AN ECOLOGICAL AND TAXONOMIC SURVEY OF THE CHLOROPHYTA OF THE JAMES RIVER BASIN, VIRGINIA

Thesis for the Degree of Ph. D.

MICHIGAN STATE UNIVERSITY

Bernard Robert Woodson, Jr.

1957

This is to certify that the

thesis entitled

AN ECOLOGICAL AND TAXONOMIC SURVEY OF THE
CHLOROPHYTA OF THE JAMES RIVER BASIN, VIRGINIA

presented by

Mr. Bernard R. Woodson, Jr.

has been accepted towards fulfillment
of the requirements for

Ph. D. degree in Botany

G. W. Prescott
Major professor

Date Dec. 6, 1957

O-169

AN ECOLOGICAL AND TAXONOMIC SURVEY

OF THE CHLOROPHYTA OF

THE JAMES RIVER BASIN, VIRGINIA

By

Bernard Robert Woodson, Jr.

AN ABSTRACT

Submitted to the School for Advanced Graduate
Studies of Michigan State University of
Agriculture and Applied Science in
partial fulfillment of the
requirements for the
degree of

DOCTOR OF PHILOSOPHY

Department of Botany and Plant Pathology

1957

Approved G. W. Prescott

Bernard Robert Woodson, Jr.

This is a study of the distribution, classification, and ecology of the Chlorophyta of the James River Basin. The chief objectives of this study have been: (1) the collection and identification of green algae (Chlorophyta) from representative points along the James River Basin; (2) the determination, where possible, of the geological or soil features and chemical factors related to the distribution of Chlorophyta along the James River Basin; (3) the assembling of ecological data related to algal development in streams in general.

This is the first detailed study made on the Chlorophyta of the James River Basin. Dr. J. C. Strickland of the University of Richmond in Richmond, Virginia has made a study of the blue-greens (Cyanophyta) of this area and several other persons have reported species from the basin. No formal study, however, has been made on the distribution and ecology of the green algae of the area covered by this investigation.

The writer has also made an attempt to discuss certain aspects of algal ecology of streams in general. This was done by using data accumulated by many phycologists and other stream biologists. This discussion does not treat all of the information that has been accumulated on stream ecology, but it is thought that enough data are presented to emphasize the importance of certain factors on algal development.

In order to carry out the major objectives of this study, representative algal and chemical samples were collected from points along the James Basin. Samples were collected from the headwaters

to the mouth on both sides of the river. Such sampling was followed throughout all seasons of the year.

Beginning in August, 1955 samples were taken from both sides of the James, making certain that representative collections were taken from each county bordering the river and so that each parent soil type of the basin was included. At least two, often more, samples were taken from streams emptying into the James from each county. A total of 97 points were sampled by the author, and Dr. J. C. Strickland of the University of Richmond contributed 16 collections.

In the summer of 1956, the same collection points were again covered. Samples were taken from the main tributaries for chemical analyses. The chemical analyses of these streams had been made by the Department of Conservation, Division of Water Resources of Virginia, but phosphorus analysis had been omitted from the data; therefore, the author made phosphorus determinations using the "Molybdate Colorimeter Method."

The samples were scrutinized in the laboratory and each species observed was recorded. A drawing was then made of the species by use of the camera lucida. Seven plates of species numbering 82, and two maps supplement the written text.

After summarizing the results of this survey, several observations can be made. (1) The number of Chlorophyta inhabiting the tributaries of the James River Basin is relatively low. (2) The pH of the streams ranges from 6.4 to 7.6. It is quite difficult to determine the direct influence of pH on the number of species; however, it was observed that the streams with the largest number of species

were slightly on the acid side of the pH scale. (3) Streams that were slightly soft (low in $CaCO_3$ content) had the greatest number of species. However, the influence of hardness as a single factor on algal distribution is difficult to determine. It is thought that other factors tend to interact with hardness to influence distribution. (4) The nitrogen-content of a stream does influence the distribution of species; however, it has been pointed out that low-content of nitrogen in a stream may be influenced by the volume of growth in the stream. If growth rate is low, the nitrogen-content may be high. (5) Pollution is considered as possibly a factor limiting the number and kinds of species inhabiting a stream. Organic pollution may tend to increase the nitrogen-content of a stream; thus, acting as a fertilizing factor. The streams in this study that seemed polluted were quite limited in numbers of species; however, those forms that were able to survive were quite prolific in their growth. (6) Current-rate seemed to greatly influence the productivity of a stream. The swifter streams in this survey were less productive than the slower. However, there were a few exceptions in that two or more streams that were quite slow were not especially productive, but this was thought to be due to other factors such as pollution, hardness, pH, turbidity, etc. In general the swifter streams were almost devoid of both algae and higher plants, but those that could survive the hazard of swift currents usually thrived quite well.

AN ECOLOGICAL AND TAXONOMIC SURVEY
OF THE CHLOROPHYTA OF
THE JAMES RIVER BASIN, VIRGINIA

By

Bernard Robert Woodson, Jr.

A THESIS

Submitted to the School for Advanced Graduate
Studies of Michigan State University of
Agriculture and Applied Science in
partial fulfillment of the
requirements for the
degree of

DOCTOR OF PHILOSOPHY

Department of Botany and Plant Pathology

1957

// /. :7

Table of Contents

ACKNOWLEDGMENTS

The writer wishes to express the most sincere thanks to Dr. G. W. Prescott, under whose guidance the following investigation was executed. His very deep interest in the welfare and progress of the writer served as a stimulus for continued pursuance of this investigation. His very helpful advice and untiring guidance have been of great inspiration to the writer during the course of this study.

A special statement of gratitude is also extended to Dr. J. C. Strickland, Department of Biology, University of Richmond, for his help in the collection of specimens from 16 stations, and for the use of literature from his personal library and the library of the University of Richmond. Grateful acknowledgment is also extended to the Virginia Academy of Science for their interest in this investigation, and for the financial grant which enabled the writer to meet some of the financial problems involved in the collection of specimens.

Sincere thanks are also extended to the Conservation Department of Virginia Polytechnic Institute for information on the soils of Virginia. Acknowledgments are also due Dr. J. L. Lockett, Head of the School of Agriculture of Virginia State College, for the use of geologic maps, and to Dr. C. C. Gray and Mr. J. H. Trotter of Virginia State College, for their assistance in making phosphorus determination tests.

etc., with the distribution of the Chlorophyta along the James River Basin. The writer also has made an attempt to discuss certain aspects of algal ecology of streams in general, using data accumulated by well-known phycologists and other stream biologists. It is hoped that enough information is presented to make this research useful to other investigators.

The writer, began this study of the distribution during the summer of 1955.

OBJECTIVES OF THIS STUDY

This is a study of the distribution, classification and ecology of the Chlorophyta of the James River Basin. The primary objectives of this study have been: (1) the collection and identification of green algae (Chlorophyta) from representative points along the James River Basin; (2) the determination, where possible, of the geological or soil features and chemical factors related to the distribution of Chlorophyta along the James River Basin; (3) the assembling of ecological data concerning algal development in streams in general.

This problem was brought to the attention of the writer by his advisor, Dr. G. W. Prescott. It was suggested that since no formal study had been made on the distribution and ecology of green algae in the area covered by this report, that it would be well to make such a survey. Several persons have reported organisms from different points in Virginia, but for the Chlorophyta along the James River Basin it is virgin territory. J. C. Strickland (1942) has made a survey of the blue-green; H. S. Forest (1954) has presented a check list of algae in the vicinity of Mountain Lake Biological Station, Virginia; S. L. Meyer (1940) has reported species of Phacus; and Vivian Farlow (1928) has reported algae of ponds from tadpole intestine. It was also suggested by Dr. Prescott that the writer try to associate as many ecological factors, parent rock, soil regions, water chemistry,

C. GEOLOGY AND CHEMICAL DESCRIPTION OF THE JAMES RIVER BASIN

1. The Soil Regions of Virginia*

Soils vary from place to place chiefly because of the action and interaction of three important factors: (1) the chemical and physical nature of the parent materials; (2) the environmental conditions under which the soils were developed (temperature, precipitation, topography, amount of drainage, natural vegetation and soil organisms); (3) the length of time these environmental factors have acted upon the parent material.

Parent materials are usually classified on the basis of whether they have remained in their original place or have been moved and redeposited, and, if the latter, by what agency. If the parent material from which the soil has been formed has not been moved, the material is known as residual and the soil is the final product of the rock underneath. If the parent material is moved, however, from its original position, it is known as transported material and is further classified on the basis of the transporting agent. Water is the main transporting agent in Virginia. It gives rise to (1) alluvial materials,

---

*Bulletin 203 - Agronomy Department of Virginia Polytechnic Institute and the Soils Conservation Service of Virginia.

those that are picked up and deposited by flowing streams from which first bottom and terrace soils are developed; and (2) marine materials which have been carried by streams and deposited in the ocean. The other transporting agent important in soil formation in Virginia is gravity. Soil material moved by gravity and run-off down steep slopes is known as colluvium. Some material which has been moved by water and gravity for short distances down slopes is also known as local alluvium.

Many conditions contribute to the effect of the environmental factors on the parent material. Other things being equal, the longer the soil material has been acted on by environmental forces, the more the soil properties will be affected by the environment and the less by parent material. Conversely, the shorter the time the environmental factors (rainfall, topography, temperature, etc.) have been working on the parent material, the more will the properties be affected by parent material.

Texture of the parent material also has a marked influence on the effect of such soil-forming factors as rainfall, temperature, etc. For example, fine-textured material such as clays retards normal water and air movements necessary for subsequent soil development. Topography is of great importance. On steep slopes normal soil erosion removes soil almost as fast as it is formed. Well-developed soils, therefore, form only on gentle rolling relief from medium-textured, soil-parent material.

There is some merit in grouping Virginia's soils on the basis of their physiographic divisions and parent materials as a natural classification. The following classification does not constitute, however, a grouping which parallels exactly the bases of categorizing described above. Four (4) main divisions and eleven (11) subdivisions of Virginia based on physiographic and soil-parent materials are described below.

APPALACHIAN DIVISION

The Appalachian Division has a total land area of about 8,000,000 acres, being next in size to the Piedmont Division (see soils map page 27a). It begins in the extreme west portion of Virginia and extends in a northeast direction across the state. The elevation ranges from 1000 feet in the lower valley part to about 4000 feet on some of the higher mountain ridges. The surface relief varies from gently sloping to steep. The larger, rougher areas of this division occur in the southwest plateau section and the Alleghany Mountains on the west. The dominant rock formations are sandstone, shale and limestone.

Three areas of the Appalachian Division are shown on the map: Appalachian Plateau, Mountains and Uplands, and Limestone Valleys. Soils of these areas are described briefly in the following pages.

Area 1

The Appalachian Plateau is in the extreme western portion of Virginia taking in most of Wise, Dickenson and Buchanan Counties and a small part of Scott, Russell and Tazewell Counties. (See soils map, page 27a). The high plateau, usually 1700 to 4200 feet in elevation is deeply cut by streams, giving a rolling to steep topography. The underlying rocks from which the soils are formed consist of acid sandstone and shales. On the smoother topography the major soils belong to the Hartsells, Wellston and Coeburn series. The soils occurring on the steeper topography belong to the Muskingum and Montevallo series. Because of the steep topography and low fetrility of the soils of this region, a large part of the uplands remain in forest. The smoother areas support some truck gardening and orchards as well as general farming, but most of the farming is done by miners and other industrial workers on a part-time basis.

Area 2

The Mountains and Uplands region comprises the Alleghany Mountains and foothills which extend throughout the northwestern portion of the state and which form the western boundary of the great Limestone Valleys of Virginia. The mountain ridges have narrow, straight-back crests usually capped with sandstone, with sides very steep to precipitous and usually stony. The ridges run in parallel series in a northeast-southwesterly direction and on many of them the skyline looks to be the same elevation for miles. These higher ridges are made up of sandstone or sandstone and shale with many of the foothills being developed from acid shale. Most of the soils belong to the Muskigum (from sandstone) or Montevallo (shale) series. They are steep, shallow, or of low fertility, and in general should remain in forest. Between the ridges are narrow valleys which in many places have been filled by materials rolled or washed from the original extremely high elevations. Between the valleys and high ridges there are often fairly wide areas of rounded shale hills which may be capped with colluvial materials. The soils above these various rock formations, owing to the broken relief and to resistant rock formations, have developed very shallow profiles and in most places rock fragments of various sizes are scattered over the surface and through the soil. Although Muskigum and Montevallo are the most extensive of the upland soils, some of the less extensive types are of considerable agricultural importance because they have a more level relief and deeper profiles. Among these are the colluvial soils of the Jefferson, Hayter, and Leadvale series.

Nearly all of the soils in the southern portion of this area are light in color, ranging from light gray to grayish-yellow and light brown in the surface and yellow or brownish-yellow in the subsoils. In local areas soils such as Allen and Wadesboro have red or reddish brown subsoils. In forested areas a small amount of leaf-mold is mixed with a few inches of the top soil, and in areas that have been in continuous pasture for many years the top inch or two is somewhat darker than the soil below. In the northern portion of the region the soils become somewhat browner in the surface and subsoils, showing the effects of a colder climate. In some of the narrow valleys between the mountain ridges where the residual limestone has not been covered by colluvial materials, soils have developed similar to those in the Limestone Valley. These areas generally occur on steep relief, but form a striking contrast to the surrounding and poorer appearing country.

Area 3

The Limestone Valleys extend throughout the northwestern part of the state lying in general between the Blue Ridge Mountains on the southeast and the Alleghany Mountains on the northwest with a total land area of about 3,800,000 acres. The elevation varies from approximately 1,000 to more than 3,000 feet in portions of southwest Virginia. The main or Great Valley of Virginia, called Shenandoah Valley varies in width from about 8 to 20 miles. It is not a valley in the sense that it has been worn down by streams. Its surface has been lowered below that of the adjacent country because of the underlying limestone which has decayed more rapidly than that of the more resistant rocks of the Blue Ridge and Appalachians. The Valley's surface relief is gently rolling, to steep. In some places streams have cut deep beds within the Valley, causing large areas of hilly and very steep topography. Throughout the Valley there are many high ridges and sharp crests and precipitous slopes. The terraces and first bottoms are nearly level and they comprise the smoothest parts of the area.

Many of the soils of the Valley are developed from rocks containing varying amounts of lime ($CaCO_3$). In general, the higher the lime-content of the underlying rock the more productive the soil of the area. The upland soils occurring at lowest relative elevations are derived from high calcic limestone and belong to the Hagerstown, Pisgah, and Decatur series. Occurring on adjacent ridges usually are soils derived from dolomitic limestone which are fairly high in chert, sandstone or both. These soils belong to the Dunmore, Frederick, Elbert, Lodi, Boloton, and Clarkeville series, and are less fertile than those from high calcic limestone, but are relatively better small grain soils.

Associated with the calcic rocks and dolomitic limestone are fairly large areas of soils formed from high calcic limestone, but containing varying amounts of shale as impurities.

These soils usually are heavier in texture than other Limestone Valley soil, and, in general, are better suited to production of pasture and forage crops. Soils belonging to the Groseclose, Bland, Carbo, Chilhowie, and Colbert series occur in this group. Associated with this group of soils are the Westmoreland soils which develop over interbeded limestone and shale on steep topography. They are especially suited to pasture and forage crops.

Also in the Limestone Valley are large areas of soils developed over shale containing varying amounts of calcium carbonate. These soils are usually shallow to bedrock, have very low storage capacity for water and are, therefore, subject to drought. Dandridge soils are developed over shale showing the presence of $CaCo_3$ within 18 inches of the surface of the soil. The teas, Litz and Berks are developed over shale low in lime and are leached free of $CaCo_3$ to at least 18 inches. Tellico soils have been mapped in the Limestone Valley over calcarous sandstone.

Just west of the Blue Ridge Mountains and also in the vicinity of the Appalachian Mountains there are rather large areas of colluvial materials, mainly sandstone and shale, that have been washed or rolled from higher slopes. From these beds the Jefferson, Allen and Hayter soils have developed. All of the Valley soils are prevailingly light in color ranging from grayish-yellow to brown in the surface soil, and from brown, brownish-yellow, yellow, yellowish-red and brownish-red to red in the subsoil. The textures are dominantly loams, silt loams, loams with fine sandy loams in case of some of the terraces and colluvium. Many areas are stony, particularly at the base of mountains and on higher knolls and ridges. In the main, subsoils are friable, but in places surface and subsoils are heavy and plastic. They have developed under forest cover, dominantly hard woods, and do not contain much organic matter. Leaching has been active and the surface soils do not contain a very high amount of plant nutrients. Free carbonate of lime is lacking in most of the soils although a majority of them are derived from limestone or materials abundant in carbonates.

On the whole, the soils from limestone are inherently fertile and by far the most productive in the Valley. Those from shale are mainly shallow and therefore droughty soils. They are among the least productive soils of this region. When used for the best-adapted crops, as small grain, good yields are obtained. In production the soils from sandstone are the least desirable; however, those soils derived from mixed sandstone and limestone, as the Lodi series, are adapted to general use, being less productive than soils derived from limestone but considerably more so than most soils derived from shale.

BLUE RIDGE DIVISION

The Blue Ridge Mountain Division runs through Virginia in a northeasterly and southwesterly direction. (See soils map page 27a) It lies between the Piedmont Plateau on the east and the Great Limestone Valley on its western border. It consists mainly of the Blue Ridge Mountains with numerous ranges. The elevation on the main ridge varies from 1,500 to 3,500 feet above sea level, but some of the peaks are much higher. The highest elevations are Mt. Rogers, 5,720 feet, and Whitetop Mountain, 5,519 feet. Both of these mountains are in Grayson County, which is often called the roof-top of Virginia.

The Blue Ridge Mountains as a whole are characterized by relatively broad rounded ridges with many steep to precipitous slopes and include spurs and sharp knobs that stand out above the lower lying hills, particularly on the eastern side adjacent to the Piedmont. In the southwest portion, Carroll, Grayson and Floyd Counties in particular, they can best be described as a plateau deeply cut by streams and broken by mountains and high hills which have round tops and steep slopes. Some of the intermountain areas here have topographical features similar to those of the Piedmont. The streams are fast flowing and have cut narrow V-type valleys far back into the mountains. Many of the bottoms, however, along the streams especially in the plateau section, are relatively wide, considering the size of the stream, and for the most part are characteristically of imperfect drainage conditions, due to seepage from higher country. In the rougher mountain sections the land is very stony and contains many large areas of rock outcrop.

The higher elevation largely accounts for the fact that the climate of the Blue Ridge Division is cooler than that of the Costal Plain or of the Piedmont. About 55 degrees F. is the average mean annual temperature for the Division, and the mean annual precipitation is about 43 inches. (According to the Western Bureau Station at Jefferson, N. C., just across the line from Grayson County, Virginia, the mean yearly precipitation is 48.86 inches.)

Area 4

For the most part, the northwest slopes of the Blue Ridge Mountains are composed of highly metamorphosed sedimentary rocks consisting of sandstone, quartzite, and shale. The soils are shallow and generally stony, with many rock outcrops. The dominant soils belong to the Ramsey, Muskingum, and Lehew series. Because it is steep, stony and low in fertility, most of this area will remain in forest.

Area 5

The Blue Ridge southeastern slopes, the eastern foot slopes and the smooth mountains tops have soils that are developed mostly from igneous and metamorphic rocks-- granite, gneiss, schist, mica schist, and in many places along the back bone of the Blue Ridge, a relatively narrow belt of greenstone. Throughout all of the region there are relatively small areas of basic rock from dyke intrusions. Other volcanic rocks are found in the northern part of this division, and also in the southwest portion in the vicinity of Troutdale and north of Flatridge.

Many of the steep mountains slopes are largely mapped as rough, stony land. The major soils from the acidic rocks belong to the Porters, Ashe, Fannin, Balfour, Watagau, Edneyville, Chandler, and Talledaga series. Those from the basic rock belong to the Rabun and Clifton series. On the Plateau and smooth mountain tops, these soils are very responsive to good soil management practices and production could be greatly increased.

Because of the cool climate of this area, the soils are frozen for longer periods during the winter; thus, soluble mineral matter is leached out less than in the warmer Piedmont and the soils are darker colored and more open and porous throughout.

Where soils have developed on steep and very steep surface relief in this mountain section, natural sheet erosion has kept pace with the weathering of underlying rocks and the soils are quite shallow. Moreover, only indefinite lines of demarcation occur between the soil horizons.

In the southwestern part of Virginia, the Blue Ridge widens out forming high table lands. These are often spoken of as intermountain areas as they occur between the higher rounded ridges. Here the surface relief is very similar to that of the Piedmont and varies from rather smooth through rolling to hilly; consequently, the soils are much deeper and the layers are well defined.

Although most of the soils in the Blue Ridge, because of their absorptive surface and open, porous subsoil nature, are not subject to severe erosion and are therefore considered less erosible than soils of the Piedmont; several soils are exceptions. Those of the Talladega and Chandler particularly, together with the closely related Fannin and Watauga, are developed from highly micaceous schist. They have floury topsoils and red or brownish-yellow, fluffy, highly micaceous subsoils. With these soils, erosion control is a major problem. Cultivation or grazing without adequate protection will lead to rapid gullying and abandonment.

The textures of most of the soils of this area are loam, silt loam, or clay loam. The color of the surface ranges from dark gray to brown. In the most important series, the subsoil ranges from dull red to brownish-yellow or brown. Soils of this area are rather crumbly throughout their profiles.

PIEDMONT DIVISION

The Piedmont Plateau makes up the largest total land area in the state including approximately 10,500,000 acres or 41 percent. (See soils map, page 27a). It passes through the central part of the state from the south in a northeasterly direction and it is about 140 miles wide at its southern end and about 40 miles at the northern end. It consists of a broad, plain-like surface, thoroughly dissected by numerous small streams. The streams flow generally in narrow, winding valleys in a southeasterly direction and have resulted in the development of a rolling to hilly surface relief. Some of the rougher topography is encountered in the western portion, near the Blue Ridge Mountains and is sometimes called the Piedmont foot hills. Due mainly to this steeper surface relief, soils in this section have developed shallower profiles than those of the wider divides of the eastern part.

The general elevation of the Piedmont ranges from about 200 feet on the eastern border to about 850 feet where it lies next to the Blue Ridge Mountains, although some of the isolated hills and ridges reach much higher elevations. There are many of these high ridges developed throughout the Piedmont area because of the rock formation being more resistant to weathering. Examples of these are Whiteoak Mountain in the central part of Pittsylvania County, capped with Triassic sandstone, and the Ridge known as Southwest Mountain which cuts across the county of Albemarle and up into Orange County and is underlain with greenstone.

There is a rather marked difference, at least from a local standpoint, in temperature and precipitation in the northern and southern parts of Virginia Piedmont. At Danville in the extreme southern end of the area, records show that the mean annual temperature is 59.3 degrees F. and the mean annual precipitation is 40.41 inches. Records compiled at Lincoln in the northern part show the mean annual temperature is 55.2 and the mean precipitation is 39.41 degrees F.

From a geological standpoint, the Piedmont Plateau is very old. It was a land area when the Coastal Plain area and the present land area west of it, except the Blue Ridge Mountains, were covered by ancient seas. The Piedmont Plateau is a region of complex rocks such as granite, diorite, diabase, greenstone, gneiss, schists, phyllite, slate, quartzite, sandstones and shales.

The large variety of soils in the Piedmont Plateau is due in part to the difference in the rock formation which have contributed materials to the soils, and in many places the soils bear direct relationship to these underlying rocks.

In textures, soils of the Piedmont are sandy loams, loams, silt loams, and clay loams. The soils are predominantly light in color, ranging from light gray to pale yellow. Those from basic rocks have a surface color of light brown to reddish-brown and those developed from red triassic shale, as the Penn soils, derive their peculiar Indian-red color largely from the parent material. All of the Piedmont soils have developed under forest cover, which is not favorable to the accumulation of organic content. In wooded areas there is usually a thin layer of leaf mold and other decayed forest debris on the surface and some organic matter mixed with the upper few inches of soil. In this region of moderate to heavy rainfall and relatively warm temperature, active leaching of the soil continues throughout the year, because the soil is not frozen to such great depths nor for as long periods as it is in latitudes further north. Because of the larger amount of leaching of soluble plant nutrients, the surface soils do not contain so large a quantity of these elements as the subsoils. Leaching is the main reason that calcium is low in the soil. Calcium is present in the mineral composition of many of the underlying materials, particularly the dark colored, basic rocks.

Climatic conditions in most of the Piedmont tend to develop soils with light gray to pale yellow surface soils and yellow to red subsoils; however, the effect of climatic change on the soils can be observed in the Piedmont of Virginia as one travels from south to north. The soils become somewhat darker both in the surface and subsoil. In the northern portion they show less of the leaching process and therefore a greater accumulation of organic matter. Closer studies of the soils from similar materials in Northern Virginia indicate that they contain relatively larger amounts of plant food nutrients in their surface soils than do the soils of the southern portion. Other striking differences of the Northern Piedmont soils developed on similar relief from similar parent rock are observed in their shallower profile and more friable subsoils. Exceptions are found in some of the heavy plastic soils developed on level to flat topography where relief and parent material have been more important than climate. Even here the soils are somewhat darker in color than their counterparts further south.

