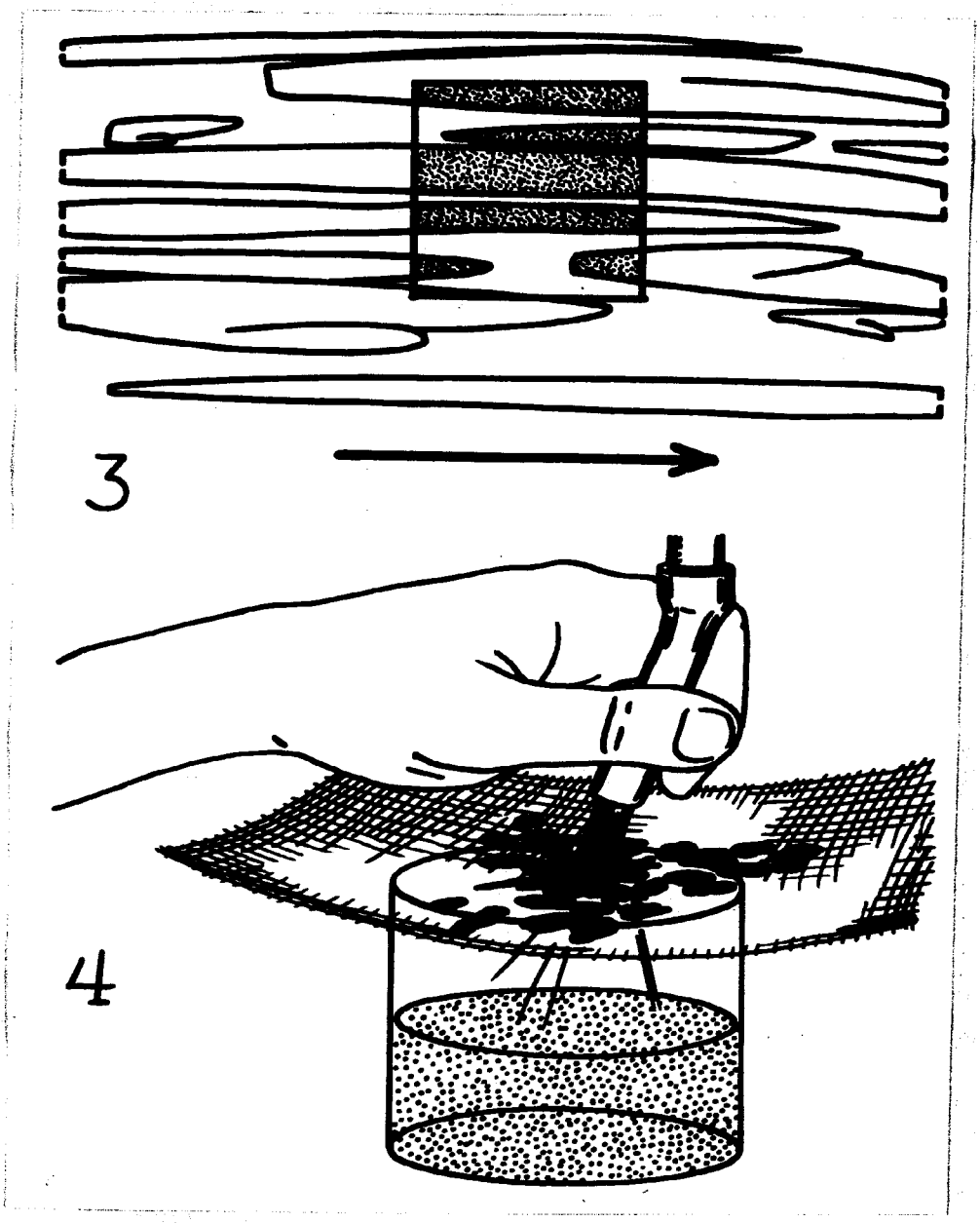
It should be noted that even the colonies of such diatom species as are macroscopically recognizable are likely to contain a number of other diatom species growing attached to or adherent in some way to the species which is principally responsible for the formation of the colony. Sometimes this is true to such an extent that observation with the microscope reveals a population of the epiphyte or cohabitant almost as large as that of the host or the dominant species. In the ecological method here employed (transect), such species of secondary rank and the part they play in the formation of the entire diatomaceous ensemble are, of necessity, ignored.

Dry weight.--In the determination of dry weight of plants of certain algal species within the stream, several possibilities were considered. Since the purpose of this study, as well as the recording of transects, was to afford a quantitative gauge of algal growth from month to month, it was necessary to analyze material from a standard area within the stream. The denudation of vegetation in an entire riffle is scarcely possible for a single worker; nor is it desirable,

since such drastic treatment would be expected to have severe repercussions on the stream for many months thereafter. A smaller typical example of standard area was therefore taken.

The following difficulties are encountered here: (1) Adequate sampling of the vegetation by the quadrat method is difficult or impossible without employing relatively large-area quadrats. (2) Denudation of large-area quadrats on so limited an area as a riffle is subject to the same drawbacks as are attendant upon denudation of the entire riffle. (3) The delimitation of a given area of the bottom and the removal of all organisms from that area, exhibits certain inherent drawbacks when applied to those fresh water algae which form tufts or streamers extending downstream from their point of attachment. No matter which of the usual methods is employed, removal of such algae from the quadrat under consideration necessitates the severance of all algal filaments from their portions which lie upstream or downstream from, and lateral to, the sampling area (Fig. 3). No deleterious effect results on the upstream side of such a quadrat, but severance of algal streamers from their downstream portions may set free large masses of algae which had their attachment somewhere within or upstream from the sampling area; thus significant ecological changes may be wrought downstream from this area. For Cladophora, which has streamers 4-8 feet in length in certain seasons, such changes may be considerable, and can invalidate all statistical work done in the immediate downstream area for some weeks thereafter.

Because of these difficulties, a different method of sampling was developed. Its principle consists in the removal of a given quantity of bottom material with all attached vegetation, no matter what position in the stream the attached vegetation occupies.



Figs. 3, 4.--Fig. 3. Diagram showing Cladophora community as seen from above, with standard 0.5 meter square area (quadrat) indicated. Fig. 4. Apparatus for washing algae for dry weight determinations.

Overlying vegetation attached upstream remains undisturbed; all algae remain, in fact, undisturbed, except those complete plants which are removed from the stream. In practice, twenty rocks are removed at random from the riffle bed by means of the grapple. The rocks are laid in a row in arbitrary order upon the bank, and alternate ones to a total of ten are then removed and placed on the pan of a spring scales, or in a pail, for weighing. If the ten rocks together weigh twelve pounds (±0.5 lb.), they are used as the sample and the other ten are returned to the stream. If the ten rocks when weighed amount to more or less than twelve pounds, one or more smaller (or larger) rocks chosen from the ten still remaining on the bank are substituted for an equal number of those being weighed, until ten rocks have been found which weigh twelve pounds (±0.5 lb.). Their algal vegetation is removed and placed in a collecting bottle. These ten rocks are then returned to the stream at a point chosen for this purpose, which is henceforth avoided when making ecological observations. The remaining ten rocks are also returned to the stream.

The ten rocks thus used in sampling the stream are assumed to represent a typical standard portion of the stream bottom, to expose a standard surface to the overlying water layer, and to be inhabited by a standard population of algae. The algal vegetation of these rocks can be harvested for dry weight determinations, but the method of removal as here adopted depends upon the species of algae being harvested. It was found preferable to take representatives of Stigeoclonium, Batrachospermum, and the bacterium Sphaerotilus by scraping with a knife. Cladophora species, however, were removed with the fingers. The necessity for this distinction may apply only to the Saline River, but in this stream the frequent association of

Cladophora with communities of appressed crustose algae contraindicates the close scraping of the rock surface with a knife. If this is done, large quantities of crustose material are removed which subsequently are virtually impossible to separate from the Cladophora filaments. Thus, in the interest of avoiding a large error which would certainly result from the inclusion of such crustose material with the Cladophora, a lesser error must be assumed: the very small Cladophora filaments are not included with the sample for dry weight determination.

In the present study, limitation of time prevented such dry weight determinations being made for more than the most important and conspicuous filamentous forms. The species chosen for these records were Cladophora glomerata, Batrachospermum boryanum, Stigeoclonium tenue, and the bacterium Sphaerotilus natans. This method is most serviceable for the large filamentous algae; it would be applicable to the crustose forms, and with greater difficulty to certain of the diatoms.

After return to the laboratory, the algal material is removed from the collecting bottles and divided for washing into portions of suitable size. It is then washed portion by portion on a ten-inch square of window screening which is supported on a glass cylinder with open ends (Fig. 4). In this washing, which must be done manually, a jet of tap water of considerable force is directed down onto the algae, and is continued for each portion of algal material until the wash water in the cylinder below is essentially free of turbidity. Stigeoclonium and Sphaerotilus are easily washed in this way. Cladophora species must be separated out and constantly untangled as they are being washed, or no amount of washing will removed all of the attached

sand and grit. After thoroughly cleaning each portion, many small grains of gravel remain nevertheless adherent to the Cladophora--these must be removed individually with fingers or forceps. When the algal material is free from mineral particles, it is placed upon a square of powder paper of known dry weight, dried to constant weight in a drying oven, and its weight determined.

The sources of error in this method are numerous. They may be summarized as follows:

1. The error resulting from the fact that only rocks within a certain size range are included in the collection. Boulders and other rocks above a certain size are too heavy to be removed from the stream by conventional methods; and rocks which are too small to be retained by the grapple are obviously not included in the sampling.
2. The error resulting from the impossibility of removing by this method all algal filaments from a rock. The relative smoothness or roughness of the rock surface is a factor contributing to this error.
3. The breakage and removal by the current (largely unknown to the operator) of small or large portions of algae while the rock is being removed from the stream bed. This is very common and almost unavoidable with Stigeoclonium tenue, Sphaerotilus, and almost any alga of more or less gelatinous texture.
4. The inclusion of numerous caddis fly webs in certain types of vegetation, particularly Cladophora.
5. The inclusion of a few small sand particles in masses of Cladophora, unavoidable unless each grain is removed by hand.

6. The greater wet weight of very large masses of algae, and the resulting slight reduction in weight (and hence in exposed surface) of the ten rocks selected for sampling.
7. The unavoidable inclusion with the benthic filamentous vegetation, of fragments of similar (or other) algae caught in the algal filaments. The most important fraction of this error is the numerous filaments of dead or living Cladophora caught or anchored in those caddis fly nets which are incorporated into the benthic vegetation. Frequently the adventive algae are branching systems which much resemble young plants growing in situ and cannot be readily distinguished from them without studying each plant individually.
8. Epiphytic algae and bacteria--a particularly important source of error in Cladophora determinations in fall and winter. Many of these epiphytes deposit carbonates outside their thalli, which can become a continuous crust about the filaments of the host, and, in this way, likewise increase its apparent dry weight.
9. The breakage and disappearance in the washing process of many algal filaments.
10. A comparative error which must be considered when the different kinds of algae are compared on this basis--resulting from the fact that Stigeoclonium can only be removed by scraping, whereas Cladophora is best removed by a plucking procedure.

Many of these sources of error, for example numbers 5 and 9, tend to balance each other to a certain extent. Nearly all are such as could by some means be avoided in whole or in part if an unlimited amount of

time were available. Future workers who become interested in such problems regarding benthic river algae will find that methods comparable in precision with those now applied to a study of fresh water and marine plankton can be worked out readily enough, but it is likely that such methods will be distinctly more time-consuming and will demand even greater care and patience on the part of the operator than do the standard plankton methods of the present time.

Colonization on sterilized rocks.--For a study of colonization and succession, large glacial polished rocks weighing 3-5 kilograms, such as occur commonly in local drift (and on the stream bottom), were collected from a morainal deposit and sterilized by heating dry in an electric oven at a temperature of 400 degrees F. for five hours. Each rock was labeled with a conspicuous number in black enamel and was placed, with the number down, at a given locality in the stream. Precise note must be taken of the date and the exact spot where the rock has been placed. Rocks of this weight are not often displaced, even in fast currents, and although trouble has occasionally been experienced in recovering certain rocks, none have been permanently lost. Finding the rocks on a subsequent date is facilitated, and their removal by the current rendered more unlikely, if they are arranged in a straight row on the stream bed, parallel to the direction of flow.

Colonization and succession is soon apparent on such rocks even when viewed through the layer of moving water. For careful observation of their vegetation, they must be removed from the water momentarily. Samples of the vegetation can be collected at this time for study in the laboratory, but it is necessary to make careful note of the portion of the surface from which the sample was taken so that

this disturbed area will not be mistaken for typical vegetation on the next inspection of the rock. As soon as observation has been completed and samples, if any, taken, the rock is returned to its position in the stream. A series of such rocks, placed in the stream on successive dates and examined at intervals of ten days thereafter, provides information as to the times and conditions of reproduction of many algae in the river and convincing evidence of algal colonization and succession on the river bed.

Plankton counts.--For determination of phytoplankton, the method of Verduin (1951) was followed in all details.

IV. DESCRIPTION OF THE SALINE RIVER

Physiography and land use.--The Saline River lies within Washtenaw and Monroe Counties in southeastern Michigan. Its total length along its axis is 40.8 miles (65.3 km.) and the total surface area of its basin is about 118.8 square miles. It takes its source in small creeks which drain agricultural land in the southwestern portion of Washtenaw County about twelve miles southwest of Ann Arbor (Fig. 1). The course and flow of the river as a whole is in a southeasterly direction. After passing the village of Saline and the city of Milan, both of which are built partly within its valley, it flows into the Raisin River near Dundee, and its waters are thence carried into Lake Erie close to the far western end of the latter. It should be emphasized that the name of the Saline is a misnomer: it is neither saline nor a river, having a small volume of flow of essentially fresh water.

The principal tributaries of the Saline have been assigned numbers in Figure 1. Certain of them, notably Tributary 15, have their origin in permanent springs with a steady flow of water, which ensures the presence of water in the river itself the year around. The majority of the tributaries originate in part from surface runoff, in part from seepage springs, and, in addition, are further augmented in their lower courses from the same two sources. The principal tributaries are more or less permanent creeks with a relatively small volume of flow. They drain land whose use is largely agricultural,

with a large percentage of the land in pasture and another considerable portion fallow or abandoned; but portions are wooded, other small portions are urban or suburban, and others are industrial or recreational in use. In many places the flood plain of the river is covered by thickets which render portions of the river difficult of access.

Glacial history.--The major portion of the upper course of the river lies upon the abandoned bed of a ponded section of the glacial Huron River. Just west of the city of Saline, the Saline River turns to the south and passes through a narrow channel cut across the Defiance Moraine. This channel was cut by the Huron River in later glacial times, when the Huron emptied for a brief period into Lake Maumee at Saline. Later the Huron was diverted to its present channel, whereupon the formerly ponded area west of Saline began to drain through the abandoned channel of the Huron across the Defiance Moraine. The drainage system thus established formed the Saline River, which therefore had at its inception an extensive headwaters system already developed (Bay, 1938).

Character of the river bed.--Drift in the Ann Arbor area, deposited in Wisconsin times as well as in earlier glaciations, is as much as four hundred feet thick (Russell and Leverett, 1908). The erosive removal of soil and smaller stony particles has resulted in massive accumulations of polished rocks in the valley of the Saline River and on the floor of the numerous riffles, especially where the river crosses the Defiance Moraine. Many of the pools, the portions of the river between adjacent riffles, manifest in this area similarly rocky bottoms which commonly are thinly covered over with sediments.

Once the river leaves the region of the Defiance Moraine and enters the bed of glacial Lake Maumee, its character changes: it

meanders more frequently; few riffles are found in the remainder of its course; and what riffles are present are less differentiated--the stony material which underlies their floors and their crests consists of pebbly detritus and of much smaller stones than those found nearly everywhere above the third Maumee beach. The bed of this lower portion of the river is composed largely of a deep deposit of silt and organic materials.

Ponds and impoundments.--Two impoundments of the river itself are currently operative. The first, located just north of the bridge on U. S. Highway 112 at Saline, is a large pond whose surface area as estimated from the Saline Quadrangle map is about 0.0060 square miles. A somewhat larger pond with a surface area as estimated from the Ypsilanti Quadrangle of about 0.0087 square miles, is found just north of the Saline River bridge in Milan. These ponds will henceforth be referred to as "Saline Pond" and "Milan Pond" respectively. The volume of flow from both ponds can be regulated to a certain degree by weirs. Mill races have been built as secondary outlets to both ponds. The mill race from Milan Pond diverts a considerable volume of water, whereas that at Saline is inactive and no flow of the water in it has been observed during the period of this study. An impoundment was present at Saline Mills until about 1946 when, according to local residents, disintegration of a portion of the dam at that point returned the river to its original level except for an unusually deep pool which remains below the site of the dam. A small impoundment is present at Saline Valley Farms on Tributary 18, and an impoundment on Tributary 16 was drained and subsequently impounded again during the course of this study. No other impoundments are believed to be extant

on the stream or any of its tributaries at the present time.

Four natural ponds are found in the headwaters portion of the Saline River, in Township 4S, Range 4E, Sections 3, 10, 11, and 12. Few observations of the stream have been made in this area. Due to the small volume of drainage issuing from these ponds, it is assumed that their importance in determining conditions within the stream is relatively less than that of at least the major tributaries which enter much further downstream. Two other ponds or small lakes occur in the headwaters region of Tributary 13.

Sources of pollution.--(1) The highest important source of pollutants in the stream is from the factory at Saline (Fig. 2). This waste enters just above the Macon Road bridge, and from the left bank (as do all other outfalls downstream). Flow from this outfall is continuous but variable. On three occasions when it was measured by the Michigan Water Resources Commission, it was determined as 302 gallons per minute (September 10, 1952), 427 gallons per minute (September 10-11, 1952, and 176 gallons per minute (September 17, 1952). The volume of flow in the river just above this point was estimated on the latter date as eight cubic feet per second (Frost and Mills, 1952).

The importance of this effluent to the life of the stream is due to its high content of certain poisons lost in plating processes. In Table 1 are shown the content in parts per million of cyanide, hexavalent chromium, and copper as determined by the personnel of the Michigan Water Resources Commission on five dates in 1949 and 1952 Frost and Mills, 1952). Information obtained from the plant chemist, Mr. Detwiler, as to the actual amounts of these poisons lost to the stream by the effluent was not in entire agreement with the data

TABLE 1

CONTENT OF CERTAIN POISONS IN THE FACTORY EFFLUENT, SALINE, MICHIGAN*

	4-7-49	4-12-49	4-14-49	9-10-52	9-17-52
Flow (g/m)	287	289	296	302	176
CN (ppm)	9.4	5.7	8.3	14.7	26.0
Cr_6 (ppm)	14.	10.	24.	8.0	16.0
Cu (ppm)	42.5	4.0	8.5	10.0	16.0

*Data from Frost and Mills, 1952.

presented in Table 1. According to this source, the amount of cyanide lost is not in excess of one part per million. Another factor which complicates the environmental picture is the procedure followed at this factory of dumping into the river two three-hundred gallon tanks of 0.5% sulfuric acid every night, together with considerable quantities of alkali which largely neutralize the acid. In numerous determinations made of the hydrogen-ion concentration of this waste, however, no great variation was ever observed (Table 2).

Raw sewage from the plant, which enters the river mixed with the industrial wastes, as well as the dilution water utilized by the plant, represent additional complicating factors. The dilution water is derived from a deep well on the company property and, according to information received from Mr. Detwiler, is relatively high in iron (ca., 4 ppm.) and carbonate content. Temperature of the outfall is more uniform than that of the river, and in winter particularly is much warmer (about 12-16° C. according to determinations made by the author) than the river water. Analyses for pH and for certain nutrients made during the course of this study are summarized in Table 2. It will be observed that inorganic phosphates are released from this outfall in

TABLE 2

ANALYSES OF THE FACTORY EFFLUENT,
SALINE, MICHIGAN

Date	pH	Phosphate P mg./l.	Nitrate N mg./l.	Organic N mg./l.
6-15-52	----	0.09	----	2.0
6-22-52	----	0.35	----	3.8
6-30-52	7.75	0.32	----	8.0
7- 8-52	7.65	5.07	----	0.5
7-15-52	8.52	0.85	----	1.2
7-21-52	8.20	0.26	----	----
7-29-52	8.45	0.62	----	1.0
8- 8-52	8.69	0.33	0.0	1.0
8-18-52	8.34	0.45	3.0	0.03
8-25-52	8.51	6.25	----	----
9- 4-52	8.85	0.64	0.5	4.0
9-15-52	8.28	0.19	2.5	1.4
9-25-52	7.69	0.27	7.5	1.0
10- 7-52	7.65	0.60	1.0	0.9
10-16-52	7.82	0.3	4.0	2.2
10-27-52	----	0.25	3.0	0.1
11- 7-52	8.38	0.13	2.0	0.2
11-17-52	9.06	0.32	2.0	3.9
11-26-52	7.05	0.10	3.0	2.0
12- 7-52	8.03	0.005	0.5	2.2
12-16-52	7.50	0.105	3.0	0.4
12-28-52	8.60	0.06	0.0	0.8
1-12-53	7.42	0.04	1.5	8.6
1-23-53	7.66	0.075	2.0	0.8
2- 4-53	7.99	0.04	1.5	2.3
2-14-53	8.52	0.46	1.4	1.3
2-24-53	7.79	0.35	1.0	1.0
3- 7-53	7.80	0.19	2.5	2.6
3-17-53	9.42	----	0.0	6.5
3-27-53	7.42	0.62	1.0	----
4- 3-53	8.15	0.50	2.5	2.3
4-16-53	----	0.19	5.0	1.7

extremely variable amounts, a minimum of 0.005 mg. per liter having been recorded on December 7, 1952, and a maximum of 6.25 mg. per liter on August 25, 1952.

(2) Saline domestic outfall.--Domestic wastes from the city of Saline (population 1533) enter as raw sewage from a single twelve-inch sewer about two hundred yards downstream from the industrial outfall. The effect of this massive accession of sewage combined with the industrial waste already in the stream is immediate and profound; for a distance of several hundred yards below this point, the river has a very polluted aspect, with black sulfurous sludge everywhere on the bottom and highly septic conditions prevailing in the water. Like the industrial effluent, this waste is more uniform in temperature than the river water, and is generally warmer in winter. A determination made October 7, 1952 showed a pH of 7.7, turbidity of 120, 3.60 milligrams per liter of inorganic phosphorus, no demonstrable nitrate nitrogen, but 21.5 milligrams per liter of organic nitrogen.

(3) A third major outfall enters the river 3.8 miles further downstream. This is the effluent from the Ypsilanti State Hospital (total population about 5000: inmates 4100, employees 900). Sewage from the hospital undergoes filtration and, in summer, chlorination, and nitrogen compounds entering at this point are in large part oxidized. No important changes in the aspect of the stream biota were evident as a result of this outfall, on the few occasions when it was visited. Analyses of a collection made December 16, 1952, showed waste entering the river from the hospital drain to have a pH of 7.3 and to contain 1.07 milligrams per liter of inorganic phosphorus, 15.0 milligrams per liter of nitrate nitrogen, and 6.0 milligrams per liter of organic nitrogen.

(4) A fourth major outfall delivers raw sewage from the city of Milan (population 2768) about 0.4 miles below the dam retaining Milan Pond. Just below this outfall a riffle occurs, all parts of which at periods of high water carry river water mixed with substantial amounts of sewage from the Milan outfall. At usual low water conditions only the north side of the riffle receives such polluted water. Below this riffle, which is the only riffle known to the writer between Mooreville and the mouth of the Saline, the river is grossly polluted by the Milan sewage and is believed, on the basis of relatively few observations and collections made downstream from Milan, to remain so throughout the year.

(5) Wastes from various residences, farms, and small institutions located near the banks of the stream find their way into the stream directly, and it is natural that pollution from these sources should be most severe in regions of heaviest population, such as Saline, Mooreville, and Milan. The effect of such drainage, however, is not any greater than would be expected for any stream of similar size which passes through inhabited country, and probably would not, of itself, be sufficient to make the stream "polluted."

Sampling stations.--At the outset of the twelve-month period of concentrated ecological study, it was necessary to select stations which would provide the most informative data about the stream not only for the season in which the study was begun but throughout the entire year. It is obviously not desirable to change stations midway through such a study. With this in mind, observations were made for some months beforehand, and it was thus possible to make a well-planned selection of stations. It was, however, impossible to predict what

problems would arise in the various parts of the stream throughout the entire year, and in some cases extensive observations of certain localities was not begun until attention had been drawn to them by unlooked-for and interesting phenomena occurring there.

The stations chosen for most intensive study are those listed under "A" below, at all of which transects and dry weight studies were made throughout much or all of the year. Water analyses were made at ten-day intervals from most of the stations in both groups "A" and "B."

A. 5. Unpolluted riffle just above the bridge on the Saline-Manchester Road, and just below the mouth of Tributary 11. A headwaters station with steady flow of water the year around, about 45% shaded in summer.

8. Unpolluted riffle about two hundred meters downstream from the Ford Dam which retains Saline Pond. This riffle shows certain temperature and other influences from the pond. It is about 35% shaded in summer.

10. (Fig. 5) Unpolluted riffle about one hundred meters downstream from Station 8. It is about 35% shaded in summer.

12. Unpolluted riffle in woods, about two hundred meters upstream from the Macon Road bridge. It is about 95% shaded in summer.

14. Polluted riffle at Saline dump, just below bridge on Macon Road. The stream at this point carries industrial wastes from the Universal Company, and is about 65% shaded in summer.

15. Heavily polluted riffle just below the sewage outlet for the city of Saline, about one hundred meters downstream



Fig. 5.--View of the Saline River in summer, 1952, just below Station 10.

from Station 14 and about 65% shaded in summer.

18. Heavily polluted riffle about one hundred meters downstream from Station 15 and about 50% shaded in summer.

In addition to the above stations, the following stations were visited, and their vegetation recorded, at ten-day intervals throughout the year, without, however, making quantitative determinations of the vegetation.

B. 9. Unpolluted pool just below Station 8. It has a maximum depth of about 1.5 meters and is about 35% shaded in summer.

13. (Fig. 6) Unpolluted riffle just above the factory outfall at Saline. It is about 35% shaded in summer.

17. Polluted pool just below Station 15. This is a long pool with a maximum depth of about 1.5 meters. Summer shade varies from about 25% to about 85%.

25. Semi-polluted riffle just above the bridge at Saline Mills. A long riffle with much swift water, and with about 25% shade in summer.

27. Semi-polluted pool just above the bridge on Maple Road, about two miles south of Saline. About 35% shaded in summer.

28. Semi-polluted riffle about eighty yards downstream from the Maple Road bridge. Shade is about 35% in summer.

32. Pool at bridge on Petersburg Road, about one mile west of Milan. Shade is about 30% in summer.

35. Heavily polluted riffle just below Wabash Railroad bridge at Milan. Shade is about 50% in summer.



Fig. 6.--View of Saline River and industrial outfall at Station 13, summer, 1952.

Numerous other stations, each indicated by a number in Figure 1, have been visited, some frequently, some only once. On such visits the vegetation, if any, was recorded, and collections were made if such were necessary to the determination of the principal forms present. In addition, analyses were often made of water samples collected on such visits.

Divisions of the river in relation to the saprobic system.--After careful observation at all seasons, it became possible to group the various parts of the stream more or less accurately within the saprobic system of Kolkwitz and Marsson (1908). The upstream Stations 1-13 are thus oligosaprobic as this term is generally used in the literature, and they are usually referred to in this paper as the "headwaters stations." Stations 15-20 and 34-37 may be regarded as belonging to the polysaprobic zone of Kolkwitz and Marsson. Stations 21-24 correspond to the α-mesosaprobic, and Stations 25-32 (principal zone of recovery), as well as Station 14, to the β-mesosaprobic zone. These terms are occasionally used in this work in reference to these respective stations; they are defined in Appendix I.

V. CLIMATOLOGICAL DATA

Total daily precipitation at the United States Weather Station at the Willow Run Airport is shown in Figure 7 for the period from May 1, 1952 to April 20, 1953. While this station is at too great a distance--fourteen miles from both Saline and Milan--to provide an accurate measurement of weather conditions in the Saline Valley, general conclusions as to weather there are possible.

The summer and fall of 1952 was a period of unusually low rainfall in southeastern Michigan. Summer precipitation recorded at Willow Run was only about one half that of the same period of 1951. Because of this, the water level in the river remained relatively low, and almost unchanged, throughout this time, with short and very infrequent periods of slightly higher water occurring at intervals (Fig. 9). A short period of unusually high water occurred on March 5 or 6, 1953. High water marks found on March 7 were about 0.6 meters above the usual level of the water at Station 5, and about 1.0 meters above the usual water level at Station 12.