Soils of the Piedmont area have been developed from three distinct geological formations; crystalline rocks, triassic and slate. These are shown on the map as areas 6, 7 and 8.

Area 6

By far the larger part of the area is underlain by crystalline rocks which have been formed and greatly altered by heat and pressure in the earth.

The crystalline rocks are divided into three main groups on the basis of their silica content: (1) those having less than 50 percent SiO_2 including quartz are considered basic rocks and on the whole are darker colored. Examples are diorite, diabase, hornblende gneiss, and greenstone, (2) those having 65 percent SiO_2 are known as acidic rocks and are generally lighter in color and are represented by granite, gneiss, and light colored schists; and (3) those having 50 to 65 percent SiO_2 are intermediate.

Some of the most important soils agriculturally and by far the most extensive soils in Virginia Piedmont are derived from weathered materials of the acidic rocks. In the southern belt, the most important of these are Cecil, Appling, Durham, Helena and Louisberg from crystalline acidic rocks such as granite, gneiss and schist. From the dark colored basic rocks have been mapped Davidson, Mecklenberg and Iredell soils. From the intermediate or mixed rocks are developed the Lloyd, Fluvanna, and Wilkes soils. From fine grained highly weathered quartz, mica, schist are areas of Madison and Louisa soils. Extending through many of the middle Piedmont counties is a large belt of fine-grained schist (serecite schist) rocks which give rise to the Tatum, Nason, York, Lignum, and Manteo soils. These are inherently of low fertility and have largely reverted to forest.

The soils which are common to the northern Piedmont in the crystalline belt are more fertile and higher in organic matter than the soils from the southern Piedmont. From the granites and light colored gneisses, are developed the Chester, Eubanks, and Brandy Wine soils. From a large greenstone belt extending from Culpeper County north are developed soils of the Fauquier, Myersville, and Catoctin soils. From the highly weathered soft mica schist are developed the Elioak, Glenelg, and Manor soils.

Area 7

Occupying mainly lower uplands of the Piedmont are soils developed in old Triassic sea basins. The underlying sedimentary rocks, which are much younger than the crystalline rocks, include brown sandstone, red shale and some conglomerate. The soils may result from sandstone, shale or a mixture of both. The more important soils developed over sandstone are the Granville, Mayodan, Wadesboro and Creedmoor soils. From the shale, and in some cases with a mixture of sandstones, are developed Bucks, Penn, Croton, Calverton and White Store soils. Over baked shale of the Triassic belt in the northern Piedmont of the state are the Brecknock and Catlett soils. Developed from darker colored basic rocks which are pushed up through the triassic plain are the Montalto and Ruxton soils. Associated with soils from triassic materials are the Rapidan Soils. These soils are developed from a rock which is made up of dark basic material surrounded by triassic shale. The Rapidan soils are very similar to those of the Davidson series. The Kelly soils with heavy plastic subsoils also have been developed from basic rock in the triassic belt. Near Leesburg and to the north is an area of the Athol soils which have developed from Triassic conglomerate, a rock composed of limestone fragments surrounded by shale.

Area 8

The so-called Caroline slate belt occurs in the southern Piedmont mainly in Southside, Virginia. This area includes 3 main formations namely: Hyco quartz porphrey, Aaron slate and Virgilina Greenstone. It comprises about 3 percent of the Virginia Piedmont area. The dominant soils are the Georgeville, Herndon, Alamance and Orange series, the latter from dark colored rocks associated with the schist. These soils are finer textured than the surrounding ones from the crystalline belt, are less well-suited for the production of bright tobacco, but are very well-suited to the production of small grains, and for forage crops.

There are, in addition to these rock formations, relatively large sedimentary deposits here and throughout the whole Piedmont that furnish materials for soils. Some of these deposits are considered very recent, such as the alluvial deposits along streams which give rise to the first-bottom soils of Congaree, Chewacla and Wehadkee, Star, Meadowville and Seneca from colluvium; some are fairly recent deposits making up the normal or low terraces from which soils of Wickham, Altavista and Roanoke have been derived; some are old high-terraces on which the Hiwassee and Masada series have formed. The soils on these old high terraces have developed well-defined horizons and are considered old soils. As a matter of fact, some are so similar to profiles of Davidson and Cecil residual soils that they are easily confused with them.

COASTAL PLAIN

The Coastal Plain Division is a low plain ranging in elevation from sea level to about 250 feet as the fall line where it borders the Piedmont. (See soils map page 27a) Many areas of Coastal Plain soils are found on higher elevations as in places, however, where they occur west of the fall line as shallow, to medium deep cappings. Where these cappings are of considerable depth, they have developed into typical Coastal Plain soils; however, where the Coastal Plain material was formed as a shallow covering the resultant soil has been influenced by the deeper Piedmont material. Here such soils as Bradley and Chesterfield occur (soils derived from a mixture of Coastal Plain and Piedmont material).

Though the southeastern portion of the area contains the largest acreage of level land, fairly large, flat, poorly-drained areas occur in the middle and northern parts as pocosins (high flat areas) or low marine terraces. The more rolling areas are always encountered in those sections served by a natural drainage system and may be in areas of relatively high elevations. Better natural drainage systems, however, have developed on the higher marine terraces. The Coastal Plain deposits, the youngest geological formation in Virginia, are comprised chiefly of heavy clays, sandy clays and sands and in places rich marl deposits have been formed from the remains of crustaceans. There are some accumulations of peat material in the southeastern part of the region, notably the Dismal Swamp.

In general, the soils of the Coastal Plain are more sandy throughout their profile than soils found in other regions of the state. There are large local areas in the Coastal Plain, however, where the soils have very heavy plastic subsoils as in some of the relatively large pocosins of Nansemond County as well as the low flat marine terraces adjoining the Nottoway, Neherrin and Nassemond Rivers in Southhampton County. In some places, particularly along the Neherrin and James Rivers the low terraces are made up of Piedmont materials and here occur sizeable areas of Wickham and Altavista soils. Differences in relief and drainage have been the controlling factors which have caused the differences in most of the upland soils of the

Coastal Plain area.

On the map the Coastal Plain area is divided into three categories: 9- the Chesapeake Bay region; 10- the Middle Coastal Plain, and 11- Flatwoods. Following is a brief description of the soils of these areas.

Area 9

The Chesapeake Bay Region, though developed for the main part on the high Sunderland Terrace with elevations of from 160 to 260 feet, includes some of the lower marine terraces. The surface relief, varying from almost level to rolling and sometimes steep along the edge of drainage ways, has influenced soil development to a marked degree. The other main influence has been the parent material which is made up of marine deposits of sand, silt, and clay. The amount of sand, silt, and/or clay not only governs the rate of development, but also the texture of the various soil layers. The more important soils developed from sands are Galestown, Kloj, Plummer, and Rutledge. From sand loam materials are developed the Sassafras, Woodstown, Dragon, and Falleington soils in which impervious hardpans have developed and soils developed are Beltsville, Leonardtown, and Chillum series.

Area 10

The Middle Coastal Plain which occurs south of the Chesapeake Bay Region between the Flatwoods and Piedmont Area is developed mainly on the Wicomico terrace in the eastern part with elevation of 60 to 90 feet and the Sunderland in the western part, which is 100 to 200 feet above sea level. It includes small areas of the lower Dismal Swamp and Chowan terraces mainly as comparatively narrow strips along some of the main estuaries.

The surface relief of the Middle Coastal Plains is quite similar to that of the Chesapeake Bay Area with the exception that it contains more and larger, relatively high, flat areas that have not been invaded by streams (pocosins). Here rather large areas of poorly and somewhat poorly drained soils have been mapped. It also has the same marine deposits and parent material as are present in Area 9. From the sandy material the main soils are Norfolk, Ruston, Moyock, and Onslow soils. From the heavier materials are developed the Craven, Lenoir, and Bladen soils.

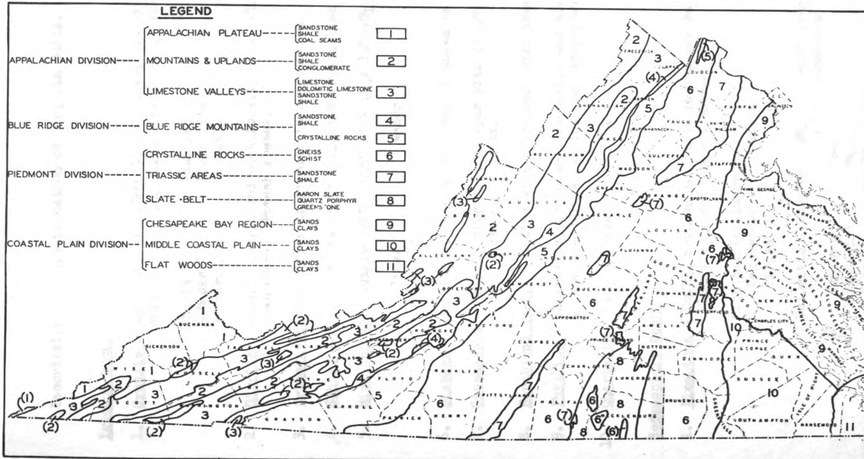
Area 11

The Flatwoods Area in the southeastern part of the state is comprised of two low, main terraces, Dismal Swamp and Prin-

cess Anne with elevations of from 0 to 25 feet above sea level. This entire area is generally flat and most of the soils are poorly drained or somewhat so; however, there are many small areas of well-drained soils which are very important locally. The Dismal Swamp occupies approximately 40 percent of this region and is covered by organic soils mapped as peat, mucky peat and swamp and mineral soils high in organic matter such as Portsmouth, Bayboro and Pocomoke. Other fairly large areas of the flatwoods section are occupied by non-agricultural land such as fresh and salt marshes, and sand dunes. The soil developed from sands are Galestown, Klej, Plummer, and Rutledge. Those from sandy loam materials are Fallsington, Dragston, Woodstown, and some Sassafras on low ridges. Soils from heavy materials are Elkton, Othello, Keyport Bertie and Mattapox.

A very interesting and more thorough discourse on the geology of the area covered by this report has been published by the Virginia Academy of Science (1950) in a book entitled— The James River Basin-- Past, Present and Future. In this book the history of the basin is discussed along with a very detailed description of the various geological regions included in the James River Basin.

PHYSIOGRAPHIC AND SOIL PARENT MATERIAL MAP OF VIRGINIA



Description and Classification of Virginia Soils.

Igneous Rocks

1. Granite - Chiefly quartz (SiO_2), orthoclase ($KAlSi_3O_8$) and ocasionally, plagioclase (feldspar). Very acid soils.

Chester	Fauquier
Eubanks	Myersville
Brandywine	Catoctin

2. Diorite - Chiefly quartz and occasionally plagioclase (feldspar). Potash absent.

3. Orthogneiss - Similiar to granite in composition.

4. Schist - Closely foliated or laminated crystalline rock.

5. Mica Schist - Quartz (SiO_2) with mica ($H_2KAl_3Si_3O_{12}$).

Elioak	Manor
Glenelg	

6. Diabase - Similiar to diorite or commonly known as diorite.

7. Greenstone - Chiefly diorite (feldspar with potash absent), dark green and compact.

8. Hornblend gneiss - Gneiss with hornblend (high iron).

9. Phyllite - Intermediate between mica schist and slate (compressed clays, shales and other rocks).

10. Quartzite - SiO_2 (Silica)

Sedementary Rocks

1. Limestone - $CaCO_3$; main variation in purity are Fe_2O_3, SiO_2, $MgCO_3$, clay and organic matter

High calcic limestone

Hagerstown	Decator
Pisgah	

Dolomitic Limestone - High in chert (very fine quartz) and/or sandstone

Dunmore	Lodi
Frederick	Bolton
Elbert	Clarksville

High calcic limestone, containing shale

Groseclose
Bland
Carbo
Chilhowie
Colbert

2. Shales - Main composition of feldspars, clays, mineral and quartz. Finely stratified.

Dandridge
Teas
Litz
Berks
Montevallo

From shale or mixture of sandstone

Bucks
Penn
Croton
Calverton
White Stone

From baked shale of Triassic belt

Brecknock
Catlett
Montalto
Buxton
Rapidan
Davidson
Kelly
Athol (Triassic conglomerate-limestone surrounded by shale).

3. Sandstone - Contains quarts and smaller quantities of other minerals such as silica, iron oxide or calcium carbonate.

Calcareous sandstone

Tellico

Sandstone, quartzite and shale

Ramsey
Muskingum
Lehew

Acid sandstone and acid shales

Hartsells
Wellington
Colburn
Granville
Mayodan
Creedmoor

4. Slate - Dense, fine-grained compression of clays, shales, and other rocks. Principal accessories-biotite, chlorite, hematite. Minor accessories - magnetite, apatite,

koaline, andalusite, rutile, pyrite, graphite, feldspar, zircon, tourmaline, and carbonaceous matter.

6. Triassic - Red sandstone.

7. Crystalline - Composed of crystals or parts of crystals.

Sedimentary Desposits

1. Alluvium - Fine material, such as sand, silt, clay, or other sediments deposited on land by streams.

   Congaree
   Chewacla
   Wehadkee

2. Colluvium - Formed from washings through gravational influence, at the base of steep slopes.

Star	Jefferson
Meadowville	Hayter
Seneca	Leadvale
	Allen

Soils dervived from sedimentary of streams originally; later effected by gravitation.

Wickham
Altovista
Roanoke
Hiwassee
Masada

From coastal plains and Piedmont Soils

Coastal plains soils - heavy clays and sandy clays (marl) and sometimes heavy plastic subsoils.

Bradley
Chesterfield
Wickham
Altavista

From sand

Galestown	Norfolk
Klej	Ruston
Plummer	Mayock
Rutledge	Onslow

From Sandy Loam

Sassafras
Woodstown
Dragston
Fallsington

From sandy clay loam and clay

Mattapex	Elkton
Matapeake	Portsmouth
Caroline	Craven
Atlee	Lenoir
Bertie	Bladen
Othello	Keyport

Organic soils

Peat
Mucky peat
Swamps

Mineral soils - high in organic matter

Portsmouth
Bayboro
Pocomake

Acid Rocks (65% SiO_2)

Soil types	Soil groups
Porters	Granite
Ashe	Gneiss
Fannin	Schists
Balfour	
Watagau	
Edneyville	Micaceous - Schist
Chandler	
Talledaga	

Basic Rocks (less than 50% SiO_2)

Soil types	Soil groups
Rayburn	Quartz
Clifton	Diorite
	Diabase
	Hornblend gneiss
	Greenstone

Soils from Acidic Crystalline Rocks

Soil types	Soil groups
Cecil	Granite
Appling	Gneiss
Durham	Schist
Helena	
Louisburg	

2. Source and Description of Chemical Factors Considered in this Paper

The chemical factors which are discussed in this paper are regarded as significant in the growth and distribution of stream algae. A brief discourse as to the source of each factor follows, but a much more detailed discussion of those which affect algal distribution and growth will be covered in another chapter of this paper under Discussion.

Silica (SiO_2) - Silica is dissolved from practically all rocks. Silica affects the usefulness of water to Man because it contributes to the formation of boiler scale. It is particularly troublesome in high-pressure boilers, because the hard scale prevents rapid transfer of heat, and may cause boiler-tube failure. It also forms deposits on the blades of steam turbines.

Iron (Fe) - Iron is dissolved from many rocks and soils and frequently from iron pipes through which the water flows. Iron in water for home uses is objectionable because it stains porcelain or enameled fixtures and clothing. Normal basic waters that contain more than a few tenths of one part per million of iron soon becomes turbid with insoluable reddish ferric oxide produced by oxidation. Surface waters, therefore, seldom contain as much as one part per million of dissolved iron.

Calcium and Magnesium (Ca and Mg) - Calcium is dissolved from practically all rocks, but it is found in greater quantities in waters that have been in contact with magnesium-bearing rocks and may contain a considerable quantity of magnesium.

Carbonate and Bicarbonate (CO_3 and HCO_3) - Bicarbonate in natural waters results from the action of dissolved carbon dioxide on carbonate rocks. Carbonate is not present in appreciable quantities in most natural surface waters and it is not present in a water that has a pH of less than about 8.3. Bicarbonate is the principal acid radical of most of the surface waters in Virginia.

Sulfate (SO_4) - Sulfate is dissolved from rocks and soils and its presence in natural waters is often associated with beds of shale and/or gypsum. It is also formed by the oxidation of sulfides and is present in noticeable quantities in waters from mines.

Chloride (Cl) - Chloride is dissolved from many rocks and soils. Sea-water encroachment is likely to increase the chloride content of a fresh water supply as sodium chloride is the predominant constituent of sea-water. The chloride content of surface water may be increased by pollution from sewage and some industrial wastes.

Nitrate (NO_3) - Nitrate in water is considered a final oxidation production of nitrogenous material and in some instances

may indicate contamination by sewage or other organic waste matter.

Dissolved Solids - The quantity reported as dissolved solids (the residue on evaporation) consists mainly of the dissolved mineral constituents in water. It may also contain some organic colloidal matter, and water of crystallization. The quantity of dissolved solids is reported in parts per million.

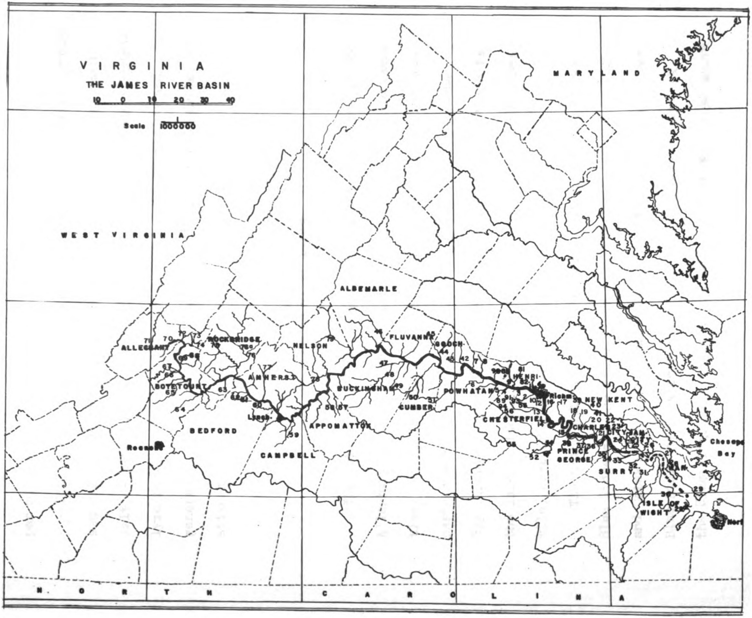
Oxygen consumed - Oxygen consumed is the amount of oxygen removed from potassium permanganate by the water when it is digested 30 minutes in a boiling water bath. It furnishes a rough indication of the oxidizable matter in the unfiltered and filtered samples and gives a partial measure of pollution materials such as sewage and oxidizable industrial wastes. Highly colored waters may have relatively high oxygen consumption, although waters that are not noticeably colored may also contain oxidizable material.

Color - In water analysis, color refers to the appearance of water that is free from suspended solids. Many turbid waters that appear yellow, red, or brown when viewed in the stream show very little color after the suspended matter has been removed. The yellow to brown color of some waters may be attributed to organic matter extracted from leaves, roots, and other vegetable matter. In some areas objectionable color in water results from industrial wastes and sewage.

(pH) - pH is the negative logarithm of the number of moles of ionized hydrogen per liter of water, and is an index of the acidity or alkalinity of water. The hydrogen-ion concentration is commonly reported as pH. A pH value of 7.0 indicates that the water is neither acid nor alkaline. Values lower than 7.0 denote increasing acidity, while values higher than 7.0 denote increasing alkalinity. The pH of water indicates its activity toward metal surfaces. As the pH increases, the corrosive action of the water decreases. The pH of most natural surface waters in Virginia ranges from 6 to 8.

Hardness - Hardness is the characteristic of water that receives the most attention with reference to industrial and domestic use. It is usually recognized by the increased quantity of soap required to produce lather.

Hardness is caused by significant cations, such as calcium, magnesium, iron, manganese, aluminum, barium, strontium, and free acid. The hardness of waters considered in this paper is caused almost entirely by calcium and magnesium. Water that has less than 60 parts per million of hardness is considered soft and is suitable for many purposes without further softening. Waters with hardness ranging from 61 to 120 parts per million are moderately hard, and waters with hardness ranging from 121 to 200 parts per million are hard. The hardness of



VIRGINIA
THE JAMES RIVER BASIN
10 0 10 20 30 40
Scale 1000000
WEST VIRGINIA
MARYLAND
ALBEMARLE
ALLEGHANY
ROCKBRIDGE
BOTETOURT
AMHERST
NELSON
FLUVANNA
BUCKINGHAM
BEDFORD
CAMPBELL
APPOMATTOX
CUMBER.
POWHATAN
GOOCH.
HENRI.
CHESTERFIEL
NEW KENT
CHARLES CITY
PRINCE GEORGE
SURRY
ISLE OF WIGHT
Lynch.
Bay
NORTH CAROLINA

surface waters in Virginia ranges from around 10 to 200 parts per million.

Total acidity - The total acidity of a natural water represents the content of free carbon dioxide, mineral acids, and salts-- especially sulfates of iron and aluminum-- which hydrolyse to give hydrogen ions. Acid waters are corrosive and generally contain excessive amounts of other objectionable constituents, such as iron, aluminum, or manganese.

3. CHEMICAL CHARACTER OF SURFACE WATERS[1] of the James River Basin

The James River has its headwaters in the mountains of the Alleghany Plateau in Craig, Alleghany, Bath and Highland Counties. It is formed by the confluence of the Jackson and Cowpasture Rivers, traverses the State, and enters Chesapeake Bay through Hampton Roads. The James River drainage basin is the largest in the State; it includes an area of 6,757 square miles west of Richmond.

The principal tributaries of the James River west of the Blue Ridge are the Maury River from the north and Craig Creek and Catawba Creek from the south. The river cuts through the Blue Ridge near Balcony Falls below Clifton Forge. East of the Blue Ridge, the principal tributaries from the north above

---

[1] Adapted from a report by Department of Conservation and Development, Charlottesville, Virginia.

Richmond are the Pedlar, Buffalo, Rockfish, Hardware, and Rivanna Rivers; and from the south are the Slate and Willis Rivers. The Appomattox River from the south and the Chickahominy River from the north enter the James below the upper limits of tidewater.

The James River passes through three areas of different geologic character. West of the Blue Ridge, it drains an area of sandstone, shale, and limestone formations; east of the Blue Ridge, it enters an area of hard crystalline rock; and east of the fall zone it traverses the sands and clays of the Coastal Plain. The tributary streams in each of these areas determine in part the chemical character of the water of the James River.

Many of the tributaries west of the Blue Ridge are sustained by large springs, which generally flow from limestone formations. Consequently, dissolved matter in the water consists mainly of the bicarbonates of calcium and magnesium.

The principal tributaries to the James River above Buchanan are the Jackson and Cowpasture Rivers and Craig Creek. The principal mineral constituents are the bicarbonates of calcium and magnesium. The waters are of average mineral content; the maximum dissolved solids for the period 1947-1948, was 164 parts per million.

At Buchanan, the James River drains an area of 2,084 square miles. Reports on the condition of the James at this point by the Conservation Department (1947-48) show the dissolved mineral matter to be composed mainly of calcium, magnesium, bicarbonate, and sulfate. The average quantity of dissolved solids was 134 parts per million and the average hardness 97 parts per million.

Waste materials enter the Jackson River between Falling Springs and its junction with the Cowpasture River, and the resultant pollution is attested by a slight increase in color and chloride-content of the James River at Buchanan over that of the Jackson River at Falling Springs and the Cowpasture River near Clifton Forge. Between Buchanan and Bent Creek the principal tributaries to the James are the Pedlar and Maury Rivers. Results of analyses of several samples collected from the river near Pedlar Mills show the water to be comparatively low in mineral content and exceedingly soft but high in silica. The mineral content of water of the Maury River near Buena Vista is less concentrated than the James River at Buchanan, but contains more magnesium and is therefore harder. Its effect on the James River is to decrease the concentration of dissolved solids.

The James River at Bent Creek has a drainage area of 3,671 square miles. The average quantity of dissolved solids and the average hardness are 119 and 81 parts per million, respectively. The mineral content of the water at this point is less concentrated and softer than that at Buchanan. This is mainly due to the soft water or low mineralization that enters the river east from Craig's Creek, etc.

The waters of all tributaries to the James River between the Bent Creek and Richmond stations are low in mineral content and are soft. The Rockfish, Hardware, Slate, Rivanna, and Willis Rivers all drain an area of crystalline rocks. The Buffalo River, which joins the James River below Bent Creek, has a high sulfate-content and is slightly acid at times because of industrial wastes that enter the stream above Norwood. However, the water is soft and its total effect on the James River is the maintenance of an average sulfate-concentration in the water at Richmond at the same level as at Bent Creek.