The year 1952 was likewise unusually warm, with temperatures of 90° F. (32° C.) recorded on thirty-three days, as compared with the usual expectancy of about thirteen such days. From one standpoint, it was unfortunate that the year in which this study was made should not have been a typical one in this respect. From another and at least equally important standpoint, it was of signal advantage to be able to observe visually the riffle beds at nearly all visits throughout

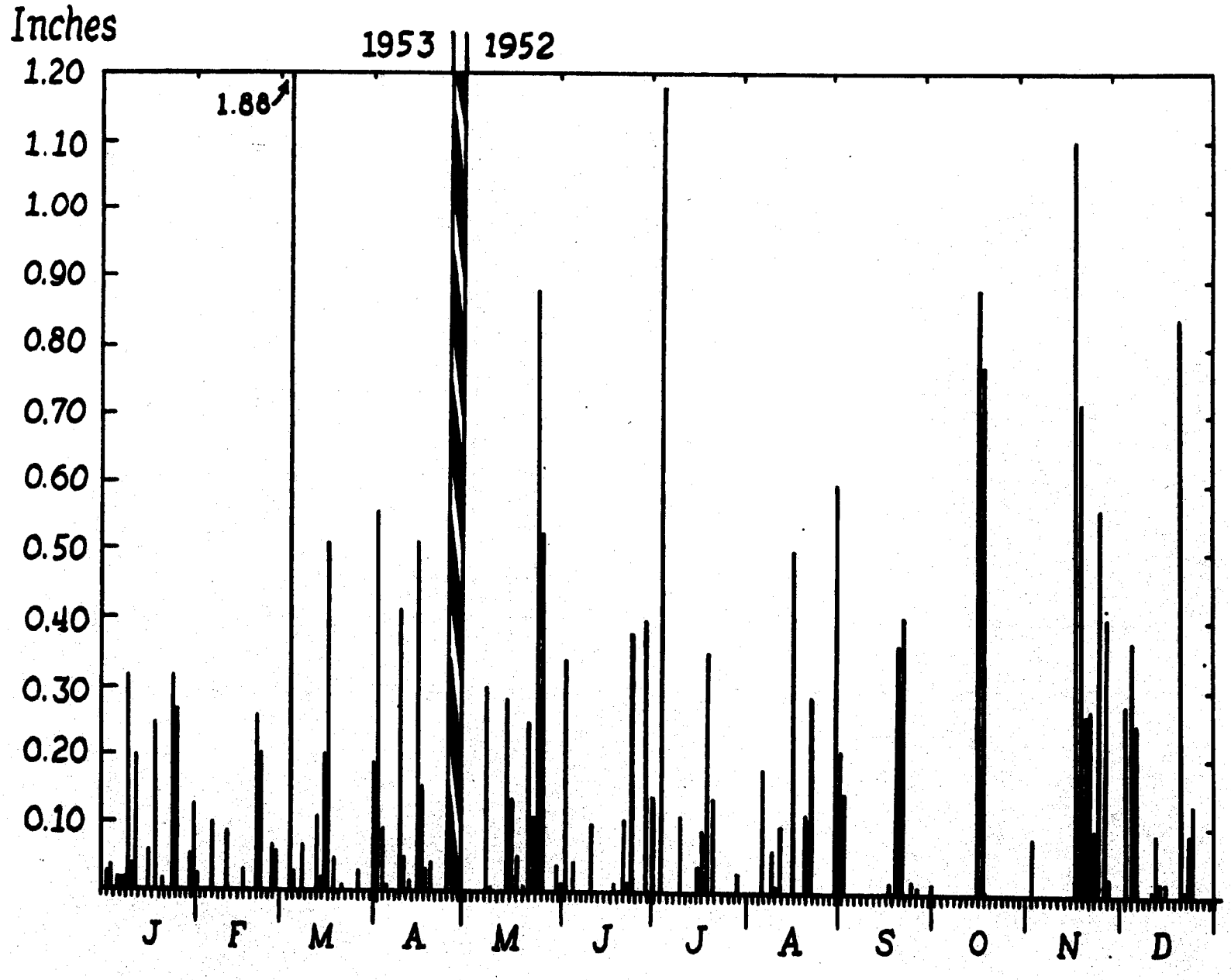
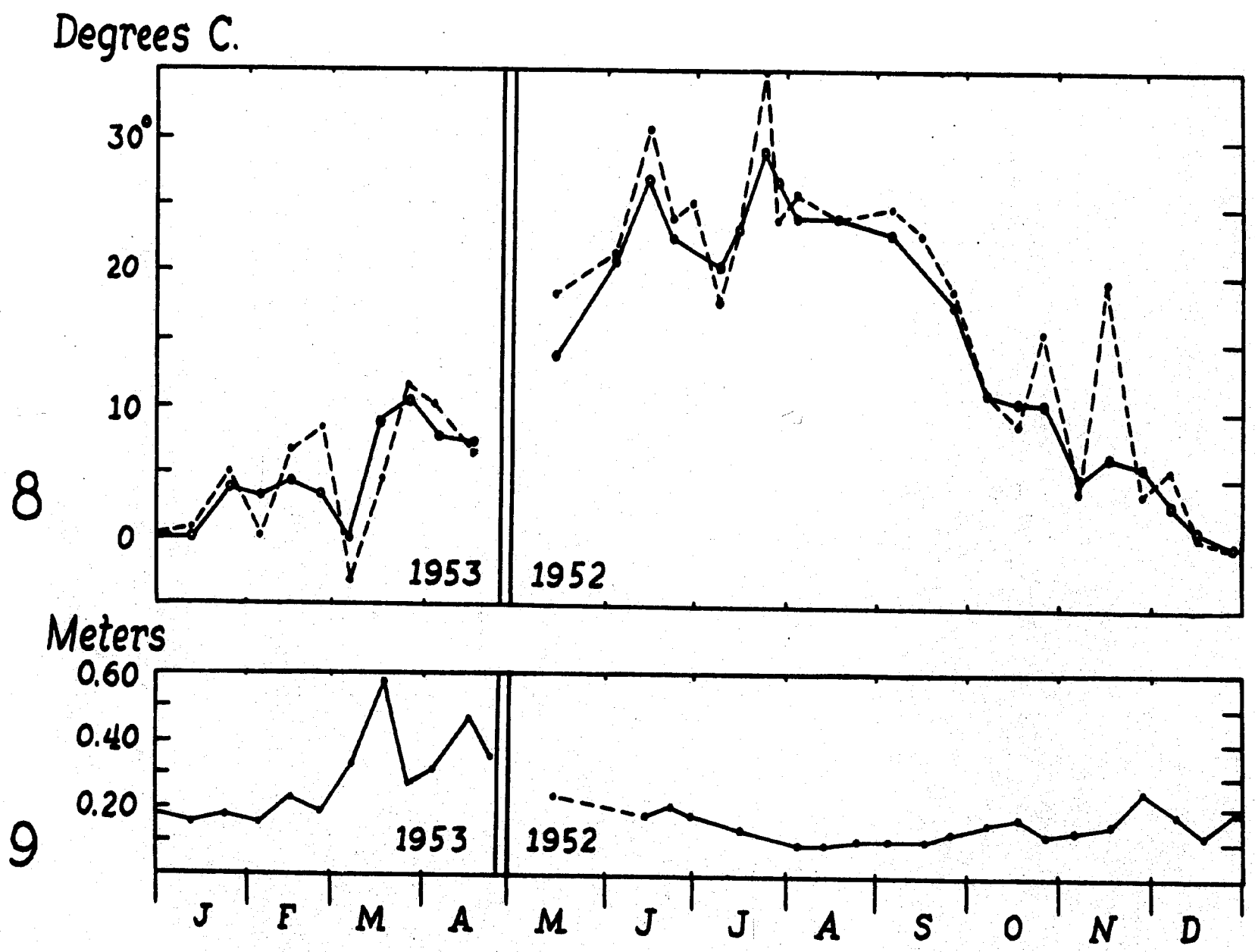


Fig. 7.--Daily rainfall in inches at Willow Run, Michigan, from May 1, 1952 to April 20, 1953.



Figs. 8, 9.--Fig. 8. Temperature of air (broken line) and of Saline River water (solid line) on sampling days from May 10, 1952 to April 15, 1953. Fig. 9. Water level at Station 8 from May 10, 1952 to April 23, 1953.

the year. Certain types of ecological work performed would have been hindered if not completely prevented by water above the level maintained in the portions of the stream which were worked most intensely.

VI. THE SALINE RIVER AS AN ALGAL HABITAT

A. Physical Variables

1. Temperature

Temperature changes of the river water followed those of the surrounding air (Figs. 8, 10), but it was evident that change was less extreme and less rapid than that of the air. Daytime water temperatures in summer were quite variable, ranging from 18° C., recorded July 28, 1952 at Station 28, to 29.5°, recorded July 21, 1952 at Station 8. The latter temperature, the maximum recorded throughout the period of this study, was 5.5° below the air temperature at that place and time. Winter temperatures were less variable than those of the summer. Whereas minimum and maximum temperatures recorded during June, July, and August were 11.5 degrees apart, those of December (1952), January, and February (1953) yielded a maximum of 5.1° and a minimum of 0.0°. It may be assumed that temperate streams of this size and character, therefore, constitute an environment which is intermediate in variability of temperature between the highly changeable environment of many terrestrial habitats, and the relatively constant surroundings of hydrophytes in lakes. This is true not only in regard to temperature changes from season to season, but in regard to diurnal temperature changes as well.

Temperatures with respect to Saline Pond.--Temperatures of the river above the pond in Saline appeared to be more readily influenced

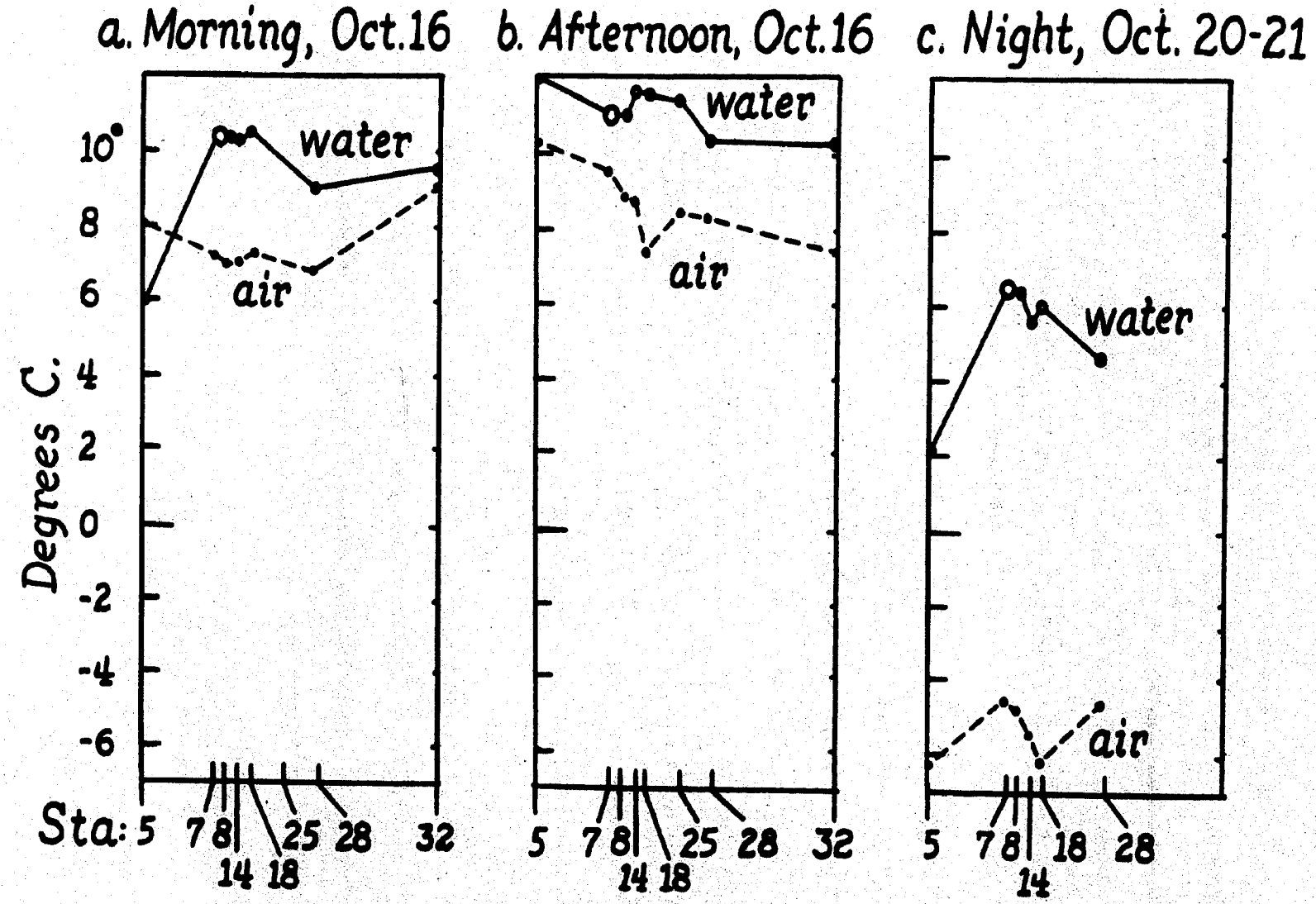
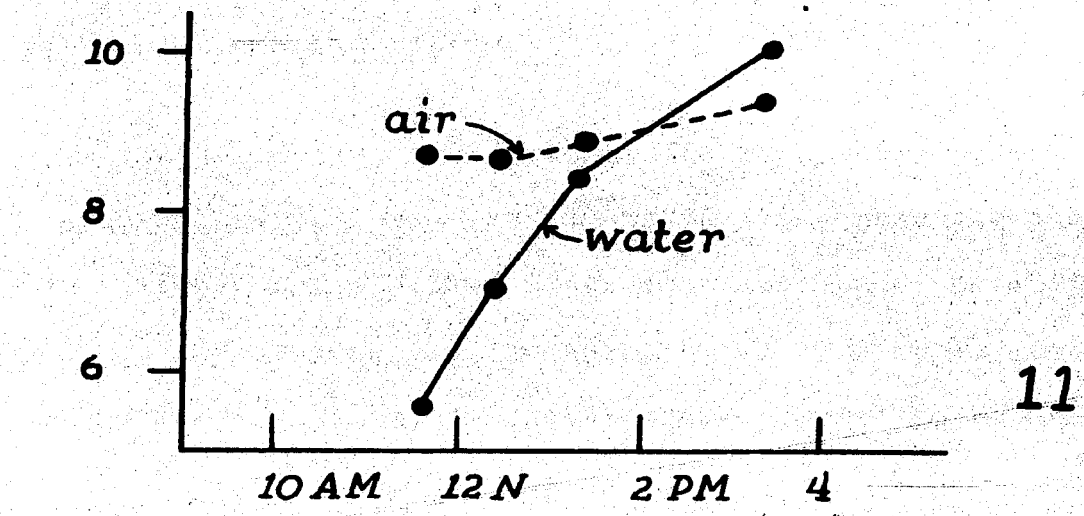


Fig. 10.--Morning, afternoon, and night temperatures of water and air at different points along the river in October 1952, immediately after the marked autumn temperature decline, showing influence of Saline Pond. Series a was begun at 9 A.M. (Station 5) and ended at 11:50 A.M. (Station 32). Series b was begun at 3:30 P.M. (Station 5) and ended at 6:10 P.M. (Station 32). Series c was begun at 11:20 P.M. (Station 5) and ended at 12:35 A.M. (Station 28). Solid line, water; broken line, air. Station 7, Saline Pond, is indicated by a larger circle.

by changes in air temperature than at stations immediately below the pond. Records based upon simultaneous readings at a series of points are unfortunately not available, since it is impossible for a single worker to obtain such readings without special apparatus. However, there seems little doubt from the October 16 data summarized in Figure 10, that the pond, at least in seasons of great thermal change, acts as a thermal stabilizer for portions of the stream immediately downstream from it. Readings made this relatively chilly day showed an increase in temperature at Station 5 (above the pond) of nearly six degrees from morning to afternoon. Surface waters of the pond itself showed an increase at Station 7 of only 1.5 degrees in the same approximate period. Station 8, just below the pond, showed an increase of 1.7 degrees, and Station 28, at two miles below the pond, an increase of 2.6 degrees. Under Section VII it is shown that the difference in temperature relations between stations above as compared with those below the pond is paralleled by certain marked floristic differences which may be dependent upon the differences in thermal phenomena at the respective habitats.

Work of the sun in warming the stream.--The data presented in Figure 10 can be utilized in demonstrating the efficacy of the sun in warming the stream. Figure 11 shows temperature data obtained October 21, 1952 at Station 5. Both this date and October 16 were days of fair weather. On each date there occurred a rise in water temperature in the morning and early afternoon, to a point exceeding the maximum recorded air temperature for those days. Since temperatures in the river bed were generally below those of the air on these dates, it seems clear that this warming effect is due directly to the work of



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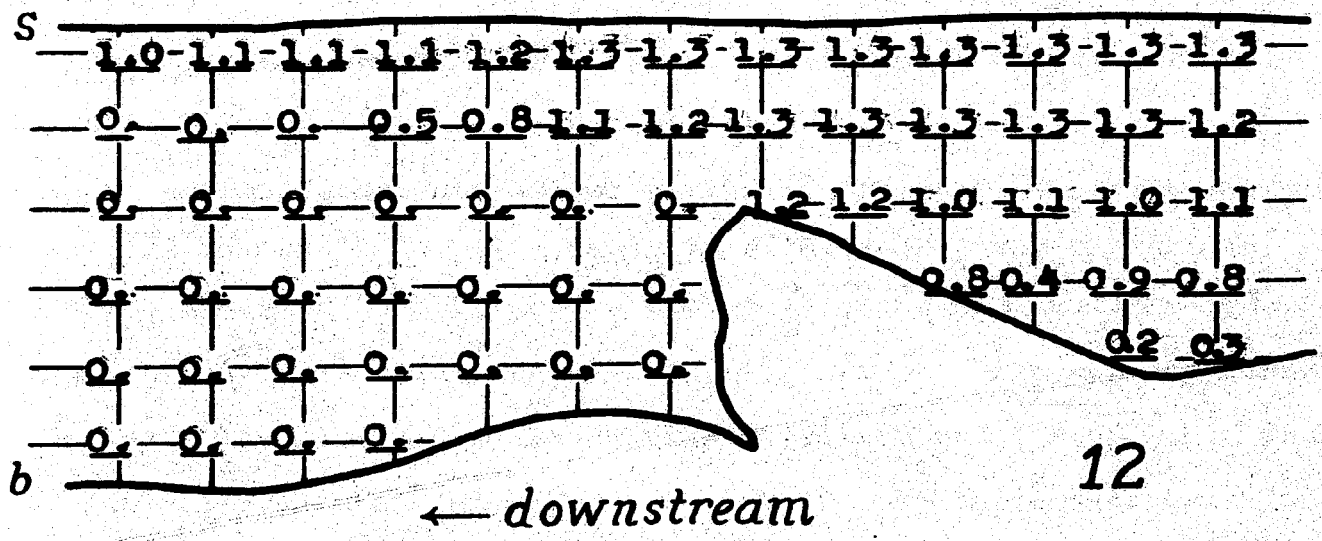

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Figs. 11, 12.--Fig. 11. Change in water and air temperatures at Station 5 on October 21, 1952. Fig. 12. Current rate (in meters per second) at various points in a vertical plane parallel to the direction of the principal current. The plane bisects a rock which protrudes from the stream bed. Readings are recorded at points one inch apart both vertically and horizontally. b, bottom; s, surface.

the sun's rays. Similar evidence of this effect has already been published by Ricker (1934), whose conclusions are corroborated by the data herewith presented.

2. Light

Diurnal variation.--The amount of light reaching algae growing near the surface of the Saline River does not appear to differ greatly in amount from that reaching low herbs which grow on adjacent banks. An alga growing in an unshaded position must therefore be able to withstand full sunlight almost unreduced in amount, but its photosynthetic system in return enjoys the advantages of copious radiant energy. This energy reaches a maximum at about 12:30 P.M. each day in the Ann Arbor region and, of course, varies in duration and intensity with the changing seasons. Figure 13 shows the amount of solar radiation reaching sunny and shaded points at the surface of the stream as well as at the bottom at a depth of seventy-five centimeters at different times on July 6, 1952. Figure 14 shows similar data made February 4, 1953 at the same locality. The former date was cloudless at Saline. The latter was essentially cloudless until 2:30 P.M., when a cloud bank prevented the making of further comparable records. It is obvious that no one position in the stream remains constantly in the sun and probably there are very few which remain constantly shaded. Peculiarities of the stream's course, the character of the bottom, and particularly the ever-present bank vegetation militate against such constancy of incident light. Hence, the amount of radiant energy reaching a given river alga can almost never, even on cloudless days, be expected to follow any one of the curves given in Figures 13 and 14, but instead, for a given depth, must range between the curve for a

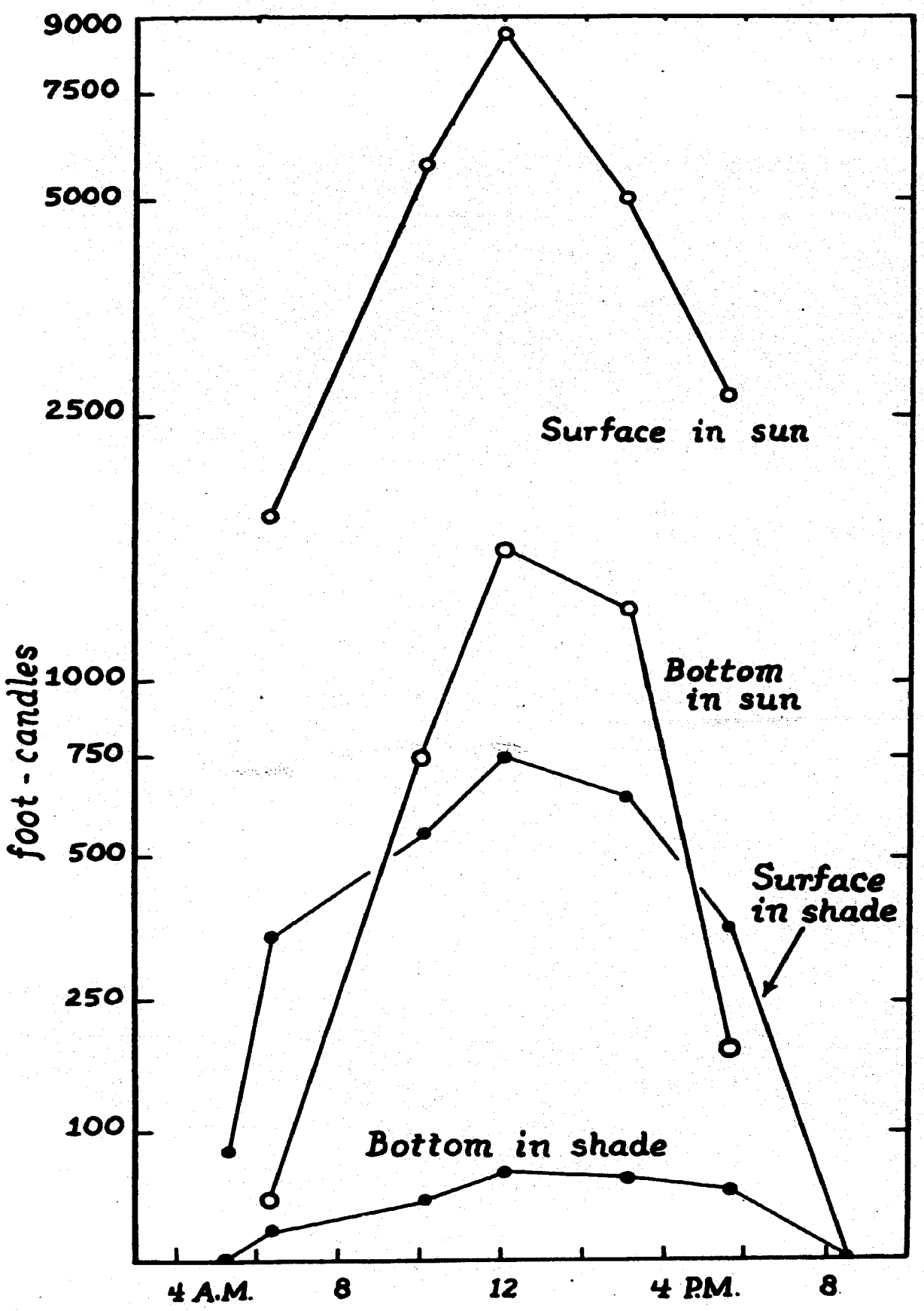


Fig. 13.--Incident light in foot-candles at surface and at bottom (at a depth of 0.75 meters) at Station 17 throughout a cloudless summer day (July 6, 1952). Note logarithmic ordinate scale.

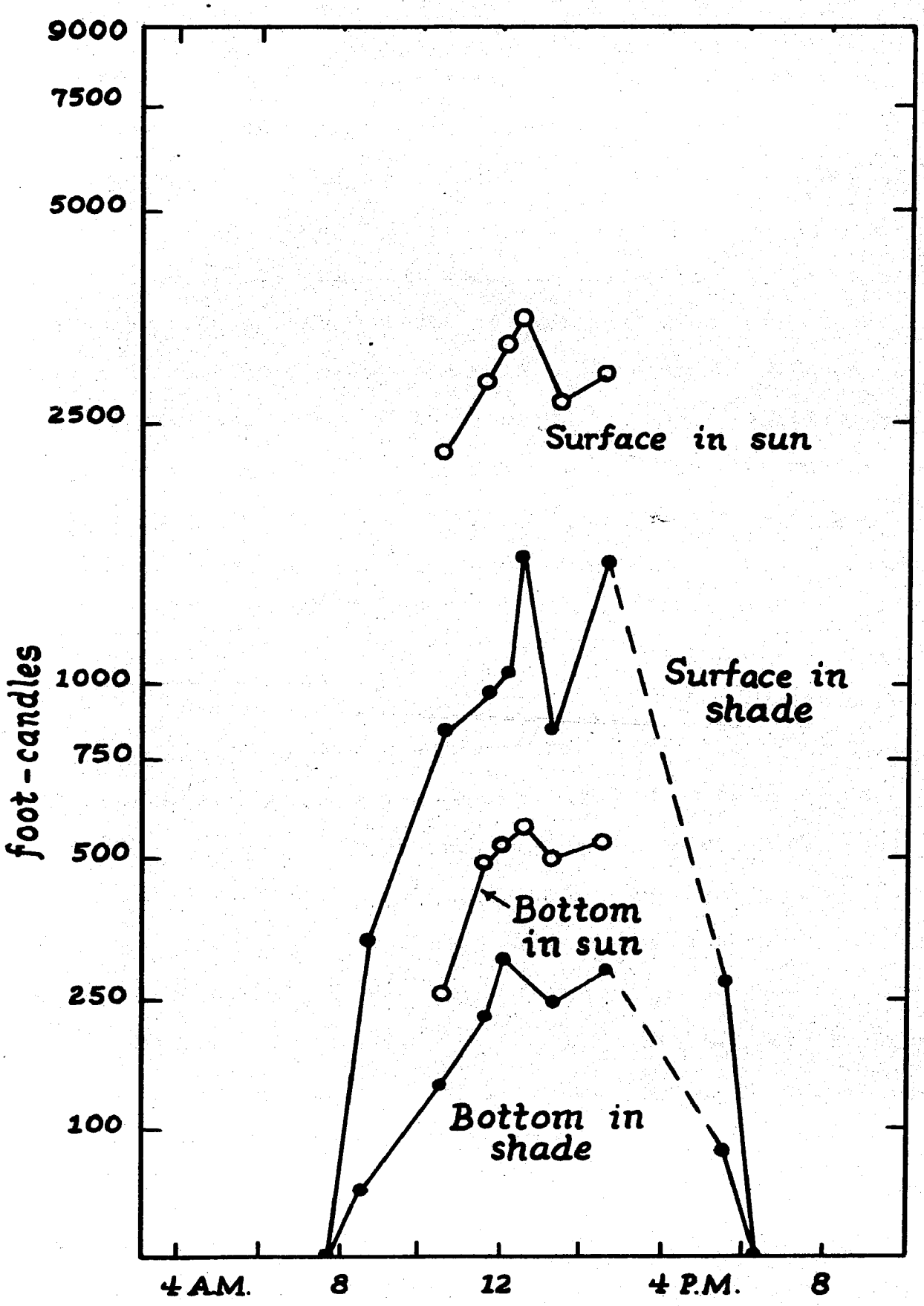


Fig. 14.--Incident light in foot-candles at surface and at bottom (at a depth of 0.75 meters at Station 17 throughout a winter day which was nearly cloudless until 2:30 P.M. Note logarithmic ordinate scale.

sunny position and that for a shaded position. Such a curve, obtained by placing the light meter in position in the water (in a community of Stigeoclonium tenue Kuetz.) at Station 14, and taking numerous readings at brief intervals throughout a nearly cloudless twenty-four hour period in September, 1952, is shown in Figure 15. It is evident that bank vegetation sharply reduces the incident light throughout a major portion of the day even at this relatively unshaded station.

While the effect of bank vegetation on the incident light reaching stream algae in summer is thus certainly a profound and controlling one, its effect in winter has not been determined by similarly ample data. From various, short-period records obtained in February, 1953, however, it seems evident that the leafless branches of overhanging trees have virtually no effect in reducing diffuse light from a cloudless sky, and that shaded riffles in winter owe this characteristic (shade) to a factor which at this latitude is inoperative in summer, namely, the trunks and large branches of trees located 20-50 meters from the stream on its southern side. Such trees, provided the sun can clear them, may have no effect on river algae in summer even though they are in full leaf, whereas in winter they sharply reduce the incident light reaching the stream.

Variation in total radiation with depth is probably of relatively minor importance in a small stream. Depth of riffles is not sufficient to reduce surface light to a significant degree, and in the Saline even pools are seldom deeper than 1.5 meters. At depths measured in Station 17, total light at sunny portions of the bottom was always greater than diffuse light at the shaded surface points. Sufficient light reached the stream bed here to permit the growth of

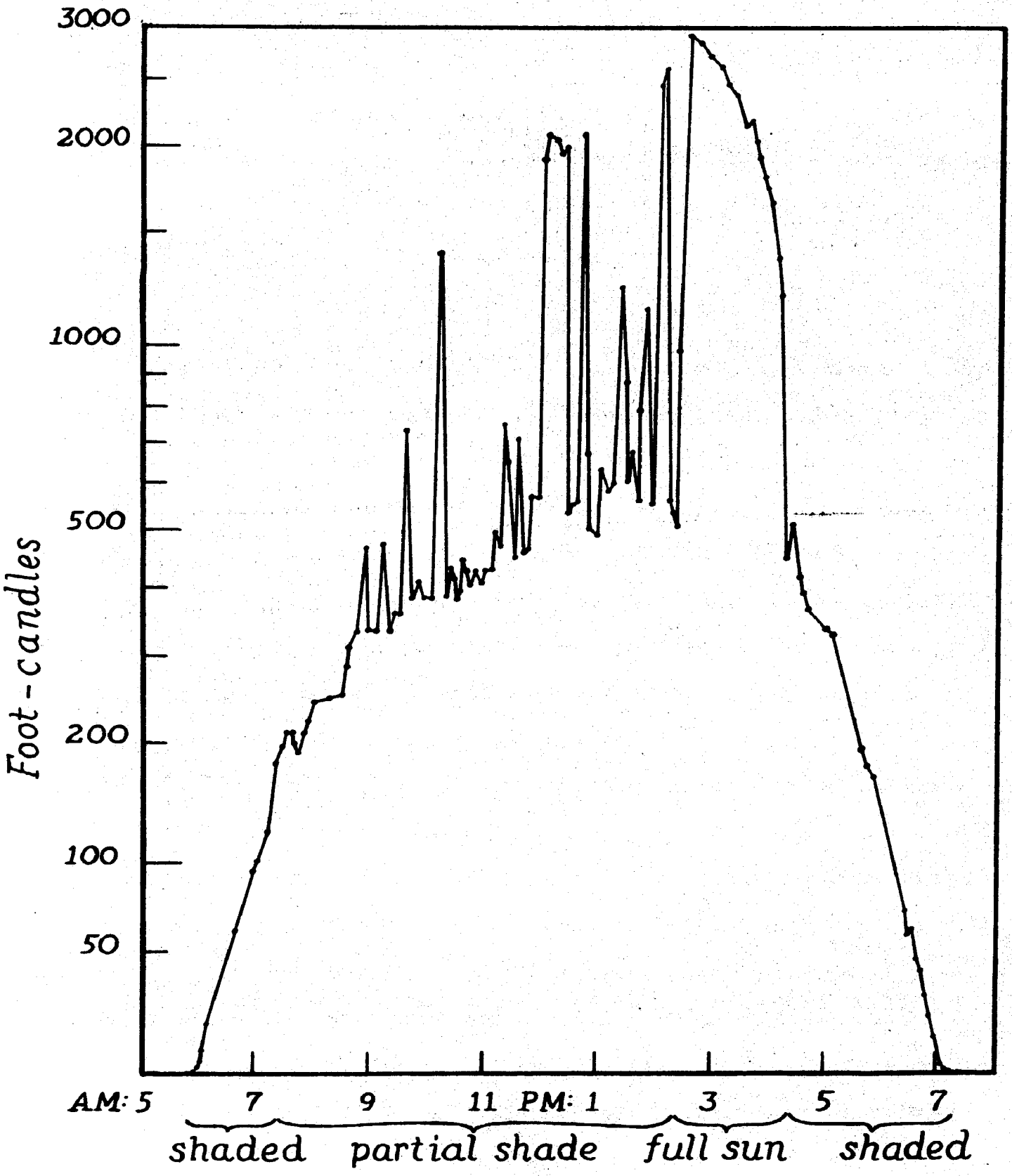


Fig. 15.--Incident light at a depth of ten centimeters in the Stigeoclonium community at Station 14, recorded at frequent intervals throughout a nearly cloudless day in late summer (September 12, 1952). Note logarithmic ordinate scale.

Navicula seminuloides Hust. apparently at all depths. With increase in stream depth, light may be expected to become a principal limiting factor in plant growth, but it seems likely that in few streams is this factor of an importance equal to that which it carries in any lake of ordinary depth.