The James River at Richmond drains an area of 6,757 square miles. The report made by the Conservation Department on the James River at Richmond in 1947-48 shows the water to have less concentration of dissolved minerals than at Bent Creek. The decrease in mineralization at this station is in accord with the tributary inflow indicated above. The average concentration of dissolved solids and the average hardness are 86 and 52 parts per million respectively.

The Appomattox and Chickahominy Rivers are the main tributaries of the James River below Richmond, entering below the upper limits of tidewater. The Appomattox River rises in Appomattox County and flows into the James at City Point. It's course parallels that of the James River until it reaches the Fall line, where it turns northeast. The Appomattox River has a drainage area above Farmville of 306 square miles, and above Mattoax of 745 square miles. The river flows over areas of crystalline, siliceous rocks; therefore, the principle characteristics of the water are its siliceous nature, quite dilute, and very soft. The quantities of dissolved solids and hardness are similar at both points.

The Chickahominy River has a drainage area of 249 square miles above Providence Forge. It rises in Hanover County, flows southeast traversing the sands and clays of the Coastal Plain and empties into the James River at During Point. The principal characteristics are its low mineralization and extreme softness. The water has considerable color which is due partly to inflow from swamp areas.

D. Methods and Procedures

In order to carry out the major objectives of this problem, representative samples, algal and chemical, were collected from points along the James River. This was done by taking samples from tributaries emptying into the James River on both sides making certain that all main streams were represented from headwaters to the mouth of the river.

It was desired that sampling be made throughout as many seasons of the year as possible.

The distance from origin to mouth of the James is approximately 300 miles, but it was necessary to travel over one thousand miles to make a complete survey of the area studied for each sampling period.

The first collections were made in the summer (August) of 1955. Samples were taken from both sides of the James making certain that representative samples were taken from each county bordering the river. This was done mainly with the desire of obtaining samples from each parent soil type. As shown by the soils map, many of the counties had the same physiography.

At least two, often many more, samples, however, were taken from streams emptying into the James from each county. This procedure was adhered to as closely as possible, for the winter collection 1955-56 and spring collection 1956. A total of 97 points were sampled by the author, and Dr. Strickland of the

University of Richmond contributed 16.

In surveying the tributaries, all macroscopic algal growths were sampled. In many instances soil samples of stream bottoms were collected even though there was no definite sign of algal growth. Also samples of twigs, leaves, rocks or other debris were collected for examination. Observations were made as to the speed of the currents of the streams, type of bottom and, where possible, the type of flora of higher plants of the stream and bordering banks. Plankton samples were also obtained from many of the larger bodies of water. The samples were preserved in Transeau's solution, known as 6-3-1 (6 parts water, 3 parts 95% ethyl alcohol and 1 part commercial formalin).

In the summer of 1956, the author again covered the same distance taking samples of water from the main tributaries for chemical analyses and also taking the pH of the explored streams. The chemical analyses of these waters had already been made by the Department of Conservation, Division of Water Resources, but phosphorus analyses had been omitted from the data by the Conservation Department of Virginia, therefore, the author made phosphorus determinations using the "Molybdate Colorimeter Method".

The materials collected were examined in the laboratory and the species found in each collection were recorded. A drawing (see plates on page 118 - 132) of each species observed was made with the camera lucida.

II. Results

A. TAXONOMIC LIST

(89 Species)

Division Chlorophyta

Class Chlorophyceae

Order Volvocales

Family Volvocaceae

Pandorina morum Bory

Eudorina elegans Ehr.

Order Tetrasporales

Family Palmellaceae

Gloeocystis gigas (Kuetz) Lagerh.

Tetraspora lubrica (Roth) Agardh

Family Coccomyxaceae

Dispora crucigenioides Printz.

Coccomyxa dispora Schmidle

Order Ulothrichales

Family Ulothrichaceae

Ulothrix tenerrima Kuetz.

U. zonata (Weber and Mohr) Kuetz.

Family Trentepohliaceae

Lochmium piluliferum Printz.

Order Microsporales

Family Microsporaceae

Microspora amoena (Kütz.) Rab.

M. willeana Lagerheim and DeToni.

Order Chaetoporales

Family Chaetophoraceae

Stigeoclonium stagnatile (Hazen) Collins

S. subsecundum Kuetz.

Chaetophora elegans (Roth) Agardh

C. incrassata (Huds.) Hazen

Draparnaldia glomerata (Vauch.) Agardh

D. platyzonata Hazen

D. plumosa (Vauch.) Agardh

Order Cladophorales

Family Cladophoraceae

Cladophora callicoma. Kuetz.

C. insignis Kuetz.

Pithophora kewenis Wittr.

Rhizoclonium hieroglyphicum (Ag.) Kütz.

Order Ulvales

Family Ulvaceae

Enteromorpha prolifera (Fl. Dan.) Agardh

Ulva lactuca Linn.

Order Oedogoniales

Family Oedogoniaceae

Oedogonium echinospermum Braun and Kuetz.

Oe. minor Witt.

Order Chlorococcales

Family Hydrodictyaceae

Hydrodictyon reticulatum (L.) Lagerheim

Pediastrum duplex - var. clathratum (Braun) Lager.

var. reticulatum Lager.

P. integrum Naegeli

P. simplex (Meyen) Lemmer.

Family Coelastraceae

Coelastrum cambricum Archer

Family Oocystaceae

Eremosphaera viridis DeBary

Family Scenedesmaceae

Scenedesmus quadricauda (Turp.) Bréb.

Order Zygnematales

Family Zygnemataceae

Spirogyra aplanospora Randhawa

Sp. cleaveana Trans.

Sp. communis (Hass.) Kuetz.

Sp. crassa Kuetz.

Sp. denticulata Trans.

Sp. insignis (Hass.) Kuetz.

Sp. mirabilis (Hass.) Kuetz.

Sp. semiornata Jao

Zygnema insiginis (Hass.) Kuetz.

Family Desmidiaceae

Closterium acerosum (Schrank) Ehrenb.

Cl. abruptum var. africanum (West) Krieger

Cl. Dianae Ehrenb.

Cl. didymotocum Ralfs

Cl. Leibleinii Kuetz.

Cl. littorale Gay

Cl. moniliferum (Bory) Ehrenb.

Cl. Pritchardianum Archer

Cl. praelongum Bréb.

Cl. rostratum Ehrenb.

Cl. tumidum Johnson

Cosmarium formosulum var. Nathorstii (Boldt) W. & W.

C. Meneghinii Bréb.

C. margaritatum (Lund.) Roy & Biss.

C. pseudoconnatum Nordst.

C. punctulatum var. subpunctulatum (Nordst.) Börg.

C. subreniforme Nordst.

Cylindrocystis diplospora Lund.

Desmidium Baileyi (Ralfs.) Nordst.

D. Schwartzii Agardh

E. Euastrum verrucosum var. alatum Wolle

Hyalotheca dessiliens (J. E. Smith) Bréb.

Hy. mucosa (Dillw.) Ehren.

Micrasterias americana (Ehren.) Ralfs.

M. sol (Ehren.) Kuetz.

M. truncata (Corda) Bréb.

Penium margaritaceum (Ehren.) Bréb.

Pleurotaenium cylindricum Ralfs

Pl. Ehrenbergii (Bréb.) DeBary

Staurastrum alternan Bréb.

Str. Brebissonii Archer

Str. Dickei Ralfs.

Str. gracile Ralfs.

Str. orbiculare var. hibernicum West & West

Str. punctulatum Bréb.

Class Charophyceae

Order Charales

Family Characeae

Tribe Nitelleae

Nitella opaca Agardh

Tribe Chareae

Chara Braunii Gmelin

C. fragilis Desv. and Loisel.

Division Euglenophyta

Class Euglenophyceae

Order Euglenales

Family Euglenaceae

Euglena Spirogyra Ehren.

Division Chrysophyta

Class Xanthophyceae

Order Heterosiphonales

Family Vaucheriaceae

Vaucheria aversa Hassall

V. discoidea Taft

V. geminata (Vauch.) DeCand.

V. sessilis (Vauch.) DeCand.

Table 1. *CHEMICAL ANALYSES IN PARTS PER MILLION CRAIGS CREEK, BOTETOURT COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	NO_3	Diss. Solid.	Cl	$CaCO_3$	P
Oct. 9, 1947													
Jan. 8, 1948	5	7.7	4.5	0.04	18	3.9	69	5.6	0.2	69	1.8	61	-
Mar. 10 -	5	7.3	5.2	.06	13	2.7	46	6.5	0.2	53	2.8	44	-
June 16 -	9	7.1	4.9	.08	5.6	1.5	18	4.6	0.2	30	1.6	20	-
Aug. 31, 1956	6	7.8	6.0	.03	14	3.0	49	6.3	0.2	58	0.6	47	.1901

Stream's Profile

Fairly Swift, rocky; Higher Aquatics - Elodea canadensis, Potamogeton sp.

* Footnote. Chemical Data taken from Bulletin No. 11 - Department of Conservation and Development, Division of Water Resource, Charlottesville, Virginia.

Species List for Craigs Creek

1. Chara sp.
2. Cosmarium formosulum var. Nathorstii
3. Cos. margaritatum
4. Cos. meneghini
5. Cos. psoudoconnatum
6. Cos. punctulatum
7. Desmidium Baileyi
8. D. Swartzii
9. Hyalotheca dissiliens
10. Lochmium piluliferum
11. Micrasterias truncata
12. Pleurotaenium Ehrenbergii
13. Spirogyra sp.
14. Staurastrum orbiculare
15. Zygnema sp.

Table 2. CHEMICAL ANALYSES IN PARTS PER MILLION
BEAVERDAM CREEK, GOOCHLAND COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	SO_4	Cl	NO_3	Diss. Solid.	HCO_3	Hard as $CaCO_3$	P
Oct. 15, 1947	10	6.8	21	.10	5.2	2.4	3.0	3.2	.1	58	35	23	-
Jan. 15, 1948	25	6.9	12	.01	3.9	1.2	6.5	3.0	.3	44	14	15	-
Feb. 11 -	5	7.1	17	-	-	-	4.3	3.2	.2	48	22	-	-
Mar. 18 -	10	7.1	17	.01	4.2	2.0	5.6	3.2	.2	47	21	19	-
June 17 -	4	7.2	20	.07	4.4	2.1	2.0	2.5	.4	53	29	20	-
Aug. 31, 1956		7.5	-	-	-	-	-	-	-	-	-	-	.2660

Stream's Profile

Fairly slow, rocky, quite poor for aquatics.

* Chemical Data taken from Bulletin No. 11 - Department of Conservation and Development Division of Water Resources, Charlottesville, Virginia.

Species List for

Beaverdam Creek, Goochland County

1. Chaetophora incrassata
2. Closterium Leibleinii
3. Draparnaldia glomerata
4. D. platyzonata
5. D. plumosa
6. Eudorina elegans
7. Pandorina morum
8. Spirogyra aplanospora
9. Sp. Cleaveana
10. Sp. mirabilis
11. Sp. semiornata
12. Stigeoglonium subsccundum
13. Tetraspora lubrica
14. Vaucheria aversa

Table 3. *CHEMICAL ANALYSES IN PARTS PER MILLION
SWIFT CREEK, CHESTERFIELD COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solids	Hardness $CaCO_3$
Oct. 15, 1947	25	6.4	15	.02	3.0	1.3	16	6.1	3.5	.2	48	13
Jan. 14, 1948	45	6.7	9.1	.01	2.1	1.4	12	7.2	3.5	.2	47	12
Mar. 18 -	20	6.8	11	2.5	1.3	2.0	20	4.3	3.0	.1	37	12
May 11 -	26	6.5	13	.04	2.7	1.0	14	3.2	2.8	.1	43	11
Aug. 31, 1956		6.8	-	-	-	-	-	-	-	-	-	-

Stream's Profile

Slightly swift, sandy and rocky, poor for aquatics.

* Chemical Data taken from Bulletin No. 11 - Department of Conservation and Development Division of Water Resources, Charlottesville, Virginia.

Species List for

Swift Creek, Chesterfield County

1. Coelastrum cambricum
2. Closterium acerosum
3. Cl. littorale
4. Cl. moniliferum
5. Cl. prolongum
6. Cosmarium Meneghinii
7. Draparnaldia plumosa
8. D. platyzonata
9. Micrasterias truncata
10. Penium margaritaceum
11. Scenedesmus quadricauda

Table 4. CHEMICAL ANALYSES IN PARTS PER MILLION
APPOMATTOX RIVER, CHESTERFIELD COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solids	$CaCO_3$	P
Oct. 10, 1946	25	7.4	-	-	6.0	3.0	37	2.6	3.2	0.2	64	27	-
June 13, 1947	10	7.1	20	0.01	6.4	2.9	39	2.2	3.5	0.5	64	28	-
Aug. 31, 1956	-	6.75	-	-	-	-	-	-	-	-	-	-	0.2746

Drainage Area 729 square miles

Stream's Profile

Fairly slow, rocky, very poor for aquatics; seemed polluted; good supply of fish.

Species List for

Appomattox River, Chesterfield County

1. Batrachospermum virgatum
2. Chaetophora elegans
3. Closterium acerosum
4. Cosmarium pseudoconnatum
5. Draparnaldia plumosa
6. Enteromorpha prolifera
7. Eremosphaera viridis
8. Eudorina elegans
9. Hyalotheca dissiliens
10. Oedogonium minus
11. Oedogonium sp.
12. Pediastrum duplex var. clathratum
13. Pithophara kewenis
14. Rhizoclonium hieroglyphicum
15. Spirogyra insignis
16. Spirogyra mirabilis
17. Staurastrum Brebissonii
18. Tetraspora lubrica
19. Ulothrix tenerrima
20. Zyguema sp.
21. Vaucheria geminata

Table 5. CHEMICAL ANALYSES IN PARTS PER MILLION
RIVIANA RIVER, FLUVANA COUNTY, PALMYRA, VIRGINIA

Date	Color	pH	SiO_2	Fe	Ca	Mg	SO_4	Cl	NO_3	Diss. Solid.	HCO_3	Hard as $CaCO_3$	P
Oct. 16, 1947	10	6.6	11	0.04	5.1	1.8	3.9	4.2	1.1	50	26	20	-
Nov. 14 -	5	6.7	11	0.07	4.6	1.3	5.6	3.0	0.1	42	20	17	-
Dec. 4 -	8	6.7	12	.10	4.6	1.5	3.8	2.8	1.0	41	18	18	-
Jan. 16, 1948	6	6.9	11	.12	4.6	1.1	5.6	3.2	0.8	39	16	16	-
Feb. 12 -	1	7.1	12	.04	3.6	1.5	6.8	3.2	0.7	40	20	15	-
Mar. 18 -	8	6.9	11	.04	3.8	1.5	3.9	3.5	0.6	39	20	16	-
Apr. 8 -	7	7.1	10	.02	4.2	1.6	4.7	2.8	0.9	38	16	17	-
May 10 -	8	6.6	11	.04	3.6	1.3	4.4	2.0	0.9	38	17	14	-
June 19 -	12	7.3	13	.02	4.4	1.5	3.0	2.6	0.8	44	23	17	-
Aug. 25 -	5	7.0	12	.04	5.4	2.1	3.8	2.9	0.7	47	24	22	-
Sept. 14 -	6	7.2	12	.01	5.3	1.9	2.7	2.8	0.2	46	25	21	-
Aug. 31, 1956	-	6.8	-	-	-	-	-	-	-	-	-	-	0.2574

Drainage Area - 675 square miles

Stream's Profile

Fairly swift, rocky, poor for higher aquatics

Species List for

Riviana River, Fluvana County, Palmyra, Virginia

1. *Batrachospermum virgatum*
2. *Cosmarium punctulatum* var. *subpunctulatum*
3. *Mougeotia* sp.
4. *Oedogonium* sp.
5. *Penium margaritaceum*
6. *Rhizoclonium hieroglyphicum*
7. *Spirogyra crassa* (non-fruiting)
8. *Stigeoclonium stagnatile*

Table 6. CHEMICAL ANALYSES IN PARTS PER MILLION
MAURY RIVER, ROCKBRIDGE COUNTY, BUENA VISTA, VIRGINIA

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$	P
Oct. 6, 1947	5	7.9	4.3	0.03	39	12.0	170	8.4	3.0	1.8	155	147	-
Nov. 3 -	15	7.5	6.8	0.03	30	6.5	124	1.0	3.2	1.1	130	102	-
Dec. 8 -	14	7.3	4.4	.03	29	7.9	118	7.9	1.8	1.5	109	105	-
Jan. 5, 1948	1	7.5	4.4	.03	29	7.0	110	9.4	2.0	1.8	109	101	-
Mar. 8 -	10	7.2	5.2	.03	14	2.7	45	8.4	1.4	1.1	64	46	-
Apr. 8 -	10	7.5	4.8	.05	18	4.0	66	6.7	2.2	1.1	73	61	-
May 17 -	5	7.5	7.8	.05	25	6.0	96	6.7	1.5	1.0	97	87	-
June 14 -	5	7.8	6.0	.04	32	9.6	139	6.4	1.8	1.7	127	119	-
July 19 -	6	8.1	6.1	.04	29	6.8	114	7.4	2.5	2.2	121	100	-
Aug. 19 -	7	8.2	3.7	.01	36	11.0	159	6.0	1.8	1.8	145	135	-
Sept. 6 -	10	7.2	3.3	.02	40	11.0	176	7.2	1.8	2.8	158	145	-
Aug. 31, 1956	-	7.8	-	-	-	-	-	-	-	-	-	-	0.1956

Drainage Area - 649 square miles

Stream's Profile

Fairly slow, large, muddy, good growth of Potamogeton and Elodea; seems polluted.

Species List

1. _Hydrodictyon reticulatum_
2. _Rhizoclonium hieroglyphicum_

Table 7. CHEMICAL ANALYSES IN PARTS PER MILLION
CATAWBA CREEK, BOTETOURT COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	SO_4	Cl	NO_3	Diss. Solid.	HCO_3	Hardness $CaCo_3$
Oct. 10, 1947	25	7.5	7.7	0.10	36	6.4	9.1	1.5	1.6	130	132	116
Nov. 7 -	1	8.0	7.6	.04	46	11	7.5	1.5	2.2	160	162	160
Jan. 8, 1948	5	8.0	5.2	.04	50	15	9.3	2.0	0.8	186	183	186
March -	2	7.9	4.7	.04	46	10	7.3	1.4	.8	164	179	156
June 17 -	2	8.3	7.5	.04	45	12	7.6	2.1	1.8	177	188	162

Stream's Profile

Slow, muddy, higher aquatics mostly grasses.

Species List for

Catawba Creek, Botetourt County

1. Cladophora insignis
2. Cosmarium formosulum
3. C. formosulum var. nathorstii
4. Pediastrum integrum
5. Spirogyra crassa

Table 8. CHEMICAL ANALYSES IN PARTS PER MILLION
FALLING CREEK, CHESTERFIELD COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$
Jan. 14, 1948	45	6.4	9.6	.01	2.7	1.1	8	8.6	6.8	.2	46	11
Mar. 16 -	10	6.6	11	.08	2.5	1.2	7	8.1	3.5	.1	39	11
May 11 -	11	6.5	14	.14	3.0	1.1	13	6.0	3.0	.1	46	12
Aug. 31, 1956	-	7.3	--	-	-	-	-	-	-	-	-	-

Stream's Profile

Fairly swift, rocky, sandy, poor for aquatics; algae on rocks.

Species List for

Falling Creek, Chesterfield County

1. *Closterium Pritchardianum*
2. *Microspora Willeana*
3. *Mougeotia* sp.
4. *Oedogonium* sp.
5. *Spirogyra aplanospora*
6. *Stigeoclonium subscecundum*
7. *Tetraspora lubrica*
8. *Ulothrix tenerrima*
9. *U. zonata*

Table 9. CHEMICAL ANALYSES IN PARTS PER MILLION
PEDLAR RIVER, AMHURST COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$	P
Oct. 13, 1947	10	6.6	13	0.06	3.5	1.1	18	2.4	1.8	0.1	34	13	-
Jan. 12, 1948	3	-	11	.08	5.9	.9	28	2.0	1.8	0.1	40	18	-
Mar. 12 -	7	7.0	11	.10	2.6	.9	14	2.8	2.0	0.3	32	10	-
June 21 -	20	7.1	14	.04	.26	1.0	17	1.4	1.5	0.3	34	11	-
Aug. 31, 1956	-	6.7	-	-	-	-	-	-	-	-	-	-	0.1908

Stream's Profile

Swift, rocky; aquatics-- liverworts and mosses on rocks; algae on rocks.

Species List for

Pedlar River, Amhurst County

1. *Closterium moniliferum*
2. *Cl. Pritchardianum*
3. *Cl. tumidum*
4. *Draparnaldia plumosa*
5. *Gloeocystis gigas*
6. *Oedogonium* sp.
7. *Staurastrum punctulatum*
8. *Vaucheria sessilis*

Table 10. CHEMICAL ANALYSES IN PARTS PER MILLION
DEEP CREEK, CUMBERLAND COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$
Oct. 11, 1946	20	6.9	22	0.32	6.6	2.6	40	3.0	4.0	0.1	70	27
June 17, 1947	20	6.9	23	.01	7.0	3.2	44	1.6	3.8	.3	75	31
Nov. 11 -	20	6.8	17	.09	4.8	1.7	24	5.3	3.8	.1	55	19

Stream's Profile

Slow, muddy, quite large; poor for aquatics.

Species List for

Deep Creek, Cumberland County

1. Closterium abruptum var. africanum
2. Cl. didymotocum
3. Cl. moniliferum
4. Cl. rostratum
5. Cosmarium formosulum var. Nathorstii
6. Cos. pseudopyramidatum
7. Cos. subreniforme var. punctulatum
8. Microspora Willeana

Table 11. CHEMICAL ANALYSES IN PARTS PER MILLION
ROCKFISH RIVER, NELSON COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$	P
Oct. 13, 1947	10	6.6	12	.10	3.4	1.3	16	2.9	1.5	0.2	33	14	-
Jan. 12, 1948	4	6.9	9.7	.03	3.4	.7	16	2.4	2.0	0.1	30	11	-
Mar. 12 -	7	6.9	10	.04	2.6	.9	13	3.1	2.2	.4	28	10	-
June 21 -	5	6.9	12	.04	3.3	.9	16	2.1	1.4	.7	34	12	-
Aug. 31, 1956	-	6.9	-	-	-	-	-	-	-	-	-	-	.2241

Stream's Profile

Fairly swift, muddy, quite turbid, no aquatics, algae on rocks and debris.

Species List

1. *Closterium moniliferum*
2. *Cosmarium punctulatum* var. *subpunctulatum*
3. *Staurastrum alternans*

Table 12. CHEMICAL ANALYSES IN PARTS PER MILLION
BUFFALO CREEK, HAMPDEN SIDNEY, VIRGINIA

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$	P
Oct. 7, 1947	6	7.3	23	0.16	6.5	2.2	40	2.0	2.4	0.1	64	25	-
Nov. 19 -	7	7.3	18	.03	5.5	2.0	30	4.4	3.5	0.3	59	26	-
Dec. 16 -	8	7.4	22	.12	5.8	2.6	38	1.0	3.5	0.2	60	25	-
Jan. 17, 1948	8	7.1	18	.24	5.0	2.3	27	3.7	2.5	0.4	55	22	-
Feb. 12 -	5	7.1	20	.04	5.4	2.4	33	3.0	2.1	0.2	55	23	-
Mar. 17 -	8	7.3	16	.10	4.2	2.0	23	4.1	2.0	0.4	48	19	-
Apr. 15	10	7.3	17	.06	5.6	2.3	37	3.0	2.2	0.4	57	23	-
May 12 -	9	7.1	18	.15	6.6	2.2	37	1.8	2.2	0.2	58	26	-
June 16 -	16	6.9	20	.01	5.9	2.8	37	2.0	2.8	0.3	62	26	-
July 7 -	3	7.1	23	.01	5.8	2.8	38	1.6	3.2	0.2	64	26	-
Aug. 20 -	5	7.5	19	.03	7.0	2.5	42	2.3	2.8	0.2	67	28	-
Sept. 18 -	5	7.3	21	.04	6.0	2.7	37	1.8	3.5	0.1	60	26	-
Aug. 31, 1956	-	6.7	-	-	-	-	-	-	-	-	-	-	0.2032

Stream's Profile

Swift, rocky; devoid of aquatics; algae scanty, on rocks

Species List for

Buffalo Creek, Hampden Sidney, Virginia

1. Closterium tumidum
2. Dispora crucigenioides
3. Euglena Spirogyra
4. Mougeotia sp.
5. Spirogyra sp.
6. Staurastrum alternans
7. Ulothrix zonata

Table 13. CHEMICAL ANALYSES IN PARTS PER MILLION
HARDWARE RIVER, FLUVANA COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCo_3$
Oct. 17, 1947	15	6.6	13	.16	4.6	1.4	25	2.6	2.5	0.1	40	17
Jan. 12, 1948	17	7.1	11	.11	3.6	.9	17	3.3	2.2	.6	34	13
Mar. 12 -	20	6.7	11	.12	4.0	1.5	17	3.0	2.5	.4	37	16
June 21 -	4	6.7	11	.04	3.4	1.1	16	2.7	1.5	.3	34	13
Aug. 31, 1956	x	6.8	-	-	-	-	-	-	-	-	-	-

Stream's Profile

Swift, rocky, seems polluted; poor for aquatics, Lythrum only.