3. Turbidity

Turbidity in the Saline River does not vary appreciably from source to mouth, with depth, or with the seasons. At the points of entry of sewage from the cities of Saline and Milan, a slight increase in turbidity is noted, which is dispersed, presumably by settling out and chemical action, within the distance of a few hundred yards. No seasonal variation in turbidity was observed. Following heavy rains, suspended matter in the river rises sharply in amount and remains relatively high for a period of about twenty-four hours, when a rapid return to the usual low turbidity can be observed. A similar increase in turbidity occurs with the melting of large quantities of snow and ice in winter and spring. The usual range of turbidity, recorded in approximately 90% of the samples, is from 6 to 20 parts per million. A maximum turbidity of 212 p. p. m. occurring after rains was recorded at Station 8 on November 17, 1952. A minimum turbidity of 4 p. p. m. was recorded on several occasions. Unusually high turbidity was observed in the stream at Station 23 on October 21, 1952, just below the entrance of Tributary 18. The tributary was at that time carrying a heavy load of silt as a result of the draining of its impoundment, which was begun some days previously by the owners. After a period of 6-7 days, this turbidity had been completely dispersed from the tributary as well as from the river.

4. Current

Rate of flow in a stream varies according to well known physical laws (Welch, 1952). Determinations have been made in the Saline River only at infrequent intervals. Average velocity on riffles was from 0.30-0.90 meters per second, with a maximum rate of 1.35 meters per second recorded under conditions of low water at Station 8. In pools, rate of flow was usually too low to permit of measurement by the Pitot tube. At many points near the sides of the stream, no surface or subsurface movements are evident even on riffles. In the area immediately downstream from large rocks, areas of no movement as well as of upstream water movements are clearly evident. The Pitot tube was inadequate to determine the extent and magnitude of minute countercurrents and cross-currents, and hence, all records of negative pressures were recorded as zero. In Figure 12 are shown velocities in a sagittal plane of, and in the immediate upstream and downstream area of a rock of average size which is well anchored in the stream bottom. It is clear that the zone of influence of the rock on the current enlarges downstream in an upward direction in such a way that at a distance of 8-10 inches (0.20-0.25 meters) downstream, the velocity of even the surface water is reduced to nearly zero. This area of slight forward or backward water movement is the habitat of the massive filamentous microphytes Cladophora glomerata (L.) Kuetz., Stigeoclonium tenue Kuetz. and Sphaerotilus natans Kuetz. It is an ecological niche peculiar in hydrobiology, exhibiting as it does little movement of water except gentle flushing from all sides; but it nevertheless fronts on both sides and above against continually renewed water in rapid movement, bearing fresh supplies of oxygen and minerals from

upstream. There seems no question but that this situation is one of the most favored in a stream as regards plant growth; the algae which inhabit it frequently exhibit a peculiar and unexplained periodicity, as shown below; but growth there is more rapid and frequently more massive than in any other situation within the stream.

Individuals of none of these three massive thallophytes are confined to such a situation, however. Good local growth of all of them can be observed in almost still water neighboring regions of rapid water. The actual amplitude in water velocity in the measurable layer which is closest to masses of these plants is thus very near the amplitude of all determinations within the stream--namely, from 0.0 to 1.35 meters per second, with optimum growth of Stigeoclonium tenue occurring at velocities of 0.35-0.85 meters per second.

Backwater areas are in part stagnant. Water in the major part of many backwater areas, however, is in slow circular movement brought about by the tangential passage of water in the main stream (Fig. 16). It seems likely that this eddying acts as an important intermediary between the stream and stagnant parts of its backwater areas, permitting a rapid and efficient exchange of oxygen and nutrients between them.

The importance of currents and eddies in algal reproduction has been observed repeatedly in virtually all parts of the stream. The benthic and semi-benthic algae of pools are particularly dependent upon eddies for their vegetative dispersal. The shoal area "A", which is shown diagrammatically in Figure 16, is typically the inside curve of a meander. It is shallow at its edge and slopes off gradually so that it exposes a wide strip of slight depth to the sun. At the same

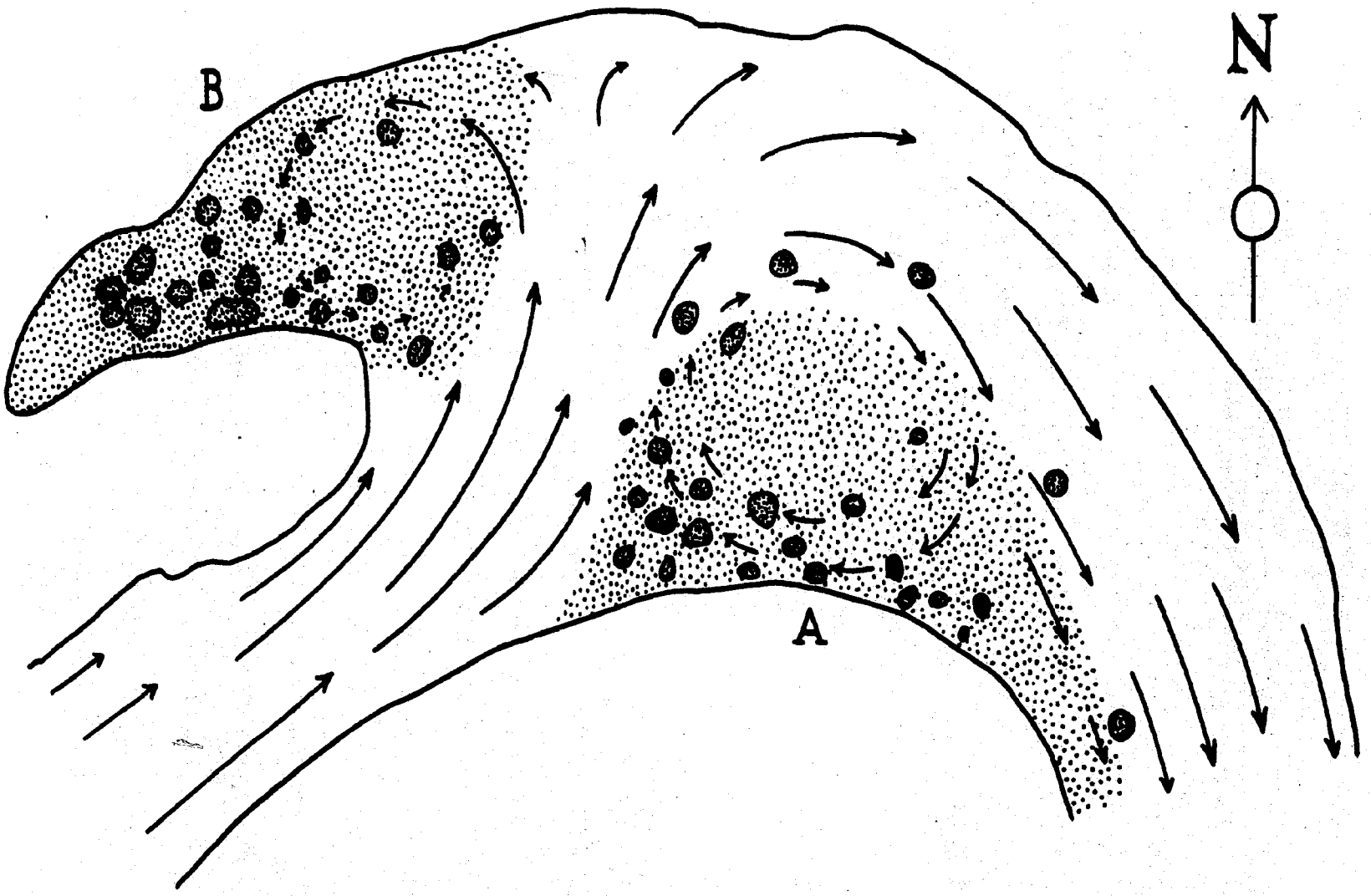


Fig. 16.--Surface view, somewhat schematic, of the Spirogyra community at Station 16. Water enters from the west from Riffle 15 and is deflected by the far bank, forming two principal eddies. Differences in rate of flow are suggested by length of arrows on map. A, shoal area, B, backwater area. Background shading indicates Spirogyra community on shallow bottom. Intensely shaded small areas indicate Spirogyra masses which have risen to surface; some of these from Shoal A are being carried downstream.

time it is usually an area of slow counter-current within which the river has dropped abundant silty sediments. Numerous algae make capital of this happy coincidence of a highly illuminated photosynthetic zone and a zone of abundant nutrients. It is, furthermore, a region well adapted to the successful dispersal of the algae, for although measurable current at the bottom (at a depth of 10-20 centimeters) is nil, the surface water is in slow circular motion. The mechanism is as follows: (1) At times of rapid photosynthesis, individual masses of the algal filaments are detached and buoyed upwards by the trapped oxygen bubbles; (2) once the algal mass has quitted the floor of such a shoal, it is carried slowly along in the eddying surface water; (3) after moving for some time in this circular manner, the algal mass may eventually be picked up by the current in the main stream, which removes it definitely from the shoal; (4) travelling downstream, it disseminates live filaments along the way. The progress of these filaments is arrested on obstructions or on new shoal areas, which in this way are themselves colonized. The clearest examples of this manner of dispersal were observed at Stations 7-13 for Oscillatoria tenuis Ag. and at Stations 15-20 for Spirogyra spp. during the summer of 1952. The elevation of algal masses by entrapped bubbles can be observed from about noon until 2-3 P.M. on sunny days in July, and the moving downstream of thousands of these floating masses, which have their origin on the floor of shoals or of pools, can be observed at least throughout the entire afternoon.

B. Chemical Variables

In this section the variability of important chemical constituents of Saline River water are discussed, and certain significant results are

summarized as graphs. A tabulation of determinations from all princi-stations is given in Appendix III.

Whereas much is known concerning the influence on aquatic organisms of the majority of chemical elements and ions discussed here (Welch,1952), the carbonate ion has not been shown to have important specific effects on algae. The determinations of carbonate are included here partly because most carbonates in river water exist in combination with the important nutrient elements calcium and magnesium.

1. Hydrogen-ion Concentration

It has been shown by Brujewicz (1931) that a definite diurnal variation in pH can occur in streams. Hence, pH data taken at various times of day and at various stations, such as the data recorded for the Saline, cannot be regarded as having more than local and temporary significance. However, it seems clear that no seasonal variation in pH occurred in the Saline, and that little if any significant change occurs from source to mouth. The sewage effluents discharged from Saline and Milan have a pH of about 7.5, slightly below that of the river, and a correspondingly slight depression of the pH of the river water can usually be observed for a short distance below these effluents. The river is well buffered, and little variation from the usual pH range of 7.8 - 8.5 is observed. No consistent difference between the pH of polluted and of clean parts of the river was observed, either in winter or in summer, in spite of the presence of a rich winter vegetation in unpolluted portions of the stream, and its absence in polluted portions generally.

2. Dissolved Oxygen

It is well known that dissolved oxygen is greatly reduced in a stream below sewage outfalls, due largely to the metabolism of abundant aerobic bacteria (Butcher, 1940, 1949; Huet, 1949). In the Saline River, such reduction is evident in the region from Station 14 to Station 28. Except for this area, dissolved oxygen is abundant throughout the upper part of the stream. Rapid flow, the presence of numerous riffles, and relatively slight depth all contribute to the generally favorable oxygen content.

Dissolved oxygen varies markedly with time of day. Determinations made in August and September, 1952 at Station 8 (Fig. 17) and at Station 17 (Fig. 19) show a slight but unmistakable decline in dissolved oxygen during the night. Shortly after dawn, the decrease in dissolved oxygen ceases, and soon an increase can be observed. Figures 18 and 20 show water and air temperatures at the same respective times and places as the oxygen determinations. Nocturnal decrease in pool 9 was much greater than at riffle 8 (Fig. 17). Observations of the diurnal change in dissolved oxygen concentration has already been recorded by Butcher, Pentelow, and Woodley (1930) and by Brujewicz (1931).

No significant variation of dissolved oxygen with depth was found in the Saline River. Presumably the stream is shallow enough, in its entire course above Milan, so that no measurable dissolved oxygen gradient ever exists between the upper and lower strata of water.

3. Carbonate

Carbonates, while generally entirely absent from the river water, were on occasion present in small amount in the downstream

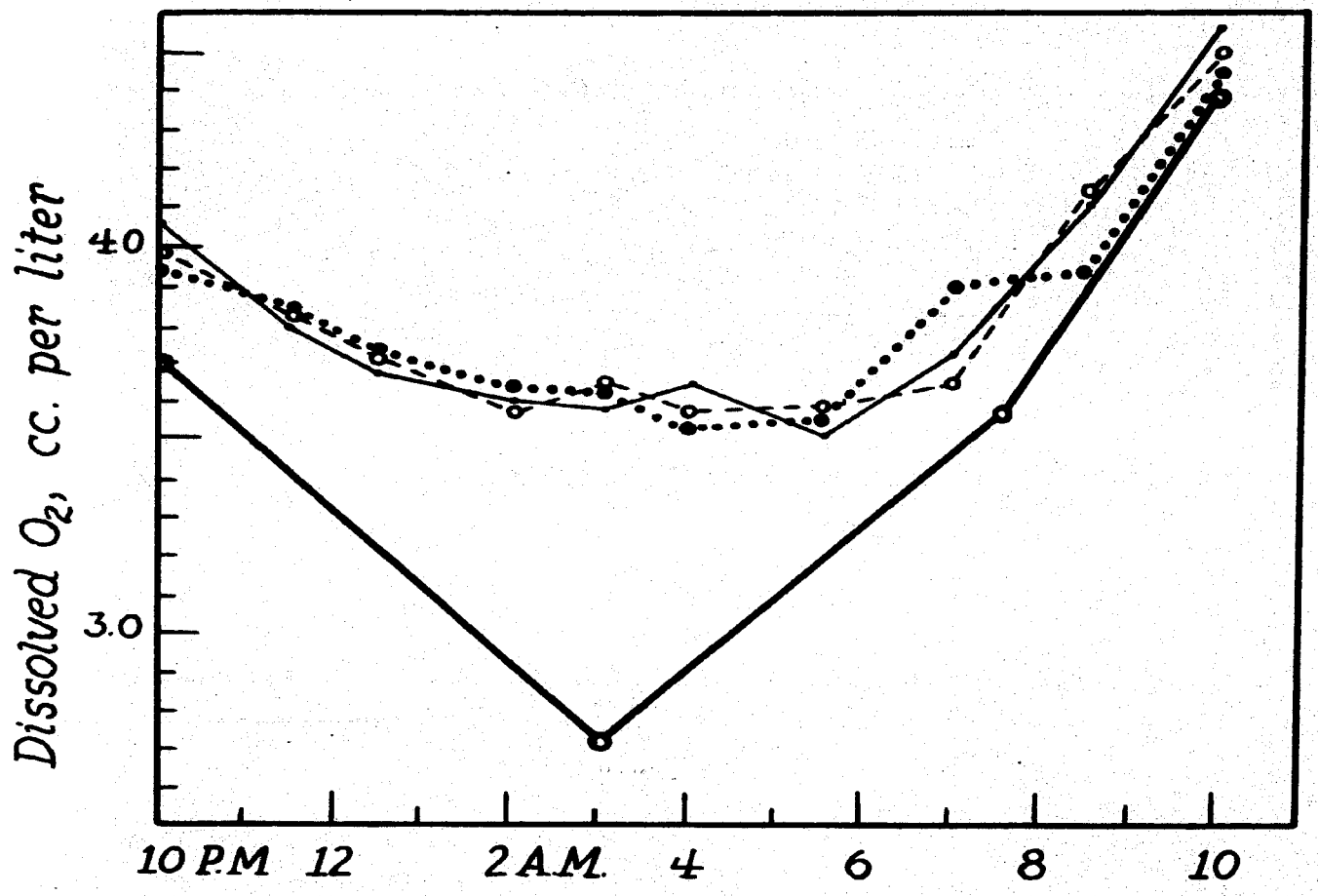


Fig. 17.—Dissolved oxygen in cubic centimeters per liter at Stations 8 and 9 (unpolluted), night of August 2 to 3, 1962. Key: ------o-- Upper portion of Riffle 8, surface, ————•—— middle of Riffle 8, surface,.....e..crest (lower portion) of Riffle 8, within a Cladophora stand, surface, ————o——Pool 9, at a depth of 0.3 meters.

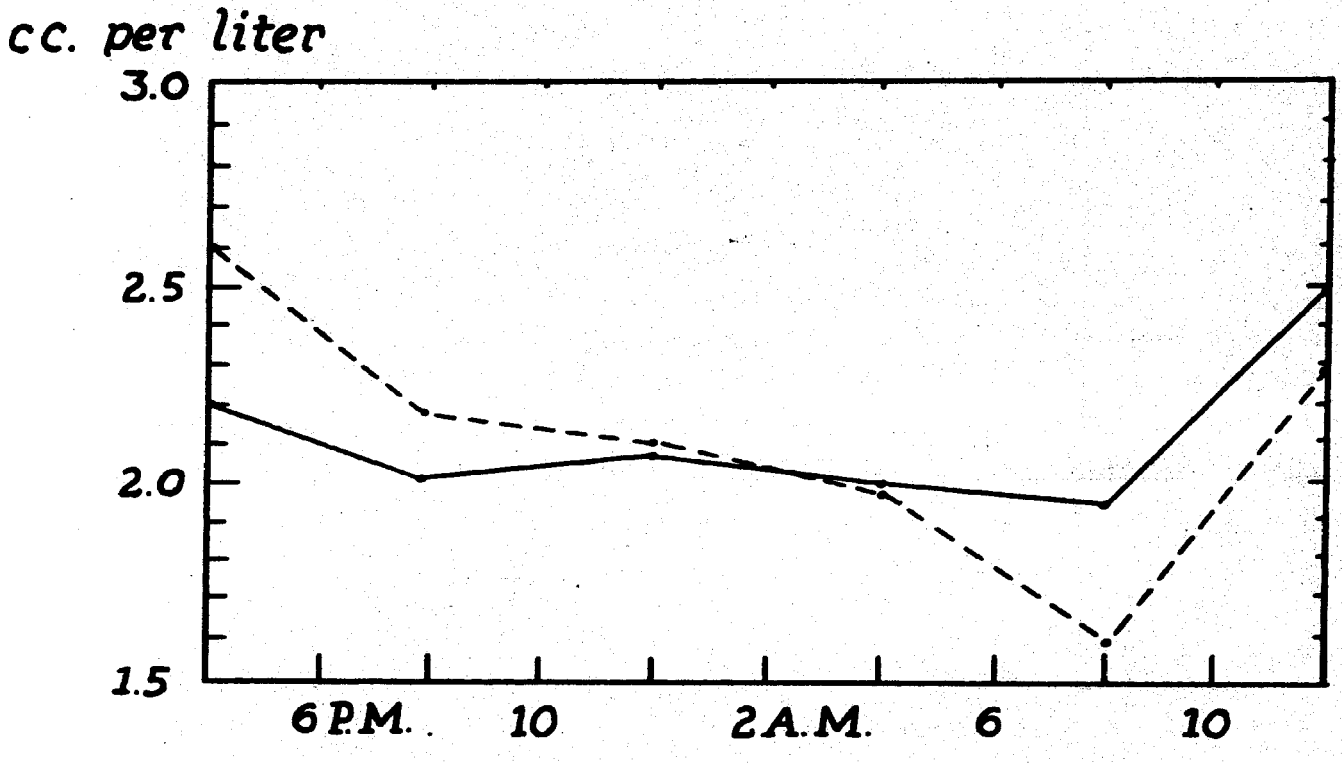
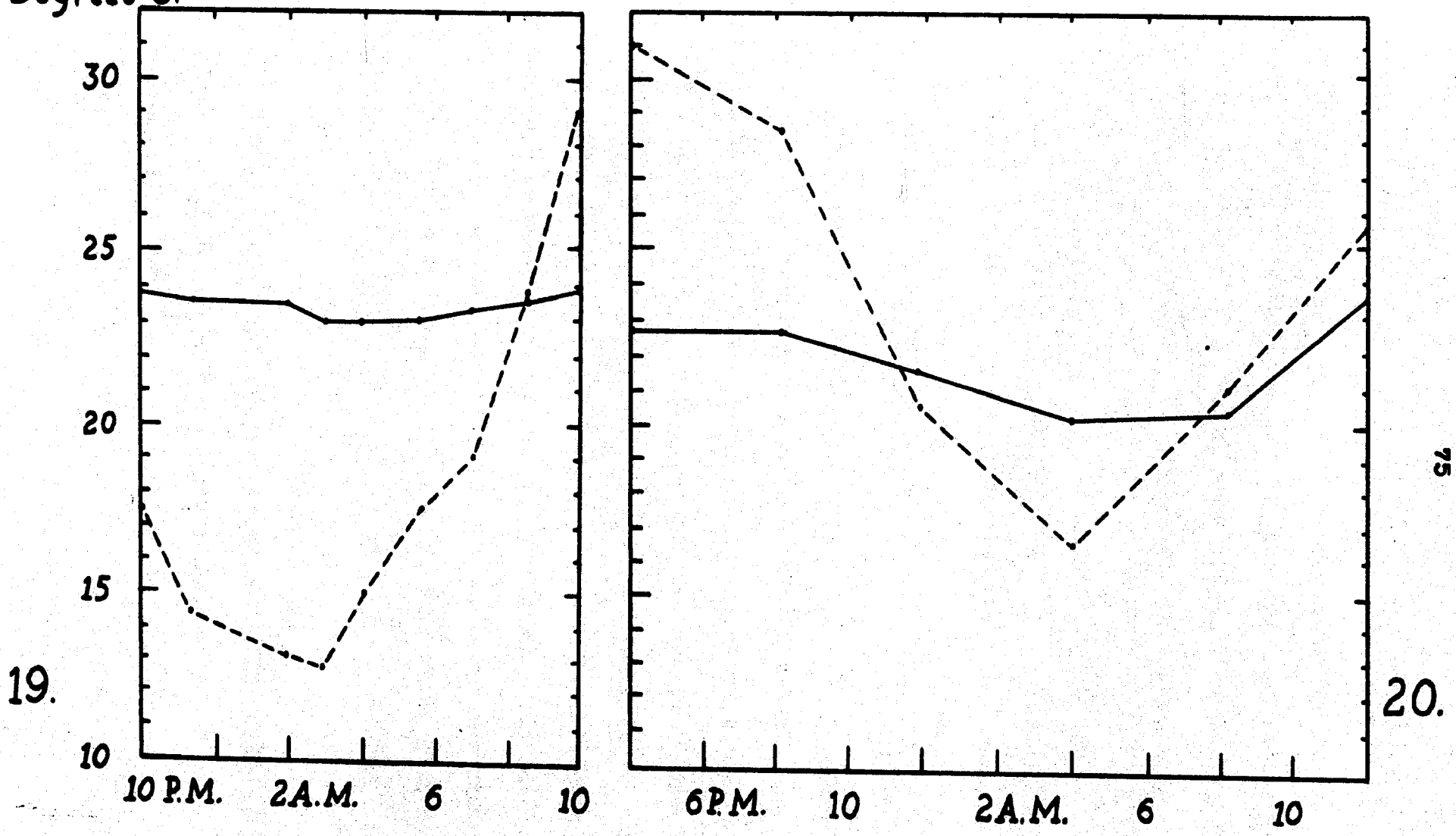


Fig. 18.--Dissolved oxygen in cubic centimeters per liter at Station 17 (polluted), night of September 12-13, 1952. Solid line, surface; broken line, at depth of 0.5 meters.



Figs. 19, 20.--Night temperatures recorded synchronously with dissolved oxygen samples represented in Figures 17 and 18. Fig. 19.--Station 8, August 2-3, 1952. Fig. 20.--Station 17, September 12-13, 1952. Solid line, water temperature; broken line, air temperature.

Stations 25-31. The maximum recorded quantity was 24.2 parts per million, found at Station 25 on September 15, 1952. Carbonate was recorded on two occasions in the factory effluent at Saline: on September 4, 1952, 37.0 p. p. m. were present; on September 15, 1952, 6.6 p. p. m. were present. On the other three days sampled, none was present.

4. Bicarbonate

Saline River water was found invariably to contain large quantities of bicarbonate. Actual amounts varied from 172.0 parts per million, recorded September 15, 1952 at Station 12, to 287.0 p. p. m., recorded the same date at Station 5. In general, Station 5 showed a slightly higher concentration of bicarbonate than other stations farther downstream, but no other consistent change with distance along the course of the stream was observed. The series of determinations made February 14, 1953, showed amounts frequently above those of summer and fall, but whether or not this indicates a general increase in bicarbonates in winter is not known. The industrial effluent at Saline always showed exceptionally large amounts of bicarbonate which varied from 273.0 p. p. m. (July 21, 1952) to 335.5 (February 25, 1953).

5. Chlorinity and Salinity

Chlorinity and salinity were determined at a series of stations on December 16, 1952. Values for both ions were found to be relatively high (chlorinity 0.125 parts per million, salinity 0.250 p. p. m.) in the effluent from the factory at Saline. But all readings in the river itself were below 0.07 p. p. m. for both determinations.

According to local residents, the Saline River owes its name to a salt spring formerly located in the river valley near Saline. The low values obtained for chlorinity and salinity throughout the course of the stream, however, would seem to demonstrate that such a spring, if it exists at all, is of little importance to the chemical make-up of the river.

6. Inorganic phosphate

Inorganic phosphates are uniformly low in unpolluted portions of the Saline River. With the entry of the effluents from the factory and from the city of Saline, they increase approximately tenfold in the stream (Fig. 21), and remain high for a distance of 200-300 meters. From about Station 20 to about Station 28, a steady decline in inorganic phosphates is apparent. Below Station 28, a slight secondary increase in phosphates due to the hospital outfall at Station 29 is evident, but they remain relatively low at Station 30 between Moorerville and Milan, and at Station 32 above the Milan outfall. Below Milan a sharp increase in inorganic phosphates is evident, due again to massive accessions of sewage.

In addition to marked differences in the amounts of inorganic phosphate within the stream at any given time, clear seasonal variation was evident (Fig. 22), with much larger amounts of phosphate recorded in polluted portions of the stream throughout the summer period than in the winter. A similar but less striking difference was evident in unpolluted portions of the river. Throughout December, 1952 and January, 1953, inorganic phosphates remained low in amount in all observed parts of the river.

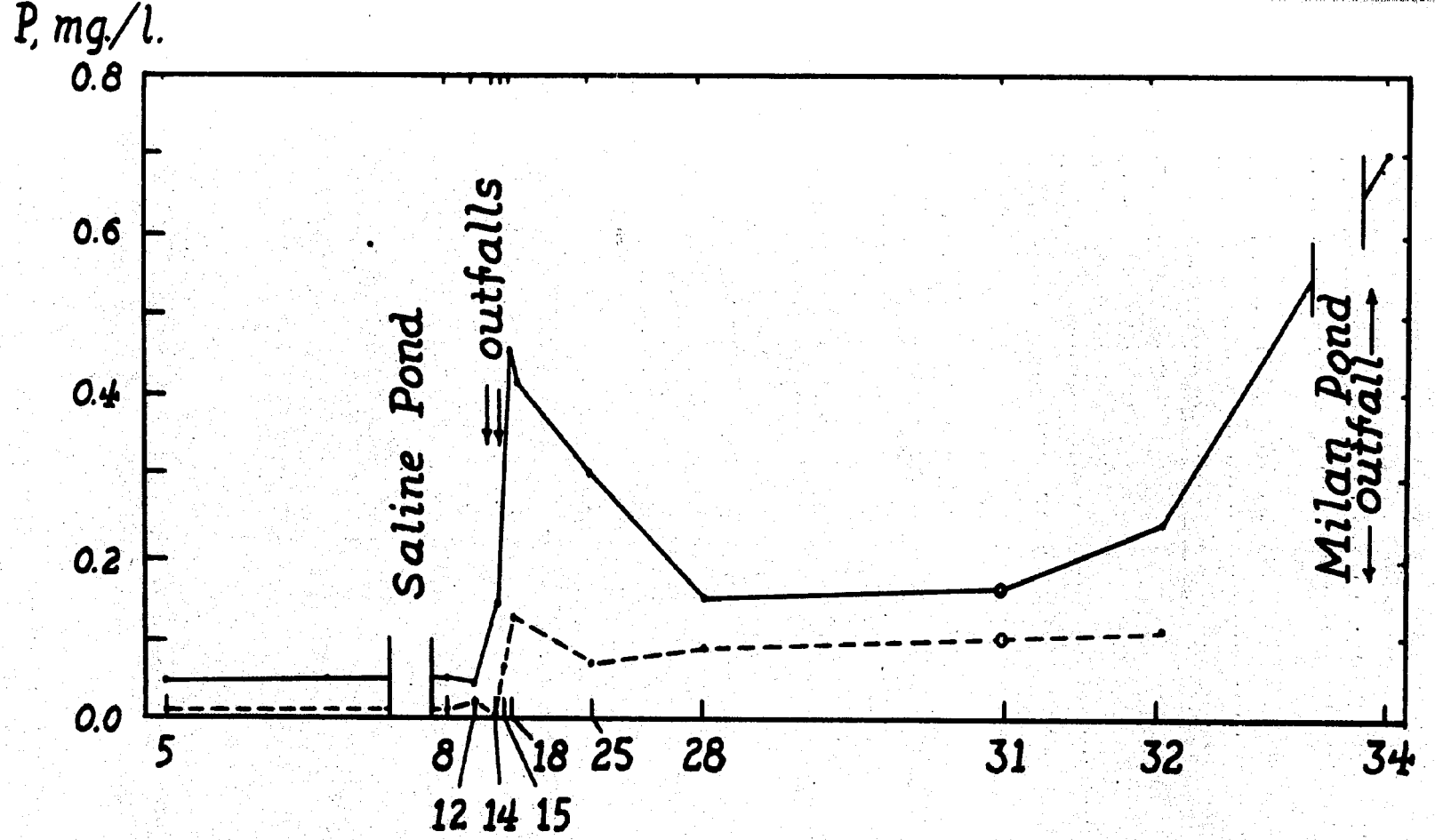
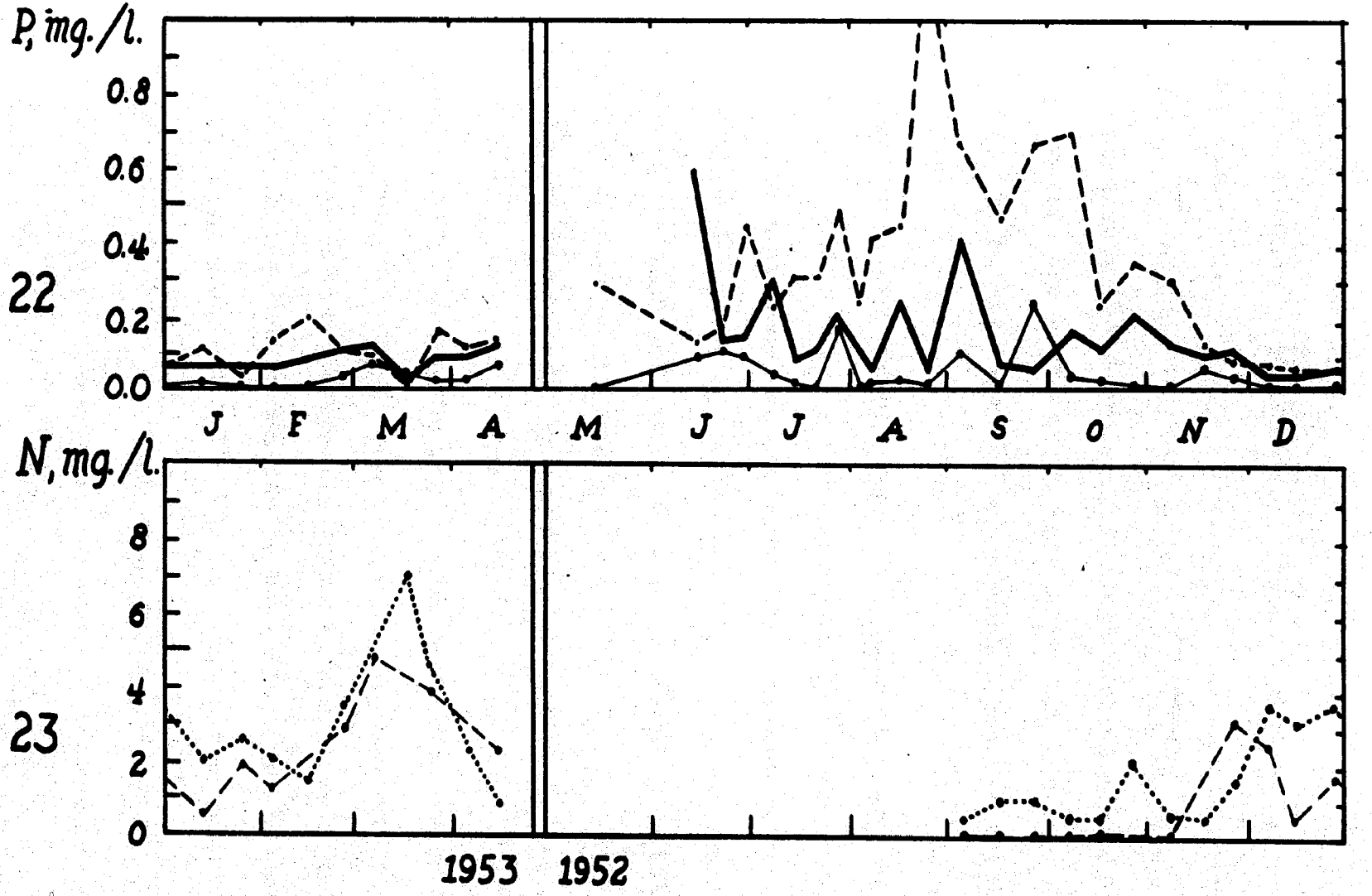


Fig. 21.--Inorganic phosphate phosphorus at various stations along the course of the Saline River. Solid line represents the period June 22-November 7, 1952. Each filled point represents an average of about seventeen readings during this period. Circles represent an average of 2-3 readings. Broken line represents the winter period December, 1952 through February, 1953. Each filled point represents an average of about eight readings made in these months.