Species List

1. Rhizoclonium hieroglyphicum

Table 14. CHEMICAL ANALYSES IN PARTS PER MILLION
CHICKAHOMINY RIVER, NEW KENT COUNTY
PROVIDENCE FORGE, VIRGINIA

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$	P
Oct. 14, 1947	30	6.0	13	0.04	5.4	1.6	10	14	7.5	0.2	64	20	-
Nov. 10, 1948	75	5.7	10	0.22	3.8	1.3	7	12	5.5	0.2	63	15	-
Dec. 12 -	34	6.1	9.9	0.12	3.4	.9	10	8.5	5.2	0.1	48	12	-
Jan.14, 1948	45	6.2	7.0	0.02	3.3	1.1	8	8.2	6.0	0.0	45	13	-
Mar. 17 -	35	6.4	4.0	0.01	3.2	1.1	8	7.0	4.8	0.0	35	12	-
Apr. 7 -	55	6.6	2.0	0.02	3.3	1.3	8	5.8	4.5	0.1	41	14	-
May 11 -	38	6.1	5.8	0.02	3.8	1.1	17	4.0	4.0	0.0	45	14	-
June 9 -	96	-	9.1	0.02	4.2	1.0	13	3.7	3.8	0.0	48	14	-
July 23 -	17	7.2	8.4	0.08	5.2	1.3	15	6.0	4.5	0.1	50	18	-
Aug. 24 -	35	-	11	0.34	4.8	1.3	16	6.1	5.8	0.1	56	17	-
Sept. 15 -	45	7.5	8.9	0.08	5.4	1.6	13	6.6	6.8	0.2	53	20	-
Aug. --	-	7.5	-	-	-	-	-	-	-	-	-	-	.2081

Drainage Area - 249 Square Miles

Stream's Profile

Fairly slow, sandy; higher aquatics - Elodea sp.;Vallisneria sp., Cyperus sp.

Species List for

Chickahominy River, New Kent County Providence Forge, Virginia

1. *Batrachospermum virgatum*
2. *Ceramium rubrum*
3. *Chaetophora elegans*
4. *Cladophora callicoma*
5. *Coelastrum cambricum*
6. *Closterium abruptum*
7. *Cl. Dianae*
8. *Cl. moniliferum*
9. *Desmidium Swartzii*
10. *Draparnaldia plumosa*
11. *Gloeocystis gigas*
12. *Hyalotheca dissiliens*
13. *H. mucosa*
14. *Microspora amoena*
15. *Mougeotia sp.*
16. *Nitella opaca*
17. *Pediastrum simplex* var. *duodenarium*
18. *P. duplex* var. *reticulatum*
19. *P. duplex* var. *clathratum*
20. *Phyllobium sp.*
21. *Rhizoclonium hieroglyphicum*
22. *Scenedesmus quadricauda*
23. *Spirogyra sp.*
24. *Stigeoclonium subsecundum*
25. *Staurastrum alternans*
26. *St. gracile*
27. *Tetraspora lubrica*
28. *Ulothrix tenerrima*
29. *U. zonata*
30. *Vaucheria aversa*
31. *V. geminata*

Table 15. CHEMICAL ANALYSES IN PARTS PER MILLION
COWPASTURE RIVER, ALLEGHANY COUNTY
Clifton Forge, Virginia

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$	P
Oct. 8, 1947	5	7.8	4.4	.02	28	3.7	96	7.5	1.5	0.1	93	85	-
Nov. 6 -	-	-	-	-	-	-	37	-	-	-	66	48	-
Dec. 11 -	2	7.3	4.1	.08	18	2.7	60	8.2	0.8	0.3	66	56	-
Jan. 9, 1948	5	7.3	4.4	.08	17	1.7	54	9.3	1.5	0.1	63	4.9	-
Feb. 5 -	6	7.3	4.9	.05	18	2.6	60	8.9	1.5	0.2	67	56	-
Mar. 10 -	5	7.0	5.0	.03	9.7	1.7	29	7.4	1.4	0.6	47	31	-
Apr. 8 -	10	7.3	5.2	.10	11	1.9	36	7.9	1.8	0.4	53	35	-
May 20 -	10	7.3	6.4	.05	17	2.3	57	6.6	1.5	0.1	63	52	-
June 16 -	6	7.6	5.9	.02	20	2.6	68	6.4	0.9	0.3	73	61	-
July 22 -	4	7.4	5.7	.02	20	2.8	69	6.0	0.8	0.3	74	55	-
Aug. 10 -	10	7.5	6.4	.02	18	2.4	63	6.8	1.1	0.3	69	74	-
Sept. 8 -	4	7.7	5.8	.01	26	2.2	88	6.4	1.2	0.2	88	-	-
Aug. 31, 1956	-	7.9	-	-	-	-	-	-	-	-	-	-	0.2001

Drainage Area - 456 Square Miles

Stream's Profile

Swift, rocky; higher aquatics - Potamogeton sp., and Lysimachia sp.

Chemical Data (except Phosphorous) taken from Bulletin No. 11 Department of Conservation and Development, Division of Water Resources, Charlottesville, Virginia

Species List for

Cowpasture River, Alleghany County
Clifton Forge, Virginia

1. Chara Braunii
2. Cladophora insignis
3. Closterium moniliferum
4. Penium margaritaceum

Table 16. CHEMICAL ANALYSES IN PARTS PER MILLION
SLATE RIVER, BUCKINGHAM COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$	P
Oct. 31, 1947	40	6.9	17	0.23	5.0	1.6	40	4.7	3.0	0.3	57	19	-
Mar. 30, 1948	5	7.1	13	.01	3.7	2.1	22	4.1	2.0	.1	38	18	-
July 29, -	14	7.4	17	.25	48	2.4	30	2.4	1.8	.3	51	22	-
Aug. 31, 1956	-	7.6	-	-	-	-	-	-	-	-	-	-	0.1416

Stream's Profile

Swift, muddy; no aquatics

Species List

Spirogyra crassa - non-fruiting

Table 17. CHEMICAL ANALYSES IN PARTS PER MILLION
WILLIS RIVER, CUMBERLAND COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	Hardness $CaCO_3$
Oct. 16, 1947	30	6.7	19	.20	6.5	3.7	30	7.8	3.8	.2	31	67
Jan. 15, 1948	40	7.0	10	.01	4.8	1.6	16	7.4	3.2	.2	19	51
Feb. 18 -	10	7.1	15	.02	7.1	2.4	28	5.3	4.5	.1	28	50
Mar. 17 -	32	-	18	.08	6.7	2.8	38	3.1	2.2	.3	28	63

Stream's Profile

Slow, sandy to muddy; poor for aquatics.

Species List for

Willis River, Cumberland County

1. Closterium littorale
2. Cl. moniliferum
3. Desmidium Baileyi
4. Eudorina elegans
5. Hyalotheca dissiliens
6. Micrasterias sol.
7. Staurastrum alternans

Table 18. CHEMICAL ANALYSES IN PARTS PER MILLION
JACKSON RIVER, ALLEGHANY COUNTY
Falling Springs, Virginia

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solids	Hardness $CaCO_3$	P
Oct. 7, 1947	5	-	6.4	0.03	41	7.8	42	43	2.0	0.1	164	134	-
Nov. 5 -	-	-	-	-	-	-	55	-	-	-	-	57	-
Dec. 9 -	3	7.5	4.5	0.04	29	4.2	86	20	1.5	0.2	102	90	-
Jan. 6, 1948	4	7.5	4.0	0.03	24	3.4	70	17	2.2	0.3	88	74	-
Feb. 3 -	1	7.5	5.0	0.04	31	5.3	91	25	1.5	0.2	118	99	-
Mar. 9 -	5	7.3	5.4	0.03	14	2.0	4.4	8.6	1.2	0.9	56	43	-
April 7 -	7	7.4	5.0	0.04	15	2.9	48	11	1.5	0.4	69	49	-
May 18 -	4	7.5	6.2	0.04	25	3.1	79	12	1.5	0.1	90	79	-
June 15 -	6	7.8	5.7	0.02	29	4.2	90	18	1.2	0.3	109	90	-
July 20 -	5	7.9	7.2	0.04	30	5.1	98	24	1.2	0.5	127	96	-
Aug. 13 -	8	7.9	5.6	0.01	22	3.3	71	11	1.5	0.4	83	68	-
Sept. 7 -	8	7.3	6.8	0.02	37	5.8	107	31	1.8	0.2	144	116	-
Aug. 31, 1956	-	6.9	-	-	-	-	-	-	-	-	-	-	0.2740

Drainage Area - 409 Square Miles

Stream's Profile

Swift, rocky, polluted from paper mill; Veronica only aquatic.

Species List for

Jackson River, Alleghany County
Falling Springs, Virginia

1. *Chara fragilis*
2. *Closterium moniliferum*
3. *Cl. tumidum*
4. *Draparnaldia plumosa*
5. *Oedogonium sp.*
6. *Spirogyra sp.*
7. *Sp. communis*

Table 19. CHEMICAL ANALYSES IN PARTS PER MILLION
FINE CREEK, POWHATAN COUNTY

Date	Color	pH	SiO_2	Fe	Ca	Mg	HCO_3	SO_4	Cl	NO_3	Diss. Solid.	$CaCO_3$
Oct. 15, 1947	35	6.6	20	.32	4.4	2.3	28	3.8	2.8	0.1	57	20
Jan. 14, 1948	50	6.5	8	.01	2.4	1.4	6	6.6	4.8	.2	44	12
Mar. 18 -	8	6.7	12	.01	3.7	1.2	17	4.4	2.8	.1	40	14
June 17 -	35	7.3	15	.13	3.8	1.6	20	3.4	2.2	.4	46	16
Aug. 31, 1956	-	6.9	-	-	-	-	-	-	-	-	-	-

Stream's Profile

Fairly slow, sandy; aquatics - *Veronica* sp.

Species List for

Fine Creek, Powhatan County

1. Batrachospermum sp.
2. Closterium Baillyanum
3. Cl. Dianae
4. Cl. Leiblenii
5. Cl. moniliferum
6. Cl. Pritchardianum
7. Coccomyxa dispora
8. Compsopogon coeruleus
9. Cosmarium Meneghinii
10. Cylindrocystis dispora
11. Desmidium Swartzii
12. Draparnaldia plumosa
13. Gloeocystis ampla
14. Hyalotheca dissiliens
15. Micrasterias americanum
16. Mic. sol
17. Microspora amoena
18. Oedogonium sp.
19. Penium margaritaceum
20. Spirogyra Cleveana
21. Sp. Lambertiana
22. Stigeoclonium subsecundum
23. Vaucheria discoidea
24. Zygnema insigne
25. Zygnema sp.

III. DISCUSSION

Ecology of River Algae

One may classify river algae largely as (a) opportunistic, those which can grow in a current as well as in standing water, or forms displaced from an upstream impoundment; (b) species mostly inhabiting flowing water. The forms represented by (b) may have a greater output photosynthetically than those of group (a). This is thought to be due to their greater growth rate and the fact that their growth is quite dense. The majority of the unicellular forms are plankters, or better still, facultative plankters, for many are capable of growing either on the bottom or possibly trapped within the meshes of filamentous algae or the mycelia of fungi. Thus, Blum (1956) indicates that river algae may be separated into phytoplankton and benthic algae.

Planktonic organisms in streams (potamoplankton) are usually few in number. It is thought that most or a majority of individuals taken in water samples are derived from the bottom of the stream either directly or after reproduction en route. Therefore, the unattached forms associated with the bottom (benthoplankton) are probably in the majority, at least in smaller streams. Benthic algae embrace several life forms; (a) single-celled species that may grow attached to almost any

support in water. (b) small filamentous forms which grow parallel or somewhat attached to each other and hence form a miniature cushion or stratum on a rock or some other substrate, (c) there are other species which may grow epiphytically or may be mingled with filaments of other forms, (d) and there are filamentous algae with large macroscopic thalli growing from a holdfast and which bear the same spatial relationship to the moving water as does a tree to the air around it. All forms can then be reduced to two types, namely (a) those like Cladophora and Tetraspora with large surface area, but with great flexibility permitting water to run through or around them; and (b) those with a greatly reduced surface, but with hard inflexible structure as Gongrosira and Phormidium. (Blum, 1956) Both of these general types are considered to grow better on rocks; however, sandy bottoms afford an unfavorable source of attachment for algae. Thus, it follows that sandy streams are expected to be very poor for benthic algae. This does not mean that algae are excluded from sand. Sandy beaches (psammon) are usually highly productive for algae and other micro-organisms. Just beneath a thin layer of sand a profuse growth of many types of algae (Chlorophyta, Cyanophyta, and diatoms) may be found, and these same forms found in the sand may not be found in the plankton of the nearby aquatic environment.

A. Algal Communities of River Flora

Blum (1956) indicates that the plant community in an aquatic habitat is much more difficult to define than a land community. He associates this with the unstable nature of the environment and the rapid changes in the component organisms. It is pointed out further by Berg (1949) that the changing character of streams from source to mouth makes it difficult to group water courses ecologically other than to parts of a water course. Further it is believed that the more heterogeneous the ecological conditions of the water the more associations and species it may be expected to support. Prescott (1951) points out, however, that aquatic plants may have a wider geographical distribution than terrestrial forms. He indicates that this is true because of the more nearly universal similarity of aquatic habitats and the somewhat greater constancy of the factors which play a role in determining distribution. Mineral nutrients in an aquatic habitat are more equally diffused and easier to obtain, temperature changes are more gradual and the annual temperature range less than in a terrestrial environment.

Eggleton (1939) in his discussion of lotic (swift water) communities indicates that population follows the rise and fall of the water level (a factor to be discussed later). The most important factor in lotic communities being the current. Thus, the swift water streams will have a different population than the sluggish ditches, cree ks, and rivers. In either type of stream, however, the types of communities remain the same, i. e. nekton, plankton, and benthos. He further points out that indigenous plankton communities of permanent, swift-water streams are usually poor for species and usually have small numbers of individuals. Sluggish-water streams in general surpass the swift current creeks and rivers in biological productivity.

Because of these above mentioned problems a complete presentation on stream vegetation may never be achieved. Further difficulty is presented by the influence of Man and his works on streams causing many natural river communities to become obliterated by human disturbances; thus, altering many factors before scientific work or study on them can be accomplished.

1. Plankton Communities

The existence of plankton in streams was noticed quite early by phycologists. Much of the early work on this subject was carried out on German rivers, but confirmations since have been obtained. Some streams, however, have been found to be quite poor in plankton, and the environment necessary for this condition has also been studied (Lauterborn, 1910).

Most phycologists and limnologists consider plankton of streams as forms that are introduced into the currents from impoundments, backwater areas, or stagnant arms of the streams. The plankton which is developed in standing waters within the river's basin is frequently destroyed, or may be filtered out down stream (Butcher 1928, Chandler 1937, Reif 1939). Often river plankters are unable to survive conditions of life within an impoundment. On the other hand, rivers whose plankton is not dominated by species from upstream lakes or ponds are likely to contain those forms which have been derived from the stream's bottom and are thus considered, as mentioned above, facultative or opportunistic plankters (Butcher 1940).

Several authors have stated that plankton in certain portions of streams shows a quantitative decrease as it passes downstream. It was observed by Richardson (1928) that a decrease of 62% of plankters within a distance of 120 miles on the Illinois River. Galtsoff (1924) reported a quantitative decrease of around 45% within a distance of 60 miles in a portion of the Mississippi River. Forbes (1928) reported that the quantity of plankton in the middle region of Illinois River was nearly 15 times greater than at the mouth. Such quantitative decrease in plankton of streams has been attributed to the current of the stream; however, this has not been conclusively demonstrated as an important factor. It is supposed by many that the current would exert its effect upon other factors as nutrients, temperatures, availability of gases, and possibly the dilution of plankton themselves; unless otherwise influenced by the macroflora.

D. C. Chandler (1937) in his study of the Huron River, Maple River and Bessey Creek observed that lake plankton entering a stream undergoes a quantitative decrease as it passes downstream. This decrease was demonstrated irrespective of season and was effective not only for total net plankton and various plankton groups, but also for the predominant individual plankters as well. He also found that the quantitative decrease in these streams was not uniform, but was small or large in different portions depending upon the presence or absence of certain environmental factors. This quantitative decrease was definitely related to aquatic vegetation, various kinds of debris, and possibly also to sedimentation.

Aquatic vegetation is believed to be one of the most important factors causing a quantitative plankton decrease in streams. Chandler (1937) found in his study that the periods of greatest decrease occurred at times when the quantity of aquatic vegetation was the largest. It has been observed that when vegetation is scarce in early summer, the plankton undergoes a small decrease as it flows downstream. On the other hand in late summer, there may be a pronounced decrease. This plankton decrease occurs where the vegetation growth is the heaviest. When the vegetation is removed, there is little or no plankton decrease (Chandler 1937).

Whereas Chandler (1937) found a relationship between aquatic plants and plankton decrease, it is not so evident as to how this correlation is determined. He noticed that there was an increase in number of forms occurring normally as plankton attached to macrophytes, and that the number of these organisms increased from early to late summer. In early summer the number can be so small that they can only be detected by microscopic examination, but in late summer the accumulation of material can be so heavy as to be easily visible upon macroscopic examination.

It is possible that much of the filtering action of the macroflora of streams is due to the presence of epiphytic forms that are attached at right angles to their substratum which increase in numbers so as to strain out many other organisms from the water.

Such debris as decaying vegetation, accumulation of twigs and branches from trees, and especially dead leaves are believed to be related to quantitative plankton decrease. In many instances when these substances settle out, they take along with them the attached plankters. Thus, such objects tend to collect plankters on their exposed surface.

Schroeder (1897) concluded that the volume of plankton present in any stream is inversely proportional to the rate of the current (as was mentioned above). Kofoid (1903, 1908) states that the most important relation of current to plankton is its effect in determining the length of time in which plankton can breed. W. E. Allen (1920) indicates that water currents above a moderate speed are distinctly inimical to plankton development. Van Oye (1926) and Galtsoff (1924) found current to be related to a scarcity of plankton in certain portions of streams. Thus, the decrease of planktons in streams is not due to any one factor but several factors. The presence of plankters in streams, basins, etc., would be determined by these and other environmental factors that would influence their growth and reproduction.

Blum (1956) lists the common algae found as plankters--*Asterionella formosa*, *Fragilaria capucina*, *F. crotonensins*, *Synedra ulna*, *S. ascus*, *Tabellaria fenestrata*, *Melosira granulata*, *M. varians*, *Stephanodiscus hantzschii*, *Dinobryon sertularia* are members of the phylum Chyrsophyta. Species of *Pediastrum*, *Scenedesmus*, *Closterium* are members of the green algae (Chlorophyta) and *Euglena* of the Eulenophyta. Many others could be added as tychoplanktons that are usually found intermingled with aquatic vegetation or form floating mats especially in ponds or lakes.

2. Benthic Communities

Benthic algae, referred to as benthos, are organisms which live on the bottom in relatively deep water. This form of algae are dominated in much of the North Temperate Zone by Cladophora glomerata which grows in riffles (shallows) and in rapidly flowing water, but never in still water (Blum 1956) (The author found Cladophora callicoma growing in a moderately swift stream in the eastern section of Virginia.) Usually other benthic algae must often grow in competition with, or shaded by, this species. In cold streams Batrachospermum, Lemanea, Thorea are members of the phylum Rhodophyta that approach the size of Cladophora. The author found Batrachospermum and Lemanea growing quite profusely during the colder months in swiftly flowing, rocky and colder streams of the eastern part of Virginia. These streams also were a little on the acid side of the pH scale, and had a tendency to be a little soft which was indicated by the low $CaCO_3$ content in comparison with the western streams. Compsopogon, another red alga , is common in the warmer climates. Compsopogon coeruleus was found by the author to be growing in the same stream with Batrachospermum (check list of species under Fine Creek). Hydrurus, a member of the ~~Chrysophy~~ceae, is widespread in cold mountain streams in Europe. This alga is a little less common in North America; the author did not encounter *H. foetidus* in Virginia, but he has collected it in Montana.

B. PHYSICAL FACTORS INFLUENCING RIVER ALGAE

1. Size of Stream

A stream is considered as being in its initial or youngest stage at its source and oldest at its mouth (Shelford, 1929). Butcher (1946) has concluded that as rivers become larger certain changes in the potamoplankton can be expected; specifically that small green and blue-green algae become relatively more important in the plankton than diatoms. Some small streams develop considerable plankton population within a few miles of their headwaters (Lackey, 1943). However, for streams in general, Eddy (1925) has concluded that the development of potamoplankton is relative to the age of the water; this is associated with the distance in time from the source of the stream. In his discourse on small steam succession, Eddy (1925) indicates that all primary hydrophytic succession initial stages should start in still or running water absolutely barren of life or the remains of previous organic occupation. (This is associated with the statement mentioned above that the stream is in its youngest stage at its source and oldest at its mouth (Shelford, 1929). Under such conditions the biotic communities in these habitats should represent the same equivalent ecological ages.

In a study on a stream near Muncie, Illinois, Eddy (1925) indicates how succession is demonstrated. This stream arose from a spring in a glacial till near the prairie level and then descended a quarter of a mile through rapids and pools to a small stream (Stony Creek) 60 feet below the prairie. The initial condition was represented by water trickling from the glacial till down into puddles formed in cow tracks. At the source, the bottom was covered by a brownish sediment of diatoms (mostly Synedra). A greenish tinge in both November and April was caused by Euglena sp. and Phacus sp.

At 40 feet diatoms and Spirogyra were abundant in November. In April Mougeotia and desmids also appeared. At 60 feet, 2 feet from the mouth, Spirogyra and diatoms were abundant in inter-rapid pools in November. In the rapids, Cladophora was abundant. (This bears out what has been mentioned above about Cladophora as a benthic form in rapid waters). In April, the same algae were abundant in the same place.

Eddy concluded that this observation demonstrates the stages in a primary sere of the succession of a small stream from its origin until middle age. The youngest stages showed the absence of filamentous algae.

A middle-age stream is described by Eddy as one represented by a stream in which the primary stream emptied. The rapids that were mentioned above represent the youngest stages after the small stream. Cladophora, Oscillatoria and filamentous diatoms were the only algae present. In the quiet sluggish pools between the rapids Spirogyra was abundant. The pools were ecologically much older than the rapids. Sandy bars were observed and larger plants were produced which held back the currents.

Thus, in the middle age of stream succession, secondary seres of oxbow and sand bar succession may arise. These two seres may parallel each other in the first stages, but the oxbow soon assumes the terrestrial aspect while the sand bar follows the prairie pond sequence. The stream itself continues into a permanent old age climax. The small stream represents youth, the medium stream middle age, and the large sluggish river with its large well-worn channel representing old age.

Eddy indicates that age will vary with the physiographic conditions, and accordingly many streams age more quickly than others after the young stage conditions become more favorable for algae. Such conditions tend to increase more rapidly in the pond so that the algal communities of an old river resemble those of a middle age pond, i. e., being filled with mud from decaying vegetation and quite shallow. As the pond ages and vegetation creeps in, the plankton declines. Kofoid (1903) indicates that the amount of plankton produced by bodies of fresh water, other things being equal, is in some inverse ratio proportional to the amount of its gross vegetation of the submerged sort.

The final stage, explains Eddy, is taken over by the uni-cellular forms until Pleurococcus on the trunks of the invading willows is usually the last trace of an all but completed algal succession.

2. Current Rate

Current rates show fluctuations over a given range. In small streams the fluctuations or variables may act in such a way that minute differences in position may be subjected to vastly different current pressures (Longwell, 1932) (Blum, 1953). In the smaller streams, such pressures may fluctuate greatly from moment to moment within a given maximum-minimum range and over a period of a few days even this range must shift markedly in response to changes in water level (Blum, 1956). The maximum speed of the water is usually attained near the surface and decreases sharply toward the bottom (Welch, 1952). Berg (1943) indicated that the micro-environment of the stream bottom is surrounded by water that is not in motion at all. Benthic algae, then, are exposed to possibly much less current pressure than that of surface water, and it is probable that massive filamentous algae on the bottom enclose between their filaments a volume of water which is essentially stationary, yet is in contact on all sides with constantly renewed water which brings fresh supplies of oxygen and essential nutrients (Blum, 1956). The fact that algae colonize so hazard a habitat as flowing water suggests they can be provided something unique in this habitat (Butcher, 1947) Cedergen, 1938).