Figs. 22, 23.--Fig. 22. Seasonal variation in inorganic phosphate phosphorus in selected portions of the Saline River during the period May 1952 to April 1953. Key: ———•— Average of headwaters Stations 5, 8, 12; – – – –•– – average of polysaprobic Stations 15 and 18; ——— average of β-mesosaprobic Stations 25 and 28. Fig. 23. Seasonal variation in nitrate nitrogen at Stations 5 and 8 during the period August 1952 to April 1953. Thin broken line, Station 5; dotted line, Station 8.

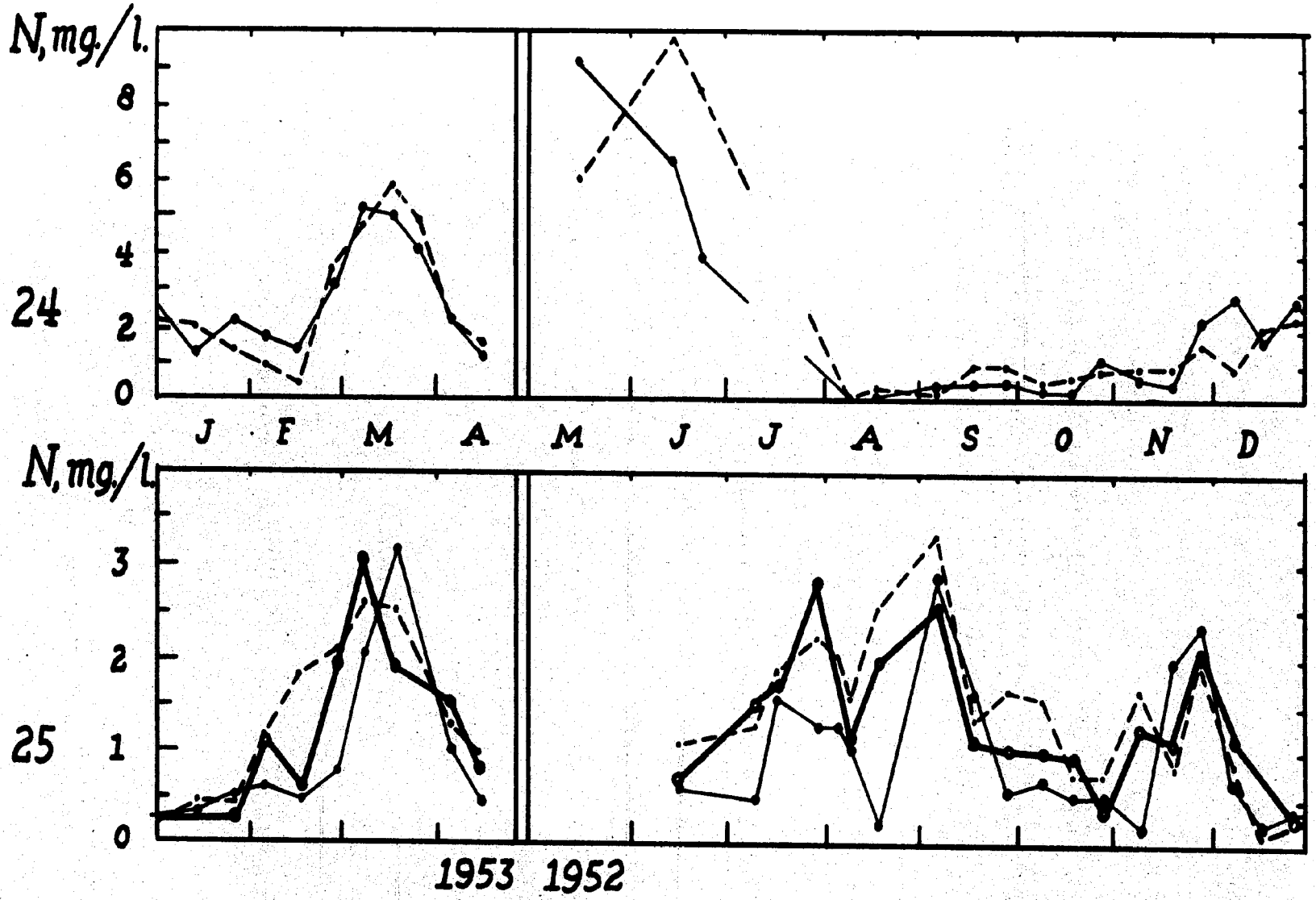
7. Nitrate

In the headwaters area, certain stations quite consistently showed 1-3 parts per million of nitrate while others as consistently showed much less or none. Station 5, for example, rarely had as much as one p. p. m., whereas Tributary 11, entering just above this station, regularly had 2-3 p. p. m., as did Stations 8-12 (Fig. 23). Although water lost from the factory effluent contains small amounts of nitrate, the nitrate-free sewage entering between Stations 14 and 15 is largely a diluent of nitrate-rich water already in the river, and Stations 15-18 are often lower in nitrates than are the stations upstream. With the progressive destruction of organic compounds and the oxidation of ammonium and nitrites, nitrates slowly increase in quantity in the lower course of the river, and at Station 32 just above Milan reach a high point of 3-5 p. p. m. which is maintained rather consistently throughout the summer.

Late summer is, in general, a period of low nitrate content in at least the upper and middle portions of the river (Stations 5-18). In November, following the disappearance from the river of nearly all the algal communities of summer and fall, a distinct rise in nitrates in these headwaters stations is evident, and throughout the winter and early spring the concentration maintained in the unpolluted stations is often higher than in the polysaprobic stations (Fig. 24).

8. Organic Nitrogen

Organic nitrogen fluctuates more from week to week than do the other chemical components determined (Fig. 25). No portion of the stream appears to be significantly low in nitrogen at any season, although generally small amounts were present at the unpolluted stations



Figs. 24, 25.--Fig. 24. Seasonal variation in nitrate nitrogen in selected portions of the Saline River during the period May 1952-April 1953. Fig. 25. Seasonal variation in organic nitrogen in selected portions of the Saline River during the period June 1952-April 1953. Key: ——•—— Average of headwaters Stations 5, 8, 12; – – – •– – – average of polysaprobic Stations 15 and 18; ——•—— average of β-mesosaprobic Stations 25 and 28.

in the period September 25-November 6, 1952, and December 15, 1952-January 10, 1953. Summer readings were generally high for unpolluted as well as for polluted portions of the river. A significant reduction in organic nitrogen occurred at nearly all stations during the first few weeks of September, 1952. This was accompanied by marked changes in the algal flora, which are discussed in Section VII. The various stations on the river usually showed quantities of organic nitrogen in relation to their position with respect to the various sewage outfalls (Fig. 26). Hence, the amounts of nitrogen present in the water were generally but not always larger at Stations 18 or 32 than elsewhere. The content of organic nitrogen was, however, maintained in the river's course downstream from Station 18 at a relatively higher level than the inorganic phosphate content; the polluted portion of the river between Saline and Milan is thus more nearly homogeneous as regards organic nitrogen than it is in regard to nitrates or phosphates, both of which exhibit significant differences from place to place.

C. Biological Variables

1. Animals

The abundant and diversified animal life inhabiting the upper, unpolluted reaches of the Saline River disappears almost entirely below Saline, and is replaced for much of the rest of the river's course by tubificids, numerous flagellates, and a few other organisms characteristic of polluted water.

Observations of animal life at Station 8 were somewhat more detailed than elsewhere. On this riffle Cambarus, Dugesia, and the

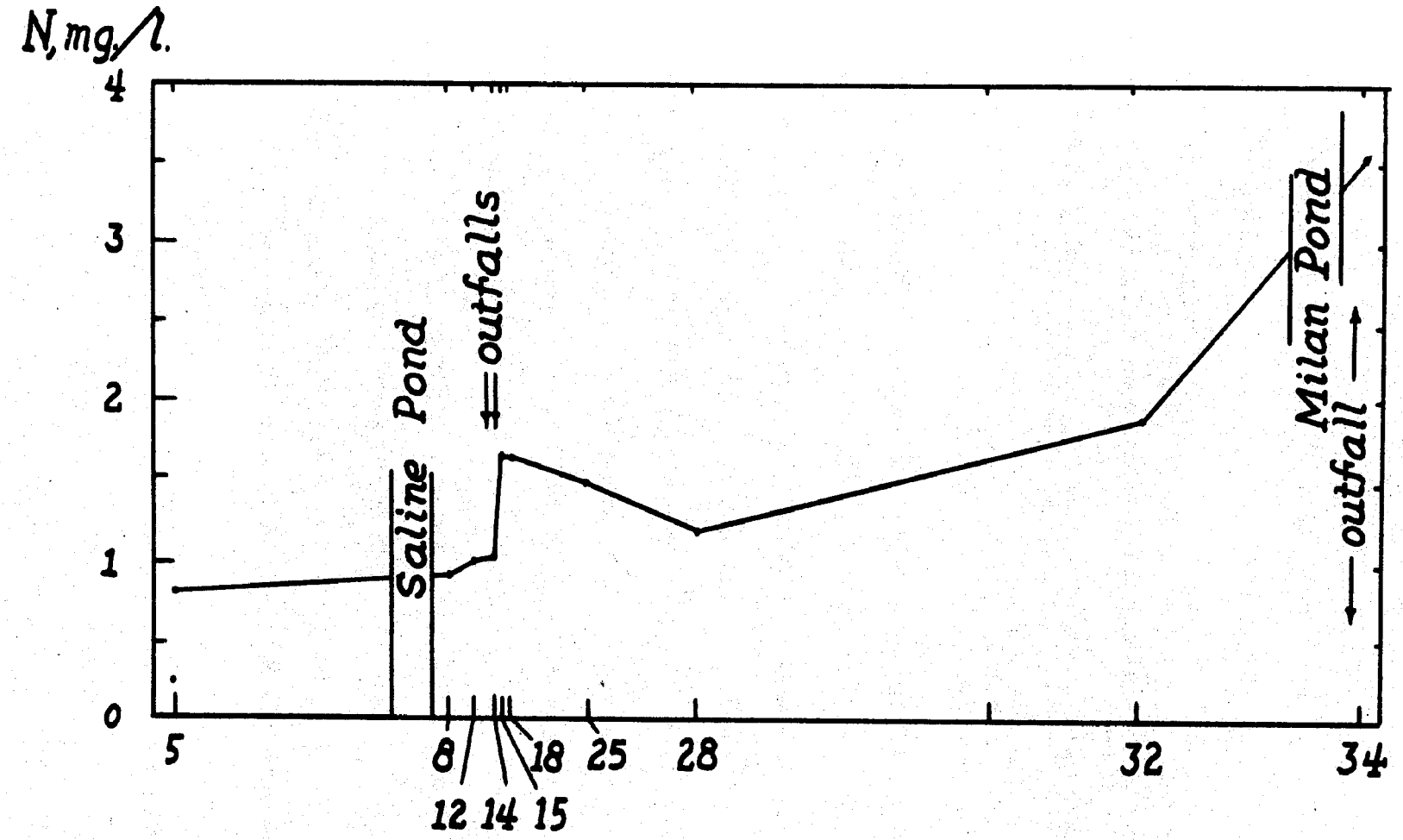


Fig. 26.--Organic nitrogen at various stations along the course of the Saline River. Each point is an average of approximately twenty-three readings made throughout the period June 15, 1952-March 7, 1953.

larvae of Trichoptera, Ephemeroptera, and Plecoptera were present and conspicuous at all times of the year. In late winter, spring, and summer the larvae of Simulium were common. At Station 12, which was heavily shaded in summer, there developed in August and September several conspicuous colonies of green sponges. No other invertebrates of any size were commonly observed in the stream, but a considerable fauna of small fish attracted anglers throughout the summer months.

Of these organisms, the most significant with respect to algal life are probably the caddis fly larvae (Trichoptera). These small creatures construct galleries (Fig. 27) in the crustose growths of Schizothrix and Phormidium which are described under Section VII. It seems probable that the larvae ingest large quantities of this semi-stony layer in which they spend their larval life. In addition to the influence on algae consequent upon the erosion of this algal layer, the larvae incorporate fragments of Cladophora and other filamentous algae into their webs, and the exposed nets which they construct trap large numbers of Oscillatoria filaments in June and July. The algal filaments thus trapped frequently can be seen to reproduce and to form colonies in situ; hence, the caddis fly web may serve as a focus for secondary dispersal of the alga. In late September, 1952, the nets of millions of these caddis flies formed a virtual floor to the riffles at Stations 8, 10, and 12, and occupied all exposed faces without exception of all stones which were surrounded by moving water. By mid-October, the great majority of these had disappeared from the stream, and in winter such caddis fly webs as remained were largely hidden by the abundant colonies of the winter diatoms. Caddis fly

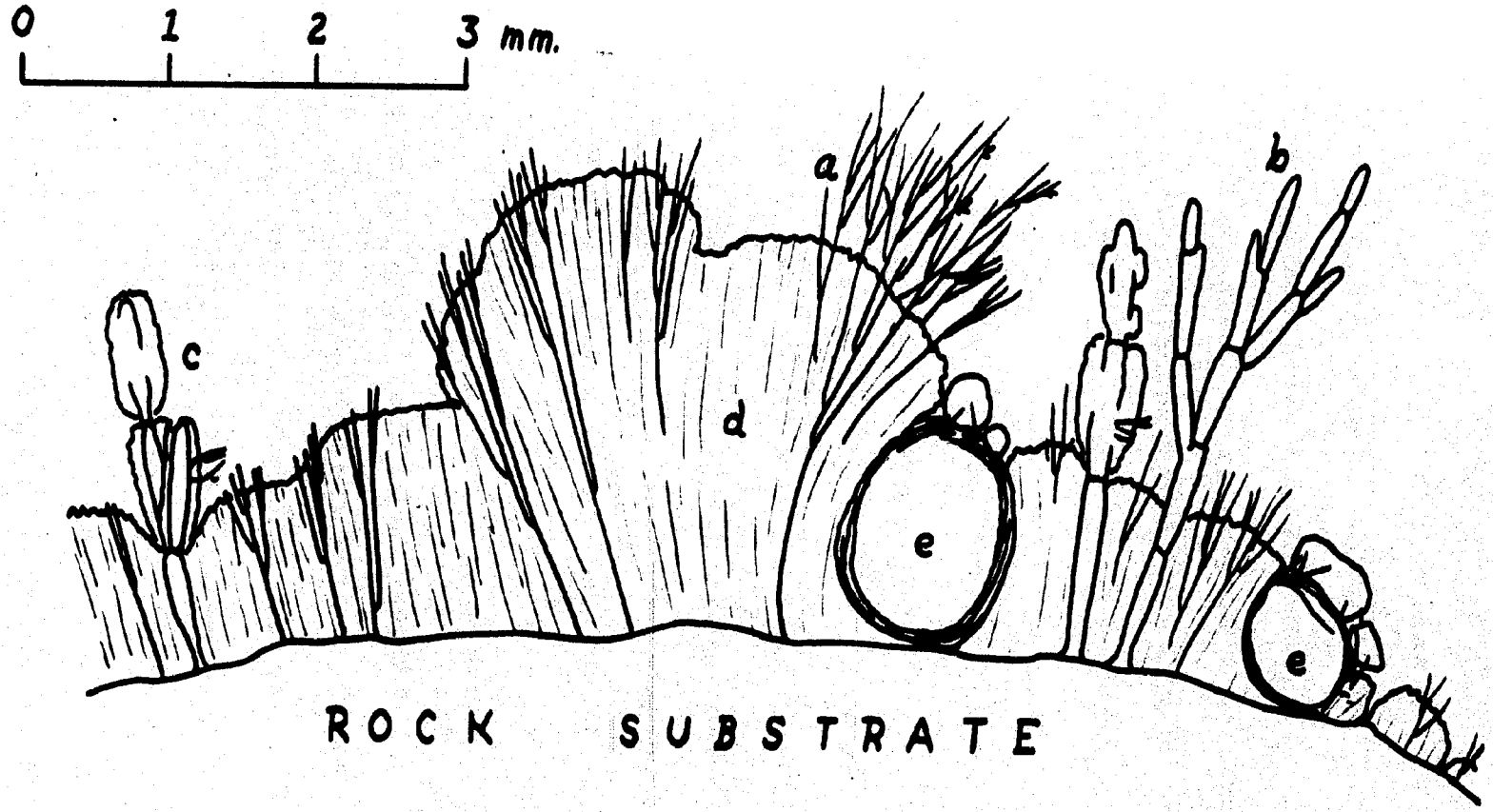


Fig. 27.--Diagram of vertical section through the crustose Phormidium-Schizothrix community as found characteristically at Stations 5-13. a, Audouinella tufts, shown exceeding the remainder of the crust at this point; b, Cladophora plant; c, partially calcified Cladophora plant; d, Phormidium-Schizothrix component of crust, locally devoid of Audouinella; e, caddisfly burrow, lined with silk. Faint vertical lines indicate orientation of Schizothrix filaments.

larvae were common in the stream throughout the year, but the massive riffle populations were in evidence only in late summer.

2. Plants

Among the ways in which other plants influence algae of the river may be mentioned the following:

Shading.--Shading by bank vegetation has been discussed under VI, A. above. Shading by aquatic plants is of little importance in the Saline River, for only Anacharis canadensis (Michx.) Planchon grows in sufficient quantity to bring about reduction of light over large areas of the stream bottom. Anacharis is not abundant in the river at any observed point below Station 6. Certain pools in the headwaters portion of the stream above Station 13 are characterized by meagre summer growths of various aquatic phanerogams, including especially Heteranthera dubia (Jacq.) MacM., Wolffia punctata Griseb., Spirodela polyrhiza (L.) Schlied., and a narrow-leaved species of Potamogeton which was never found in fruit. Probably none of these has more than local influence on the stream environment. At certain riffles, notably Station 12, aquatic mosses (Fontinalis sp. and Fissidens grandifrons Brid.) are common.

The shading of crustose or appressed algae on riffles by Cladophora and other large filamentous algae is very considerable at certain seasons. Cladophora glomerata grows in extremely dense skeins in late spring. Light determinations made with the light meter held directly below certain of these skeins and pointing vertically upwards frequently gave readings of 0.0 foot-candles at midday. Certain others of such skeins gave readings, according to their size and density, intermediate between zero and the quantity of incident light at comparable

depths outside the algal community. Inasmuch as these algal masses move constantly back and forth in response to shifting currents, it is unlikely that any one point on the stream bottom is in permanent shade because of them. Nevertheless, many parts of the riffle unquestionably receive greatly reduced light because of these large algae.

Epiphytism.--Many benthic algae of streams are epiphytes on other algae or on higher aquatic plants. Because of the relative scarcity of phanerogams in the stream, and because of the absence of conspicuous algal growths on them, the diatoms epiphytic on or supported by these plants have not been given careful study. The large river algae, however, particularly Cladophora glomerata and Oedogonium spp. are host to a variety of important epiphytes which include Gomphonema spp., Cymbella spp., Synedra spp., Cocconeis placentula Ehr., Diatoma vulgare Bory, Melosira varians C. A. Ag., and Audouinella violacea (Kuetz.) Hamel.

Growth of the supporting plant is of great importance to the epiphyte if the epiphyte is more or less restricted to this relationship (e.g., Cocconeis placentula, usually found in abundance only on Cladophora or Oedogonium), or when the growth of the epiphyte is greatly enhanced in the presence of large numbers of small irregularities in the attachment surface, such as is provided by small Cladophora plants (e.g., Diatoma and Audouinella, which colonize abundantly basal portions of Cladophora filaments). The growth of the epiphyte, likewise, can be of vital importance to the supporting plant, as in the case of the winter diatoms Diatoma vulgare and Gomphonema olivaceum (Lyngb.) Kuetz., which grow so abundantly about the Cladophora filaments

which they epiphytize, that they may form a cylinder as much as 4 mm. thick on all sides about the supporting filament. While it has not been demonstrated that these diatoms are responsible for the static winter condition of Cladophora in the Saline, such a relationship remains one of the more plausible explanations for this phenomenon.

Straining.--Large and small filamentous algae of all types function as traps for plankton and other sestonic materials. This straining process is of little importance in deep, slow-moving water. The layer of water moving across the riffles, however, is dispersed into a relatively thin sheet, all parts of which come repeatedly into contact with masses of benthic algae. These masses trap and strain out large numbers of living plankton organisms (Chandler, 1937), thus reducing the reproduction within the stream of forms (Dinobryon, Scenedesmus) adapted to a planktonic existence, and providing a site for the reproduction and dissemination of essentially benthic forms such as Oscillatoria tenuis which, unable themselves to attach on the riffles, are nevertheless greatly benefited by the favorable conditions there, and grow locally in a luxuriant manner when by some external means they find anchorage.

VII. THE ALGAL COMMUNITIES

The following discussion of communities includes some groupings of algae of one species and some groupings of many species. Certain of these communities within the Saline River are attached units of communal life (e.g., the Phormidium-Schizothrix) which are known from other streams, where they exhibit a similar and rather precise composition. Future research may very well show that they represent a widespread association characteristic of streams of a certain type throughout the world. Others (e.g., the Navicula seminuloides layer) grow massively in virtually unialgal colonies within the Saline, but since such massive growth has not been recorded in other streams, and since only one species is involved, considerable doubt may be raised as to the applicability of the term "community" with respect to them. If the stream is considered apart from other streams, the term appears to be readily applicable. A third category of algal groupings would be the relatively haphazard mingling of two to many unattached species. These groupings exhibit no constant composition from place to place within the stream. Frequently, too, their composition changes rapidly from week to week. Such algal societies do not appear to the writer to merit consideration as formal communities, and they are not so considered in this paper.

As regards the second group (unialgal colonies growing massively), however, the term "community" is distinctly more acceptable; they are designated thus in the present work. An essentially different

treatment would be to consider such unialgal stands as seasonal aspects of a more permanent community. This terminology does not, however, express adequately the absolute dominance which such massive growths manifest at certain seasons (e.g., the Diatoma and Gomphonema vegetations in winter); neither does it take into account the fact that they grow at levels essentially different from that of the permanent communities. In the Saline River these vegetations would, under such a system of nomenclature, become winter aspects of the permanent Phormidium-Schizothrix community. The latter association has already been described as a community without reference to its winter aspect (Fritsch, 1949). On the other hand, Butcher (1932a) has described a winter Diatoma-Gomphonema community in a stream from which the Phormidium-Schizothrix is apparently absent. As for the Saline, the writer prefers to regard these three units (1. Phormidium-Schizothrix, 2. Diatoma, 3. Gomphonema) as distinct communities until such a time as they are shown to exhibit similar spatial relationships in other streams. Other comparable vegetations are also termed "communities" in this paper. It should be emphasized that the different units which are here termed "communities" are not necessarily of the same communal rank or importance.

A. Benthic Algae of the Unpolluted Portion

1. Permanent Crustose Communities

Phormidium-Schizothrix-Audouinella (Fig. 27, 28).--This community is one of the most distinctive within the stream. It consists essentially of parallel filaments of Schizothrix pulvinata (Kuetz.) Gom. and S. lacustris A. Br. mixed with larger filaments of Phormidium



Fig. 28.--Surface view of Phormidium-Schizothrix crust, X 8.

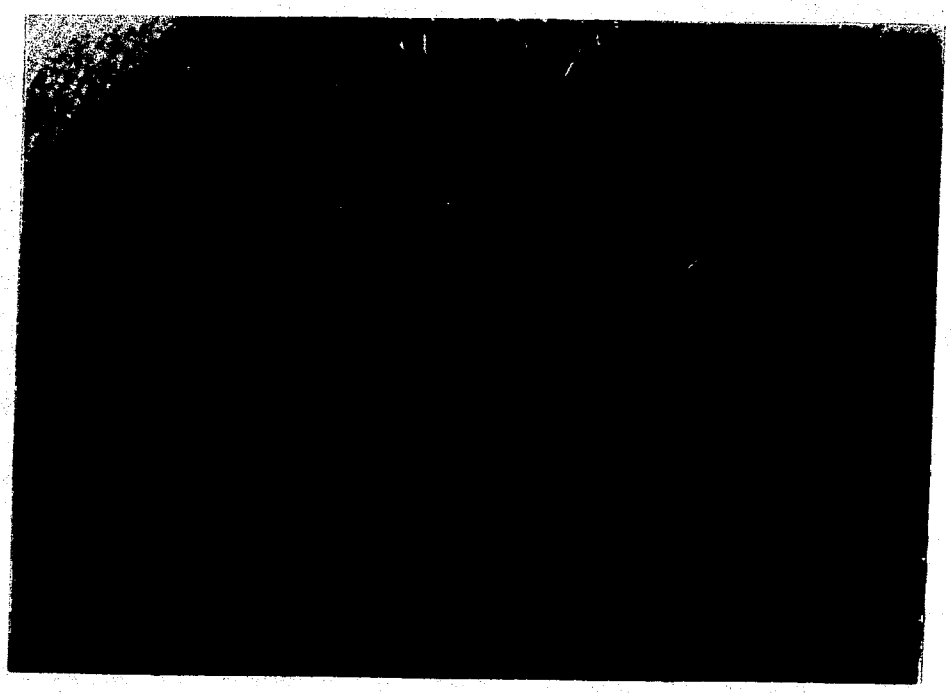


Fig. 29.--Portion of Amphithrix-Gongrosira community dissected out to show the component species (a) Amphithrix janthina var. torulosa and (b) Gongrosira debaryana. The material was decalcified with dilute acid before dissection. X 310.

incrustatum (Naegeli) Gom. which have no definite orientation. The Schizothrix filaments are attached to the rock surface, to which they are more or less perpendicular. The Phormidium filaments are apparently not attached to the rock but lie more or less coiled or twisted within the matrix of closely packed filaments and sheaths, in part empty, of Schizothrix. Mixed with these three blue-green algae are branched plants of Audouinella violacea (Kuetz.) Hamel and Cladophora glomerata (L.) Kuetz. This species of Audouinella is an almost constant member of this community and is found in about ninety-five per cent of the specimens examined. It is attached to the rock face directly, like the Schizothrix, and grows parallel to the latter and at a rate permitting the tips of its filaments to reach into the open water a slight distance beyond the tips of the Schizothrix filaments. The Cladophora is not a part of the community in the same sense as is Audouinella, for it is found more often apart from the crusts of the Phormidium-Schizothrix community. Only minute basal cells of the dense Cladophora tufts are attached to or within the crust formed by the blue-greens. Many Cladophora plants are attached directly to the rock surface, frequently surrounded by, or piercing, this crust.

All parts of this community are encrusted with calcium carbonate which is deposited as a result of algal photosynthesis (Pia, 1933, Welch, 1952). The carbonate deposits are found between the sheaths of Schizothrix and Phormidium and external to the filaments of Audouinella. The deposits must be removed by treatment with dilute acid before the algae can be studied microscopically.

Probably all members of this community are capable of growing alone without contact with either of the others. However, the

Phormidium is seldom found in a pure state, and may be dependent on the presence of Schizothrix tufts for the development of its colonizing hormogonia. When the Schizothrix species are found almost alone, with a relatively small admixture of Audouinella and Phormidium, the crust formed is relatively thin and friable; with abundant Phormidium filaments in the ensemble, the crustose layer becomes more massive and more stony in consistency. Its surface is then much roughened (Fig. 28) and the crust may reach a total thickness of five millimeters. Such a development occurs only on riffles, although a thin crustose growth of Schizothrix species is fairly widespread in many pools with a rocky floor. The Audouinella is frequently found growing alone, particularly in headwaters riffles such as Station 5, and sometimes it grows epiphytically upon basal portions of Cladophora. Basal portions of both algae may become invested by a shell of calcium carbonate, but this deposit is never found on either alga for more than a few millimeters distal from its point of attachment.

The crustose structure here described is apparently identical with the Phormidium-Schizothrix community recently described by Fritsch (1949, 1950, 1951) as occurring in certain calcareous British streams. Although the presence of Phormidium incrustatum has been verified in numerous streams of continental Europe, it appears that no careful description of this very distinctive community was made before that of Fritsch. Inasmuch as both British and American records are from streams high in lime, it is to be expected that calcareous streams of similar type in other parts of the world will likewise be found to possess such a community. We may infer from brief descriptions of Kann (1943), for example, that a similar community is to be found in

many of the streams draining the north slope of the Austrian Alps in the basin of the Danube.

Development of the algae making up this community has been followed upon sterilized rocks placed in the stream. Rocks placed in the stream on August 18, 1952, the earliest date upon which such rocks were placed on unpolluted riffles, had developed by December 15 minute, meagre growths of Schizothrix and Audouinella, only rarely admixed with Phormidium. Even after eight months in the stream, no structure at all comparable to the mature Phormidium-Schizothrix crust had been formed. Rocks placed in the stream after August 18 showed no colonization whatever by any of these algae throughout the fall and winter months. It may be concluded, therefore, that the mature crust such as is shown in Figure 28 requires a year or more for its development on a bare area. It may also be concluded that the six-month period of observation frequently employed by Butcher and other British workers, and based upon the removal at monthly intervals of slides anchored in the stream, is entirely inadequate for the observation of successional changes leading to the development of a climax vegetation such as is found in this Michigan stream.

That the size of rocks colonized has any effect upon the formation of the Phormidium-Schizothrix community has not been demonstrated clearly; however, careful search has never revealed the presence of a mature, well-developed Phormidium-Schizothrix crust on rocks smaller than about 6 x 6 x 6 cm. On well-anchored but very small rocks, a crust of Schizothrix and Audouinella, as well as Audouinella tufts alone, may be found, but they are seldom mixed with Phormidium incrustatum. The rocks colonized by these algae are of widely different

types, including limestone, gneiss, quartzite, granite gneiss, diabase, and mudstone. No differences in algal colonization or in algal vegetation as a result of the composition of the rock forming the substrate were ever observed. Furthermore, all of the attached species appeared to be capable of colonizing all rocks, indiscriminate of type, found on the stream bed.