It has been observed that only certain algae will grow in rapid water, and that usually these will grow much more luxuriantly where the current is very rapid than where there is little current. In comparison of more rapid parts of a riffle which supported growth of Cladophora with quieter parts of the same riffle where no Cladophora was to be found, no sifnificant difference in dissolved oxygen during day or night was observed (Blum, 1953). When the riffle was compared with deeper, quieter water immediately adjacent, the concentration of dissolved oxygen in the riffle was distinctly higher at night than in the pool. The organic phosphate content has been observed to be higher in faster water of riffles (Blum 1956). This is not indicated as sufficient to account for the incomparable better growth in waters of the riffles, nor that the increased nutrients are not actually the result of improved algal growth rather than the cause of their growth. It has been indicated by Neel (1951) that greater consumption of nutrients occurs in rapids than in pools, but this would appear to depend on the density and nature of the biota of the respective habitat. Guimaraes (1950) observed that Brazilian waters of rapid streams are less productive than the larger, slow-moving rivers, and that the rapids are less productive than the quieter portions. It is believed that such a response is not associated with oxygen supply entirely as may be for the current itself. On the other hand, current-rate may influence the amount of dissolved oxygen. Butcher (1946) observed that there is clearly some physical difference between still and running water which may be connected simply with movement.

Abdin (1948), Allen (1920), Cilleuls (1926), Fritsch (1905) agree that rapid streams are likely to carry a greatly reduced potamoplankton. Schroeder (1898) formulated the rule that the gradient of a stream is inversely proportional to the density of its plankton. Welch (1952) has indicated that floods are destructive to stream invertebrates and Galtsoff (1924) and Fjerdingstad (1950) have cited examples of the depletion of plankton by rapids or a cataract. A rapid current, therefore, represents a mechanical danger for phytoplankton organisms, but on the other hand the attached or other benthic algae are in some way benefited by moderate current.

It has been stated by Kofoid (1903, 1908) that the most important relation of current to plankton is its effect in determining the length of time in which plankton can breed. W. E. Allen (1920) came to the conclusion that water currents above a moderate speed are distinctly inimical to plankton development. Van Oye (1926) and Galtsoff (1924) found current to be related to a scarcity of plankton in certain portions of streams. (This was mentioned above under the heading of "Plankton Communities").

It can be observed at this point that the usual vegetation of rapids in the temperate zone is almost limited to the lower cryptogams; the aquatic angiosperms have thus far been largely unsuccessful in establishing themselves in such a habitat.

3. Water Level

Fluctuating water level may be important principally for the changes which it causes in velocity and direction. At times of low water, the volume of flow and current rate declines, nutrient depletion is increased, and nutrient replacement is decreased. When the water level is quite low, the mouths of river at sea level may become brackish, and smaller streams may stop flowing completely. Under the latter conditions, a stream may be converted into a series of pools, and either death or dormancy may result in the riffle biota.

Chandler (1937), Denis (1921), Kofoid (1903, Schorler marked changes (Blum 1956). The bottom may even be eroded by large debris carried by currents and eventually deposited on the banks or shallows. Muttkowski (1929) has observed that some mountain streams are raging torrents in rainy seasons, but may be virtually dry the remainder of the year.

Flood water may also bring about a great change in plankton (Cilleuls, 1928; Kofoid, 1903; Oye, 1926; Pearsall, 1923). There is a sharp decline in plankton with rising water level as drainage water dilutes the stream proper. It has been observed that when spring flood waters drop, a major plankton pulse frequently follows upon such recession (Kofoid, 1903; K. Meyer, 1928; Reinhard, 1931; Rice, 1938; Schallgruber, 1944).

4. Depth of Stream

It is probable that nearly all streams which maintain a given water level for several weeks exhibit some zonation of the attached algae. Blum (1956) has indicated that he has observed such zonation in streams of southern Michigan. He indicates that the best place to observe such zonation is on the sides of large boulders which break the surface of the waters. Needham and Christenson (1927) have recorded zonation of nymphs and larvae of aquatic insects living on rocks in streams, and it is thought that many algal forms exhibit similar patterns of distribution. Djakonoff (1925) has indicated such zonation

(1907) have observed that production of phytoplankton is increased in periods of low water, and that euplankton organisms become more abundant at this time. Chandler indicates that this is probably associated with proportion of water volume to exposed surfaces to which plankters might adhere; these being vegetation or other objects. Batard (1932) observed that the Mayenne, a slow river in France may flow only during the rainy season. It is observed that both photosynthesis and decomposition exert their greatest effect upon the environment under low-water conditions (Neel, 1951), and it is thought that these processes are themselves profoundly influenced by approaching stagnation. Cilleuls (1927) observed that in the Thouet, another slow stream of France, plankton often show similarities to pond plankton. Transeau (1916) observed that fresh-water algae seemed to fruit more abundantly at periods of high water than at low water; however, he indicates that the factors involved are more complex than just water level or current-rate.

During periods of floods, there might be great changes in the physical nature of a stream; increase in surface current, local currents on riffles change their orientation, attached algae and other organisms are torn away from their substrate (Kurz, 1922). Rocks are transported for short distances, mineral particles are carried in great abundance; turbidity increases greatly, and the chemistry of the water undergoes on steamers in the Volga (Germany). He observed that the upper partly emergent layer (20-100 cm. wide) was dominated by (*Pleurocapsa fluviatilis* (Cyanophyta). Next to this was a submerged band, 30-35 cm. wide of *Cladophora* and *Stigeoclonium* (Chlorophyta). A third band, 50-60 cm. wide, was composed of diatoms (*Cymbella*, *Gomphonema*, etc. Chrysophyta). Scheele (1954) has reported zonation of diatoms in drains in Germany.

Depths of rivers in general, is not very great. It is thought that algal growth in surface streams is not usually limited because of reduced light. However, Ellis (1936) reports that in the extremely turbid waters of the lower Mississippi, light is reduced so rapidly with increasing depth that the latter becomes a sharply limiting factor for small benthic and even for planktonic algae. In clear streams, however, it is possible for some algae (*Cladophora*) to grow at considerable depth; some have been reported growing at depths of 20 to 100 ft. (Blum, 1956) (From notes of Prescott he indicates a depth of 40-200 ft.)

5. Temperature of the Stream

Natural waters possess a uniformity of temperature from day to day; however, a property of water in general is that of slowness to changes in temperature. Although temperature conditions in streams are essentially different from those of lakes, this moderation of temperature is characteristic of both.

The change in temperature of a stream is much less rapid in the region downstream from impoundments. In seasons of great thermal change, the pond impoundment acts as a stabilizer which eliminates great diurnal fluctuations in water temperatures in the stream. Blum (1953) has made the observation that certain floristic differences between different parts of the course of a stream are due to such differences in thermal phenomena.

In temperate regions the period of maximum change in temperature comes in spring and fall. Since there also are profound changes taking place at this time in the available light, in the chemistry of the water and the biota, it is often impossible on the basis of field observations, to draw any reliable conclusions as to the precise relation between temperature and any specific photosynthetic organism or group or organism.

The period of maximum growth for most algae is during the warm season; however, even though this growth is often dependent upon warmer temperature, there is little evidence that the blooms and rapid seasonal development of various algae occur as a direct result of temperature rise. These pulses may apparently come at any time or times during the spring, summer, or fall, and also be of relatively brief duration. In Virginia, the tempe ature may be as high in the spring, for short duration, as during the summer. There have been years of late fall or times when the summers seem to grade into the winters. There have also been experiences of balmy days in December and January. Such temperatures of several days duration could effect the flora, to a certain degree, of small streams. It has been observed that brook algae are better adapted to low rather than to high temperatures. *Ulothrix zonata* grows best below 15° C. and can produce zoospores in ice water at 0-1° C. (Oltmanns, 1922-1923).

Van Oye (1926) reported that there may be little seasonl change in temperature, and it may be concluded that any seasonal change in the vegetation of such streams is not directly due to temperature change.

Some observations have been made on the influence of temperature in general on the flora, but the usual conclusions are that many factors are altered during the cold season which may have no causal connection directly to temperature (Pearsall, 1923). However, Budde (1928, 1930) has concluded that temperature is the limiting factor in the distribution of some diatoms (*Diatoma hiemale*). Such forms could not survive in the warmer waters, being accustomed to lower temperature

(3^0 - 10^0C.).

It must be remembered that most streams are of such slight depth (as mentioned above) that no real stratification occurs in moving water. Behning (1928) observed this to be true in so large a stream as the Volga (Germany). It has been observed that when two water masses exhibiting essential physical or chemical differences occupy an impoundment, there is seldom much mixing between the two with the result that a warm layer may be found above a colder layer. Ellis (1936) has reported on hydroelectric impoundment and he states that they may be composed of a "warm, muddy river" flowing over a "cold clear lake" which exhibit no water movement in the lower stratum (hypolimnion) and little in the temperature change (thermocline). Fridman (1934) illustrated another example of stratification on the Kama (U.S.S.R.) in the presence of relatively warm industrial sewage spreading out over the surface of the water without much affecting the deeper water. In general, differences in vegetation of temperate streams within a small area are not usually caused by temperature differences. However, for vegetation changes from source to mouth, as well as for seasonal changes, temperature remains one of the more plausible causative agents (Blum, 1956). Chandler (1944) has observed that temperature had very little effect on spring pulses in Lake Erie; the change in temperature being only very slight. However, one can observe that such drastic changes in temperature that are associated with the seasons should and do effect algal growth. (This will be discussed further under the title of periodicity.)

6. Light Reaching the Stream

It is understood that algal photosynthesis and growth are as dependent on light as are the same processes in higher green plants. The quantity, quality, seasonal duration, relation of light to depth of the aquatic medium or the position in a subaerial environment, altitude and latitude of the habitat, the specific requirement for various wave lengths, lunar radiation, the light intensity and/or duration in relation to cha nge in the life history are all the factors that are to be considered in the effect of light upon algal development.

Blum (1953) has observed that light reaching algae growing near the surface does not appear to differ greatly in amount from that reaching low herbs which grow on adjacent banks. Such algae growing in an unshaded position must therefore be able to withstand full sunlight almost unreduced in amount. In most streams there are few positions on the bottom that remain constantly in the sun, however, there are very few also which remain constantly shaded. The amount of shade over the stream's course, the nature of the bottom, and generally the bank vegetation determine the constancy of incident light. One would not expect the same quantity or quality of light to fall on a river alga to be the same as that falling on the surface of the earth. Thus, bank vegetation must alter or reduce the amount of light both in the summer and other seasons of the year. The limbs of trees as well as trunks serve to shade the streams somewhat in the winter (Blum, 1953). In temperate regions, however, the degree of shading is not as great in winter due to the leafless branches.

The effects of deep shade on stream algae are evident in the magre vegetation of streams passing through the mature beech--maple community of northeastern United States, whereas the same stream passing through a clearing is generally well-populated with algae (Blum, 1956). Transeau (1916) observed that algae established in shaded portions of streams are able to grow but may never reproduce there. Reese (1937) observed that shading greatly reduced algal colonization on slides that he had placed in the Rheidol and Melindwr streams (England). The author has found Batrachospermum growing in cold streams shaded by bridges, trees, etc.; thus exhibiting opposite results from those of Reese. Luther (1954) has reported Hildenbrandia, another red alga, growing on the sides and undersides of rocks; thus being quite shade-tolerant. From Butcher's (1946) experiments it was observed that the greatest amount of algal growth was associated with the greater amount of sunlight; thus, it may be concluded that fair weather induces more rapid growth of the algae.

Prescott (1951) has indicated that illumination as an ecological factor determines that most algae occupy what is termed the photosynthetic zone, the upper 2-5 meters of waters. Of course he has reference to lakes, and most lakes may be a little deeper than streams; however, the same may hold true for streams. He further indicates that turbidity, color, and amount of disturbances at the surface all help to determine the depth to which light favorable for photosynthesis will penetrate. One must also consider the amount of light loss at the surface through reflection and because of further reduction by absorption and diffusion, photosynthetic plants are limited to the upper levels. Prescott associates the presence of greater quantity of dissolved oxygen in this stream to this fact. (A factor to be discussed later).

7. Turbidity of the Stream

Turbidity may not have much importance in a smaller stream, but in a large river bearing heavy silt loam, the light can be reduced to a point which curtails or completely prevents plant growth, including that of the phytoplankton. Eddy (1934) has observed a decrease in phytoplankton due to the reduction in light penetration caused in part by the plankton itself. Ellis (1936) found that light was reduced in the Mississippi River to one millionth of its surface intensity at depths of only 200 to 400 mm.

Such reductions are uncommon in smaller streams in the temperate zone; however, high turbidities (200-300 p. p. m.) occur in eroded watersheds after heavy rains and following the melting of large quantities of snow and ice in winter and spring (Blum, 1953; Radischtschev, 1925). Such turbidity is usually dispersed in smaller streams within a period of two or three days, partly by settling and partly by flushing out by fresh supplies of water. It has been noted that sewage effluents cause an increase in turbidity; however, this decreases with distance downstream unless the volume of sewage is not in excess in relation to volume of water which dilutes it.

Blum (1956) has observed that after periods of heavy turbidity, large filamentous algae such as *Cladophora glomerata*, may serve as traps for silt. These forms may become so burdened with silt that the lower portions may become completely screened from light. Soon the plant is semi-rigid with its load of silt, and under these conditions much of it is killed or torn away (Blum, 1956).

C. Chemical Conditions of the Stream

Obviously the chemistry of the water habitat is directly related to and for the most part determined by the physico-chemical nature of geological formation. The mineral matter in natural waters is dissolved principally from the rocks and soils with which it has come in contact and will vary with the geology and the topography of the area. The underlying rocks together with the chemistry of the soil through which water passes, or over which it collects, determine the composition of solutes in the aquatic environment, and the physiology of inhabiting organisms in other ways. Ancient or igneous rock formations determine soft or acid water habitats in contrast to basic waters resulting from drainage through sedimentary rocks especially limestone.

The chemical character of surface waters will change throughout the year as a result of variations in climate, diversions and impoundment, and pollution by waste material.

The quantity of dissolved salts in streams of water during flood stage is usually relatively small; however, during dry periods, a large proportion of the water is ground-water flow and the stream's water is generally more concentrated. The range in concentration of dissolved mineral matter is dependent on solubility of the mineral substances in the soil and rock. The length of time the water is in contact with this substrate is also important in determining the chemical nature of the water. A stream that traverses areas of limestone or dolomite outcrops normally carries in solution much more dissolved material, especially calcium carbonate, than a stream that is in contact with less soluble crystalline rocks.

There are several factors which may tend to regulate the length of time the water is in contact with earth materials; topography, vegetation, the physical nature of geological formations, and dams or other obstructions. Topography influences chemical character in that it regulates to some extent the speed with which precipitation reaches the main stream. Areas of steep gradient are drained rapidly whereas areas of little relief are drained slowly. Vegetation, or lack of vegetation, influences the rate at which run-off reaches the streams. Variations in the porosity and permeability of the superficial deposits allow water to percolate at different rates to the underground storage and thereby affect the surface run-off. As an example of this, various parts of the Shenandoah Valley where faulted limestone formations and solution channels are found close to the land surface, there are more rapid percolations to underground storage than in parts of the Piedmont where there are thick soil coverings of clay or clay-loam.

The collection and storage of water behind dams tend to regulate the chemical quality of a stream by mixing of flood waters with those impounded at low flow, resulting in a water of more uniform composition.

In addition to those factors already mentioned the use of streams for the disposal of sewage and industrial waste material and diversion for industrial and agricultural use may cause unpredictable changes in the chemical character of the stream. Lackey (1938) has made an observation of surface waters polluted by acid mine drainage and he has indicated that there is a noticeable change in color from almost clear to a deep copper or brown color. The water may be clear, but appear colored because of the color of the bed or bottom of the stream being lined with a deposit of iron oxide. The author encountered one such stream (Tye River) in the western portion of the state. No aquatic life was apparent and definitely no algae were found in the collection. Such waters are highly acid and are quite destructive to fish and other aquatic life.

Lackey's (1938) observations indicated that few species of plants inhabit streams that are polluted by mine drainage. The low pH of these streams seems to be the factor of limitation. He observed that at pH of 3.7 or lower blue-greens were completely absent. Oscillatoria was the only blue-green observed below the pH of 7.0. He lists six genera of green algae with *Ulothrix zonata* being the most common. *Stigeoclonium* was also fairly abundant with *Mougeotia* and *Cladophora* occurring occasionally. Naviculoid diatoms were often quite numerous in many samples; one species of *Tabellaria* was noted.

Lackey's samples indicated a very decided tolerance for highly acid conditions on the part of *Chlamydomonas* sp., *Chromulina* sp., *Euglena mutabilis*, *Oxytricha*, *Navicula*, *Ulothrix zonata*. Of these forms *Euglena mutabilis*, *Oxytricha*, *Navicula* were abundant. The *Euglena* was especially so, being responsible for the green coating, and often completely obscuring the surface beneath. His observation was that *Euglena* was the most characteristic of acid streams, and he has concluded that their presence in such highly acid waters demonstrates that there are few environments on this earth not suitable to some form of life.

The effects of sewage pollution on increase in nitrogenous compounds will be discussed in a later section of this paper. Lists or discussions of the species characteristic of the different zones of polluted streams may be found presented by Blum (1953), Budde (1930), Butcher (1947), Fadeev (1926), Fjerdinstad (1950), Huet (1949), Kehr (1941), Kolkwitz (1911), Liebmann (1942), Wiebe (1928).

1. Dissolved Gases in Streams

Biologically, dissolved atmospheric gases have the same significance in streams as they have in many other waters. Behavior of these gases is similar in both lenitic (quiet) and lotic (swift) habitats, although the influence of the current is such that oxygen is seldom depleted in streams (Blum 1956).

The influence of gases on algal ecology is determined by the quantity and quality at different depths in the aquatic medium; the relation of gases to water temperature and satuation co-efficients; the altitude and atmospheric concentrations; the specificity of algae for differing concentrations in the water medium; and the relation of diminished oxygen and the initiation of reproductive phases.

a. Oxygen

Prescott (1951) indicates that oxygen is one of the primary limiting and determining factors in phytoplankton ecology. This may also be indicated for most other forms of life as well. Photosynthetic organisms may be completely independent of free oxygen in daylight. Such forms can maintain the required amount of oxygen needed for respiration if carbon dioxide and other factors are favorable. The night presents a different problem since they are required to draw upon free oxygen in the surrounding medium for respiration. Prescott has made an observation on excessive algal growth in warm shallow waters in which the oxygen supply may be reduced to a point below the amount normally required by the fauna; thus, the algae may act as indicators or agents in determining the quantity and kinds of animal life which a body of water may support at different levels.

Griffiths (1923) has divided bodies of water into those which at certain seasons have a lower layer deficient in oxygen and those which are at all times well aerated. The former, he finds, supports diatoms and peridinians, and the latter Chlorophyceae, especially Protococcales (See Prescott, 1939).

Fjerdingstad (1950) has observed that even under highly polluted conditions, oxygen may reach super-saturation. However, the course of dissolved oxygen on a stream profile is dependent on many diverse factors. Sioli (1954) and Wehrle (1942) have observed that streams issuing from springs tend to be low in dissolved oxygen. Powers (1928) has indicated that the upper course of most streams in temperate regions is well-aerated. Observations on sewage outfalls have shown that oxygen may be depressed, other things being equal. Jarnefelt (1949) has observed that impoundment of a stream or the retardation of its flow, as in the lower course of most streams where deposition and decomposition of bottom sediments occur, may likewise serve to depress the dissolved oxygen. However, abundant vegetation of the benthic or phytoplankton forms, may alter this tendency towards depressed oxygen. Powers (1928) has indicated that many rivers which drain lakes have a higher dissolved oxygen content than the waters of rivers not fed by lakes. Foged (1948) and Jarnefelt (1949) have observed that in the "seasonal variation" in dissolved oxygen, the values are somewhat higher in winter than in summer. Welch (1952) has observed that complete exhaustion of oxygen may occur at night in highly productive lagoons. A similar condition is probably present in streams which stop flowing in dry periods of summer and fall, or which flow only during a rainy season.

b. Carbon Dioxide

Jarnefelt (1949) has observed that the profile curve for carbon dioxide resembles the curve for dissolved oxygen in reverse, with an increase in one occurring in response to factors which tend to depress the other. The presence of a cataract tend to increase the dissolved oxygen sharply, but remove significant amounts of carbon dioxide from the water.

Burr (1941) has noted that carbon dioxide and carbon dioxide tension are critically important, and only those bodies of water that are abundantly supplied with this gas, free or at least available, can support a luxuriant growth of algae. Many factors tend to regulate the quantity of carbon dioxide and these factors in turn may be related to the climatic conditions and geology of the distant past (Prescott, 1951). Temperature of the water at different times of the year and in different strata, the amount of carbon dioxide released by respiration, the chemical nature of the bottom and the overturn of organic matter by bacteria, and the geographical and the physiographical features of the terrain surrounding the water are factors which may influence the quantity of carbon dioxide in a stream.

An adequate supply of carbon dioxide is essential; however, an increase in carbon dioxide tension, certainly if rapid, may either kill fish or seriously upset their physiological processes. Death is thought to be due to the failure in elimination of carbon dioxide from the body due to the high concentration of carbon dioxide in the water, or indirectly through ionization which form harmful concentrations of carbonic acid (Powers, Shields, and Hickman, 1939). Prescott (1951) has indicated that because of the importance of carbon dioxide in the lake's metabolism, a radical unbalancing of the amount of this gas in solution is noticed throughout the entire biological cycle. He further states that a minimum amount will limit the quantity of phytoplankton a body of water may support. A boundless supply, together with other favorable conditions, may influence the development of an abundant water bloom, followed by a series of disturbed biological conditions. The presence of this gas may be associated with the presence of carbonates in the water.

During the day, photosynthesis tends to reduce the free carbon dioxide and to increase the dissolved oxygen; whereas respiration has the opposite effect. Diurnal pulse occurs as a result of these two processes as observed by Berg (1943), Blum (1953), Brujewicz (1931), Butcher, et al (1930), Denham (1938), Hanoaka (1948); oxygen depressed during the night and carbon dioxide during the day. Neel (1951) describes a limestone stream in which free carbon dioxide is present only during a brief period in early autumn.

2. pH of the Stream

Welch (1952) has indicated that unless streams are polluted by acid drainage from mines or other such sources, they do not obtain highly acid conditions similar to those of bogs and moor water. Lackey has recorded pH 1.8 - 3.0 in streams receiving mine seepage (as mentioned above). Conrad (1942) has reported the tendency of certain small streams draining temperate moorland areas to be somewhat acid in their headwaters, but approach neutrality downstream in proportion to the distance from headwaters areas.

It is evident by many observers that neutral or slightly alkaline conditions which are characteristic of most temperate streams appear to be prerequisite for the majority of algal species inhabiting flowing water. Foged (1948), Hustedt (1939), and Prescott (1951) have pointed out that alkaline lakes have many more species of plants than acid lakes. Lackey (1938-39) has suggested that the same may be true for streams. Hard waters (alkaline) are usually producers of profuse algal growth, particularly in fresh water habitats and especially if they have been enriched with nitrogen and phosphorus. In fresh water there is a calciphilic (hard-water inhabitant) algal flora in which diatoms and blue-greens predominate. On the other hand, soft-waters (of low pH) lack high concentrations of nutrients, therefore, do not develop profuse growths or blooms. Lakes and bogs may become enriched with organic acids and nutrients, resulting from decomposition of organic matter and hence may support a calciphobic (acid-loving) flora. Such a flora, principally desmids with an association of certain blue-green algae, may be rich both in quantity and number of species.

It is probable that most streams which possess some limestone in solution are pretty well buffered and exhibit little variations in pH beyond the range of 6.8-8.8. Diurnal variation in pH have been recorded by Brujewicz (1931) and Hanoaka (1948) with the oxidation and formation of organic acids. Cowles (1923) has observed that in a small creek the rapids tend to be somewhat more alkaline than pools; it has been suggested that this is due to the removal of free carbon dioxide from the rapids. Photosynthesis tends to remove carbon dioxide and may result in an annual variation in the H-ion concentration; Rice (1938) has reported this for the Thames. Here the pH attained a value of 8.5 in the spring, at the time of the phytoplankton maximum, and was relatively low in summer, fall and winter. Unusually high pH values may be characteristic of the water near beds of benthic algae or other aquatic plants during daylight hours (Blum, 1956). Prescott (1939) states that when phytoplankton is low, pH is low and conductivity is high, and when phytoplankton increases during the season, conductivity becomes less due to the consumption of electrolytic salts and the pH rises with the precipitation of carbonates.

3. Calcium

Calcium behaves in streams much as in other fresh waters. A large number of algae and other organisms precipitate the monocarbonate in essentially the same way, but it is not always easy to determine which algae are lime-formers and which are lime-perforators (Woronochin, 1932).

Butcher (1949) has observed that the absence or near absence of calcium from the water may result in a peculiar flora that includes many blue-greens. Waters rich in lime tend to be rich in algae; other things being equal, however. Reinhard (1931) cites the Minnesota River as a stream which contains abundant carbonates which produced an average volume of plankton six times that of the St. Croix River which is poor in carbonates and contains humid acids. Butcher (1949) concluded that calcium is not the factor which determines the presence of the principal species; however, he has indicated that in distinguishing eutrophic (shallow) from oligotrophic (deep) streams in Britain several of the dissolved mineral salts are involved. Prescott (1951) has indicated that eutrophic lakes are alkaline with a pH ranging from 7.2 to 9.5; there is an abundance of both nitrogen and phosphorus. He refers to this type as a "Cyanophycean Lake" because of the predominance of blue-green. The oligotrophic type is usually quite poor for growth of microflora, but the green algae predominate; therefore, he refers to this type as "Chlorophycean Lakes."

4. Phosphorus

Pearsall (1930) has observed that unlike the sea and fresh-water lakes where surface nutrients are frequently depleted early in the season of favorable temperature, rivers do not generally exhibit marked depletion, although marked fluctuation is characteristic. In waters where phosphates are almost insoluble, they might represent limiting factors (Blum, 1956). Berg (1943) and Blum (1953) have observed that there is a distinct increase in dissolved inorganic phosphates during summer months; however, the phosphates do not necessarily diminish to limiting levels in other months. Prescott (1951) has indicated that phytoplankton populations are observed to be high during low phosphorus concentration. These organisms utilize the elements in their metabolism and return the elements to the environment after death. Atkins (1923) has shown that the lack of phosphates limits the growth of algal plankton so that circulatory movements must be effective in replenishing the supply; this permits of renewed growth. Sawyer (1943-44) has indicated that inorganic phosphorus is critical to phytoplankton productivity by controlling the rate at which growth occurs. (See W. E. Wade, 1949)

In regions where substantial amounts of agricultural drainage or sewage empty into a stream, an increase in phosphorus usually occur. At or below such points for considerable distances, there is a favorable effect on algal growth.

5. Nitrogen

Blum (1953), Butcher (1924), Kofoid (1903), Pearsall (1923) have observed that nitrates are in more abundance at times of heavy rains or melting snow; thus being at a high level during the winter and spring months when streams are high and plant growth is greatly reduced. Wade (1949) has indicated that nitrogen content is highest in February and March, but varies considerably during the summer months. He cites from Mortimer's (1939) reports that certain productive lakes in England in the summer of 1938 showed less total nitrogen in the outflow than in the inflow water and that the difference in excess of that stored in bottom mud represented nitrogen loss. He cites from reports by Pennington (1942) that there was a loss of nitrogen from cultures of algae and bacteria apparently indicating the liberation of gaseous nitrogen; thus, suggesting that this loss may be partially responsible for fluctuation in the total nitrogen content during the summer.

Wade (1949) has correlated nitrite and nitrate consumption with phytoplankton development. He indicates that lowest phytoplankton organisms were present when nitrites and nitrates were most abundant. The greatest quantity of phytoplankters were present when nitrites and nitrates were the lowest. He has concluded that the nitrogenous material served as nutrients for phytoplankton and their profuse growth had reduced the values of nitrites and nitrates. Sawyer (1943-44) found that inorganic nitrogen was reduced after bloom conditions occurred in the Wanbesa Lake, Wisconsin. Sawyer has also indicated that inorganic nitrogen is critical in the productivity of phytoplankton by limiting the amount that could be produced.

The profound fertilizing effect of nitrogenous compounds is evident in most polluted streams. Depending largely on the respective volumes of flow of the stream and of the outfall and on the degree to which the sewage has been decomposed before being delivered to the stream, a changing flora may be found downstream from the outfall, with various algae becoming dominant as successively distant reaches of the river become, as a result of microbial action, rich in amino acids, then in ammonium compounds, and finally in nitrites and nitrates. Many algal species have been used, along with many invertebrates, as indicators of stream pollution (Budde, 1928; Fjerdingstad, 1950; Huet, 1949; Liebmann, 1942). Although many organisms are useful as indicators of pollution, they are not unerring. Fadeev (1926) has indicated that the algae are more useful if they are growing on the bottom. Budde

(1930), Fjerdingstad (1950) and Wiebe (1928) have indicated that they are more useful if they are present in large numbers.

Zones of pollution as represented by their flora are not always permanent, but may be expected to advance downstream at any time when increased pollution increases the amount of decomposing solids. Blum (1953), Butcher (1937), Gaufin and Tarzwell (1955), Pentlow et al (1938) have indicated that the same phenomenon may occur in winter when cold weather retards bacterial action to the extent that certain algae that are characteristic of nitrite and nitrate rich waters tend to thrive at certain points downstream distant from their summer habitats.

It has been generally observed by many phycologists and limnologists that the most significant effect of organic pollution in a stream is usually one of fertilization and enrichment. The total number of species may be reduced; however, those which grow are more than likely to be quite prolific. Brinley (1942) and Butcher (1940), have observed that the density of both benthon and plankton may temporarily be reduced by large amounts of sewage. Lackey (1942) has stated that the greatest effect is when anaerobic conditions prevail. Butcher (1949) has observed also that if the organic matter is increased too much, the normal life may be completely destroyed and the algae are likely to be entirely eradicated for certain portions of the stream. Butcher has observed that Nitzschia palea, Gomphonema parvulum, Phormidium uncinatum or P. autumnale, Ulothrix zonata, Stigeoclonium tenue and various species of Oscillatoria may become benthic forms downstream from this zone of putrefaction. In the streams that seemed polluted which were observed by the author, the blue-greens seemed to form dense mats on the bottoms. Blum (1953), Lefevre (1950) have observed that the algae as a whole exhibit augmented growth immediately at or possibly a short distance downstream from the outfall.

Prescott (1951) has associated phytoplankton production with the presence of both nitrogen and phosphorus. When phytoplankton is high, nitrates are low. When the phytoplankton decreases, the nitrates are increased. He associates this with the fact that nitrogen compounds are used by the organisms and incorporated in their productivity, and when they die, these elements or compounds become a part of the water chemistry again. He states that the nitrogen enters into the phytoplankton cycle. Such nitrogen content is also dependent upon several physical processes in and around the water as run-off from farm-land (Prescott, 1951). He states that the nature of the bacterial flora, the chemistry of the drainage waters, and the presence or absence of nitrogenfixing bacteria or algae (blue-greens are known to fix nitrogen also: De, 1939; Fogg, 1942; Fritsch and De, 1938; Hutchinson, 1944; Allison and Morris, 1930) are a few of the more important factors determining the nitrogen content. He has also made the observation that high oxygen content may permit rich plankton flora, but low nitrogen or the absence of nitrogen may exclude many kinds of algae. He observes that some members of the blue-greens that are usually rich in proteins require a medium rich in nitrogenous compounds. The fact that some blue-greens are able to fix nitrogen may be also involved as well.

The influence of these various chemical factors has been pretty well demonstrated. It is well to state also that even though these substances as nitrate content, carbon dioxide, phosphorus, calcium, and other elements are important in determining the abundance of the algal flora, they also may influence the kinds of species present. Prescott (1951) has made the observation that qualitative selections operate in algal ecology, and phycologists are able to use the presence of certain species or groups of species as indicators of physical-chemical conditions in the body of water. He has stated that the experienced phycologist or limnologist can estimate, by observing the quality and quantity of algal flora, especially the phytoplankters, the acidity or alkalinity (approximately) of the water. One can also determine the relative abundance of carbon dioxide, and can predict whether there is a rich or poor supply of nitrates; and can tell something about other limnological features in a habitat.

6. Brackish Streams

Usually those streams which empty into the sea will exhibit at their mouths a region of varying salinity which will fluctuate with the tides and to a certain extent with the seasons (Blum, 1956). Under such conditions the flora will change; those species limited to fresh water will be killed off, and those species that are characteristic of brackish conditions will make their appearance (Arnoldi, 1922; Brockman, 1908; Hamel, 1924; Lauterborn, 1918; Olson, 1941; Purdy, 1916; Swirenko, 1926).

Some of the fresh-water algae grow successfully in brackish water possibly as a result of increased concentrations of limiting salts or other nutrients. Hamel (1924) has observed *Cladophora glomerata* as one such form. The author has observed *Ulothrix zonata* growing at the mouth of the James where the water is very brackish. Blum cites reports by Wood and Straughan (1953) in the reduction in size as sexual retardation in *Lemanea fucina*, a fresh-water red alga; this organism was exposed to tidal action twice daily.

Purdy (1916), Waser, *et al* (1943) have stated that tidal actions are usually favorable on polluted streams since such actions tend to mix sewage and other forms of pollution with great quantities of water.

Kolbe (1932) has observed that acids and alkalis of industrial wastes tend to neutralize each other thereby resulting in an increased salinity downstream from outfalls. This condition tends to influence the growth and reproduction of such forms that are halophytic and salt resistant, as diatoms (Blum, 1956).

Often streams are polluted by industrial wastes that have a stimulating or toxic effect. Quite often one can observe the difference in growth of certain forms above and below the entrance of such wastes; the fauna and flora may be quite different for both regions. Also in some cases there may be little physico-chemical difference between such a stream and tributary, and they will vary in respect to one or more factors. This difference may suggest the role played by such factors that are introduced by the tributary.

Blum (1953) cites the presence of certain poisons that are dumped into streams which may result in a suppression, in an extensive area below the outfall, of organisms that are abundant above the outfall. He has observed that *Cladophora glomerata* behaved in this way, returning to the stream only after dilution and precipitation had occurred.

D. Distribution of Algae in Streams

Most river algae will reproduce by using the vegetative method only. Most benthic species have basal holdfast portions (Ulothrix, Oedogonium), and many species exhibit basal portions which can persist from year to year (Cladophora, Stigeoclonium), giving rise to new branches to replace those that are broken off. In most instances the only cells remaining in the unfavorable period are those which occupy protected positions as rock crevices or partially covered by superficial sediments. From such positions, they can repopulate the stream during a subsequent favorable period (Blum, 1956). Some species may pass the unfavorable period as thick walled spores; however, others are as dependent upon sheaths or a reduced protoplast for winter protection as they are upon such resting spores (Strom, 1924).

Blum (1956) cites the fact that most observations on sexual reproduction have been worked out in the laboratory in standing water; however, many forms do not readily adjust or grow under these conditions; therefore, the information is incomplete on each species. For strictly benthic forms, sexual reproduction and dissemination are dependent upon currents.

Such forms as Lemanea or Batrachospermum which lack motile stages are completely dependent upon the currents of streams.

Cedergren (1938), Oltmanns (1922-23), and Smith (1950) have observed that Vaucheria appears to fruit more frequently in quiet waters than in currents. Israelson (1949) has observed that the same is true for certain species of Spirogyra. Blum (1953) states that he has observed no sexual reproduction in stream communities of Spirogyra during a period of nearly two years. The community, consisting of several species, increased and decreased and occasionally nearly disappeared throughout this period. The species of Spirogyra observed by the author in the fruiting conditions were collected from slow flowing streams or quiet backwater pools or pockets. It would appear then that there is a direct correlation between current and sexual reproduction of certain forms. Transeau (1916) has stated that flowing water is generally supposed to retard fruiting by furnishing improved vegetative conditions. Hence, one should expect a retarding effect on fruiting which would show clearly in the relative time of fruiting in ponds and streams. He states further that his observations have not produced such results as retardation by running water. He states that the evidence shows that the external factors which induce sexual reproduction are much less than the number that will induce zoospore-formation.

Zoospores may be formed throughout the life cycle at very short intervals, but the sex organs usually develop at a definite time.

Transeau (1916) discusses the relationship of high and low water with the production of fruiting bodies by algae. He found in his studies that high water tends to induce fruiting in algae. He states that in the three years that he made his observations that there was no question that in the eastern regions of Illinois at least (1) the greatest number of species fruit sexually, (2) a particular species fruits most abundantly, and (3) when a species produces more than one kind of spore, the greatest variety of spores occur during periods of high water.

Transeau reasons that the prevailing idea that algae fruit during low water stages may be connected with the fact that such a large number of algae fruit in late spring when the rainfall is decreasing and the water levels are lowering. He states that this is a coincidence of the lowering water level with the time of fruiting and there is no causal relation between the two. He reasons further that if the weather conditions are such that the water level does not fall at the time of year that these organisms fruit, the fruiting will not only take place but the amount will be increased.

1. Colonization

Blum (1956) speaks of colonization as being applicable to colonization of upstream areas concurrent with the headward growth of the stream by organisms already established in downstream or parallel waterways. Eddy (1934) discusses colonization by plankton in which he regards the first occurrence of stable conditions in the streams in summer as the earliest opportunity for permanent colonization. He emphasizes the age of the water in plankton production and provides evidence that true plankton organisms are likely to appear in streams at a point six to ten days below the source, if other conditions, particularly of temperature and turbidity are favorable. Eddy (1925) has indicated that the first colonists in a stream are probably diatoms and *Euglena*, whose resistant states permit wide dispersal. Summerhayes (1923) has observed that the first units of a flora in streams of recent glacial origin are unicellular algae.

In the work of Butcher (1946) there is little evidence of succession in the algal communities he has investigated. He cites that in the *Cocconeis*- (diatom) *Chamaesiphon* (blue-green) community, the latter arrives later than the other forms, but they exhibit no true succession. Some of the communities are regarded as representing a true climax, but their development is apparently accomplished with no steps separating invasion from climax conditions. Blum (1956) states that the indications are that algal succession within a stream is less sterotyped and probably more intricate than certain well-known successions of plants on land.

2. Climax Conditions of Streams

Eddy (1934) has concluded that not only land communities exhibit "Climatic" climax conditions, but also such conditions are to be found in permanent streams. Such fresh water communities, he observed, reach maturity and show aspects comparable to terrestrial communities. The generation and life-span of dominant algae are so much shorter than those of most dominant vascular plants that such climatic conditions can be achieved in a relatively shorter time, and more rapid succession is expected (Blum, 1956). Blum has also indicated that for short-lived microphytes, a single growing season in a temperate region may be long enough to represent a permanent climate.

Panknin (1941) has concluded that seasonal communities which assume temporary dominance, should not be regarded as constituting seasonal associations, but rather as making up seasonal aspects of the entire associations.

Butcher (1937), has observed that it is exceptional to find extensive areas inhabited by recognizable groups of algal species which seem to maintain a definite order of dominance or inferiority with respect to each other throughout all the season; however, such relationship is more commonly found if higher aquatic plants are considered. Extensive stands consisting of one or more species of dominant algae are relatively more common than among land communities. Lefevre (1950) and McCombie (1952) have suggested that certain dominant species that reach bloom stages tend to secrete inhibiting substances in the medium which retard or prevent the growth of other algal forms. His observations were made on canals in which there were blooms of Aphanizomenon gracile or Oscillatoria planctonica which inhibited growth of Cosmarium Lundelli and other plankton algae. McCombie (1952) has stated that often phytoplankton synthesizes antibiotics which inhibit the growth of other organisms. Lefevre (1950) found that the filtrate from cultures of Scenedesmus quadricauda appeared to have an inhibitory effect upon Pediastuum Boryanum and several other green algae. Pandorina morum seemed to have a dual effect upon the same species; it caused a marked increase in reserve material and inhibited cell division. Thus, Lefèvre (1950) has suggested that such secretions of antibiotics by dominant algal species might be an important factor bringing about unispecific composition reported for water blooms. Theodore R. Rice, Fishery Research Biologist * has suggested that intensive blooms of one species might well affect the growth of another species; thus, exerting an influence on seasonal succession of species in the body of water concerned. Akehurst (1931)* reasoned that, if attempts to correlate fluctuations with chemical and physical factors failed, the complicated actions of toxins should be considered. Such toxins are believed by him to originate from phytoplankton which may inhibit the growth of some species but stimulate the growth of others.

It is suggested that secretions produced by species in bloom may inhibit further growth of the species itself. Pratt (1940)* working with *Chlorella vulgaris* found this to be true; Roche (1948)* found *Chlorella* to inhibit the growth of *Asterionella formosa* also. However, Storey (Worthington 1943)* found that water of Lake Windermere, when an *Asterionella* bloom is disappearing, is unsuitable for preparation of culture medium for *Asterionella*.

Although little mention is made of inhibiting substances being produced by organisms producing blooms in streams, certainly in slow moving streams where conditions are more favorable for blooms such antibiotics could be concentrated enough

---

* Fishery Bulletin. 87, 1950

to produce a unispecific climax.

The Phormidium-Schizothrix-Audouinella epilithic community has been described as an example of a climax in flowing water (Blum, 1956). Eddy (1934) has concluded that certain organisms which are seasonal dominants in the early stages of plankton development in a stream, later become perennials when the conditions of life within the stream become more stable. Blum (1956) has stated that it has not been fully determined whether rivers in general favor the production of one or more given communities of phytoplankton which can be found with regularity over a large area.

3. Periodicity in Streams

Transeau (1916) has divided algae into seven (7) classes on the basis of their periods of greatest abundance, the duration of their vegetative cycle, and the times of their reproduction.

a. Winter Annual

These begin their vegetative cycle in autumn, increase up to the time of freezing, and endure over the winter under ice. During protracted winter thaws, which usually occur in January, they may develop further and even fruit. Their period reaches a climax in March and April. Sexual reproduction may occur at any time from November to April and zoospores are formed from the beginning through the period of increase. Aplanospores and akinetes develop mostly during the period of decline. Some examples of algae belonging to this type as were found by Transeau in Illinois are Vaucheria geminata, Vaucheria sessilis, Draparnaldia plumosa, Tetraspora lubrica and Stigeoclonium lubricum-various.

b. Spring Annuals

These are forms in which the vegetative period begins in late autumn or early spring, reaches a climax in May and declines in June. Sexual reproduction occurs in April, May and June, and zoospores are formed mostly in early spring, with aplanospores and akinetes during the period of maximum abundance and decline. This type includes, according to waters of Illinois, the largest number of species, among which are Spirogyra varians, Spirogyra Weberi, Zygnema stellinum, Oedogonium rutescens, and Ulothrix variabilis.

c. Summer Annuals

The vegetative period of the algae of this class begins in early spring and culminates in July and August. The decline is gradual and extends through the autumn months. Sexual reproduction occurs in July, August and September. Zoospores, when formed are most abundant in spring and early summer. Aplanospores develop mostly in August and September. Examples cited of this class (according to Transeau) are Spirogyra decimina, S. maxima, Schizomeris Leibleinii, Calothrix stagnalis and Oedogonium Vaucherii.

d. Autumn Annuals

These species begin their vegetative development in late spring, increase through the summer and have their period of maximum abundance in autumn. They may disappear at the time of freezing or gradually through the winter. Sexual reproduction usually occurs during September, October, and November. Among the algae of this class (again according to Transeau) are represented by Spirogyra nitida, Rivuluria natans, Oedogonium crassum-amplum, Spirogyra setiformis, and Oedogonium obtruncatum.

e. Perennials

This group includes forms in which the vegetative cycle goes on from year to year without interruption. The algae may become very scarce during unfavorable periods, but they are capable of at least maintaining themselves without the production of reproductive bodies. These forms commonly reach their greatest development during the summer and early autumn. Sexual reproduction occurs mostly in late spring or early autumn, sometimes in both. Zoospores are most abundant in spring and summer, frequently they are produced also in autumn. Transeau cites Cladophora glomerata, Rhizoclonium hieroglyphicum, Pithophora oedogonia, Pleurococcus vulgaris and Oedogonium *grande* as representatives of this group.

f. *Ephemerals*--

Are species with very short vegetative cycles, usually enduring for days, at most for weeks. Generations succeed one another rapidly through the periods of favorable conditions. Because of the varying capacities to respond to environmental conditions the generations may overlap. The species of this group are mostly soil-surface or plankton forms. Few are found to reproduce sexually and zoospores, aplanospores and akinetes are the usual means of increase, of dissemination and passing through an unfavorable period. The soil forms are favored by wet weather, and all the forms may be found in greater or less abundance in all but the winter months. This group include such forms as *Botrydium Walrothii*, *Scenedesmus quadricauda*, *Pediastrum Boryanum*, and *Vaucheria terrestris*.

g. *Irregulars*

Among this group may be found representatives that may be effected by various combinations of environmental conditions. The period between maxima may be of more or less than a year's duration. It is always a possibility that they may be missed if collections are made according to seasons. In other words the periods of maximum development may have occurred without a reference to season; their presence may be of very short duration.

It must be remembered that in respect to periodicity in general, forms that are found in one locality a given season may be completely absent in another.

Blum (1953), Cilleuls (1932), Hupp (1943), Kofoid (1903), and Rice (1938) have observed that streams seem to exhibit considerable constancy regarding densities of their plankton or benthic vegetation. However, Chandler (1937), Meyer (1923), Poretzkii (1925) have pointed out differences in the year to year development pattern. It must be remembered that a year's work upon a single stream may prove inadequate in that it reveals conditions essentially unlike the preceding and following years. Brinkley (1942) and others have observed that the principal phytoplankton pulse is evident during the warm seasons, if there is one; however, Kofoid (1908), Ruttner (1953) and others have observed such forms as Crucigenia rectangularis, Pediastrum Boryanum, Fragilaria capucina, Meridion circulare and Synedra ulna frequently exhibiting population maxima in winter. Some species of algae exhibit great variability in production, remaining uncommon in one year and becoming a dominant the next, exhibiting a pulse at widely variable times throughout the year, or a single pulse in one year and two or more in another (Blum, 1956).

Seldom rivers will exhibit blooms, as has been suggested above under Climax, but occasionally this phenomenon does occur.

Organisms that have been found to be responsible for such blooms are *Thallassiosira fluviatilis* (Budde, 1928), *Synedra delicatissima* (Couger, 1941), *Microcystis flos-aquae* (Issatchenko, 1924), *Anabaena spiroides* (Batard, 1932 and Denis, 1921), *Aphanizomenon flos--aquae* (Christyuk, 1926) and *Pandorina morum* (Lackey, 1942). Blum (1956) states that most river blooms appear to be due to the sudden reproduction of a single species; however, Sorensen (1948) cites an example in which several species of the Volvocales are involved. Lauterborn (1918) has recorded water blooms caused by a variety of diatoms in the Rhine estuaries.

There seems to be a correlation between abundant nutrients and abundant phytoplankton (as has been already mentioned above under chemical conditions), the plankton pulse usually following the period of highest concentration of nutrients, as nitrites and nitrates, in such a manner that the maximum development of phytoplankton is preceded by a decrease in nutrients (Hupp, 1943; Kofoid, 1903; Reese, 1937). It has been discussed above, under another topic, that plankton maximum occurred at a time when nitrates had passed a high level and were decreasing during this period. However, given sufficient warmth and a series of favorable days, it is believed that the water chemistry becomes the factor which determines the production of a dense plankton and of a dense benthic vegetation.

Seasonal and perennial species are included among benthic algae. Blum (1956) has observed that single species may be dominant over most of a stream, but it is more common to find a number of dominants with various parts of the stream having different dominant communities. Pentelow (1938), has observed that the algal vegetation remains more or less the same throughout the year; however, Blum (1953-54), Brown (1908), Budde (1930), Butcher (1932), Jürgensen (1935) and others have observed that there may be seasonal variations. Budde (1928, '30), Ström (1927) have observed that such seasonal aspects seem to be more marked in upland than in lowland streams.

Blum (1956) has cited the striking phenomena of frequent abrupt changes in algal vegetation within streams from source to mouth. The spacing at weekly intervals of visits to a particular small stream may find a complete change in algal species. Budde (1930) has concluded that an extended period of low water with little change in hydrographic conditions is conducive to the full development of benthic organisms. Jaag (1938) has concluded that a period of several cloudy days can induce detachment and disappearance of certain algae. Fritsch (1906) has stated that periodicity of some forms depends on that of their epiphytes, and Jaag (1938) indicates that the epiphytes are dependent upon their algal substratum. Blum (1935) concludes that leafing-out of bank vegetation brings sharp changes in the vegetation.

The most abundant filamentous alga in streams throughout the world is Cladophora glomerata. Blum (1953), found it to be highly sensitive to iron and relatively tolerant to high pH values. It has been observed to be tolerant to large amounts of sewage (Blum, 1953; Pentlow, 1938; Purdy, 1916; Waser, 1943). Hamel (1924) and Pringsheim (1949) have found it to be tolerant to weak salinity. Butcher (1932) has indicated a summer growth period of one month and Budde (1928) has observed several months growth period. It's growth is usually inconspicuous in winter; however, Jürgensen (1935) has recorded full development of this species in February and March, Raabe (1951) in mid-October, and Jagg (1938) has found it throughout the winter. List (1930) has observed that swarmers may be produced throughout the year. Zacharow (1924) has indicated that freezing is not necessarily fatal to Cladophora's growth. Blum (1953) and Pentelow (1938) have indicated that it may exhibit very rapid growth in spring only to disappear very suddenly in late June or early July. It has been indicated that high waters may cause such variations; however, Cladophora exhibits generally poor growth in warmer streams in mid-summer. It has been suggested that temperatures higher than 25°C. is not conducive for good growth. Blum (1953) and Jagg (1938) have observed that Cladophora reacts adversely to reduced light, but Zacharow (1924) had found that it can be kept in the dark for several weeks without entirely succumbing. Blum (1956) has suggested that further study is needed to explain the coming and going of such vegetation.