That the volume of flow has some effect upon the Phormidium-Schizothrix community is possible, for it is never found in well developed condition in the headwaters portion of the stream above Station 6. However, there are so many variables that change with distance along the river's course, that it is impossible to fix with certainty the cause of this phenomenon.

It is probable that a major portion of the growth of this complex algal layer takes place during specific seasons. However, its external changes are slow and difficult to observe. Hence, its periodicity, if any, was not investigated, and it is referred to here as a "permanent crustose community."

The Phormidium-Schizothrix community appears to represent the benthic climax on riffles, and is probably as clear an example of a climax community as this stream can offer. It occupies nearly all exposed rock surfaces on all unshaded rocky riffles in the course of the stream between Station 5 and Station 13. Other algae surpass and shade it at certain seasons, but these are only temporary species which disappear from the stream after a few weeks or months of dominance. Between these seasons in which it assumes a secondary role, the Phormidium-Schizothrix community remains the dominant and permanent occupant of the most desirable algal habitats. It may be compared with the eutrophic

"climax" community of primary food producers in deep temperate lakes. However, the principal food producers in lakes are the phytoplankters (Lindeman, 1942), a "life-form" which is of little importance on riffles, where the vast bulk of organic production must occur in the benthos.

In this connection, it may be stated that results of both chemical and biological studies of portions of the Saline River above and below Saline Pond indicate that eutrophy is greater below the pond and that production is correspondingly higher, a supposition which is borne out by the following facts: (1) that nitrates are consistently higher at Station 8 than at Station 5 above the pond; and (2) that growth of nearly all algae[3] is distinctly more luxuriant at Stations 8 and 10 below the pond, than above the pond. These algae include (a) the Phormidium-Schizothrix community, which forms a thicker crust below the pond, (b) the winter diatoms Diatoma vulgare Bory and Gomphonema olivaceum (Lyngb.) Kuetz., and (c) Cladophora glomerata (L.) Kuetz. in spring. These observations may be considered as the basis for a hypothesis concerning the eutrophication of streams in general, namely that eutrophy of a lotic habitat may be brought about directly by an upstream pond or impoundment in which eutrophic conditions prevail. Too little is known of the processes of eutrophication in unpolluted streams to admit of general statements concerning the trophic evolution of a stream lacking impoundments. The conclusion, however, seems clear that the Saline Pond (which appears to the author to be eutrophic) is instrumental in the eutrophication of habitats downstream

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[3]An exception is Audouinella violacea (Kuetz.) Hamel, which is characteristic of oligotrophic habitats in this as in other streams of the world.

from it, and that this pond-stream relationship may be of profound importance in streams generally.

It is known (Lindeman, 1942) that eutrophy in lakes is accompanied by relatively high productivity in the primary food producers (autotrophic plants). That this phenomenon is true of certain streams seems possible or probable from the observations cited above for the Saline River.

Amphithrix-Gongrosira.--A second crustose community found on riffles in unpolluted portions of the river is made up of the blue-green alga Amphithrix janthina var. torulosa Gom. and the green alga Gongrosira debaryana Rabenh. (Fig. 29). Typically these algae form calcified, cone- or cushion-shaped growths upon rocks, with filaments of both components radiating outward from the truncated point of the cone. Usually the shape of the colony is not evident without dissection, since the "cone" is often imbedded in the Phormidium-Schizothrix community with the surfaces of both communities confluent. Except for having a slightly greener color, and a less roughened surface, it resembles outwardly and appears to be a part of the dominant crustose community.

Its composition is very constant, and the algae of the Phormidium-Schizothrix community seem to be excluded completely from it, except in the very early stages of growth. Whether or not the Phormidium-Schizothrix community can overgrow it and destroy it, is unknown.

The Amphithrix-Gongrosira community is most conspicuous in September. In this month its dark green cushions can be observed widespread in swift water, on newly exposed or recently overturned rocks, and this is assumed to be its period of maximum growth. However, the

cushions can be found in the stream at all seasons, and no data are at hand to show why or exactly when many colonies seemingly disappear in the fall, nor to show the extent of the apparent seasonal change. Due to the close examination required to distinguish this community from the Phormidium-Schizothrix, and to its rather sporadic occurrence, it proved unfeasable to determine this community routinely in the field, and, hence, it was not recorded on the transects. It was never observed in the polluted portion of the stream.

Sterilized rocks placed in Riffle 8 on August 18, 1952, developed within eight weeks several colonies of Amphithrix janthina var. torulosa. Somewhat later, growths of colonizing Schizothrix and Audouinella were to be found. It appears, therefore, that these three genera represent pioneers in the succession which terminates in the full development of their respective communities. No further new colonization by Amphithrix was observed throughout the fall and winter months, and even eight months after the rocks had been placed in the stream, no growth of Gongrosira in the Amphithrix tufts was yet evident.

2. Summer Communities

Cladophora glomerata (L.) Kuetz. (Fig. 55).--This is the most abundant and conspicuous filamentous alga in unpolluted parts of the Saline River, as it appears to be in most streams throughout the world. It is known to be highly sensitive to iron (Budde, 1930, Uspenski, 1927) and relatively tolerant to high pH values (Uspenski, 1927). Numerous workers including Purdy (1930) and Waser, Bloechliger, and Thomas (1943) have observed that it is tolerant to relatively large amounts of sewage in the water. Its annual periodicity has been described by Brown (1908) and Budde (1928, 1932). Brown states that its

maximum development is from April to June, whereas Budde describes a later maximum (May to August). Cladophoraceae are known generally to be absent from completely quiet waters (Fritsch, 1906), and Jaag (1938) states that development of C. glomerata is greatly dependent upon abundant light. Except as regards periodicity, results from the Saline River are largely in support of all these conclusions.

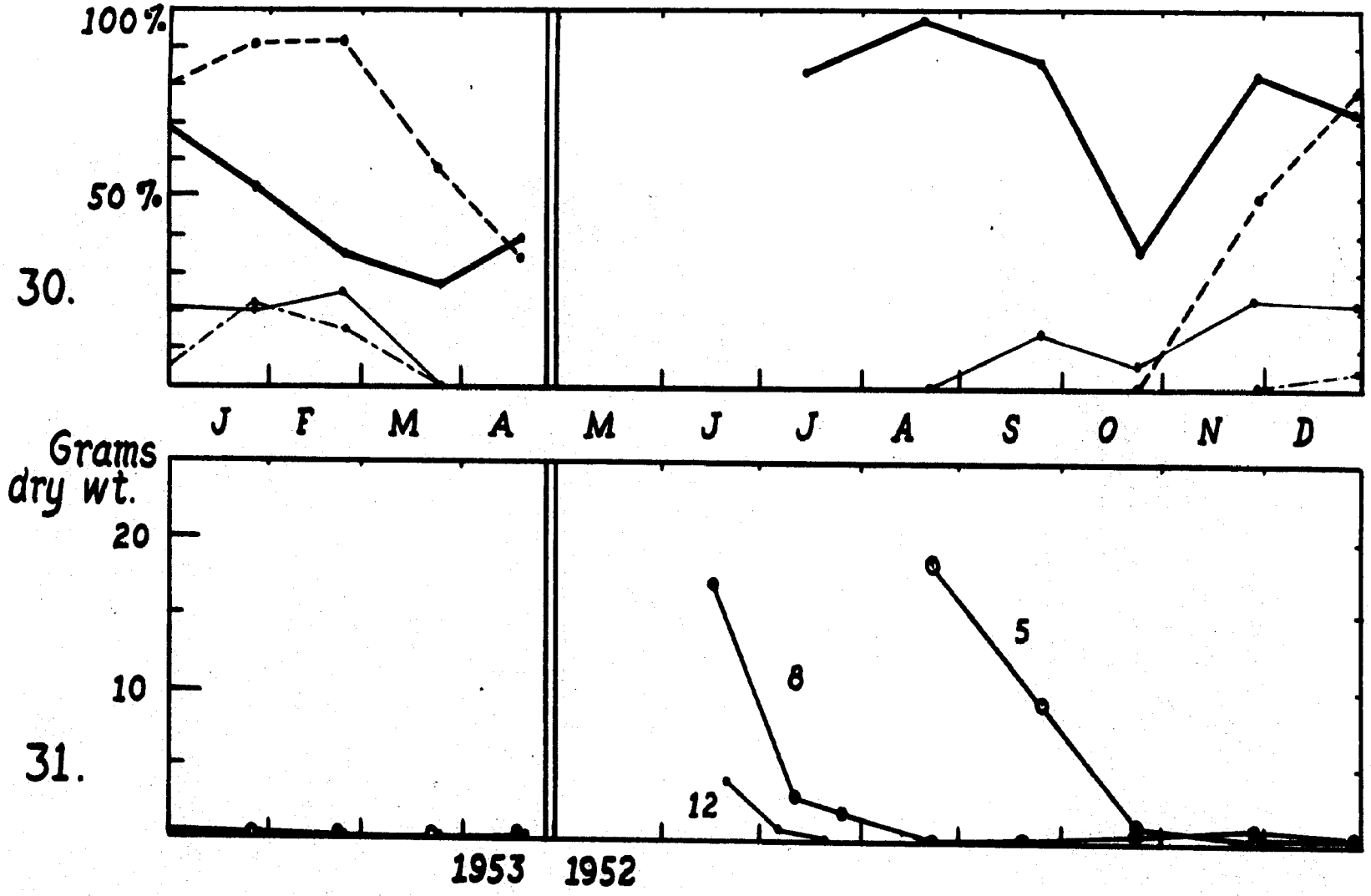
In the Saline River, C. glomerata is present in virtually all rocky riffles, as well as on rocks in shallow portions of pools (where its growth is greatly reduced) in all parts of the river above the industrial outfall at Saline. Between this outfall and Milan it has never been observed in the river proper, although small plants are present in summer on rocks near water line in Milan Pond. Since no riffles are known to be present in the area between Mooreville and Milan, it may be supposed that its absence from the lower portion of this course is due to the lack of suitable riffles, but it is clear that its absence from the upper course between Stations 14 and 28, which includes numerous well developed riffles, is due to the affluents entering the river at Saline. Below Milan, a single riffle is known in the stream proper (Station 34); this was inhabited during the summer of 1952 by numerous small plants of C. glomerata mixed with other algae. The entire course of the stream between Saline and Milan from which Cladophora is absent has a total length of 13.1 miles (21.0 km.).

From the data available, it is impossible to establish with precision which of the components of the industrial effluent is responsible for the elimination of Cladophora glomerata from the stream. It seems probable that, in view of the extreme sensitivity of this species to iron, the iron content of this effluent would be sufficient

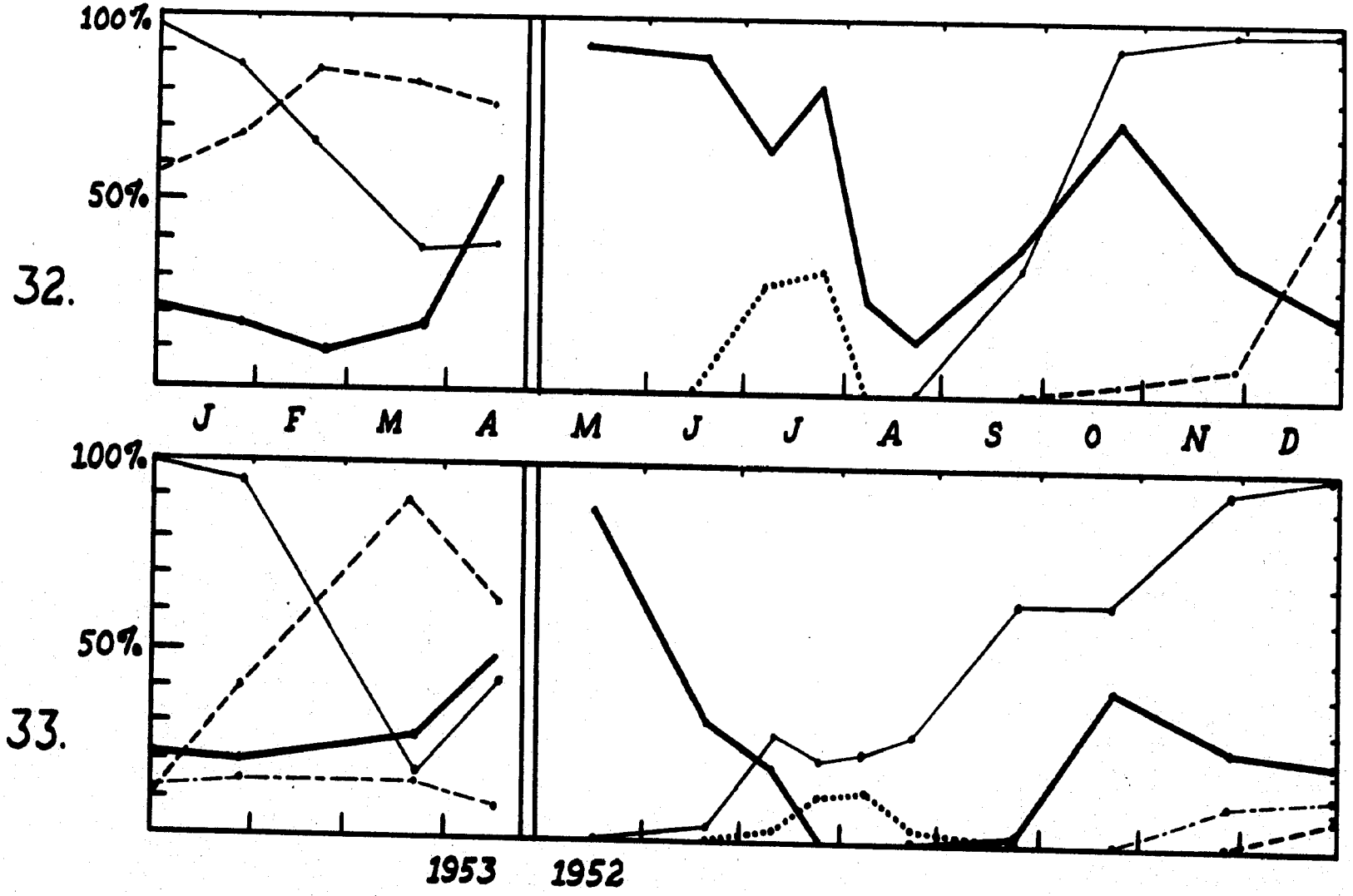
to preclude any growth; very likely any one of the other three or four "poisonous" ions entering the stream at this point would, even in the absence of iron, be sufficient to eliminate this species from the stream.

Another peculiarity in the distribution of C. glomerata in the stream is the presence of a few rather large plants at the crests of certain riffles while the species is greatly reduced or absent elsewhere on the riffle. This is usually the condition in unshaded riffles throughout the fall and winter period. There is no observable or measurable difference between upper and lower parts of the riffles except for a slightly higher current rate at the crest of the riffle. In an effort to explain this distribution on the basis of reduced amounts of dissolved oxygen in upper parts of the riffle, oxygen determinations were made at Station 8 throughout the night of August 2-3, 1952, at three points distributed in linear fashion from the upper parts of the riffle to its crest, where a few Cladophora plants were growing (Fig. 17). Absolutely no consistent difference was observed in the amounts of dissolved oxygen when parts of the riffle were compared, although a significant difference was observed when the riffle was compared with the pool just beyond it. Some factor other than dissolved oxygen limits Cladophora to the crests of riffles at these stations in summer and fall.

Figures 30-32 show variation in important components of the vegetation at Stations 5, 8, and 12, and are based upon transects made at approximately monthly intervals throughout the year. These records show that Cladophora plants are present throughout the year in unshaded riffles of the unpolluted portion. While minor pulses



Figs. 30, 31.--Fig 30, Seasonal variation in frequency of algae at Station 5. Key: ——●—— Cladophora glomerata, - - - - - - - Gomphonema olivaceum, ——·—— Draparnaldia plumosa, ——·—— total diatoms other than Gomphonema olivaceum; winter values for the "total diatom" vegetation represent almost pure stands of Diatoma vulgare. Fig. 31. Seasonal variation in dry weight of Cladophora glomerata removed from ten arbitrarily selected rocks as described in text. Numbers refer to the three headwaters stations at which this sampling was done.



Figs. 32, 33.--Fig. 32. Seasonal variation in frequency of important algae at Station 8 (unpolluted). Fig. 33. Seasonal variation in frequency of algae at Station 12 (unpolluted, heavily shaded in summer). Key: ——— Cladophora glomerata, – – – – Gomphonema olivaceum, ——— total diatoms other than Gomphonema olivaceum, ...Oscillatoria tenuis community, – – – – Botrachospermum borryanum. Winter values for the "total diatom" vegetation represent almost pure stands of Diatoma vulgare.

in the growth of Cladophora, occurring at various times of the year and probably influenced by extended periods of sunny weather, are evident from such transect studies, the principal variation is more evident when dry weights of algae are compared on a month-to-month basis (Fig. 33). A period of rapid growth occurs in spring, values for which contrast sharply with the period of greatly reduced dry weight extending from summer or fall throughout the winter. The terminus of the spring period of maximum growth is much more poorly marked. It is evident from the curves shown in Figures 8 and 33 that values for Cladophora at Station 8 (unshaded) were reduced sharply about four weeks after day temperatures of 15° were regularly attained in the stream, whereas at Station 5 (unshaded) the massive Cladophora vegetation is maintained for approximately three months after such temperatures are attained. It seems probable, therefore, that the summer decline in Cladophora which is here manifest is not due to lack of tolerance to higher temperatures, as is assumed by Thurman and Kuehne (1931).

There is at least one other way in which temperatures may be of importance in this problem, however. While there is no essential difference in day temperatures at Stations 5 and 8, there is a marked difference in night temperatures, with values at Station 5 unquestionably descending, for at least a few hours on cool summer nights, below 15° (data for a cool autumn night are shown in Figure 11), whereas at Station 8 night temperatures are greatly moderated by the Saline Pond. It seems possible that the marked difference between the Cladophora vegetation at Stations 5 and 8 is due to the dependence of certain reproductive processes on at least short periods of cool temper-

atures. The only other consistent physico-chemical difference observed between these two stations in summer was the presence of small amounts of nitrate in the water at Station 8 and an almost total absence of nitrate at Station 5.

While it might be supposed that the sudden disappearance of Cladophora at Station 8 in June was due to a period of high water and swift current at that time, the evidence from rainfall (Fig. 7) and water level (Fig. 9) gives no support to this supposition. Unfortunately, chemical data from this period are lacking, so that it is impossible to state whether or not any sharp changes in nutrients present in the water are correlated with this disappearance. Since the physical variables showed no significant changes at this time, the sudden reduction in Cladophora here cannot at present be correlated with any single environmental change.

The behavior of Cladophora at Riffle 12, which was heavily shaded in summer (Fig. 32) was, however, essentially different from its behavior in unshaded stations. At Station 12, a marked spring growth of Cladophora took place as at other stations, but its rapid disappearance in June and July with the leafing out of overhanging and surrounding deciduous trees was striking and complete. No Cladophora whatever was present in the riffle throughout a six-week period from July 20 to September 10, in sharp contrast to the condition at Stations 8 and 10, both of which showed a marked upsurge in Cladophora in mid-July. In late September, with the beginning of leaf fall, a meagre growth of Cladophora was found in scattered parts of the riffle, and for the remainder of the year the Cladophora vegetation was equivalent to that on the unshaded riffles. This behavior is in agreement with

the observation of Jaag (1938) that a series of cloudy days suffices to reduce sharply the amount of C. glomerata in the upper Rhine.

Morphologic differences were evident between the fall or winter condition of the Cladophora plants and their condition for several days before detachment in late June. The characteristic glomerate plants were modified by the pronounced elongation (in May) of numerous main filaments and the detachment of the majority of the glomerate ends, giving the plants a stringy, fibrous appearance. Following a period of five to six weeks in May and June during which these fibrous skeins, which attain a length of one to two meters, virtually cover the floor of all riffles both shaded and unshaded, the plants detach by the breakage of a cell near the basal cell and are, of course, immediately carried downstream, leaving behind on the rock only the minute basal filaments of relatively few cells. Since the much elongated skeins have meanwhile become intricately tangled by water currents with other Cladophora plants growing around them, the detachment of one plant may occasion a simultaneous removal of many plants from a given portion of the riffle. The sudden disappearance in this way of the massive spring Cladophora vegetation leaves the riffle relatively bare except for the widespread crustose communities, which thus become suddenly exposed after remaining in heavy shade throughout the late spring. Limited growth of Cladophora may apparently take place at any time from the remaining basal filaments, and glomerate portions of such of these small plants as remain in late winter presumably produce a spring crop of gametes and zoospores.

According to List (1930) zoospores of C. glomerata are liberated throughout almost the entire year, but available evidence indicates

that such may not be the case in the Saline River. Abundant colonization by Cladophora on sterilized rocks placed in the river at Station 8 occurred between August 18 and September 23, 1952, but no further colonization whatever was observed on such rocks throughout the fall and winter period, in spite of the continued presence of numerous well developed and glomerate, albeit small, plants on this and upstream riffles.

There appears to be no limit at either end of the scale to the size of rock upon which motile cells of Cladophora can establish themselves. All of the largest boulders in the unpolluted riffles show a good growth of Cladophora in May and June, and well developed plants with attached basal cells have been found on rock particles so small as to weigh only about fifty milligrams when dried. Small rock particles are seldom found exposed on the bed of a riffle, and would, of course, be unable to provide anchorage there for any alga, but such particles are abundantly found enmeshed within the masses of large Cladophora plants, and many are utilized for the attachment of germlings of the same species. A large plant of Cladophora in spring or summer acquires a host of such rock particles, and through the germination of motile reproductive cells within the relatively quiet water at the center of the mass of filaments, comes to serve as a veritable marsupium for the growth of innumerable offspring of itself or of upstream plants. All such younger individuals are, of course, doomed to become river debris upon the detachment of the encompassing parent.

Lyngbya aestuarii (Mert.) Liebm.--This blue-green alga grew inconspicuously at Station 8 and was occasionally recorded from other unpolluted riffles. It forms a whitish, cobwebby net over the surface

of the Phormidium-Schizothrix crust, on a few scattered rocks. The whitish color of this net is due to the heavily calcified sheaths which surround and enclose the blue-green trichomes. Lyngbya aestuarii is known to be present from July through September, and is absent in the fall and winter months, but the dates of its appearance and departure were not determined precisely.

Oscillatoria Community.--In the Saline River this benthic community is dominated by Oscillatoria tenuis Ag. In early summer it is found widespread on pool bottoms where even a small amount of silt has accumulated, the Oscillatoria penetrating the upper layers of silt and trapping more mineral particles among the exposed filaments. The complex of Oscillatoria and silt thus constituted permits the growth of numerous algae mixed in with O. tenuis. These include:

Merismopedia convoluta Bréb.
Oscillatoria princeps Vauch.
Spirulina major Kuetz.
Pediastrum duplex Mayen
Scenedesmus abundans (Kirch.) Chod.
Scenedesmus arcuatus var. platydisca G. M. Smith
Ankistrodesmus falcatus (Corda) Ralfs
Euglena oxyuris Schmarda
Cymbella spp.
Navicula cryptocephala var. intermedia Grun.

This community is first evident in late May on silty banks in shallow portions of pools. Eventually, it may spread over the entire pool bottom and to shady portions of the riffles. By touching bottom with a pole, it can easily be dislodged in large or small masses which then float to the surface and move downstream. As described under Section VI, A, above, the masses of Oscillatoria with their contained silt and other algae are naturally torn from the bottom when at midday or thereabouts sufficient oxygen becomes trapped in the reticulum of

filaments to overcome the weight of the mass of silt. Unlike Cladophora plants, which, once dislodged, are usually unable to grow successfully where they become snagged downstream, the Oscillatoria and other algae entrapped in its meshes profit from this dislodgment to propagate themselves over the entire downstream area which is ecologically adapted to their growth. Although sufficient quantities of the Oscillatoria community arrived daily throughout July as far downstream as Station 18 to "seed" the polluted course of the stream, only Euglena oxyuris and Navicula cryptocephala were ever found below Station 14 in such a condition as to suggest their successful growth; none of the other species typical of the Oscillatoria community survived the heavy concentration of pollutants at Stations 14 and 15.

A growth maximum was reached by O. tenuis in July and August (Figs. 31, 32). The time of this maximum agrees in general with a similar maximum recorded by Butcher (1924). Although this species disappeared from the riffles of the Saline shortly after this time, it remained on certain shaded banks in the unpolluted portion of the river until late in October. The growth of O. tenuis in pools seems to be consequent upon its sensitivity to bright light, for on riffles it grew conspicuously only in markedly shaded situations.

Spirogyra Communities.--None of the numerous species of Spirogyra found in the stream was ever found in fruiting condition throughout the period of this study and the writer was unable to induce fruiting in the laboratory. The species were therefore not determinable, with the exception of S. fluviatilis Hilse which occurs in the Saline, as it probably does in the majority of streams in northeastern United States, and is almost surely recognizable in vegetative

condition from the fact that it is one of the very few attached Spirogyras. Numerous other species of Spirogyra were found in the unpolluted course of the stream. Usually they occur as floating inhabitants of quiet, very shallow, water at the side of riffles or pools, or on shoals where the deposits of silt and contained organic material provide abundant nutrients. These species frequently grow together in such a way that the visible mass of filaments is a complex of three or more species. Rapid changes occur in these algal masses. Local growth is surprisingly fast at certain periods, and the disappearance may be equally rapid and superficially inexplicable. After an initial attempt to record the comings and goings of such Spirogyra communities in the summer months, observations were reduced to frequent collections from the principal stations.

Spirogyra fluviatilis was present throughout the stream, being commonly found attached to rocks or anchored in a silt deposit in shallow portions of pools, as well as attached to rocks in many riffles. It attained a maximum of development in August. Its growth was not confined to summer months, although it was not recorded in the period from December through February.

Other species of Spirogyra, found mostly in summer in the unpolluted portion of the Saline River, may be listed as follows:

TABLE 3

SPIROGYRA SPECIES OF UNPOLLUTED WATER

Species	End walls	Filament diameter	Chloroplasts, number and type
1.	Non-replicate	58 - 70μ	3, closely wound
2.	Non-replicate	22 - 24μ	1
3.	Non-replicate	30 - 32μ	1, closely wound
4.	Replicate	26 - 31μ	1

Summer diatom communities.--Various diatoms were found abundantly in the river throughout the summer as benthic algae both in riffles and in pools. The most important are listed below:

Synedra ulna (Nitzsch) Ehr.
Synedra acus Kuetz.
Cymbella prostrata (Bréb.) Cl.
Cymbella affinis Kuetz.
Cymbella tumida Van H.
Cymbella ventricosa Kuetz.
Navicula viridula Kuetz.
Navicula cryptocephala Kuetz.
Navicula cryptocephala var. intermedia Grun.
Navicula gracilis Ehr.
Melosira varians C. A. Ag.

Such diatoms usually occurred in mixtures of various species, forming a brown layer on silty banks or on protected portions of rocks. Cymbella prostrata forms the most conspicuous summer growths, which are gelatinous in appearance and somewhat resemble the winter vegetation dominated by Gomphonema olivaceum. The habit of growth is different, however, inasmuch as the Cymbella characteristically forms gelatinous cylinders about submerged roots or Cladophora germlings, whereas the Gomphonema is mostly confined to large rocks. The impossibility of determining macroscopically the diatom species contained in these homogeneous brown layers rendered necessary the recording of the diatoms as a group in the transect studies. Starting about October 10, it became possible to distinguish one species, Diatoma vulgare Bory, which from that time on dominated and eclipsed all the other diatoms. Transect records of diatoms between May 15 and October 10, therefore, refer to several species growing together in quantity sufficient to form a visible growth. After October 10, only Diatoma is recorded, with the equally distinctive Gomphonema olivaceum also recorded by name after its appearance in late November.

3. Winter Communities

Diatoma-Gomphonema Community.--This "community" (Butcher, 1932) is really composed of two distinctive and competitive algae whose growth maxima do not coincide. The first of these to appear, Diatoma vulgare Bory (Fig. 49), grows in extremely dense stands of short filaments on rocks in riffles. Its distribution in space is intriguing: in winter it was absolutely dominant in unpolluted riffles below Saline Pond, whereas it was entirely absent as a dominant alga in all known riffles in the stream proper above the pond. In certain of the upper tributaries, however, particularly in Tributary 11, it was extraordinarily abundant, a condition which contrasted in striking manner with that at Station 5, immediately below the mouth of the tributary, where little of the Diatoma was to be found. In seeking the cause for this peculiarity of distribution, it was found that both Tributary 11 and Stations 8-12 maintain relatively high concentrations of nitrate throughout the winter, whereas Station 5 remained as consistently low in nitrates (Fig. 23). From this evidence, it would appear that the dominance of Diatoma may be dependent upon the presence of abundant nitrates; but when this hypothesis was tested upon the Huron River and other streams in the vicinity of Ann Arbor, quite contrary results were obtained. Apart from the difference in nitrate content, no significant physico-chemical differences in the water between Stations 5 and 8 could be observed by the procedures employed.

Colonies of Diatoma vulgare are common in all polluted riffles of the Saline River in winter, but nowhere does it achieve dominance as it does in the unpolluted stations.

The other principal diatom of the winter period, Gomphonema

olivaceum (Lyngb.) Kuetz. (Fig. 50), grows in colonies with the individual cells attached at the ends of minute, ramifying pedicels. As the living cells grow and reproduce, the pedicels become confluent and form conspicuous masses of gelatinous material as much as one centimeter in thickness on exposed rocks. This species is common on riffles and co-dominant in late winter throughout the unpolluted portion of the river. Although it can be found in winter in polluted portions of the river, its colonies there remain small and do not become macroscopically visible until late in March.

In streams of Thuringia, Kolbe (1932) describes a spring maximum of Diatoma vulgare. Raabe (1951) states that Gomphonema olivaceum in Holstein reaches its maximum in March. The Diatoma vegetation of the Saline River rose to dominance in the autumn of 1952 as soon as water temperatures had fallen below about 15° centigrade (Figs. 8, 30-32). Throughout the early winter period, the dominance of this form was uncontested on all riffles below Station 7. As the winter progressed, colonies of Gomphonema olivaceum gradually but surely took over the sites occupied by Diatoma, and by February 15 had largely replaced the latter. In late February, the growth of Gomphonema was indeed luxuriant, and fully as massive as the Cladophora vegetation of late May. Diatoma disappeared as a dominant form about March 1; the disappearance of Gomphonema corresponded with the general rise in water temperature in mid-April. Isolated cells of both could, however, be found throughout the year. The detachment and disappearance of Diatoma was slow and imperceptible, due to the small size of the individual Diatoma filaments. The tan-colored colonies of Gomphonema, however, detached and floated downstream conspicuously in large,

gelatinous masses, starting about February 15.

Abundant reproduction was exhibited by Diatoma throughout early winter. All sterilized rocks placed in the riffles between October 27 and March 1 were quickly colonized by this alga, often so rapidly that the new colonies were visible to the eye within ten days. Colonization by Gomphonema was equally rapid, but did not begin until about November 25. From this date on through February 15, all sterilized rocks placed in the stream soon acquired new colonies of both principal diatoms and little else.