4. Local Distribution

Blum (1956) has stated that most small streams consist of a series of alternating shallow areas ("shallows", "riffles") and deep areas ("pools"). In the shallow areas there is much more abrasion due to the swifter currents. Blum suggests that there should be a difference in chemical constitution of shallows and pools, but indicates that little has been done to prove this. However, from observations that have been presented, there seem to be differences in the algal flora of shallow parts of streams and the deeper pools of the same stream. Blum (1956) has observed that Ulothrix sp., Stigeoclonium tenue and Diatoma vulgare are characteristic of riffles and tend to drop out as massive components of the vegetation when pool conditions develop. He cites Spirogyra sp., Euglena sp. and other unattached forms as being slow current inhabitants. He further suggests that within riffles or shallows, certain areas seem to be more favorable than others for the larger algae. He cites Cladophora glomerata as being limited to the far downstream portion of shallows where water movement is slightly more rapid.

Observation will show that the sides of streams are usually more shallow than the central portion, and the current is usually slower as well. Also the sides are more shaded than the central portion. Thus, if one wished to refer to, or to sample a representative part of a stream, the sides would be found to be less so than the central portion. If one were making a survey to determine the typical benthic flora of a stream, samples should be confined to the central portion.

Blum (1956) has concluded that the evolution of distinctive river plankton forms has been retarded by the difficulties which plankton organisms experience in the dissemination of offspring to other basins. He states further that the stream seems to represent an unfavorable environment for plankters, not entirely because of the mechanical and physical insecurity, but also because of the inherent "dead end" nature of streams, emptying their products into the ocean, and death occurring to all forms that are unable to survive brackish or marine conditions.

IV. ECOLOGY OF THE JAMES RIVER BASIN

The number of species of Chlorophyta (82) along with three species of Rhodophyta and four species of Chrysophyta (Vaucheria) seems quite low for the area covered in this study. There are many factors, however that might contribute to such a low number of species. This was brought out in the discussion of ecological factors influencing the growth of algae in the preceding chapter. In this discussion it was indicated that many forms may be missed in collections due to the fact that they may reach their climax and disappear (before they may be collected) especially so if one is only making seasonal surveys as was done in this study. Another factor that may influence the number of species is rate of current. Many forms are unable to inhabit the swifter streams, becoming more or less planktonic as they mature: thus they are carried away by the currents if there are no other plants, or debris with which they may become entangled. Many streams, because of the swiftness of the currents, therefore, are unfavorable for most planktonic forms as well as for many attached forms. The pH of the water may determine what species will inhabit a particular stream. This factor was also considered in the preceding chapter. Although mentioned but not discussed in the preceding chapter was the influence of pollution on the distribution of species.

The above mentioned factors are only a few of the possibly numerous ones which may influence the number of different kinds of species that may inhabit a particular stream or streams of a particular locality. Table 20 includes 20 streams that are considered as possibly the main drainage points of the James River Basin. In this table the pH, hardness ($CaCo_3$-content), nitrogen (NO_3-content), pollution and swiftness of the stream are considered. The number of genera found in each stream is divided into those that are considered planktonic and those that are normally attached or filamentous. On the basis of these data, a discussion follows on the possible influence of such factors on the number of species observed in this study.

Hardness and pH of the Water

It has been indicated that the acidity or alkalinity of a stream will influence the development of certain forms of algae; however, it has been observed that many forms will grow in a wide pH range. It is well to mention here that most streams will not reach a high acid condition similar to bogs or even other forms of lakes unless they are being polluted by mines or industrial wastes. (Welch, 1952; Lackey, 1938, Conrad, 1942) Even in these instances, dilution

Explanation of Symbols - Table 20

Abo. - Above

Bel. - Below

Pol. - Pollution

R. O. F. - Rate of flow

Sl. - Slow

Sw. - Swift

N. O. S. - Number of Species

Plak. - Plankton

Atch. - Attached

Lo. - Low

Hi. - High

Table 20. SUMMARY OF RESULTS ON TWENTY STREAMS

Streams	pH		$CaCO_3$		NO_3		Pol.		R.O.F.		N.o.S.	
	Bel. 7.2	Abo. 7.2	Lo.	Hi.	Lo.	Hi.	+	-	Sl.	Sw.	Plak.	Atch.
Craigs Creek		7.5	43		0.2			-		x	11	4
Beaverdam Creek	7.1		19		0.24			-	x		3	11
Swift Creek	6.6		12		0.15		+			x	9	2
Appomatox River	7.0		27		0.35		+		x		7	13
Riviana River	7.0		17		0.7			-		x	2	6
Maury River		7.4		104		1.6	+		x		0	2
Catawba Creek		7.5		154		1.4	+		x		3	2
Falling Creek	6.5		47		0.13		+			x	1	8
Pedlar River	6.9		13		0.2			-		x	5	3
Deep Creek	6.8		26		0.16			-	x		7	1

Table 20. - Cont. SUMMARY OF RESULTS ON TWENTY STREAMS

Streams	pH		$CaCO_3$		NO_3		Pol.		R.O.F.		N.o.S.	
	Bel. 7.2	Abo. 7.2	Lo.	Hi.	Lo.	Hi.	+	-	Sl.	Sw.	Plak.	Atch.
Rockfish River	6.8		12		0.35		+			x	3	0
Buffalo Creek	7.2		24		0.25		+			x	4	3
Hardware River	6.8		15		0.35		+			x	0	1
Chickahominy River	6.4		49		0.09			-	x		14	17
Cowpasture River		7.4		61	0.26			-		x	2	2
Slate River	7.2		19		0.23		+			x	0	1
Willis River	6.9		26		0.2		+		x		7	0
Jackson River		7.6		83	0.3		+			x	2	5
Fine Creek	6.8		15		0.2			-	x		14	11

plays an important part in that the greater the distance from the source of the pollution the less the concentration of the contaminating substance. It has been suggested by many phycologists that neutral or slightly alkaline conditions which are characteristic of most temperate streams appear to be necessary for the growth of most of the algal species inhabiting flowing water. (Blum, 1956; Welch, 1952) Examining the data outlined on table 20, it is observed that no direct correlation can be made as to the importance of pH on the number of species. Craig Creek has an average pH of 7.5 and fifteen (15) species. Catawba Creek on the other hand has a pH of 7.5, but only five species. Jackson River has a pH of 7.6, and its species number only seven. Even though we do not see a positive correlation here, it has been observed by some phycologists (Foged 1948), Hustedt (1939), and Prescott (1951) that alkaline waters have more species of plants than acid; at least this was found to be true for lakes and possibly true also for streams. However, pH becomes a controlling factor when the water reaches very acid or very alkaline range. In this survey, the range was from 6.4 - 7.6. Ordinarily we expect the maximum growth rate within this range, other factors being favorable.

Hardness was analyzed on the bases of the total amount of calcium carbonate ($CaCo_3$) in the water. There is a correlation between pH and hardness of water in that streams that are considered hard are usually alkaline and those that are considered soft are usually acid; however, the amount of $CaCo_3$ may vary depending upon the degree of breakdown of this substance by organisms inhabiting the stream. Streams with less than 61 p. p. m. of $CaCo_3$ are considered as soft and streams above 61 p. p. m. are considered hard. It has been suggested that slightly hard waters (alkaline) are more productive than soft (acid). (Foged, 1948; Hustedt, 1939; Prescott, 1951). In this study it was found that streams a little on the acid side were more productive than those somewhat on the alkaline side. Maury River had a pH of 7.4 and hardness of 104 p. p. m., but only two species were found. The two species that were observed however, were growing quite profusely, but at different times of the year; Rhizoclonium hieroglyphicum was collected in March and Hydrodictyum reticulatum was collected in August. Catawba Creek had a pH of 7.5 and a hardness of 154 p. p. m.; however, there were only five species observed. Jackson River had a pH of 7.6 and a hardness of 83 p. p. m., but only seven species were observed. There seems to be a little inconsistency in the data on Craigs Creek in that the pH (7.5) indicates a slightly alkaline condition, but the hardness is quite low (43 p.p.m.). The forms of plants observed (Chara, Elodea, Potamogeton, etc.) are considered calciphilic forms. However, the fact that much of the lime is taken out of the stream in metabolism and by becoming encrusted on the stalks of Chara and the other plants that were growing rather profusely, may explain the generally low concentration of $CaCo_3$ in the stream chemistry.

The streams that were slightly acid and/or soft were: Swift Creek which had a pH of 6.6 and a hardness of 12 p.p.m.; with 11 species observed; Falling Creek had a pH of 6.5 and hardness of 47 p.p.m., with nine species observed; Chickahominy River had a pH of 6.4 and hardness of 49 p.p.m., with 31 species observed; Fine Creek had a pH of 6.8 and a hardness of 15 p.p.m. with 25 species observed; however Hardware River had a pH of 6.8 and a hardness of 15 p.p.m., but only one species was observed. The Appomattox River had a pH of 7.0 (neutral) and a hardness of 27 p.p.m., but twenty species were observed. Riviana River was also neutral and had a hardness of 17 p.p.m., but only eight species were observed. Even though the streams that were slightly acid seem to be more productive as to species number, there does not seem to be consistency in production as exemplified by the total number of soft-water streams. In other words, the factor of hardness is an important one in algal distribution, but apparently it is not the controlling factor. Possibly one can state that it is the interaction of other factors along with pH and/or hardness.

Nitrogen Content of the Stream

It has been suggested that nitrates are more abundant during the winter and spring months when streams are high and plant growth greatly reduced. (Blum, 1953; Butcher, 1924; Kofoid, 1903; Pearsall, 1923; Wade, 1949) Such changes may be explained by the greater consumption of nitrates when plants are growing quite profusely; (Prescott, 1951; Sawyer, 1943-44; Wade, 1949) thus tending to lower the total concentration of nitrates in the water chemistry. In this study the most productive streams had very low concentration of nitrates. To cite a few, Chickahominy River had 0.09 p.p.m. nitrates, but had 31 species observed; Swift Creek had 0.15 p.p.m. of nitrates, and 11 species observed; Fine Creek had 0.2 p.p.m. nitrates, and 25 species observed. However, there were some streams in this survey that had equally low nitrate content, but quite poor species distribution. Again to cite a few-- Slate River had 0.23 p.p.m., but only one species; Hardware River with only 0.35 p.p.m., and one species observed

Rockfish River with 0.35 p.p.m., and only three species observed. It can be stated here, however, that none of the streams with more than 0.5 p.p.m. were very productive. Maury River had a nitrate content of 1.6 p.p.m., but only two species were observed; Catawba Creek had 1.4 p.p.m. of nitrates and only five species; and Riviana River had 0.7 p.p.m. nitrates, but only eight species observed. Thus, it can be generalized from these results that low nitrogen content may not enhance algal distribution, but increased algal growth may bring about a decrease in nitrogen content of a stream by utilization of the nitrate in metabolism. (Pennington, 1942; Prescott, 1951; Sawyer, 1943-44; Wade, 1949) Although pollution is to be considered later, it can be stated here that organic pollution may tend to increase the nitrogen content of a stream; (Blum, 1956; Butcher, 1949; Brinkley, 1942; Lackey, 1942) therefore, Maury River with high nitrogen content seemed to be quite polluted also. Catawba Creek with the other high reading of 1.4 p.p.m. also seemed polluted and was quite turbid or muddy.

Stream Pollution

It has been stated in the preceding chapter of this paper that many algal species can be utilized as indicators of pollution; (Budde, 1928; Fjerdingstad, 1950; Huet, 1949; Liebmann,

1942) however, no attempt has been made in this study to indicate which species of Chlorophyta is an indicator of pollution. In polluted streams the total number of species may be reduced; however, those that will grow are more than likely to be quite prolific. (Brinkley, 1942; Butcher, 1940; Lackey, 1942) Many species of Oscillatoria, a blue-green alga, may form dense mats in polluted streams. This was observed by the author in some of the streams that seemed polluted (in this survey) such as The Maury River. This is a rather large slow-flowing stream, and very little algal growth was observed outside of the two species cited; but quite good growths of Potamogeton crispus and Elodea canadensis were observed. The Appomattox River is another rather large stream that seemed polluted from sewage; however, quite a few species were observed to be growing in or around the stream in backwashes or quiet pools formed from overflow of the stream. Many of the streams that seemed polluted were almost devoid of algal forms and higher plants as well. Rockfish River is an example of such a stream; there were only three species of algae observed and no higher aquatic plants. Another example of such a stream is the Hardware River with only one species of algae and limited aquatic higher plants. The Jackson River is another polluted stream (although the pollution is due to waste from a paper-mill rather than sewage pollution) with very low algal distribution and limited aquatic higher plants. Thus, it can be concluded that pollution does tend to influence the number and kind of algal forms that will inhabit a particular stream.

Rate of Flow

It has been stated above that flowing water presents a hazard for the development of plants in general. (Butcher, 1947; Cedergren, 1938) The swifter streams are usually devoid of higher aquatic plants, and only a few filamentous algal species are able to survive the rapids. Cladophora has been cited as one genus that does very well in the swifter streams. (Blum, 1953) In general, however, the slower streams are more productive. The possible reasons for such variation in the two types of streams-- slow vs. fast-- have been given above under the discussion of stream ecology; (Butcher, 1946; Blum, 1956; Neel, 1951; Guimaraes, 1950); however, one can readily see the hazard involved in such a habitat. Many plankton forms, because of their habit of growth, are unable to populate swifter streams. (Abdin, 1948; Allen, 1920; Cilleuls, 1926; Fritsch, 1905) Since there streams are usually poor for higher aquatics and in many instances quite poor for filamentous forms of algae, the plankton are carried down stream much more rapidly than they can reporduce or repopulate any particular portion of the stream. (Allen, 1920; Kofoid, 1903; 1908; Van Oye, 1926; Galtsoff, 1924) In the slower streams, all things being equal, these plankton forms are trapped between the higher aquatic plants and also between the filaments of the attached algal forms; thus they are able to increase their number.

In this survey it was observed that the swifter streams were a little less productive as far as numbers of species than the slower. There are a few exceptions that should be cited here. Maury River was quite slow, yet it had only two species observed; however, it was quite hard, muddy and polluted which may account for the small number of forms. Craigs Creek was fairly swift; however, 15 species were observed. It also can be noted here that the planktonic forms of this stream out-number the filamentous, but mention has been made above of the fact that this stream was very well populated by Chara, Elodea, Potamogeton, etc. which served as traps for these plankters. These aquatics were growing in the quieter portions of the stream. The Appomattox River, also a slow stream, had twice as many filamentous algae as plankters. On the other hand, Fine Creek, also a slow stream, had more plankters than filamentous species. Chickahominy River, which is also a slow stream, had almost as many plankters as filamentous forms. Even though no great difference can be observed here in the productiveness of a stream as to plankton or filamentous forms being affected by current rate, it can be observed that those streams that were poor for aquatics were also quite poor for plankters. Slate River had no aquatics and no plankters; however, it did have a very good growth of Spirogyra. The Hardware River was another poor stream for aquatics, and no plankters were observed either; however, there was a very fair growth of Rhizoclonium. The Jackson River was very poor for aquatics also, but had a rich growth of Spirogyra, Draparnaldia, Chara, etc.; however, only two species of plankters were observed. Of course it should be mentioned here that most of the plankters considered in this survey are desmids, and these forms are considered calciphobic (acid-loving); however, there are exceptions to every rule for a few desmids, i. e. Closterium moniliferum, Cl. tumidum, will thrive just as well in a slightly alkaline habitat as in an acid one.

Summary of Discussion

In summarizing the results of this survey, several observations can be made.

1. The number of species of Chlorophyta inhabiting the tributaries of the James River Basin is quite low.
2. The pH of these streams range from 6.4 - 7.6. Within this range, it was quite difficult to determine the influence of pH on the number of species; however, the streams that had the largest number of species were slightly on the acid side of the pH scale. It has been suggested that the pH exerts its greatest influence when quite low on the acid side or quite high on the alkaline side of the scale.
3. Streams that were slightly soft or low in $CaCo_3$ content had the greatest number of species; however, on the basis of hardness alone it is quite difficult to determine the direct influence of this one factor on the distribution of species in this study. Rather, it is thought that other factors interacting with hardness tend to influence the distribution.
4. The nitrogen content of a stream does influence the distribution of species; however, the low content of nitrogen in a stream may be influenced by the volume

of growth in a stream. When growth rate is low, then nitrogen-content may be high.

5. Pollution may be a factor limiting the number and kinds of species that will inhabit a particular stream. Organic pollution may tend to increase the nitrogen-content of a stream; therefore, acting as a fertilizing factor. The streams in this study that seemed polluted were quite poor for numbers of species; however, those forms that were able to survive were quite prolific in their growth.
6. The swifter streams in this survey were less productive than the slower. There were a few exceptions in that two or more of the slower streams were not especially productive, but this was thought to be due to other factors as pollution, hardness, pH, turbidity, etc. In general the swifter streams were almost devoid of both algae and higher aquatic plants, but those that could survive the hazard of swift currents usually thrived very well.

PLATE I

1. *Spirogyra insignis*
2. *S. communis*
3. *S. mirabilis*
4. *Vaucheria sessilis*
5. *Spirogyra Cleaveana*
6. *Vaucheria aversa*
7. *V. discoidea*; zygote
8. *V. discoidea*
9. *V. discoidea*
10. *V. geminata*

1. <u>Nitella</u> <u>opaca</u>
2. <u>Chara</u> <u>fragilis</u>
3. <u>C.</u> <u>Braunii</u>
4. <u>Nitella</u> <u>opaca</u>
5. <u>Batrachospermum</u> sp. nov. Spermatium
6. <u>Batrachospermum</u> sp. nov. (?)
7. <u>Enteromorpha</u> <u>prolifera</u>
8. <u>Ulva</u> <u>lactuca</u>
9. <u>Compsopogan</u> <u>coeruleus</u>
10. <u>Batrachospermum</u> <u>virgatum</u>
11. <u>B.</u> <u>virgatum</u>
12. <u>Compsopogan</u> <u>coeruleus</u>
13. <u>Stigeoclonium</u> <u>stagnatile</u>
14. <u>S.</u> <u>stagnatile</u>
15. <u>Draparnaldia</u> <u>glomerata</u>

1. Coelastrum cambricum

2. Pediastrum simplex var. duodenarium

3. P. integrum

4. Cosmarium Meneghini

5. C. pseudopyramidatum

6. Gloeocystis gigas

7. Tetraspora lubrica

8. T. lubrica

9. Dispora crucigenicides

10. Pediastrum duplex var. reticulatum

11. Ceramium rubrum

12. Eudorina elegans

13. Lochmium piluliferum. Printz.

14. " "

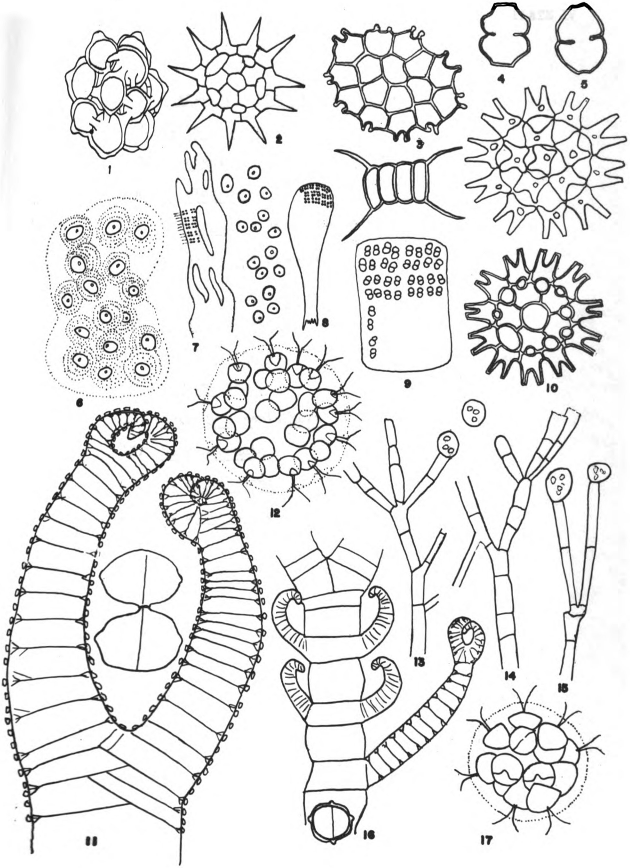
15. " "

16. Ceramium rubrum

17. Pandorina morum

18. Scenedesmus quadricauda

19. Pediastrum duplex var. clathratum



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

PLATE IV

1. Chaetophora incrassata
2. C. incrassata
3. C. elegans
4. C. elegans
5. C. elegans - Habit sketch
6. Draparnaldia plumosa
7. D. platyzonata
8. D. platyzonata
9. D. platyzonata
10. Zygnema insigne
11. Spirogyra semiornata
12. S. semiornata
13. S. aplanospora
14. S. aplanospora

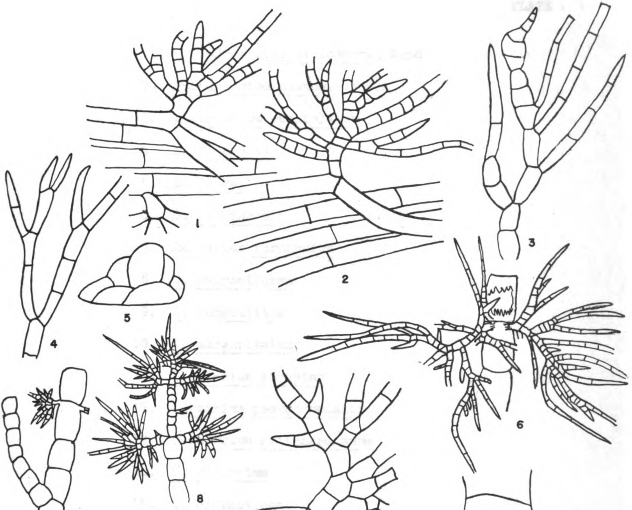

1
2
3
4
5
6
7
8
9
10
11
12
13
14

PLATE V

1. Cylindrocystis diplospora. Lund
2. Spondylosium planum. Wolle
3. Staurastrum punctulatum
4. S. alternans
5. S. Dickei
6. S. Brebissonii
7. Cosmarium formosulum
8. C. subreniforme
9. C. punctulatum
10. C. margaritatum
11. Closterium abruptum
12. Cosmarium pseudoconnatum
13. Closterium Pritchardianum
14. C. rostratum
15. C. didymotocum
16. C. Leiblienii
17. Pleurotaenium Ehrenbergii
18. Closterium didymotocum
19. C. abruptum
20. C. acerosum
21. Closterium Pritchardianum
22. Cl. tumidum

23. Cl. monilifermum

24. Cl. littorale

25. Cl. Dianae

26. Cl. praelongum

27. Cl. abruptum var. africanum. Kreiger

28. Desmidium Baileyii

29. Closterium acerosum

PLATE VI

1. Cladophora callicoma
2. C. callicoma
3. C. callicoma
4. Rhizoclonium hieroglyphicum
5. R. hieroglyphicum
6. Microspora amoena
7. Pithophora kewenis
8. Cladophora callicoma
9. Oedogonium minus
10. O. echinospermum
11. Microspora tumidula
12. M. tumidula
13. M. Willeana
14. M. Willeana
15. Ulothrix tenerrima
16. U. tenerrima
17. U. zonata
18. U. zonata
19. Stigeoclonium subsecundum
20. S. subsecundum
21. S. subsecundum
22. S. subsecundum
23. Oedogonium sp. - Androsporangium

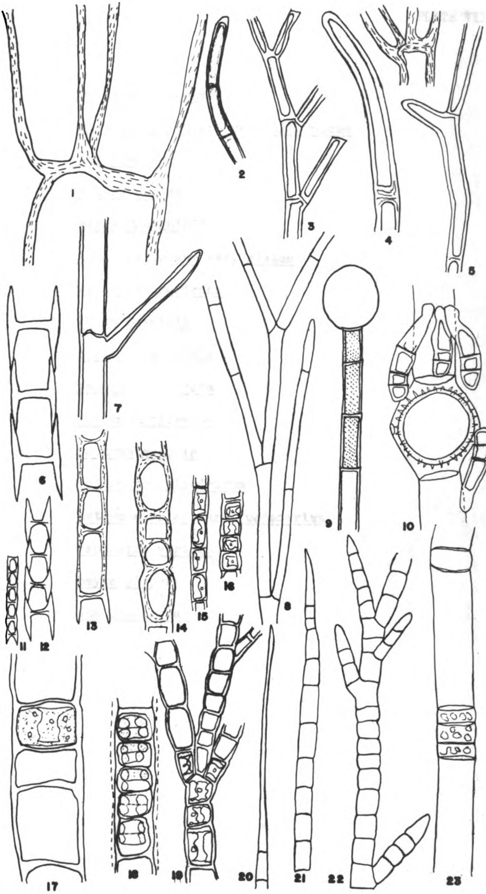

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

PLATE VII

1. Penium margaritaceum
2. Staurastrum orbiculare var. hibernicum
3. Micrasterias sol
4. Hyalotheca mucosa
5. Cosmarium Meneghinii
6. Euastrum verrucosum var. alatum
7. Micrasterias americana
8. Desmidium Swartzii
9. Hyalotheca dissiliens
10. Micrasterias truncata
11. Closterium Baillyanum
12. Staurastrum gracile
13. Pleurotaenium cylindricum
14. Pediastrum simplex var. duodenarium
15. Eremosphaeria viridis
16. Coccomyxa dispora
17. Euglena Spirogyra


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17

BIBLIOGRAPHY

Abdin, G. 1948. Physical and chemical investigations relating to algal growth in the River Nile, Cairo. Bull. Inst. Egypte, 29: 19-44.