Batrachospermum boryanum Sirod.--This freshwater red alga is common in late winter and early spring in the headwaters of Tributary 15 as well as at Stations 10 and 12 in the river itself. It has never been found below Station 12. It grows attached to rocks in a manner similar to Cladophora glomerata. Its growth is slow and is greatly enhanced by a certain amount of shade, as in other members of this genus. In this connection, it is interesting to note its virtual confinement to the shaded portions of Tributary 15 and to the heavily shaded Station 12 in the Saline River system, in spite of the fact that the erect portion of the alga grows only in the cold season when the protection offered by surrounding trees is in part removed by the temporary absence of leaves.

The first erect portions of Batrachospermum make their appearance in mid-November. They grow slowly throughout the winter, attaining a maximum size about April 1 (Figs. 32, 33). Presumably the growing season is climaxed at least in some plants by sexual reproduction and cystocarp formation, although no cystocarpic material was ever found in the Saline. With the advent of higher water temperatures, the

erect portions detach and disappear, with some individuals remaining in place until about May 20.

Growth of the erect portions may be supposed to be from "Chantransia" filaments which are indistinguishable from Audouinella violacea, a component of the permanent, crustose Phormidium-Schizothrix vegetation. In view of the widespread presence of this crustose community at Station 12, it proved impossible to locate and to distinguish the Chantransia stages which were destined to produce erect portions of Batrachospermum. None of the sterilized rocks placed in the stream at intervals from August 22, 1952, on showed any production of erect portions of Batrachospermum in the winter of 1952-53. This is not, however, conclusive evidence bearing on reproductive habits of Batrachospermum, inasmuch as a majority of rocks native to the riffle (Station 12) never developed any erect portions.

Ulothrix tenuissima Kuetz.--This alga grew abundantly at water line on rocks in the shaded Riffle 12 throughout the late winter period. It was also observed in a few shaded situations in Station 8, as well as in certain tributaries, during the same season. It was never found in polluted portions of the stream.

4. Other Algae

Following is a list of algal species, other than those discussed above, observed in the period 1951-53 in unpolluted regions of the river. The very abundant Bacillariophyta (diatoms), save for the important species discussed above, have not been determined and, hence, are omitted.

Summer Algae

Myxophyceae:

Merismopedia tenuissima Lemm.
Merismopedia glauca (Ehrenb.) Naeg.
Merismopedia convoluta Bréb.
Entophysalis rivularis (Kuetz.) Dr.
Anabaena sp.
Spirulina major Kuetz.
Oscillatoria princeps Vauch.
Phormidium autumnale (Ag.) Gom.
Phormidium retzii (Ag.) Gom.
Calothrix braunii Bornet & Flahault

Chlorophyceae:

Chlamydomonas sp.
Stigeoclonium tenue Kuetz.
Chaetophora elegans Ag.
Chaetophora pisiformis Ag.
Schizomeris leibleinii Kuetz.
Coelastrum microporum Naeg.
Scenedesmus dimorphus (Turp.) Kuetz.
Scenedesmus abundans (Kirch.) Chod.
Scenedesmus arcuatus var. platydisca G. M. Smith
Pediastrum tetras var. tetraodon (Corda) Rab.
Pediastrum integrum Naeg.
Pediastrum duplex Mayen
Pediastrum duplex var. cohaerens Bohlin
Ankistrodesmus falcatus (Corda) Ralfs
Oedogonium spp. (sterile)
1. diam. 10-17 μ
2. diam. 20-23 μ
3. diam. 34-44 μ
4. diam. 44-51 μ
5. diam. 49 μ

Rhizoclonium hieroglyphicum Kuetz.
Cosmarium spp.
Closterium spp.
Zygnema sp. (sterile) diam. 37-41 μ
Mougeotia sp. (sterile) diam. 28 μ

Charales:

Chara contraria A. Br.

Rhodophyceae:

Asterocytis smaragdina Reinsch

Heterokontae:

Vaucheria schleicheri de Wildeman

Euglenophyta:

Euglena oxyuris Schmarda

Winter Algae

Myxophyceae:

Phormidium autumnale (Ag.) Gom.

Chlorophyceae:

Draparnaldia plumosa Ag.
Pediastrum integrum Naeg.
Pediastrum duplex var. cohaerens Bohlin
Scenedesmus quadricauda (Turp.) Bréb.
Rhizoclonium hieroglyphicum Kuetz.
Oedogonium sp. (sterile) diam. 34-41 μ
Zygnema spp. (sterile)
1. diam. 34 μ
2. diam. 41 μ
3. diam. 47 μ

Heterokontae:

Tribonema minus West
Tribonema bombycinum Derbès & Solier

Chrysophyceae:

Dinobryon divergens Ehr.
Dinobryon bavaricum Pascher

B. Benthic Algae of the Polluted Portion

1. Permanent Crustose Communities

Navicula seminuloides Hust.[4]--This extremely minute diatom has an interesting distribution: it is found nowhere in the unpolluted portion of the stream, but is present on virtually every rock in the river below the industrial outfall at Saline for at least two miles (3.2 kilometers) downstream. It is not confined to riffles, although its best growth is made in riffles. It is found only on rocks or

[4]This is a tentative determination made by Dr. E. Manguin.

other permanent supports, and as it secretes abundant limy material, it comes in time to form calcareous layers of considerable thickness on the supporting rock. As new diatom cells are formed by division, the cells adjacent to the rock become buried and fossilized in a slowly accumulating deposit of calcium carbonate. These crusts measure up to three millimeters in thickness. The outer layers of the crust are usually brighter green than the inner, indicating the greater abundance of living cells in the outer layers. Throughout much of the year, the crust is covered over and hidden by the heavy growths of Nitzschia palea, Stigeoclonium tenue, Sphaerotilus natans, or other algae of the heavily polluted area. When one or another of these superficial algae experiences widespread removal from its substratum, the Navicula vegetation becomes momentarily visible, until such time as it again becomes covered by silt, by new growth of diatoms, or by regeneration of the superficial algae.

The Navicula seminuloides crust is present throughout the year and shows little if any seasonal fluctuation in amount. It may be presumed to profit in its growth from temporarily improved light conditions when other algae are not screening it from above.

The presence of this alga at a depth of 0.7-1.0 meters in Pool 17 raises the question as to whether or not the water of this highly polluted habitat is ever anaerobic. Tests for dissolved oxygen made throughout a warm summer night, however, failed to show any decrease in dissolved oxygen below 1.5 c. c. per liter, even in deep water at this station; hence, it may be supposed that the surrounding water never becomes entirely devoid of oxygen.

2. Summer Communities

a. Algae of Rapid Water

Stigeoclonium tenue Kuetz. (Fig. 55).--This is the largest alga in the polluted course of the river. Its branched filaments form long, massive, almost fluid streamers in riffles throughout much of the year. Like Cladophora, it is never found in entirely quiet water. Remarkably enough, it can resist the pull of water currents up to 1.35 meters per second, but if it and the rock to which it is attached be removed from the water, its own weight with that of the contained water will frequently be sufficient to pull a large plant from the rock to which it is attached. At Riffle 14, immediately below the industrial outfall at Saline, its spring growth is more luxuriant than at any other known point in the river. At this place and time, numerous plants 0.40-0.50 meters in length can be seen. Downstream from this point, its growth is less massive, and the amount of Stigeoclonium bears, in rough terms, an inverse relationship to the distance from the Saline outfalls. Thus, at Station 25, at Saline Mills, a good summer growth consisting of many large plants, may be found, whereas at Station 28, only much smaller plants are present, and growth of these, moreover, is greatly restricted in time. Below this point, due in part to the absence of suitable riffles, Stigeoclonium is much less abundant. This alga is not confined to polluted portions of the river, but its occurrence above the polluted course of the river is, by contrast, highly sporadic.

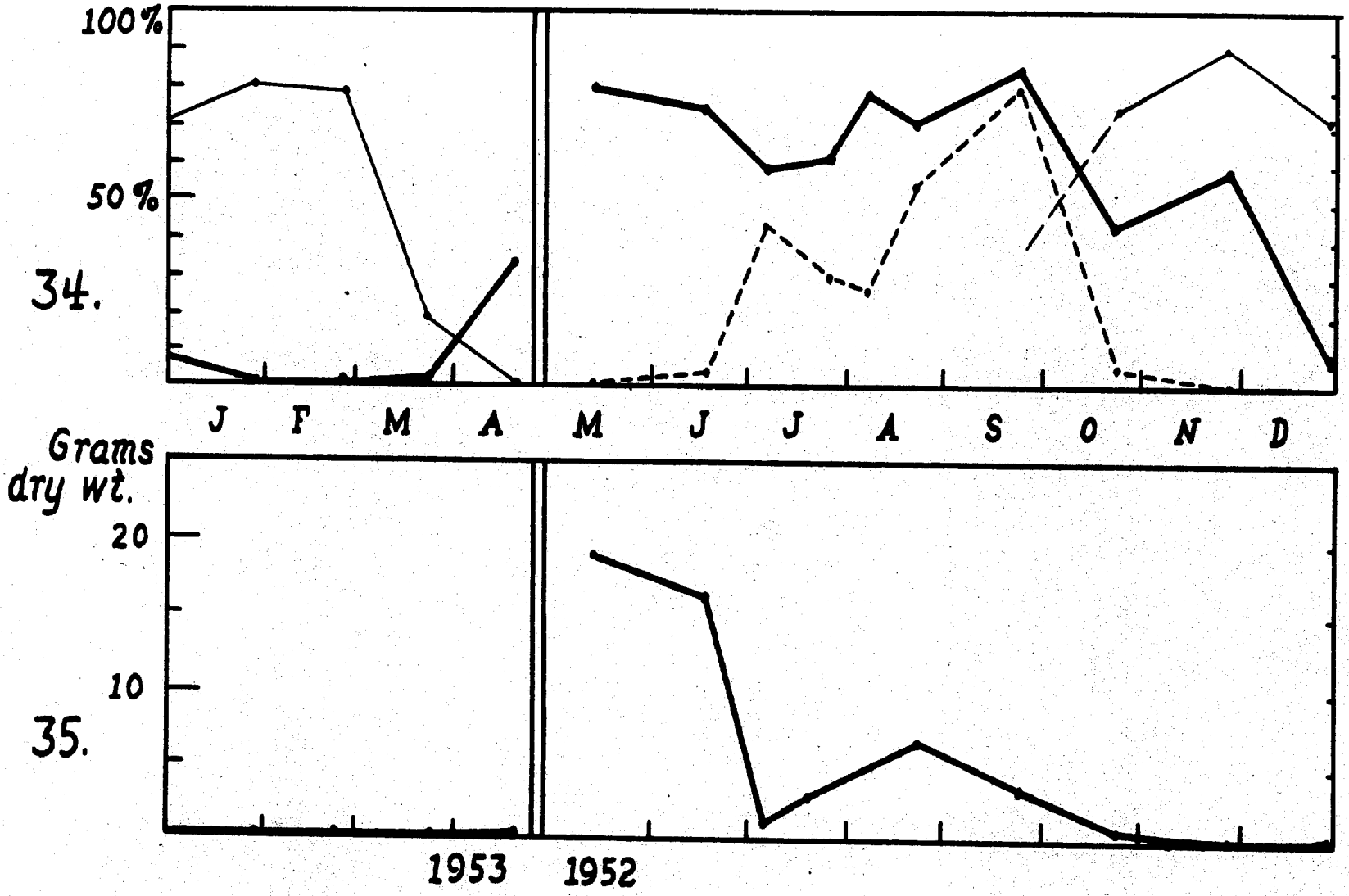
In general, good growth of Stigeoclonium tenue was limited to the warm months. Small plants were, however, abundant in winter at certain stations, although throughout much of the winter the alga was

completely missing at Station 14, where its best spring growth was attained. Its periodicity can be best discussed by referring to the individual stations in order:

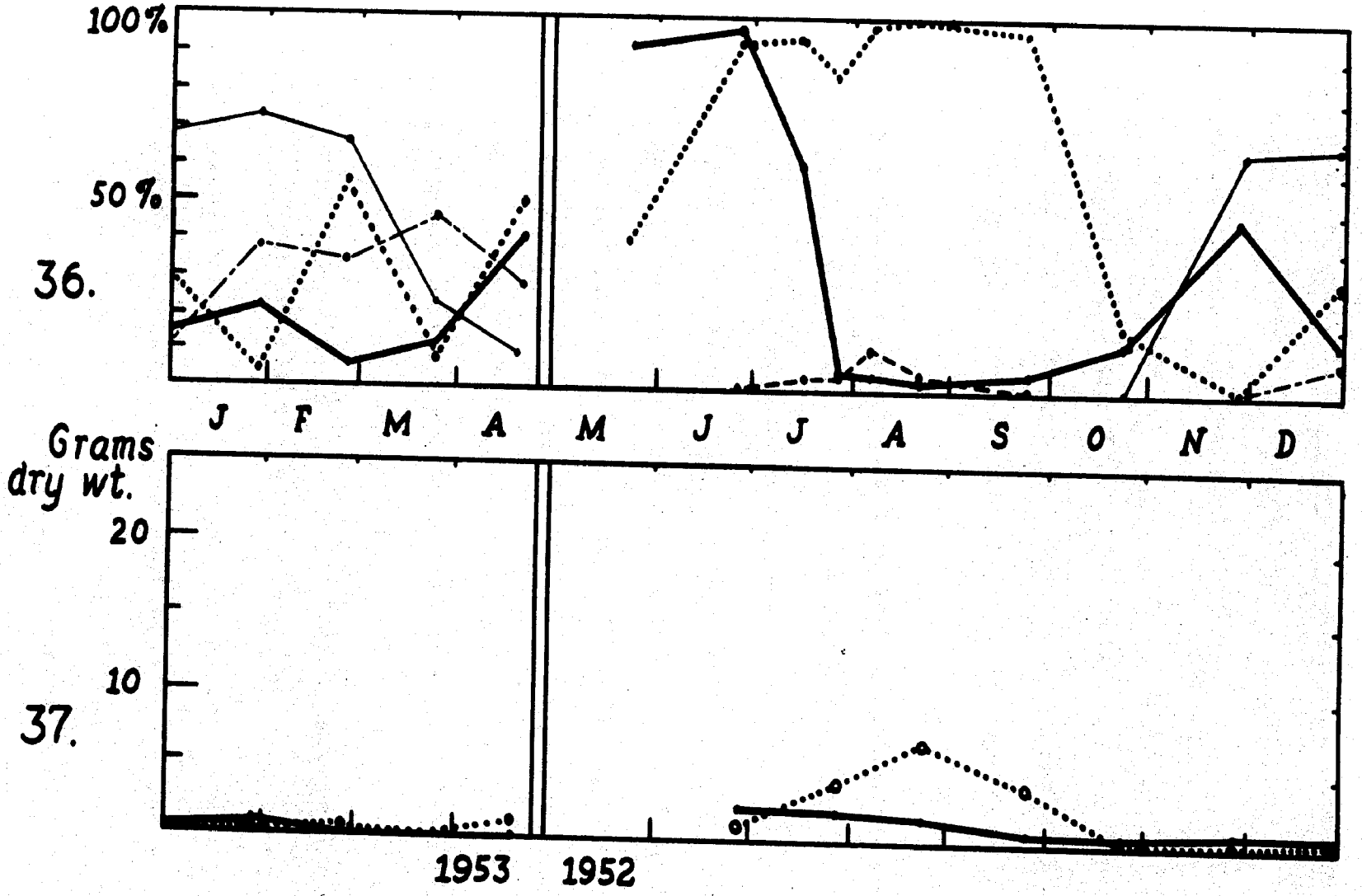
Station 14 (Figs. 34, 35). In late winter no erect portions of Stigeoclonium were visible at this station. In view of its growth, albeit sparse, at stations downstream from this point, it would appear that the combination of low temperature with either (a) the industrial poisons introduced just above this station, or (b) smaller amounts of nutrient substances than are present at downstream stations, is sufficient to eliminate it completely. In May there occurred a notable upsurge of great magnitude, followed by a marked reduction in June. Subsequent increases occurred early in August and in mid-September, each followed by periods of decline. In early October a permanent decline set in, and few or no plants were to be found throughout the winter.

Stations 15 and 18 (Figs. 36, 37). These two heavily polluted stations behaved more or less as a unit throughout the period of the study. In late winter, small Stigeoclonium plants appeared at the crests of these riffles, but the remainder of each riffle was almost devoid of Stigeoclonium.

A great development of this alga took place in May as at Station 14, but in Stations 15 and 18 Stigeoclonium was quickly destroyed and replaced, about July 1, by the vigorously growing bacterium Sphaerotilus natans Kuetz. Throughout the warm months, Sphaerotilus was completely dominant on both these riffles, with only a few Stigeoclonium plants retaining a foothold at the crests of riffles where the current velocity appeared to be a limiting factor for



Figs. 34, 35.--Fig. 34. Seasonal variation in frequency of important algae at Station 14 (effects of industrial pollution). Key: ———— Stigeoclonium tenue, - - - - - - Nitzschia palea, ———— Diatoma vulgare. Fig. 35. Seasonal variation in dry weight of Stigeoclonium tenue removed from ten arbitrarily selected rocks (as described in text) at Station 14.



Figs. 36, 37.--Fig. 36. Seasonal variation in frequency of organisms at Station 18 (effects of industrial pollution plus sewage). Fig. 37. Seasonal variation in dry weight of Stigeoclonium tenue and Sphaerotilus natans removed from ten arbitrarily selected rocks (as described in text) at Station 18. Key: ———— Stigeoclonium tenue, ...Sphaerotilus natans, - - - - - - Nitzschia palea. ———— Diatoma vulgare, ——— — unknown Heterokontean alga.

the heavy and extremely fragile thalli of Sphaerotilus. With the widespread detachment of Sphaerotilus as soon as water temperatures fell below about 15° C., Stigeoclonium experienced a brief and moderate recrudescence, but again fell off to virtual disappearance in the latter part of December.

Station 25 (Fig. 38). This station, at a distance of one mile (1.6 km.) below the Saline outfalls, has at least a reduced vegetation of Stigeoclonium throughout the year, even in winter months when Stigeoclonium is practically or entirely wanting at Stations 14, 15, and 18. The small plants present here in March and April grow rapidly in May to their maximum size as at the upstream stations cited. At Station 25 a marked reduction occurred, however, only in late July, and came at a time when the Stigeoclonium at Station 14 was in full development. This regression was followed by two periods of marked growth, each followed by a decline. The first of these growth periods reached a climax in late August, the second in mid-September. Later in September, well before a similar decline at Station 14, the Stigeoclonium vegetation fell off to a few small plants which remained, however, in good condition throughout the winter.

Station 28 (Fig. 39). Growth of Stigeoclonium at this station, at a distance of two miles (3.2 km.) below the Saline outfalls, was greatly curtailed by comparison with upstream stations. Throughout much of the year, rocks in this riffle were covered with a minute growth of Stigeoclonium (Fig. 40), apparently of S. tenue[5]. The colonies of these dwarf plants were somewhat stony in nature due to

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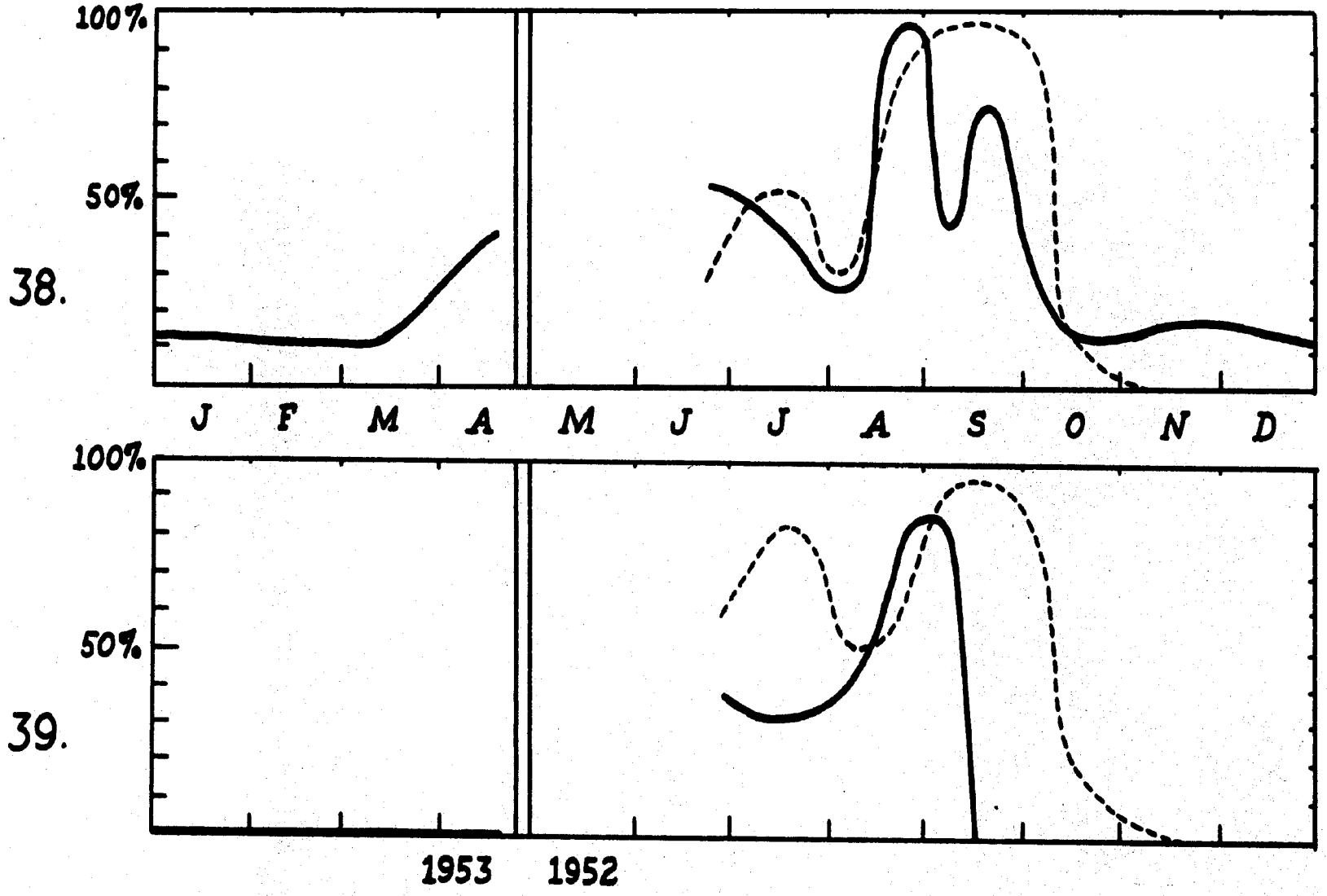
[5]It is impossible at present to obtain greater precision in determinations within this genus, which is poorly known taxonomically and made up of species notoriously variable in form.



Figs. 38, 39.--Seasonal variation in estimated frequency of Stigeoclonium tenue and Nitzschia palea at mesosaprobic stations, showing recovery after pollution. Fig. 38, Station 25. Fig. 39, Station 28. Key: ———— Stigeoclonium tenue, - - - - - - Nitzschia palea. These curves are not based on measured transects, but on visual estimates.

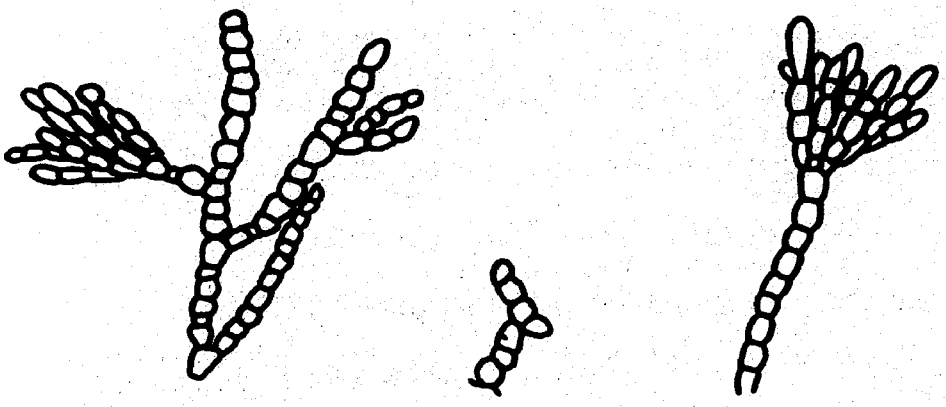


Fig. 40.--Stigeoclonium tenue (?), encrusted dwarf type found at Station 28. X490.



Fig. 41.--Mass of Sphaerotilus natans (b) surrounding numerous Spirogyra filaments (a), as found at Station 18 in the summer of 1952. X2.

the presence of a calcareous sheath precipitated by the individual filaments. What morphologic or genetic relation these plants may have to the ordinary erect plants of this species is not known. While no development of the usual erect plants took place throughout the first half of the year, a most sudden and remarkable development of such plants occurred in mid-August. Within a fortnight, the entire riffle floor developed a massive Stigeoclonium vegetation with plants up to 0.40 meters in length. This vegetation was ephemeral, however, and disappeared in the second week of September more quickly than it had come. This disappearance coincided precisely in time with the regression in Stigeoclonium at Station 25, but at Station 28 it was complete, no erect portions of plants whatever remaining in the stream. The disappearance did not coincide with any apparent reduction in the co-dominant Nitzschia vegetation. After September 18, no further Stigeoclonium was to be found in the stream at this point throughout the remainder of the year.

An attempt was made to correlate the disappearance of Stigeoclonium with conditions within the stream, but it may be said at the outset that convincing evidence of correlation with any single environmental factor was not obtained. The noteworthy disappearance of Stigeoclonium at Station 28 long before its permanent reduction elsewhere confuses the picture markedly. The general reduction at Stations 14 and 25 in early October can conceivably be correlated with a variety of environmental changes occurring at this time: (1) marked reduction in temperature, (2) marked reduction in light, (3) reduction in nutrients, including both inorganic phosphorus (Fig. 22) and organic nitrogen (Fig. 26), (4) reduction in the rate of bacterial action in

the stream, due in part to the great decrease in Sphaerotilus occurring at this time (Fig. 35). There is no clear evidence, however, that any one of these factors is the principal one operative. It seems very possible that a given combination of them may be responsible for the striking seasonal changes observed in the Stigeoclonium and here recorded.

Nitzschia palea (Kuetz.) W. Smith (Fig. 52).--While this species is not confined to rapidly moving water, it is co-dominant on riffles (with Stigeoclonium tenue) in the polluted course of the river. Although, as with nearly all other algae of the Saline River, its photosynthesis results in deposition of a certain amount of calcium carbonate outside of the cells, the carbonate does not fix it to the substrate, and its means of attachment in rapid water is far from evident. Nevertheless, it is able, along with N. linearis W. Smith, which accompanies it nearly everywhere, to maintain its position and to reproduce, in late summer, in water moving at a rate of at least 0.40 meters per second. Where it grows in abundance, it forms a rich brown layer as much as one millimeter in thickness, on rocks on sandy or gravelly portions of the bottom (thus somewhat consolidating the bottom), or on mats of Sphaerotilus. It grows everywhere in very shallow water, from the water's edge to a depth of about ten centimeters; hence, it is especially conspicuous on shoals, in shallow backwater areas, and in riffles. It is lacking from heavily shaded areas.

This species has been found sparsely above the Saline outfalls, but its massive growth, accompanied by N. linearis, occurs only in the polluted portion. Immediately below the industrial outfall at Saline, in fact, colonies of this alga are conspicuous on bottom sand in

August and September. In shallow water in the entire course of the stream beyond this point, as far downstream as Station 32, its growth is prodigious.

Numerous European authors (Marsson, 1908, Budde, 1930, Kolbe, 1932, Schroeder, 1939, Butcher, 1949, Hornung, 1951) have described the enhanced growth of N. palea in polluted water, and it is well known generally as an inhabitant of the α- and β-mesosaprobic zones in polluted streams. Of particular interest is the statement by Schroeder (1939) that it tolerates relatively large amounts of copper in the water. This tolerance is evident in the Saline, as is the parallel tolerance of this species (as well as of Stigeoclonium tenue) to chromium and cyanide, both of which are introduced in large amounts by the factory effluent.

Nitzschia palea is conspicuous in the river only in the warm months (Figs. 34, 36, 38, 39). It was first seen in early June, and increased rapidly at all observed points throughout late June and early July. A marked decline occurred in late July; this was followed by a period of very rapid growth early in August. Throughout much of August and all of September, Nitzschia was more conspicuous than any other alga, and undoubtedly exceeded all other algae in dry weight.

After this period of dominance, the entire Nitzschia vegetation disappeared in early October with great rapidity. At all observed stations this decline began at approximately the same time but was completed more rapidly at Stations 25 and 28 than at Stations 14 and 38. As with the almost simultaneous reduction in Stigeoclonium tenue, this decline may be correlated with numerous environmental changes, any one of which may be responsible for it.

b. Algae of Quiet Water

Spirogyra spp.--Numerous species of Spirogyra inhabit the pools, shoals, and backwater areas of the polluted portion of the river. As in the upper course of the river, S. fluviatilis is common on rocks and silt-covered banks in shallow water, thus achieving the distinction of being the sole alga which shows little or no response to the pollutants entering at Saline. In addition, several other unattached species were present and grew luxuriantly in summer on the bottom or just above the bottom. Among these species, the following are most abundant:

TABLE 4

SPIROGYRA SPECIES OF POLLUTED WATER

Species	End walls	Filament diameter	Chloroplasts, number and type
1.	Non-replicate	58 - 70μ	3, closely wound
4.	Replicate	26 - 31μ	1
5.	Non-replicate	27 - 31μ	1
6.	Non-replicate	33 - 36μ	1, loosely wound

The species in this table numbered 1 and 4 apparently correspond with species to which the same respective numbers were applied in the discussion (above) of algae of the unpolluted portion of the stream.

Throughout late summer and much of the autumn of 1952, certain of these Spirogyra species grew rapidly at Stations 16 and 17 just below the sources of the pollutants where the concentration of nutrients in the water, as well, presumably, as of the metallic poisons, was greatest. Since these stations were observed carefully throughout the year, the principal changes occurring here will be summarized.

Throughout July, August, and September, the vegetation consisted of masses of S. fluviatilis and of Species 1 and 5 mixed together. These masses covered virtually the entire bottom of Pool 17, and were particularly rich in shallow backwater areas. It appears possible that the Spirogyra of this pool was the center of dispersal for much or all of the remainder of the stream. Spirogyra was first observed here in quantity in mid-June, and early in July the mechanism of dispersal from shoals which is described above (Fig. 16) was already in operation at this station. From this time on, every day of fair weather witnessed the rising and movement downstream of hundreds of masses of living filaments, each carrying a portion of the silty stream bottom which was torn away by the disengagement of the algal mass. In this way, the algae unquestionably played a considerable role in the transport downstream of undecomposed solids, and, hence, in the self-purification of the stream.

At the time of maximum development of this massive vegetation, Spirogyra extended from this pool (17) to Riffle 18 just below, and both attached and unattached masses were recorded on transects made at Riffle 18 in July, August, and September. At this time, abundant Spirogyra filaments were found to be growing on the riffle surrounded by Sphaerotilus tufts (Fig. 41). Unfortunately, time did not permit the study of the genesis of this relationship, i.e., whether Sphaerotilus by its own growth came to surround tufts of Spirogyra, or whether the Spirogyra filaments, influenced by constantly shifting water currents, were slowly threaded into the Sphaerotilus mats. The appearance of these mats suggested the latter origin rather than the former.

The benthic masses of Spirogyra remained in mid-current in

Pool 17, somewhat reduced in amount in the autumn months, until about January 1, when the last of these masses disappeared. The Spirogyra in the shallow backwater areas at this station never entirely disappeared throughout the period of this study, and no significant change in species composition was observed with the changing seasons.

Closterium-Euglena community.--In areas of quiet water in a stream, silt and other transported materials are deposited. In a stream bearing sewage, such silt banks are extremely rich in organic materials. As the banks build up by sedimentation, thick deposits of grey or black mud are formed which constantly disperse into the supernatant water layer larger quantities of nitrites and nitrates than are present in the fresh sewage or in the stream itself. The combination of environmental factors which influence such a silt bank, including maximum light, nutrients in high concentration, water which usually is constantly but slowly replaced, high temperatures, and, in the Saline, the presence of poisons of industrial origin, permit the growth of a limited number of algae, but these grow luxuriantly, forming small green patches on such silty areas. The Nitzschia species characteristic of this portion of the river in the entire course from Station 15 to Station 28, form an ubiquitous background for these green colonies and are indeed mixed invariably with the other algae forming the colonies. These other algae include particularly the desmid Closterium acerosum (Schrank) Ehr., the flagellates Euglena acus Ehr. and E. oxyuris Schmarda, and the diatom Navicula cuspidata Kuetz. Of these, the large banana-shaped cells of Closterium acerosum are most conspicuous, and can be seen clearly with the unaided eye if a small portion of such a colony be spread out on a sheet of white paper. All

of these species are well known to be characteristic of European polluted waters, although no records have been found of an equally massive development of Closterium acerosum in other streams.

This vegetation is not as widespread as either the Spirogyra or the Nitzschia vegetation, although its development is approximately synchronous with that of the latter. The Closterium-Euglena vegetation was at its maximum density in August and September, 1952. It disappeared in the first week of October at the same time as, and quite possibly in response to the same environmental changes that induced, the reduction in the Nitzschia vegetation.

3. Winter Algae

a. Algae of Rapid Water

Diatoma vulgare Bory.--This diatom, so characteristic of the fall and winter months in the unpolluted riffles, was found throughout the latter months of winter in all the polluted riffles, but in exceedingly reduced amount, constituting probably less than one per cent of its production per unit area in upstream riffles. Its habit of growth was likewise somewhat different in polluted stations: instead of forming filaments 1-2 centimeters in length, it formed minute tufted colonies or masses not more than 2-3 millimeters in length. Its development in polluted riffles was, moreover, much slower than in upstream riffles; at Stations 8 and 10 (unpolluted), for example, Diatoma achieved virtually its maximum development by October 20, 1952, whereas at Station 18 (polluted), this was not achieved until about November 25. Its usual substrate here was living or moribund filaments of Stigeoclonium, or the mats of Sphaerotilus, which it colonized extensively,

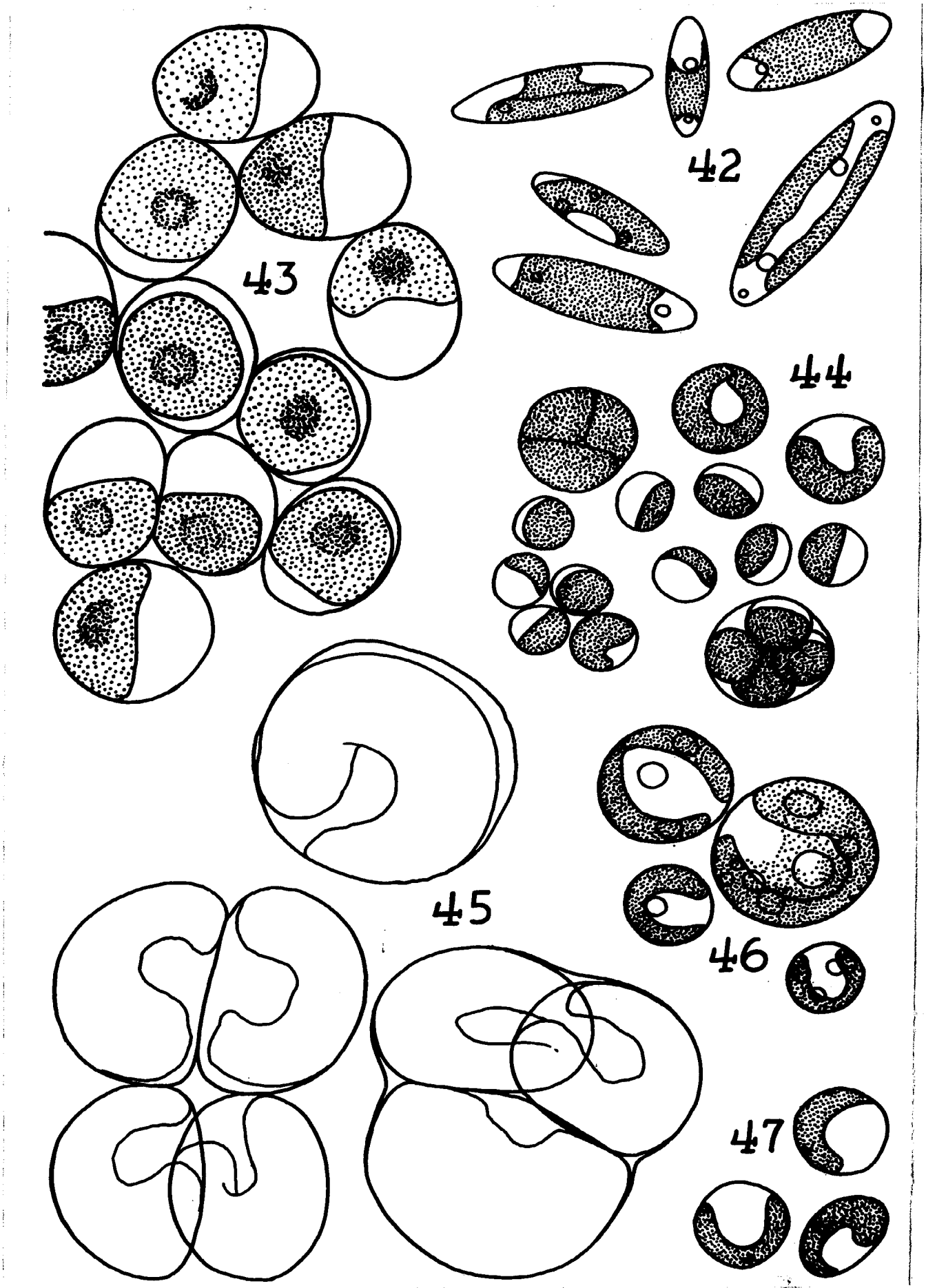
although, as at upstream stations, it was frequently found attached to rocks directly.

Tetraspora cylindrica (Wahlenb.) Ag.--This alga, found only rarely in upstream stations, is characteristic in late winter of the polysaprobic Riffles 15 and 18, where it forms globose or cylindric colonies about one centimeter in diameter. Here it is limited, more so than any other alga in the stream, to the downstream, protected faces of rocks in the riffle. It is, besides, almost limited to those rocks at the very crest of the riffle.

Tetraspora showed, however, two maxima at different times of the year, and, surprisingly, at entirely different stations. In the β-mesosaprobic Stations 25 and 28 it was present throughout much or all of the year. On occasional visits, no Tetraspora could be found, but it was nevertheless recorded in practically every month of the year from both stations. Its best growth was attained in late September at Station 28, where numerous long, laciniate thalli were to be found. After October 15, no large plants were recorded at either station, although small, pea-like colonies were usually present.

In the polysaprobic Stations 15 and 18, its growth as described above was confined to the winter months--it was recorded from about January 1 through April 15, with maximum development attained about February 25. The lacinate form of thallus found characteristically at Station 28 was never found at these stations.

An undetermined organism (Fig. 42) appeared in January in both 1952 and 1953 on rocks in the deeper portions of riffles. It never achieved dominance, although in January and February its total production was probably as great as that of any other alga on the polluted



Figs. 42-47.--Fig. 42. Unknown heterokontean alga. Figs. 43, 44, 46, 47. Chlorococcum spp. Fig. 43. Species 4. Fig. 44. Species 1. Fig. 45. Protococcus sp. Fig. 46. Chlorococcum species 3. Fig. 47. Chlorococcum species 2. Fig. 45, X 480. All other figures, X 600.

riffles. In horizontal extent, it ranged from Station 15 to Station 28. Its growth consisted of minute, cushion-like, dark brown to black colonies on both large and small rocks. Because of their color, these colonies were not easily confused with colonies of diatoms or other algae. Growth in the polysaprobic stations did not appear to be any more or less abundant than in the mesosaprobic stations further downstream.

The tan to brown color of the chloroplast of this alga, and the absence of demonstrable starch, suggests that it should be classified in the Heterokontae. Neither cell division not motile cells have been observed. The shape of the cell is constant, and resembles that of a naviculoid diatom. The diameter of the cell across the short axis varies from 2.0 to 4.0μ. Its length varies from 5.0 to 11.5μ. The chloroplast is parietal and discoid or irregular in shape; it is usually single, but occasionally two are observed.

In seasonal extent, this organism was present from mid-January throughout February and March. Its disappearance preceded slightly the spring flux in Stigeoclonium at these polluted stations.

Chlorococcum community.--Four undetermined species of Chlorococcum, accompanied by a species apparently belonging to Protococcus, were dominant in very shallow water on rocks from water line to a depth of only five centimeters. These species grow mixed in green colonies or layers which are conspicuous on shoals and at the edge of stony riffles. In horizontal extent, they are found from the Saline domestic outfall as far as Station 25 but no further. They are limited, therefore, to water with the highest content of organic substances. Their

distribution in time is confined to the winter months, from late January to late March.

In view of the uncertain status of the older species within the genus Chlorococcum (Starr, 1952) and the apparent impossibility of attaching species names without culture studies, no attempt has been made to fit these forms into known species. They are, therefore, described briefly (Table 5) in order of increasing size. While it is very likely that two or more of these represent a single species, such an assumption cannot be made without prolonged observation *in vitro* of each form. A description of the Protococcus species found in the Chlorococcum community is included.

TABLE 5

COCCOID ALGAE OF POLLUTED WATER

	Cell shape	Cell measurements	Variability in size	Chloroplast
1. Chlorococcum sp. (Fig. 44)	spherical	1.6 - 3.8μ	variable	plate- or cup-like
2. Chlorococcum sp. (Fig. 47)	spherical	2.0 - 2.4μ	uniform	plate-like
3. Chlorococcum sp. (Fig. 46)	spherical	2.2 - 5.5μ	variable	cup-like
4. Chlorococcum sp. (Fig. 43)	ovoid	3.3 - 5.5 X 4.4 - 7.7μ	uniform	plate-like
5. Protococcus sp. (Fig. 45)	ovoid or spherical	6.6 - 8.8 X 6.6 - 11.0μ	uniform	cup-like

b. Algae of Quiet Water

Euglena.--Throughout autumn and early winter, several square inches of shallow silt banks near Stations 14, 15, and 17 were frequently covered by conspicuous green sheets which, upon examination,

proved to be composed entirely of Euglena species, especially E. sociabilis Dangeard and E. viridis Ehrenb. Such abundant growth of Euglena had not been observed in downstream stations until January 23, 1953, when the entire river bottom, with the exception of riffles and of deep water in midstream, was found to be covered by a similar massive Euglena population from Station 15 to Station 38 and beyond, a distance of nearly eleven miles (17.7 kilometers). The principal species composing this population was E. sociabilis, but numerous other species, including E. viridis, E. stellata Mainx, E. chadefaudii Bourrelly, and E. schmitzii Gojdics, were mixed in. This conspicuous growth of Euglena remained, somewhat reduced in amount after February 1, until about March 15, at which time its extent had diminished, and become approximately as in much of the fall and early winter.

C. Plankton

The plankton of the Saline River reflected in general the organisms present on the bottom, although the larger algae, such as Cladophora and Spirogyra, were as a rule not adequately represented. Other benthic filamentous organisms, notably Sphaerotilus and Stigeoclonium, were much better represented. The plankton was not sampled at regular intervals, but it was evident from the few samplings scattered throughout the year that great variations both qualitative and quantitative obtained in the plankton just as in the bottom organisms. What influence was exerted on variations in the lotic plankton by the time of day and atmospheric conditions, was not investigated, and it appears, in fact, that this relationship has not yet been worked out.

Unquestionably, this relationship is a function of the species in question as well, probably, as of other environmental factors.

Samplings made January 16, 1953, show a minimal number of plankton organisms at nearly all stations, in spite of the fact that detachment and movement downstream of the benthic Diatoma community must have been occurring to a certain extent on both dates. The July 21, 1952, sampling, while made at relatively few stations, contained in small amount representatives of the Oscillatoria vegetation of the unpolluted stations. The principal feature of the plankton on this date, however, was the high concentration of Nitzschia palea recorded at Stations 15 and 28.

On August 18 (Fig. 48), the upstream stations, including the Saline Pond, showed few plankton organisms apart from relatively large numbers of naviculoid diatoms at Station 8. In the stations throughout the β-mesosaprobic zone, however, the massive benthic vegetation of Nitzschia palea was reflected clearly in the plankton, the maximum concentration of Nitzschia being recorded at Station 28 (450,000 per liter) with stations further downstream exhibiting a marked reduction in Nitzschia (to total absence at Station 34). At Station 25, fragments of the Sphaerotilus vegetation from the polysaprobic zone upstream were well represented in the plankton, but disappeared completely at Station 32 and downstream from that point. Stigeoclonium tenue and Closterium acerosum were likewise both represented in the plankton at Station 25, whereas at Station 28 the very heavy plankton population was composed almost entirely of Nitzschia palea. Streptococcoid bacteria of unknown provenance were abundant in the lower portion of of the sampled area.

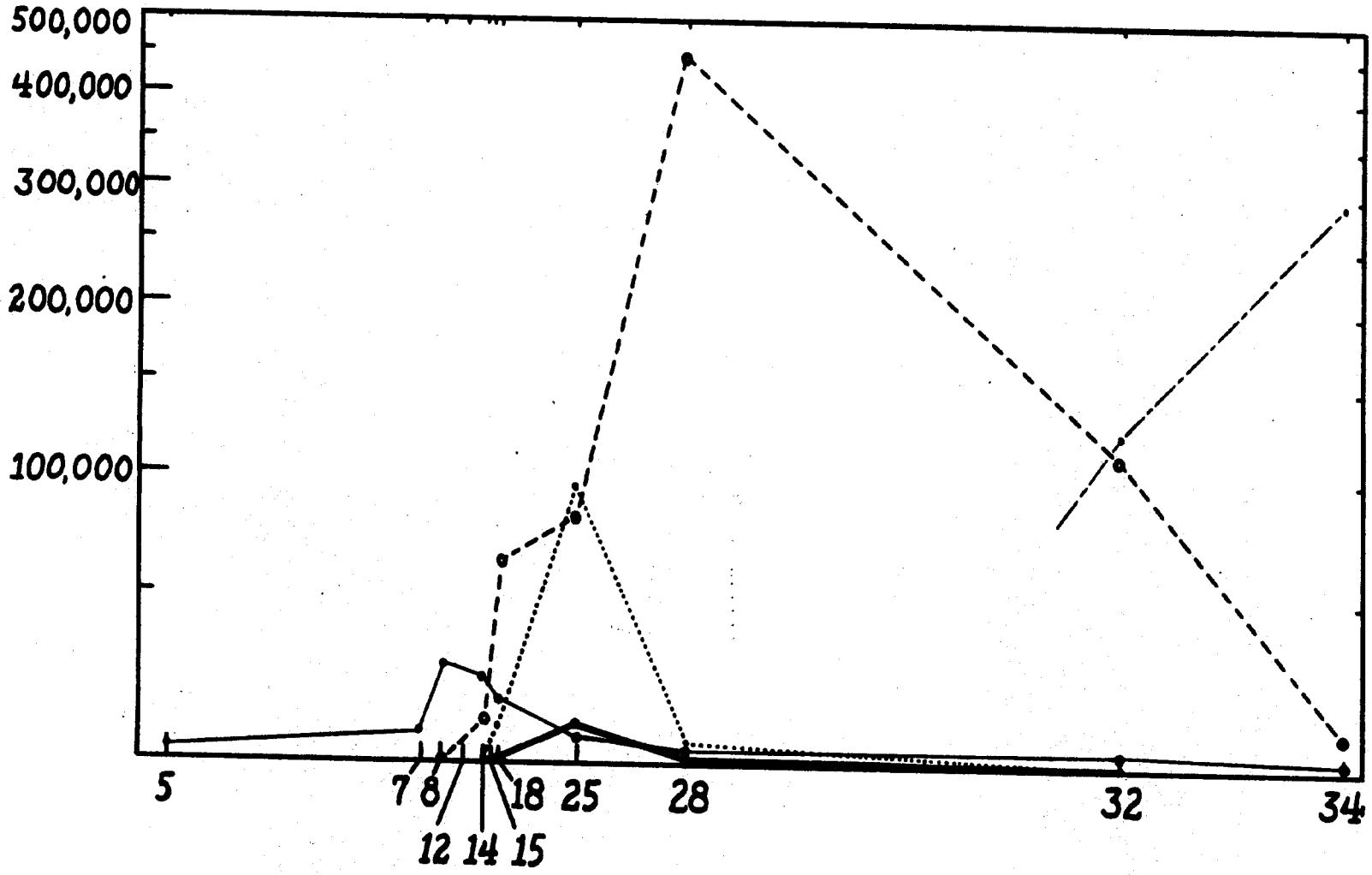
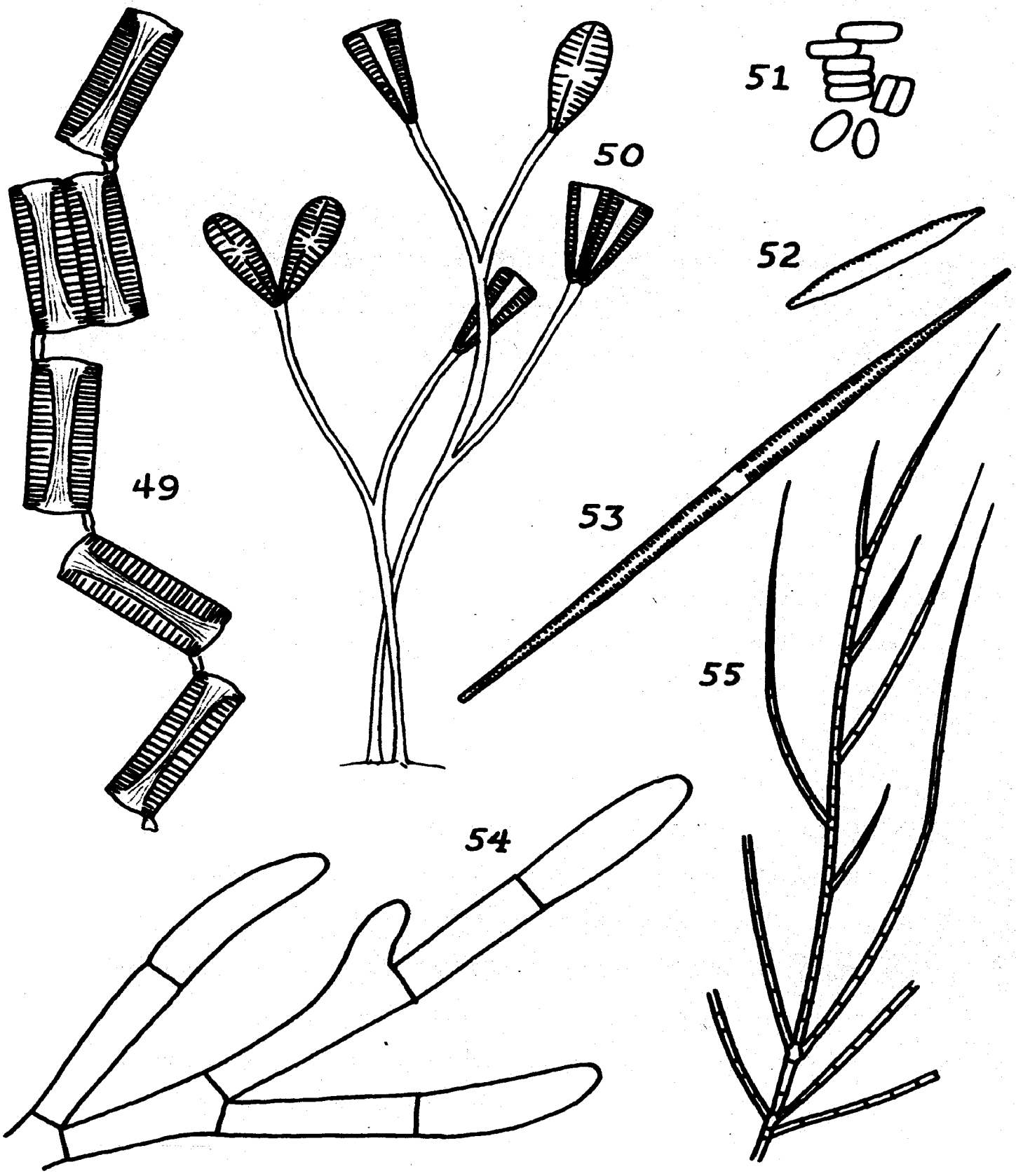


Fig. 48.--Number of units per liter of important plankton organisms found at different points in the Saline River on August 18, 1952. Key: ——•—— total Naviculoid diatoms, - - - -•- Nitzschia palea, ... Sphaerotilus natans, ———— Stigeoclonium tenue, —·—·— streptococcoid bacteria. Note logarithmic ordinate scale.

On October 16 the plankton was greatly reduced by comparison with the August sampling. Insignificant amounts of plankton organisms were present at unpolluted and polluted stations with the exception of Station 32, where large amounts of Synedra acus Kuetz. (Fig. 53) were present, as well as considerable amounts of Nitzschia palea. Polluted stations upstream from this point showed, in comparison, minute amounts of Synedra acus but significant amounts of N. palea. Both Dinobryon sertularia Ehrenb. and D. bavaricum Pascher were found in the plankton of Saline Pond on this date and were present in all sampled stations below the pond. The large amount of S. acus in both morning and afternoon samplings made on this date can be explained only by assuming abundant reproduction of this typically planktonic organism within the river between Stations 28 and 32 at this time, or in one of the intermediate tributaries. Possibly this reproduction occurred principally in the impoundment on Tributary 18. However, no evidence is at hand to support any of these conjectures.

The plankton of the Saline River shows, in the portion investigated, no essential conflict with Butcher's conclusion (1932) that small streams generally lack a plankton distinctive from, and over and above, their benthic organisms. All of the common plankton algae observed in the Saline, with the exception of the October plankton of Synedra acus, and of those forms which clearly originate in an impoundment such as Saline Pond, are obviously of benthic derivation.



Figs. 49-55.--Fig. 49. Diatoma vulgare. Fig. 50. Gomphonema olivaceum. Fig. 51. Navicula seminuloides (?). Fig. 52. Nitzschia palea. Fig. 53. Synedra acus. Fig. 54. Cladophora glomerata. Fig. 55. Stigeoclonium tenue. Figs. 49-53, X 800. Figs. 54, 55, X 150.

VIII. SUMMARY

1. The algal vegetation of the Saline River was studied throughout a period of eighteen months in 1951-53, with exact qualitative and quantitative records maintained throughout a twelve-month period. Determinations were made at regular intervals of a variety of environmental physico-chemical variables which may be supposed to influence algal growth.

2. The upper course of the Saline River is unpolluted and mildly alkaline, has a high bicarbonate content, usually abundant nutrients, and has an algal vegetation which includes Cladophora glomerata in spring, Diatoma vulgare and Gomphonema olivaceum in winter, and a calcified Phormidium-Schizothrix community which is present throughout the year.

3. The lower course of the river is influenced by industrial wastes and sewage entering the river principally at Saline and Milan. Below the industrial outfall at Saline, the water contains chromium, copper, and cyanide ions. and the flora of the upper course disappears almost completely, being replaced by a luxuriant flora of Stigeoclonium tenue and other species. Below the domestic sewage outfall at Saline, the summer riffle vegetation is dominated by the bacterium Sphaerotilus and the diatom Nitzschia palea; at other seasons Stigeoclonium tenue Tetraspora cylindrica, and Navicula seminuloides are present on riffles, whereas the pools are dominated by Spirogyra spp.

4. No marked change is observed in the flora of the middle

course of the stream between Saline Mills and Milan. Below Milan, Cladophora returns to the stream upon a single riffle. A massive accession of sewage at Milan pollutes the stream again at this riffle, and the stream remains polluted for the remainder of its course.

5. Temperature data are presented to show that the impoundment at Saline acts as a temperature stabilizer for the portion of the stream immediately below it.

6. Inorganic phosphates, moderately low to low in the upper course of the stream, increase sharply immediately below the Saline outfalls and remain relatively high for most of the remainder of the stream. They are uniformly low in winter at all stations and are, by contrast, relatively high throughout the other seasons.

7. Nitrates are shown to be reduced below the Saline sewage affluent, but increase markedly in amount in the lower course of the stream. They are more abundant in the cold months than in the warm months.

8. Organic nitrogen is more variable than the other nutrients tested for, but is generally plentiful throughout the stream's course. It increases sharply in amount below the Saline outfalls and remains relatively high. Unlike the nitrates, organic nitrogen is more abundant in the water in summer than in winter.

9. Periodicity of the principal algae is described and is summarized in Figures 30-39.

10. Certain evident changes in algal growth were synchronous with certain marked environmental changes; these are summarized in Section VII in the discussions of the individual algae. The rise to dominance of the principal algal vegetations of summer, as well as

their subsequent disappearance, both occurred when not one but many profound changes were taking place in atmospheric as well as other physico-chemical factors. The presence of more than one variable thus renders inconclusive any generalization expressing a relationship of algal growth to environmental condition.

11. The fact, noted for many algae in many different parts of the river, that major changes occur in growth when the 15° C. mark is passed with either rising or falling temperature, may in itself be significant.

12. Riffles shaded by deciduous trees showed marked differences from unshaded riffles in the amount of vegetation present in summer as well as in certain responses of organisms characteristic of the winter period.

13. The following organisms can be considered markedly resistant to the presence of chromium, copper, iron, and cyanide; possibly also they profit from the presence of one or more of these pollutants: Stigeoclonium tenue, Tetraspora cylindrica, Closterium acerosum, Nitzschia palea, N. linearis, Navicula seminuloides, Navicula cuspidata, Euglena sociabilis, E. viridis, E. acus, E. oxyuris, E. stellata, E. chadefaudii, and E. schmitzii.

APPENDIX I

DISCUSSION OF SPECIAL HYDROBIOLOGICAL TERMS EMPLOYED IN THIS PAPER

The saprobic system.--As originally established by Kolkwitz and Marsson (1908) the saprobic system divided streams or the parts of streams on the basis of the degree of pollution characterizing them. A stream or zone low in dissolved oxygen and high in organic nitrogen, as is frequently the case for some distance below important sewage outfalls, is called "polysaprobic," and is characterized by abundant fungi and bacteria, few or no autotrophic plants, and almost no invertebrate animals. Advancing downstream from this zone, the observer will find (1) the α-mesosaprobic zone, characterized by abundant amino acids and certain tolerant algae and invertebrates, (2) the β-mesosaprobic zone, in which the ammonium compounds are particularly abundant, and (3) the oligosaprobic zone, in which oxidation has proceeded nearly to completion and the water has become relatively clear and clean. The system has been modified considerably by recent workers, and the precise position taken by many stream organisms in these respective zones is not yet entirely established. Recent discussions of the organisms characterizing the different zones can be found in Nowak, 1940, Andersson and Lundh, 1948, and Fjerdingstad, 1950.

Eutrophication.--This term refers to the processes occurring within an aquatic habitat which bring about an increase in organic sediments and permit greatly enhanced production at all levels of the

food chains which operate there. The original state of a lake is oligotrophic, characterized by relatively little nutrient material, and certain other concomitant qualities. With the accumulation of sediments both inorganic and organic and with decrease in depth, a lake, given certain physical and biotic conditions, slowly takes on a eutrophic nature: shoals are formed, putrefaction takes place in bottom deposits, blooms of phytoplankters are common, and biological production is high.

Other terms pertaining to streams.--The headwater portion of a stream is usually composed of alternating pools and riffles. The pool is occupied by relatively deep water in slow movement. At its point of overflow, the water is dispersed in a shallow, swiftly moving layer which crosses a bed of resistant rocky material and enters the next pool downstream. The shallow layer of swiftly moving water and its rocky bed together constitute a riffle, or, if the volume of flow is great, a rapids. The riffle surface is uneven because of the swift current at this point and the presence of rocks or other bottom obstructions which come close to, or break, the surface. Lotic refers to running water (both pools and riffles) as opposed to lenitic, which pertains to standing water (lakes, ponds, etc.).

Benthic or benthal organisms are those composing the benthos, namely, the assemblage of animals and plants attached to or associated in some way with the bottom (Welch, 1952). Certain authors restrict the term to organisms present on the bottom but capable of moving from place to place, as Paramoecium or Oscillatoria, and employ the term "periphyton" for organisms actually attached to the bottom, as Cladophora. In this paper, the term "benthic" or "benthal" is used

in the wider sense. As opposed to the benthos, the plankton consists of the small living organisms which are transported passively by water currents. The plankton of streams is designated by the special term potamoplankton. Seston is a more comprehensive term than plankton; it refers to the entire assemblage of objects or organisms both living and non-living which float or swim in water.

APPENDIX II

LISTING BY COUNTRY OF THE PRINCIPAL ECOLOGICAL STUDIES OF THE ALGAE OF STREAMS

In the following list are given, first the name of the stream, second the type of work carried on, and lastly the worker and date of publication. Work on benthic algae is indicated by "B." Reports including one or more chemical determinations of water, or a discussion of chemical conditions, are indicated by "C." Reports including phytoplankton studies are indicated by "P." A lower case "p" (periodicity) following the letter indicates that that factor or determination has been followed throughout a twelvemonth period or very nearly a twelvemonth period. Under Varia et ignota are listed papers which do not name or mention any specific stream, and papers which concern a series of small streams. The list includes the most important and extensive studies chosen from a much larger tabulation of such works.

ARGENTINA				
Rio de la Plata		C_p	P_p	Guarrera 1950
AUSTRIA				
Danube (Donau)			P_p	Brunnthaler 1900
BELGIUM				
By Colas	B	C	P	Conrad 1942
CHINA				
Kialing	B			Jao 1944

CZECHOSLOVOKIA				
Balinka	B	C		Nowak 1940
DENMARK				
Braende Aa	B	C		Foged 1948, 1948a
Lindved Aa	B	C		Foged 1947a, 1948a
Mølleaa	B	C	P	Fjerdingstad 1950
Odense Aa	B	C		Foged 1947a, 1948a
Stavis Aa	B	C		Foged 1947, 1948a
Vindinge Aa	B	C		Foged 1948, 1948a
EGYPT				
Nile		C_p		Abdin 1948
Nile	B_p		P_p	Abdin 1948a
ENGLAND				
Hull	B_p	C_p		Butcher 1940
Hull	B_p	C_p		Butcher 1946
Tees	B_p			Butcher 1932
Thames			P_p	Fritsch 1903
Thames		C_p	P_p	Rice 1938
Wharfe		C_p	P_p	Butcher 1924
Wharfe		C_p	P	Pearsall 1930
Varia et ignota	B			Butcher 1932a
Varia et ignota	B			Butcher 1932b
FRANCE				
Garonne	B_p			Comère 1906
Loire			P_p	des Cilleuls 1929
Loire		C	P_p	des Cilleuls 1932
Mayenne			P_p	Batard 1932

FRANCE (continued)				
Midou			P_p	Batard 1932a
Seine	B		P	Allorge 1921
Seine		C	P	Lefèvre 1950
Thouet		C	P_p	des Cilleuls 1929
Vienne			P	des Cilleuls 1929
Varia et ignota	B_p			Comère 1906
Varia et ignota			P	des Cilleuls 1928
Varia et ignota	B		P	Germain 1936
Varia et ignota	B			Guinochet 1938
GERMANY				
Dortmund--Emskanal		C_p	P_p	Quirmbach 1912
Eder	B	C		Budde 1935
Gauchach	B_p	C	P	Wehrle 1942
Havel			P_p	Bethge 1915
Havel			P_p	Krieger 1927
Kossau	B_p	C		Raabe 1951
Kuehrener Au	B_p	C		Raabe 1951
Lippe	B_p	C_p		Budde 1932
Lenne	B_p			Budde 1930
Main	B_p	C	P_p	Juergensen 1935
Moehne	B_p		P_p	Budde 1930
Mulde	B	C	P	Schroeder 1939
Rhine	not seen			Lauterborn 1910
Rhine	B_p		P_p	Jaag 1938
Ruhr	B_p	C_p	P_p	Budde 1930
Schwentine	B_p	C		Raabe 1951

GERMANY (continued)				
Sibirner Grund	B_p	C		Raabe 1951
Spree			P_p	Rosenthal 1914
Tensfelder Au	B	C		Raabe 1951
Volme	B			Budde 1930
Warthe (see under Poland)				
Werse		C_p	P_p	Quirmbach 1912
Weser		C	P_p	Lemmermann 1907
Wilzsch	B	C		Schroeder 1939
Wutach	B_p	C	P	Wehrle 1942
Varia et ignota			P	Zacharias 1898
Varia et ignota	B	C		Budde 1933
Varia et ignota		C	P	Seeler 1935
INDIA				
Cooum	B_p	C_p		Iyengar and Venkataraman 1951
IRELAND				
Shannon			P_p	Southern and Gardiner 1938
JAVA				
Tjikoenir			P_p	van Oye 1924
Tjimoeloe			P_p	van Oye 1924
POLAND				
Biała Przemsza			P_p	Starmach 1938
Vistula (Wisła)		C_p	P_p	Wysocka 1950
Vistula (Wisła)	B			Wysocka 1952
Vistula (Wisła)			P_p	Starmach 1938
Warthe			P_p	Bennin 1922

POLAND (continued)				
Warthe			P_p	Hoppowna 1925
RUSSIA				
Kljasma		C	P	Brujewicz 1931
Moskow	B_p	C		Uspenski 1927
Oka			P_p	Meyer 1923
Tschatschinka	B	C		Uspenski 1927
Volga	B	C_p	P_p	Behning 1928
Volga		C	P_p	Behning 1929
SPAIN				
Varia et ignota	B			Budde 1929
Varia et ignota	B			Margalef 1948
SWEDEN				
Vegeån	B	C		Andersson and Lundh 1948
Varia et ignota	B	C		Israelson 1942
Varia et ignota	B			Israelson 1949
SWITZERLAND				
Limmat	B_p		P_p	Limanowska 1912
Rhine	B_p		P_p	Jaag 1938
UNITED STATES OF AMERICA				
Bessey Creek (Mich.)			P	Chandler 1937
Chippewa (Wis.)			P	Wiebs 1928
Conestoga (Pa.)	B	C		Patrick 1949
Des Moines (Ia.)		C	P_p	Starrett and Patrick 1952
Huron (Mich.)			P_p	Chandler 1937
Huron (Mich.)			P	Chandler 1939

UNITED STATES OF AMERICA (continued)

Illinois (Ill.)	B	C_p	P	Forbes and Richardson 1913
Illinois (Ill.)		C_p	P_p	Kofoid 1903, 1908
Mississippi (Minn., Wis.)			P	Wiebs 1928
Mississippi (Minn.)			P	Reinhard 1931
Ohio and tributaries (Pa., N. Y., Ohio, W. Va., Ky., Ill.)		C	P	Ohio River Pollution Control 1944
Scioto (Ohio)		C	P	Lackey 1941
Scioto (Ohio)		C	P	Kehr et al. 1941
San Joaquin (Cal.)			P_p	Allen 1920
Sangamon (Ill.)		C	P	Eddy 1932
Varia et ignota				
(Ind.)	B_p			Brown 1908
(Utah)	B			Norrington 1927
(W. Va.)	B	C		Lackey 1938

APPENDIX III

TABLE 6

HYDROGEN-ION DETERMINATIONS[a]

Date	Sta. 5	8	12	12	15	18	25	28	32	34N[b]	34S
5-14-52	----	8.15	8.43	----	8.35	8.35	----	----	----	----	----
6-30-52	----	8.05	7.99	8.06	7.75	7.90	----	8.24	----	7.70	7.90
7- 8-52	----	7.86	7.97	8.11	8.01	8.07	8.27	7.89	7.96	7.87	7.87
7-15-52	----	8.07	8.10	8.14	7.96	8.16	8.25	7.90	7.92	7.76	7.88
7-21-52	----	8.04	7.87	7.86	7.91	8.06	7.97	7.73	----	----	----
7-29-52	8.26	8.21	8.22	8.29	8.02	7.96	8.55	8.21	7.97	8.01	8.00
8- 3-52	----	8.22	----	8.14	7.85	----	----	----	----	----	----
8-8,9-52	8.00	8.36	8.03	8.39	8.20	8.23	8.00	8.25	8.18	----	8.06
8-18-52	----	8.40	8.19	8.28	8.10	8.41	8.52	8.48	8.34	----	8.21
8-25-52	----	8.26	8.31	8.34	8.21	8.30	8.41	8.30	8.19	----	8.05
9- 4-52	8.30	8.10	----	8.17	7.85	7.85	8.34	8.51	----	----	----
9-15-52	7.99	8.04	7.96	7.98	----	8.06	8.43	8.42	8.31	----	8.26
9-25-52	7.90	8.05	----	8.09	8.05	8.05	8.20	8.12	----	8.28	8.39
10- 7-52	----	8.10	----	8.21	----	8.15	8.00	8.12	8.08	7.83	8.00
10-16-52	7.82	8.16	----	8.11	----	8.31	8.36	8.16	8.16	----	----
11- 7-52	8.43	8.49	8.36	8.45	----	8.41	8.38	8.08	----	----	----
11-17-52	----	7.93	7.99	7.99	----	8.15	8.07	8.18	----	----	----
11-26-52	7.80	8.20	----	8.11	8.02	8.10	8.09	8.05	8.01	8.04	7.97
12- 7-52	7.99	8.02	----	8.12	8.11	----	8.40	8.09	----	----	----
12-16-52	7.92	8.05	----	8.19	8.15	----	7.99	8.03	7.88	----	----
12-28-52	8.05	8.20	7.94	8.39	----	8.40	8.24	----	----	----	----
1-12-53	7.92	8.05	7.82	8.12	8.12	----	----	----	----	----	----
1-23-53	8.05	8.16	8.18	8.16	8.32	----	8.28	8.19	8.12	----	----
2- 4-53	8.02	8.08	8.14	8.39	----	8.25	8.39	8.32	8.32	----	----
2-14-53	----	8.12	8.11	8.41	----	8.25	8.20	8.11	8.18	----	----
2-24-53	7.83	8.07	7.98	8.20	----	7.76	8.05	8.00	----	----	----
3- 7-53	7.29	----	7.59	7.58	----	7.60	7.79	8.01	----	----	----
3-17-53	----	7.82	7.78	8.01	7.86	7.82	7.83	7.84	7.80	----	----
3-27-53	7.63	7.92	7.61	7.88	7.90	7.93	7.75	7.99	----	----	----
4- 3-53	----	8.07	8.00	8.23	8.22	8.22	8.24	8.28	8.11	----	----

[a]Blank spaces indicate that no determination was made.
[b]N indicates the north side of this riffle; S, the south side.

TABLE 7

PHOSPHATE DETERMINATIONS*

Date	Milligrams of inorganic phosphate phosphorus per liter Sta. 5	8	12	14	15	18	25	28	32	34N	34S
5-14-52	----	0.00	0.00	----	0.20	0.40	----	----	----	----	----
6-15-52	----	0.01	0.01	----	0.14	----	----	0.06	----	----	0.13
6-22-52	----	0.10	0.12	0.10	0.25	0.12	0.17	0.12	----	----	----
6-30-52	----	0.09	0.11	0.12	0.45	0.47	----	0.15	----	0.58	0.57
7- 8-52	----	0.06	0.02	0.15	0.16	0.28	0.07	0.52	0.45	0.66	0.73
7-15-52	----	0.02	0.03	0.03	0.31	0.31	0.06	0.13	0.31	0.55	0.63
7-21-52	----	0.00	0.00	0.00	0.22	0.41	0.17	0.07	----	----	----
7-29-52	0.12	0.30	0.12	0.13	0.50	0.48	0.31	0.12	0.33	0.78	0.86
8- 3-52	----	0.00	----	0.01	0.26	----	----	----	----	----	----
8- 8-52	0.00	0.05	0.02	0.04	0.41	0.44	0.07	0.04	0.26	----	0.70
8-18-52	0.03	0.03	0.04	0.05	0.36	0.54	0.44	0.07	0.25	----	0.53
8-25-52	----	0.02	----	0.95	1.18	1.34	0.06	0.03	0.29	----	0.35
9- 4-52	0.16	0.07	----	0.07	0.70	0.65	0.42	0.42	----	----	----
9-15-52	0.01	0.01	0.01	0.19	----	0.48	0.15	0.02	0.12	----	0.13
9-25-52	0.50	0.02	----	0.36	0.75	0.62	0.04	0.10	0.33	0.60	0.04
10- 7-52	0.05	0.03	----	0.33	----	0.70	----	0.18	0.35	1.56	1.50
10-16-52	0.03	0.02	----	0.02	----	0.24	0.15	0.09	0.13	----	----
10-27-52	----	0.01	0.00	0.02	----	0.36	0.10	0.35	0.20	1.04	0.24
11- 7-52	0.00	0.01	0.00	0.04	----	0.31	0.12	0.14	----	----	----
11-17-52	----	0.11	0.04	0.18	----	0.13	0.13	0.09	----	----	----
11-26-52	0.02	0.06	----	0.04	0.09	0.09	0.16	0.06	0.13	0.35	0.19
12- 7-52	0.00	0.00	----	0.01	0.07	----	0.07	0.01	----	----	----
12-16-52	0.00	0.00	----	0.00	0.07	----	0.07	0.02	0.12	----	----
12-28-52	0.00	0.00	0.01	0.01	----	0.07	0.07	----	----	----	----
1-12-53	0.01	0.02	0.04	0.04	0.12	----	----	----	----	----	----
1-23-53	0.00	0.00	0.00	0.00	0.04	----	0.07	0.05	0.06	----	----
2- 4-53	0.00	0.00	0.01	0.02	----	0.15	0.09	0.04	0.13	----	----
2-14-53	----	0.01	0.01	0.01	----	0.21	0.13	0.06	0.15	----	----
2-24-53	0.02	0.04	0.07	0.03	----	0.11	0.12	0.11	0.07	----	----
3- 7-53	0.10	----	0.07	0.07	----	0.12	0.10	0.10	----	----	----
3-17-53	----	0.04	----	0.02	0.04	0.03	0.01	0.01	----	----	----
3-27-53	0.02	0.04	0.03	0.09	0.26	0.10	0.11	0.09	----	----	----
4- 3-53	----	0.02	0.04	0.06	0.16	0.11	0.12	0.09	0.07	----	----
4-16-53	0.10	0.06	0.09	0.08	0.15	----	----	0.13	----	----	----

*Blank spaces indicate that no determination was made.

TABLE 8

NITRATE DETERMINATIONS*

Date	Milligrams of nitrate nitrogen per liter Sta. 5	8	12	14	15	18	25	28	32	34N	34S
5-14-52	----	12.5	6.0	----	10.0	2.0	----	----	----	----	----
6-15-52	----	6.0	7.0	----	15.0	----	----	3.0	----	----	35.0
6-22-52	----	5.0	3.0	8.0	10.0	7.0	10.0	7.0	----	----	----
8- 8-52	----	8.0	10.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0
8-18-52	----	7.0	0.0	0.2	0.0	0.5	0.5	0.0	1.0	1.0	----
9- 4-52	0.0	0.5	----	0.0	0.5	0.2	0.5	0.5	----	----	----
9-15-52	0.0	1.0	0.5	1.0	----	1.0	2.0	0.5	3.5	2.5	2.5
9-25-52	0.0	1.0	----	2.5	1.0	1.0	1.0	2.0	8.0	4.0	0.5
10- 7-52	0.0	0.5	----	1.0	----	0.5	0.5	0.5	1.0	0.5	0.5
10-16-52	0.0	0.5	----	0.5	----	0.7	1.5	1.5	1.5	----	----
10-27-52	----	2.0	0.5	2.0	----	1.0	1.0	1.0	3.0	1.0	3.0
11- 7-52	0.0	0.5	1.5	1.5	----	1.0	1.0	1.5	----	----	----
11-17-52	----	0.5	0.5	1.0	----	1.0	1.0	1.0	----	----	----
11-26-52	3.0	1.5	----	1.5	1.5	2.0	2.0	2.0	3.0	2.0	2.0
12- 7-52	2.5	3.5	----	1.0	1.0	----	2.0	1.0	----	----	----
12-16-52	0.5	3.0	----	1.5	2.0	----	2.0	3.0	2.0	----	----
12-28-52	1.7	3.5	3.5	3.0	----	2.5	2.0	----	----	----	----
1-12-53	0.5	2.0	1.5	1.5	2.0	----	----	----	----	----	----
1-23-53	2.0	2.5	2.0	2.5	1.5	----	2.0	2.0	2.0	----	----
2- 4-53	1.2	2.0	2.0	2.2	----	1.0	1.0	1.5	2.2	----	----
2-14-53	----	1.4	1.4	0.5	----	0.5	0.5	0.8	----	----	----
2-24-53	3.0	3.5	3.5	1.0	1.5	2.0	2.5	3.0	----	----	----
3- 7-53	5.0	----	5.5	5.0	----	5.0	5.0	5.5	----	----	----
3-17-53	----	7.0	3.0	7.0	6.0	6.0	5.0	7.0	5.0	----	----
3-27-53	4.0	4.5	4.0	4.0	6.0	3.5	3.5	4.5	----	----	----
4- 3-53	----	2.5	2.0	1.5	2.0	2.5	2.5	2.5	3.0	----	----
4-16-53	2.0	1.0	1.0	1.0	1.5	----	----	1.0	----	----	----

*Blank spaces indicate that no determinations was made.

TABLE 9

ORGANIC NITROGEN DETERMINATIONS*

Date	Milligrams per liter										
	Sta. 5	8	12	14	15	18	25	28	32	34N	34S
6-15-52	---	0.5	0.8	---	1.1	---	---	0.7	---	---	0.3
7- 8-52	---	0.5	0.5	3.0	1.3	1.3	2.0	1.0	2.2	6.0	7.3
7-15-52	---	1.5	1.7	1.6	2.1	1.6	2.1	1.5	3.0	2.6	2.0
7-29-52	---	0.6	2.0	0.0	1.9	2.5	3.5	2.2	1.7	2.4	5.6
8- 3-52	---	1.3	---	0.8	2.0	---	---	---	---	---	---
8-8,9-52	---	1.3	0.8	1.7	1.7	1.3	1.1	1.2	1.7	---	2.3
8-18-52	---	0.2	0.2	1.8	2.2	2.9	2.1	1.8	2.5	---	2.7
9- 4-52	2.0	3.7	---	2.5	3.7	2.8	2.7	2.4	---	---	---
9-15-52	1.5	1.6	---	1.8	---	1.3	1.0	1.2	1.5	---	1.4
9-25-52	0.5	0.6	---	0.9	1.5	1.7	---	1.0	1.3	3.5	1.0
10- 7-52	0.8	0.5	---	0.4	---	1.5	0.4	1.5	2.5	5.6	6.7
10-16-52	0.5	0.5	---	2.0	---	0.7	1.0	0.8	1.9	---	---
10-27-52	---	0.4	0.4	0.1	---	0.7	0.2	0.6	0.9	2.5	0.0
11- 7-52	0.0	0.0	0.8	0.7	---	1.6	1.3	1.2	---	---	---
11-17-52	---	0.9	3.0	1.5	---	0.8	0.7	1.2	---	---	---
11-26-52	2.5	2.0	---	1.2	1.9	2.0	1.9	2.1	2.3	3.1	7.6
12- 7-52	0.8	0.5	---	0.7	0.8	---	1.0	0.8	---	---	---
12-16-52	0.2	0.0	---	0.2	0.1	---	0.2	0.3	1.5	---	---
12-28-52	0.1	0.1	0.8	0.1	---	0.2	1.3	---	---	---	---
1-12-53	0.5	0.1	0.6	0.3	0.5	---	---	---	---	---	---
1-23-53	0.5	0.4	0.7	0.3	0.5	---	0.3	0.3	2.3	---	---
2- 4-53	0.7	0.8	0.8	0.7	---	1.2	1.3	1.1	1.5	---	---
2-14-53	---	0.4	0.6	0.3	---	1.8	0.9	0.4	1.0	---	---
2-24-53	0.5	1.5	0.5	1.2	2.7	1.5	2.4	1.5	---	---	---
3- 7-53	1.6	2.3	2.3	3.5	---	2.6	3.1	3.1	---	---	---
3-17-53	---	6.5	1.2	3.9	4.0	0.9	1.5	2.3	2.8	---	---
4- 3-53	---	1.4	0.7	1.3	0.9	1.6	1.5	1.6	2.2	---	---
4-16-53	0.5	0.5	0.6	0.6	1.0	---	---	0.8	---	---	---

*Blank spaces indicate that no determination was made.

TABLE 10

FREQUENCY DATA*

Date	Oscillatoria community	Phormidium-Schizothrix	Cladophora glomerata	Draparnaldia plumosa	Stigeoclonium tenue	Spirogyra fluviatilis	Audouinella violacea (growing apart from Phormidium-Schizothrix)	Gomphonema olivaceum	Other Diatoms
Station 5									
7-12-52	0	57	83	0	0	28	--	0	0
8-22-52	0	40	98	0	0	42	--	0	0
9-23-52	0	38	86	0	0	1.5	--	0	16
10-21-52	0	46	37	0	0	0	--	0	0
11-29-52	0	--	83	0	0	0	58	50	0
12-31-52	0	--	72	5	0	0	64	79	22
1-29-53	0	--	53	23	0	0	77	90	23
2-24-53	0	--	36	16	0	0	77	92	27
3-24-53	0	--	28	0	0	0	59	57	0
4-21-53	0	--	41	0	0	0	40	37	7
Station 8									
5-12-52	0	69	93	0	0	0	0	0	0
6-15-52	0	71	89	0	0	0	0	0	0
7-10-52	29	69	65	0	15	0	0	0	0
7-25-52	33	87	82	0	0	9	0	0	0
8- 8-52	0	65	26	0	0	0	0	0	0
8-22-52	0	83	15	0	2	0	0	0	0
9-23-52	0	76	40	0	2	0	0	0	34
10-21-52	0	66	73	0	0	0	0	2.5	92
11-29-52	0	--	37	0	4	0	0	8	98
12-31-52	0	--	22	0	0	0	0	57	97
1-29-53	0	--	18	0	0	0	0	68	87
2-24-53	0	--	10	0	0	0	0	85	66
3-24-53	0	--	19	0	0	0	0	83	37
4-21-53	0	--	58	0	0	0	0	78	38

*Figures represent frequency percentages of each organism. Blanks indicate that presence or absence of that organism was not recorded for that day.

TABLE 10 (Continued)

Date	Oscillatoria community	Phormidium-Schizothrix	Cladophora glomerata	Draparnaldia plumosa	Stigeoclonium tenue	Spirogyra fluviatilis	Audouinella violacea (growing apart from Phormidium-Schizothrix)	Batrachospermum boryanum	Gomphonema olivaceum	Other diatoms
Station 10										
6-18-52	0	50	87	0	0	1.5	0	0	0	0
7- 6-52	0	43	45	0	1	5	0	0	0	34
7-25-52	0	61	79	0	1.5	0	0	0	0	7
8- 8-52	0	40	70	0	0	6	0	0	0	10
8-22-52	0	31	34	0	1.3	1	0	0	0	28
9-23-52	0	46	34	0	0	1	0	0	0	25
10-21-52	0	--	70	0	0	0	0	0	0	96
Station 12										
5-15-52	0	49	88	0	0	0	0	0	0	0
6-18-52	0	31	33	0	0	0	0	0	0	4
7-10-52	2.5	47	23	0	0	0	0	0	0	28
7-25-52	4	59	0	0	0	0	0	0	0	21
8- 8-52	13	22	0	0	0	0	0	0	0	23
8-22-52	3	41	0	0	0	0	0	0	0	28
9-23-52	0	54	2	0	0	0	2	0	0	63
10-21-52	0	--	41	0	0	0	0	0	0	62
11-28-52	0	--	26	0	0	0	0	11	0	95
12-31-52	0	--	22	0	0	0	0	12	8	100
1-29-53	0	--	20	0	0	0	2	15	40	95
3-24-53	0	--	26	0	0	0	0	14	88	16
4-21-53	0	--	49	0	0	0	0	8	63	42

TABLE 10 (Continued)

Date	Stigeoclonium tenue	Tetraspora cylindrica	Spirogyra sp.	Unknown Heterokontean alga	Navicula seminuloides	Nitzschia palea	Gomphonema olivaceum	Other diatoms	Sphaerotilus natans
Station 14									
5-15-52	79	0	0	0	--	0	0	0	0
6-18-52	75	0	0	0	--	4.5	0	0	0
7- 6-52	59	0	0	0	--	44	0	0	0
7-25-52	61	0	0	0	--	30	0	0	0
8- 8-52	79	0	0	0	--	25	0	0	0
8-22-52	70	0	0	0	--	59	0	0	0
9-23-52	85	0	0	0	--	80	0	0	0
10-19-52	44	0	0	0	--	5	0	73	0
11-28-52	59	0	0	0	--	0	0	90	0
12-31-52	8	0	0	0	68	0	0	71	0
1-29-53	0	0	0	0	59	0	0	80	0
2-27-53	0	0	0	0	78	0	13	78	0
3-24-53	2	7	0	3	60	0	79	18	0
4-21-53	35	5	0	0	41	0	100	0	0
Station 15									
6-27-52	76	0	0	0	--	9	0	0	42
7-25-52	29	0	0	0	--	0	0	0	100
8-[illegible]8-52	8	0	0	0	--	0	0	0	100
8-22-52	2	0	0	0	--	12	0	0	100
9-19-52	18	0	0	0	--	10	0	0	24
Station 18									
5-20-52	92	0	0	0	--	0	0	0	41
6-27-52	97	0	0	0	--	0	0	0	92
7-15-52	68	0	0	0	--	4	0	0	94
7-26-52	4	0	3	0	--	4	0	0	84
8- 8-52	4	0	9	0	--	12	0	0	99
8-22-52	3	0	6	0	--	5	0	0	100
9-23-52	5	0	14	0	--	0	0	0	96
10-19-52	14	0	0	0	15	0	0	3	19
11-28-52	48	0	0	0	31	0	0	65	6
12-31-52	15	0	0	0	23	0	0	68	32
1-29-53	23	13	0	37	--	0	0	72	4
2-27-53	7	7	0	36	--	0	0	66	55
3-24-53	12	34	0	46	--	0	72	22	8
4-21-53	42	13	0	29	--	0	100	8	50

TABLE 11

DRY WEIGHT DATA*

Dry weight of algae removed from standard area of stream bottom (ten rocks selected as described in text)

Date	Cladophora				Batrachospermum
	Sta. 5	Sta. 8	Sta. 10	Sta. 12	Sta. 12
6-18-52	----	16.95	2.56	3.61	0.00
7- 5-52	----	2.86	0.44	0.06	0.00
7-10-52	----	----	----	----	----
7-21-52	----	2.10	0.34	0.01	0.00
8-22-52	18.88	0.00	0.00	0.00	0.00
9-23-52	9.55	0.45	----	0.00	0.00
10-24-52	0.76	0.22	0.57	0.00	0.00
11-28-52	0.08	0.11	----	0.02	0.00
12-31-52	0.03	0.02	----	0.00	0.00
1-29-53	0.14	0.01	----	0.00	0.02
2-24-53	0.02	0.00	----	0.03	0.00
3-24-53	0.00	0.00	----	0.03	0.19
4-21-53	0.16	0.04	----	0.02	0.01

Date	Stigeoclonium		Sphaerotilus
	Sta. 14	Sta. 18	Sta. 18
5-15-52	19.10	----	----
6-18-52	16.38	----	----
6-27-52	----	1.60	0.68
7- 5-52	1.13	----	----
7-21-52	2.48	2.25	3.58
8-22-52	5.18	2.00	5.56
9-23-52	2.85	0.44	3.95
10-24-52	0.23	0.40	0.00
11-28-52	0.13	1.01	0.00
12-31-52	0.00	0.97	0.26
1-29-53	0.00	0.03	0.05
2-24-53	0.00	0.00	0.00
3-24-53	0.00	0.01	0.00
4-21-53	0.07	0.05	1.20

*Blank spaces indicate that no determination was made. All results are given in grams.

TABLE 12

PLANKTON DATA*

Number of units per liter July 21, 1952	Sta. 7	Sta. 8	Sta. 15 (backwater)	Sta. 28
Navicula cuspidata				
Other naviculoids	39,500	13,000	22,000	1,000
Diatoma sp.				
Synedra sp.				
Synedra acus				
Nitzschia palea			216,000	454,000
Nitzschia sp.				
Gomphonema sp.				
Cymbella sp.		2,500		500
Melosira granulata				
Melosira varians		1,000		2,500
Euglena acus		1,000		2,000
Euglena sp.			12,000	1,000
Dinobryon sertularia	1,000			
Dinobryon bavaricum				
Scenedesmus sp.			14,000	
Actinastrum hantzschii				
Pediastrum sp.				
Stigeoclonium tenue			5,000	
Spirogyra sp.	5,000			23,000
Closterium acerosum				
Oscillatoria sp.	13,000	6,000	2,000	2,000
Sphaerotilus sp.			11,000	57,000
Streptococcoid bacteria				
Fungus spores				
Rhizopoda				
Rotifera				

*Blank spaces indicate absence of that species.

TABLE 12 (Continued)

Number of units per liter August 18, 1952	Stations above Saline domestic outfall			
	Sta. 5	Sta. 7	Sta. 8	Sta. 14
Navicula cuspidata				
Other naviculoids	1,000	5,500	28,500	31,500
Diatoma sp.				
Synedra sp.				
Synedra acus		1,000	500	
Nitzschia palea				
Nitzschia sp.				
Gomphonema sp.				
Cymbella sp.				1,000
Melosira granulata		2,500		1,000
Melosira varians				
Euglena acus		500	500	
Euglena sp.				
Dinobryon sertularia		2,500	6,500	2,000
Dinobryon bavaricum				
Scenedesmus sp.		3,000	1,500	500
Actinastrum hantzschii				
Pediastrum sp.				
Stigeoclonium tenue				
Spirogyra sp.	7,000			
Closterium acerosum				
Oscillatoria sp.			500	
Sphaerotilus sp.				
Streptococcoid bacteria				
Fungus spores				
Rhizopoda				
Rotifera				

TABLE 12 (Continued)

Number of units per liter August 18, 1952	Stations below Saline domestic outfall Sta. 18	Sta. 25	Sta. 28	Sta. 32	Sta. 34
Navicula cuspidata					
Other naviculoids	18,000	5,500	4,000	4,000	3,000
Diatoma sp.					
Synedra acus		500		500	
Synedra sp.					
Nitzschia palea	54,000	78,000	450,000	112,000	
Nitzschia sp.					
Gomphonema sp.					
Cymbella sp.	6,000			500	
Melosira granulata	2,000			5,500	1,000
Melosira varians					
Euglena acus					500
Euglena sp.				3,000	
Dinobryon sertularia	4,000	500	500	7,000	500
Dinobryon bavaricum					
Scenedesmus sp.	1,000	1,000	500	1,000	500
Actinastrum hantzschii					4,000
Pediastrum sp.					
Stigeoclonium tenue		7,000	3,500		
Spirogyra sp.		2,000	10,500		
Closterium acerosum		4,500	2,000		
Oscillatoria sp.	4,000	4,000			
Sphaerotilus sp.	6,000	99,500	4,500		
Streptococcoid bacteria				126,500	298,000
Fungus spores					
Rhizopoda					
Rotifera	1,000		500		

TABLE 12 (Continued)

Number of units per liter A.M., October 16, 1952	Stations 5	7	8	18	25	28	32
Navicula cuspidata							
Other naviculoids	2,500	45,000	11,500	5,500	16,000	4,000	2,000
Diatoma sp.			4,000	500			
Synedra acus		12,000	2,000	2,500	8,000	3,700	180,000
Synedra sp.			2,000	1,000			
Nitzschia palea				500		10,000	119,000
Nitzschia sp.				1,000		4,500	10,000
Gomphonema sp.							
Cymbella sp.	1,000	2,000	500	1,000			
Melosira granulata							
Melosira varians				500			2,000
Euglena acus							
Euglena sp.				500			
Dinobryon sertularia		6,000	14,500	13,000	6,000	10,000	3,000
Dinobryon bavaricum		16,000	6,500	12,500	24,000	17,500	5,000
Scenedesmus sp.						500	
Actinastrum hantzschii							
Pediastrum sp.							
Stigeoclonium tenue					8,000	2,000	
Spirogyra sp.		20,000					
Closterium acerosum							
Oscillatoria sp.		7,000	1,000				
Sphaerotilus sp.				1,000			
Streptococcoid bacteria							
Fungus spores							
Rhizopoda							
Rotifera							

TABLE 12 (Continued)

Number of units per liter P.M., October 16, 1952	Stations 5	7	8	18	25	28	32
Navicula cuspidata						500	
Other naviculoids	5,000	5,000	42,000	14,000	4,500	6,000	10,000
Diatoma sp.			3,000				
Synedra acus		6,000	12,000	10,000	1,500	2,000	214,000
Synedra sp.			3,000	1,000	1,500	1,500	3,000
Nitzschia palea				2,500	23,500	17,500	46,000
Nitzschia sp.				2,000		500	5,000
Gomphonema sp.							
Cymbella sp.	1,000		1,000		1,000		
Melosira granulata		3,000	4,000	1,500			
Melosira varians							1,000
Euglena acus							
Euglena sp.							
Dinobryon sertularia		21,000	16,000	12,000	4,000	5,000	6,000
Dinobryon bavaricum		50,000	13,000	26,500	5,000	5,000	9,000
Scenedesmus sp.				500			
Actinastrum hantzschii							
Pediastrum sp.							
Stigeoclonium tenue					2,000		
Spirogyra sp.							
Closterium acerosum							
Oscillatoria sp.		5,000			1,000		
Sphaerotilus sp.							
Streptococcoid bacteria							
Fungus spores							
Rhizopoda							500
Rotifera							

TABLE 12 (Continued)

Number of units per liter January 23, 1953	Stations 5	8	18	25	28	38
Navicula cuspidata						
Other naviculoids		1,250	1,700	5,500	500	
Diatoma sp.	900		1,700			1,500
Synedra sp.		500	1,000	1,000		500
Synedra acus						
Nitzschia palea						
Nitzschia sp.	24,000	2,500	3,250	1,000	500	
Gomphonema sp.			750	500		500
Cymbella sp.			250			
Melosira granulata						
Melosira varians						500
Euglena acus						
Euglena sp.			2,000	500		12,000
Dinobryon sertularia						
Dinobryon bavaricum						
Scenedesmus sp.						
Actinastrum hantzschii						
Pediastrum sp.						
Stigeoclonium tenue					500	
Spirogyra sp.						
Closterium acerosum						
Oscillatoria sp.						
Sphaerotilus sp.						
Streptococcoid bacteria						
Fungus spores					27,000	
Rhizopoda						
Rotifera						

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