Allen, G. O. 1954. An annotated key to the Nitelleae of North America. Bull. Torrey. Bot. Club., 1: 35-60.

Allen, W. E. 1920. A quantitative and statistical study of the plankton of the San Joaquin River. Univ. Cal., Publ. Zool., 22: 1-292. Pl. 1-12.

Allison, F. E. and Morris, H. J. 1930. Nitrogen fixation by blue-green algae. Science, 71: 221-223.

Anderson, Emma N., and Walker, Elda R. 1920. An ecological study of the algae of some sandhill lakes. Trans. Amer. Microsc. Soc., 39: 51-85; Figs. 1-17.

Arnoldi, V. M. 1922. Algues des rivieres des steppes. Jour. Soc. Bot. Russ., 7:61-72.

Atkins, W. R. 1923. The phosphate content of fresh and salt waters in its relationship to the growth of the algal plankton. Jour. Marine Biol. Assoc., 13: 119-150.

Batard, C. 1932. Notes on the phytoplankton of the Mayenne Bull. Mayenne Science, 1931/2: 1-14.

Behning, A. 1928. Das Leben der Wolga, zugleich eine Einfuhrung in die Fluss-Biologie. In: A. Thienemann, Die Binnengewasser, Bd. 5, 162 pp., 2 pl.

Berg, K. 1943. Physiographical studies on the River Susaa. Fel. Lim. Scand. No. 1. 174 pp.

_______. 1949. Remarks on some Danish river studies. Verh. Int. Ver. Theoret. Ang. Lim., 10: 76-79.

Birge, E. A., and Juday, C. 1911. The inland lakes of Wisconsin. The dissolved gases of the water and their biological significance. Bull. Wis. Geol. and Nat. Hist. Surv., Sci. Ser., 22: 1-259; Figs. 1-142.

__________. 1922. The inland lakes of Wisconsin. The plankton. I. Sci. Ser., 27: 1-137.

Blum, J. L. 1953. The ecology of algae growing in the Saline River, Michigan, with special reference to water pollution. Doc. thesis, Univ. Mich., ix + 176 pp.

Blum, J. L. 1954. Evidence for a diurnal pulse in stream phytoplankton. Science, 119: 732-734.

__________. 1956. The Ecology of River Algae. Bot. Review. Vol. 22. No. 5.

__________. The application of the climax concept to algal communities of streams. Ecology (in press).

Brinley, F. J. 1942. The effect of the sewage from Nashville upon the plankton population of the Cumberland River. Jour. Tenn. Acad. Sci., 17: 179-183.

Brockmann, C. 1908. Das Plankton im Brackwasser der Wesermundung. Aus der Heimat-Fur die Heimat. n.f., 1: 32-57.

Brown, H. D. 1908. Algal periodicity in certain ponds and streams. Bull. Terrey Bot. Club, 35: 223-248.

Brown, Helen J. 1929. The algal family Vaucheriaceae. Trans. Amer. Micro. Soc., 1: 86-117.

Brujewicz, J. 1931. Tagliche Schwankungen der hydrochemischen Faktoren im Flusswasser. Verh. Int. Ver. Theoret. Ang. Lim., 5: 442-457.

Budde, H. 1928. Die Algenflora des Sauerlandischen Gebirgsbaches. Arch. Hydrobiol., 19: 433-520.

________. 1930. Die Algenflora der Ruhr. Ibid., 21: 559-648. pls. 33-36.

Burr, Geo. O. 1941. Photosynthesis of algae and other aquatic plants. In a symposium on Hydrobiology. Madison.

Butcher, R. W. 1924. The plankton of the River Wharfe. (Yorkshire) Naturalist. 1924: 175-180; 211-214.

____________. 1928. Biological changes brought about by sewage effluents in small streams. Proc. Assoc. Managers Sewage Disposal Works (Kew), 1928: 168-185.

____________. 1932. Studies in the ecology of rivers. II. The microflora of rivers with special reference to the algae on the river-bed. Ann. Bot., 46: 813-861. Pls. 33, 34.

____________. 1937. Survey of the river Tees. III. The non-tidal reaches - chemical and biological. Dept. Sci. and Ind. Res. Water Poll. Res. Tech. Pap. 6.

Butcher, R. W. 1940. Studies in the ecology of rivers, IV. Observations on the growth and distribution of the sessile algae in the River Hull, Yorkshire. Jour. Ecol., 28: 210-223.

____________. 1946. Studies in the ecology of rivers. VI. Algal growth in certain highly calcareous streams. Ibid., 33: 268-283.

____________. 1947. Studies in the ecology of rivers. VII. The algae of organically enriched water. Ibid., 35: 186-191.

____________. 1949. Problems of distribution of sessile algae in running water. Vehr. Int. Ver. Theoret. Ang. Lim., 10: 98-103.

Butcher, R. W., Pentelow, F. T. K., and Woodley, J. W. A. 1930. Variations in the composition of river waters. Int. Rev. Ges. Hydrobiel. Hydrogr., 24: 47-80.

Campbell, D. H. 1886. Plants of the Detroit River. Bull. Torr. Bot. Club, 13: 93-94.

Cedergren, G. R. 1938. Reofila eller det rinnande vattnets algsamhallen. Svensk Bot. Tidskr., 32: 362-373.

Chambers, C. O. 1912. The relation of algae to dissolved oxygen and carbon dioxide, with special reference to carbonates. 23rd Ann. Rep. Missouri Bot. Gard., 1912: 171-207.

Chandler, D. C. 1937. Fate of typical lake plankton in streams. Ecol. Monogr., 7: 445-479. 1939. Plankton entering the Huron River from Portage and Base Line Lakes, Michigan. Trans. Amer. Microsc. Soc., 58: 24-41.

____________. 1944. Linnological studies of western Lake Erie. IV. Ibid., 63: 203-236.

Christjuk, P. M. 1926. Eine Wasserblute am Don. Aphanizomenon flos-aquae. Mitt. Nordkaukas. Univ., 11: 49-51.

Cilleuls, J. Des. 1926. Le phytoplancton de la Loire. Compt. Rend. Acad. Sci. (Paris), 182: 649-651.

____________. 1927. Le phytoplancton du Thouet, affluent de la Loire. Compt. Rend. Acad. Sci. (Paris) 184: 389-391.

____________. 1928. Revue generale des études sur le plancton des grands fleuves ou rivieres. Int. Rev. Ges. Hydrobiol. Hydrogr., 20: 174-206.

Cilleuls, J. Des. 1932. Contribution nouvelle a l'etude du phytoplancton de la Loire. Inter. Rev. Ges. Hydrobiol. & Hydrogr. 27: 120-129.

Collins, F. S. 1909, 1912, 1918. Green algae of North America. Tufts College Studies. Reprinted by G. E. Stechert Co., New York.

Conn, H. W., and Webster, L. W. 1908. A preliminary report on the algae of the fresh waters of Connecticut. Conn. State Geol. & Nat. Hist. Surv., Bull. 10: 1-78. Pls. 1-44.

Conrad, W. 1942. Sur la faune et la flore d'un ruisseau de l'Ardenne belge. Mém. Mus. Roy. Hist. Nat. Belg., I, 95: 1-177. Pls. 1, 2.

Cowles, R. P. 1928. The Hydrogen ion concentration of a creek, its waterfall, swamp, and ponds. Ecology, 4: 402-416.

Croasdale, Hannah T. 1933. The freshwater algae of Woods Hole and vicinity. Philadelphia.

De, P. K. 1939. The role of blue-green algae in nitrogen-fixation in rice fields. Proc. Roy. Soc. London, 127: 121-139.

Denham, S. C. A. 1938. A limnological investigation of the West Fork and Common Branch of White River. Invest. Indiana Lakes & Streams, 1: 17-71.

______________ 1934. A study of fresh-water plankton communities. Ill. Biol. Monogr., 12: 1-93.

Denis, M. 1921. Une fleur d'eau sur la Mayenne. Bull. de Mayenne-Sci., 1921: 1-3. 1 Pl.

Djakonoff, F. F. 1925. Einige Beobachtungen über den Benuihs an den Dampfern der unteren Wolga. Arb. Biol. Wolgastation, 8: 135-156.

Eddy, S. 1925. Fresh water algal succession. Trans. Amer. Microsc. Soc., 44: 138-147.

______ 1934. A study of fresh-water plankton communities. Ill. Biol. Monogr., 12: 1-93.

Eggleton, F. E. 1939. Fresh-water communities. Amer. Mid. Nat., 21(1): 56-74.

Ellis, M. M. 1936. Erosion silt as a factor in aquatic environments. Ecology, 17: 29-42.

Engler, A. and Prantl K. 1927. Die naturlichen Pflanzefamilien. Leipzig. Vol. 3. Printz, Henrik. Chlorophyceae. p. 1-463.

Fadeev, N. N. 1926. Preliminary report of the sanitary-biological survey of the northern Donets basin, November 1924-April 1925. Prec. Comm. Sanit. Biol. Survery N. Donets and Trib. (Lopan and Ud), 1: 3-12.

Farlow, V. 1928. Algae of ponds from intestines of tadpoles. Biol. Bull., 55: 443-448.

Fjerdingstad, E. 1950. The microflora of the River Molleaa with special reference to the relation of the benthal algae to pollution. Fol. Limnol. Scandivav. No. 5. 123 pp. 1 pl.

Foged, N. 1948. Diatoms in water courses in Funen. IV-VI. Danks. Bot. Ark., 12(9): 1-53 + 2 pp., Ibid. (12): 1-110 + 2 pp.

Fogg, G. E. 1942. Studies on nitrogen fixation by blue-greens. Lemm. Jour. Exper. Biol., 19: 78-87.

Forbes, S. A. 1928. The biological survey of a river system, its objects, methods, and results. Ill. Div. Nat. Hist. Survey, 17: 277-284.

Forest, H. S. 1954. Checklist of algae in the vicinity of Mt. Lake Biol. Station, Va. Castanea, 19: 88-104.

Fridman, G. M. 1939. (Materials for the study of the effect of industrial sewage on the bottom life of the River Kama.) Trav. Inst. Rech. Biol. Perm., 8: 72-92.

Fritsch, F. E. 1905. Algological notes. VI. The plankton of some English rivers. Ann. Bot., 19: 163-167.

__________. 1929. The encrusting algal communities of certain fast-flowing streams. New Phytol., 28: 165-196. Pl. 5.

__________. 1938. Nitrogen fixation by blue-green algae. Nature, 142: 878.

Fritsch, F. E., and De, P. K. 1942. An ecological and taxonomic study of the algae of British soils. II. Consideration of the species observed. Ann. Bot., 6(n. s.): 371-395; Figs. 1-8.

Galtsoff, P. S. 1924. Limnological observations in the upper Mississippi. U. S. Bur. Fish., Bull., 39: 347-483.

Gaufin, A. R., and Tarzwell, C. M. 1955. Environmental changes in a polluted stream during winter. Amer. Midl. Nat., 54: 78-88.

Guimaraes, J. R. A. 1930. Consideraçoes sobre a capacidade biogenica des aguas. Rev. Indust. Animal (Sao Paulo), I: 508-514.

Groves, I. and Bullock Webster, G. R. 1917, 1924. British Charaphyta. Ray. Soc. London. Vol. 1, 2.

Hamel, G. 1924. Le cours inferieur de la Rance. Bull. Mus. Hist. Nat. (Paris), 30: 414-416.

Hanoaka, T. 1948. Hydrological and hydrobiological observation of Tikuma River. II. Cont. Centr. Fish. Sta. Japan, 1946: 48-50.

__________. 1948. Hydrological and hydrobiological observation of the Tikuma River. III. Ibid., 137-140.

Hazen, T. E. 1902. The Ulothricaceae and Chaetophoraceac of the United States. Mem. Torr. Bot. Club, 11: 135-250.

Huet, M. 1949. La Pollution des Eaux. L'analyse biologique des eaux polluées. Trav., Stat. Recherches Groenendaal. Tr. D. Bull. Centre Belge d'Etude et de Documentation des Eaux, No. 5, 6. 31 pp.

Hupp, E. R. 1943. Plankton and its relationship to chemical factors and environment in White River Canal, Indianapolis, Indiana. Butler Univ., Bot. Stud., 6: 30-50.

Hustedt, F. 1939. Diatomeen aus den Pyrenaen. Ber. Deut. Bot. Ges., 56: 543-572.

Hutchinson, G. E. 1944. Limnological studies in Connecticut. VII. A critical examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology, 25: 3-26.

Hylander, C. J. 1928. The algae of Conneticut. Conn. Geol. and Nat. Hist. Surv., 42: 1-245; pls. 1-28.

Irénée, Marie F. 1939. Flore desmidale de la region de Montreal. La Prarie, 547. pp. 69 pls.

Israelson, G. 1949. On some attached Zygnemales and their significance in classifying streams. Bot. Not., 1949: 313-358.

Issatchonko, B. 1924. A' propos de deux cas de reproduction en masse de Cyanophycées. Rev. Alg., 1: 104-106.

Iyengar, M. O. P., and Venkataramna, G. 1951. The ecology and seasonal succession of the River Cooum at Madras with special reference to the Diatomaceae. Jour. Madras Univ., 21: 140-192. Pl. 1.

Jaag, O. 1938. Die Kryptogamenflora des Rheinfalls und des Hochrheins von Stein bis Eglisau. Mitt. Naturf. Ges. Schaffhausen, 14: 1-158. Pl. 1-18.

Jao, C. C. 1944. Studies on the fresh-water algae of China. XII. The attached algal communities of the Kialing River. Sinensia, 15: 61-73.

Jarnefelt, H. 1949. Der Einfluss der Stromschnellen auf den Sauerstoffund Kohlensauregehalt und das pH des Wassers im Flusse Vuoksi. Very. Int. Ver. Theoret. Ang. Lim., 10: 210-215.

Jurgensen, Charlotte. 1935. Die Mainalgen bei Wurzburg. Arch. Hydrobiol., 28: 361-414. Pl. 4-6.

Kehr, R. W., Purdy, W. C., Lackey, J. B., Placak, O. R., and Burns, W. E. 1941. A study of the pollution and natural purification of the Scioto River. (U.S.A.) Public Health Bull. No. 276. xii + 153 pp.

Kofoid, C. A. 1903. The plankton of the Illinois River, 1894-1899, with introductory note upon the hydrography of the Illinois River and its basin. Part I. Quantitative investigations and general results. Bull. Ill. State Lab. Nat. Hist., 6: 95-629. Pl. 1-50.

___________. 1908. The plankton of the Illinois River, 1894-1899 with introductory notes upon the hydrography of the Illinois River and its basin. Part II. Constituent organisms and their seasonal distribution. Bull. Ill. State Lab. Nat. Hist., 8: i-vii, 1-355. Pl. 1-5.

Kolbe, R. W. 1932. Grundlinien einer allgemeinen Okologie der Diatomeen. Ergebn. Biol., 8: 221-348.

Kolkwitz, R. 1911. Die Beziehungen des Kleinplanktons zum Chemismus der Gewasser. Mitt. Kgl. Prufungsanst. Wasserversorgung Abwasserbeseitigung, 14: 145-215.

Krieger, W. 1933. Die Desmidaceen, Rabenhorst's Kryptogamenflora Deutsch Österv. Schweiz. Leipzig. 13(1): 1-375. Pls. 1-96.

Kurz, A. 1922. Grundriss einer Algenflora des appenzellischen Mittelund Vorderlandes. Jahrb. St. Gall. Naturwiss. Ges. 58(II): 67-152. Pl. 1, 2.

Lackey, J. B. 1938. The flora and fauna of surface waters polluted by acid mine drainage. (U.S.A.) Public Health Rep., 53: 1499-1507.

___________. 1939. Aquatic life in waters polluted by acid mine waste. (U.S.A.) Public Health Rep., 54: 740-746.

___________. 1941. The significance of plankton in relation to the sanitary conditions of streams. In: A Symposium on Hydrobiology. Madison, Wisconsin. (pp. 311-328).

___________. 1942. The effects of distillery wastes and waters on the microscopic flora and fauna of a small creek. (U.S.A.) Public Health Rep., 58: 253-260.

___________. 1942. The plankton algae and protozoa of two Tennessee rivers. Amer. Midl. Nat., 27: 191-202.

Lackey, J. B., Wattie, Elsie, Kachmar, J. F., and Placak, O. R. 1943. Some plankton relationships in a small unpolluted stream. Ibid., 30: 403-425.

Lauterborn, R. 1910. Die Vegetation des Oberrheins. Verh. Naturhist. Mediz. Ver. Heidelberg, n.F., 20: 450-502.

___________. 1918. Die geographische und biologische Gliederung des Rheinstroms. Sitzber. Heidelberg. Akad. Wiss. Klasse 7B(Biol. Wiss.) (6): 1-61. 9B (1): 1-87.

Lefèvre, M. 1950. Influence des deversements d'eaus usées de la region parisenne sur le plancton de la Seine. Ann. Sta. Centr. d'Hydrobiol. Appl., 3: 153-171.

Liebmann, H. 1942. Uber den Einfluss der Verkrautung auf den Selbstreinigungsvorgang in der Salle unterhalb Hof. Vom Wasser, 14: 92-102.

Lindeman, Raymond L. 1941. Seasonal food cycle dynamics in a senescent lake. Amer. Midl. Nat., 26: 636-672.

_______________. 1942. The trophic-dynamic aspect of ecology. Ecology, 23: 399-418.

List, H. 1930. Die Entwicklungsgeschichte von Cladophora glomerata Kützing. Arch. Protistank. 72: 453-481.

Luther, H. 1949. Vorschlag zu einer okologischen Grundeinteilung der Hydrophyten. Acta Bot. Fenn., 44: 1-15.

________. 1954. Uber krustenbewuchs an Steinen fliessender Gewasser, speziell in Sudfinnland, Ibid., 55: 1-61.

Macan, T. T. and Worthington, E. B. 1951. Life in lakes and rivers. svi, 272 pp. 72 pl.

McCombie, A. M. 1952. Factors influencing the Growth of Phytoplankton. Dept. Zoology, Univ. Toronto.

McInteer, B. B. 1938. Distribution of the algae of Kentucky in relation to soil regions. Castanea: Jour. So. App. Bot. Club., 3: 33-35.

Meyer, K. 1923. Das Phytoplankton des Flusse Oka bei Murom in den Jahren 1919-1921. Arb. Biol. Oka-Stat. Murom, 2: 13-61.

________. 1928. Introduction to the algological flora of the River Oka and its valley. I. The Oka. Arb. Biol. Oka-Stat. Murom, 5: 4-53.

Meyer, S. L. 1940. Genus Phacus Dujardin. Virginia Jour. Sci., I(5): 117-118.

Muttowski, R. A. 1929. The ecology of trout streams in Yellowstone National Park. Roosevelt Wildlife Ann., 2: 154-240.

Needham, J. G. and Christenson, R. O. 1927. Economic insects in some streams of northern Utah. Utah Agr. Exp. Sta., Bull. 201. 36 pp.

Neel, J. K. 1951. Interrelations of certain physical and chemical features in a headwater limestone stream. Ecology, 32: 368-391.

Olson, R. A. 1941. Studies of the effects of industrial pollution in the lower Patapsco River area. 1. The Curtis Bay Region. Chesapeake Biol. Lab. Public. No. 43. 40 pp.

Oltmanns, F. Morphologie und Biologie der Algen. 2 Aufl. 3 vols. 1922-23.

Oye, P. van. 1924. Zur Biologie des Potamoplanktons auf Java (2 Aufsatz). Int. Rev. Ges. Hydrobiol. Hydrogr., 12: 48-59.

________. 1926. Le Potamoplancton du Ruki au congobelge et des pays chauds en general. Int. Rev. Ges. Hydrobiol. Hydrogr., 16: 1-50.

Panknin, W. 1941. Die Vegetation einiger seen in der Umbegung Von Joachimsthal. Bibl. Bot., 119, vii, 162 pp.

Patrick, R. 1950. Biological Measure of Stream Conditions. Reprint Sewage and Industrial Wastes, Vol. 22, No. 7.

Pearsall, W. H. 1921. A suggestion as to factors influencing the distribution of free-floating vegetation. Ibid., 9: 241-253.

______________. 1923. A theory of diatom periodicity. Jour. Ecol., 11: 165-183.

Pearsall, Wilt. 1930. Biological Survey of the River Wharfe. Ibid., 18: 273-305.

Pentelow, F. T. K. 1938. An investigation of the effects of milk wastes on the Bristol Avon. Min. Agr. Fish., Fishery Invest. I. 4(1): 1-76. Pl. 1-3.

Poretzkill, V. S. 1925. Beobachtungen uber da Diatomeen-plankton des Flusses Grosse Nevka (Leningrad) im Winter 1923-24.Russ. Hydrobiol. Zeits., 4: 201-213.

Powers, E. B. 1928. The carbon dioxide tension, oxygen content, the pH and the alkali reserve of natural waters mostly of the western portion of the United States. Puget Sound Biol. Stat. Publ., 5: 381-391.

Powers, E. B., Shields, A. R., and Hickman, M. E. 1939. The mortality of fishes in Norris Lake. Jour. Tenn. Acad. Sci., 14: 239-260.

Prat, S. 1929. Studie o Biolithogenesi. 187 pp. 13 pl.

Prescott, G. W. 1939. Some relationships of phydoplankton to limnology and aquatic biology. Amer. Assoc. Adv. Sci. Publ. 10: 65-78.

______________. 1951. Algae of the Western Great Lakes Region. Cranbrook Press.

______________. 1954. How to know the freshwater algae. Wm. C. Brown Company, Dubuque, Iowa.

Pringsheim, E. G. and Pringsheim, Olga. 1949. The growth requirements of Porphyridium cruentum, with remarks on the ecology of brackish water algae. Jour. Ecol., 37: 57-64.

Printz, H. 1927. Chlorophyceae. In: Engler and Prantl. Die Naturl. Pflanzenfamilism Leipzig.

Purdy, W. C. 1916. Potomac plankton and environmental factors. In: Cummings, H. S. Investigation of pollution and sanitary conditions of the Potomac watershed with special reference to self-purification to the shellfish and the sanitary conditions of the shellfish in the lower Potomac River. (U.S.A.) Hygenic Lab. Bull. Publ. Health Serv. No. 104, pp. 130-191.

Raabe, Hidegard. 1951. Die Diatomeenflora Der ostholsteinischen Fliessgewasser. Arch. Hydrobiol., 44: 521-638.

Radischtschev, W. P. 1925. Uber die Schaebstoffe des Wolgawassers bei Saratow, Arb. Biol. Wolga Stat., 8: 116-124.

Reese, Mary J. 1937. The microflora of the non-calcareous streams Rheidol and Melindwr with special reference to water pollution from lead mines in Cardiganshire. Jour. Ecol., 25: 386-407. Pl. 21.

Reif, C. B. 1939. The effect of stream conditions on lake plankton, Trans. Amer. Micros. Soc., 58: 398-403.

Reinhard, E. G. 1931. The plankton ecology of the upper Mississippi, Minneapolis to Winona. Ecol. Monogr., 1: 395-464; Figs. 1-11.

______________. 1931. The plankton ecology of the upper Mississippi, Minneapolis to Winona. Ecol. Monogr., 1: 395-464.

______________. 1941. Note on Aphanizomenon with a description of a new species. Amer. Jour. Bot., 28: 326-329.

Rice, C. H. 1938. Studies in the phytoplankton of the River Thames (1928-1932) I. Ann. Bot. n.s., 2: 539-557. II Ibid., 559-581.

Richardson, R. E. 1928. The bottom fauna of the Middle Illinois River, 1913-1925. Ill. Nat. Hist. Survey, Bull. 17: 387-475.

Ricker, W. E. 1934. An ecological classification of certain Ontario streams. Univ. Toronto Stud., Biol. Ser., 37: 1-114.

Riley, Gordon A. 1939. Correlations in aquatic ecology, with an example of their application to problems of plankton productivity. Jour. Marine Res., 2: 56-73; Figs. 14-16.

Roach, L. S. 1932. An ecological study of the plankton of the Hocking River. Bull. Ohio Biol. Survey, 5: 253-279.

Robinson, C. B. 1906. The Chareae of North America, Bull. N. Y. Bot. Garden, 4: 244-308.

Roy, H. K. 1955. Plankton ecology of the River Hooghly at Palta, West Bengal. Ecology, 35: 169-175.

Ruttner, F. 1953. Fundamentals of limnology. Trans. from German by D. G. Frey and F. E. J. Fry. xi, 242 pp.

Sandell, 1951. Colorimetric methods of analysis. pp. 508-509.

Sawyer, C. W. 1944. Investigation of odor nuisance occurring in Madison Lakes particularly Lakes Monona, Waubesa and Kegonsa from July 1942 to July 1943. Mimeographed Report.

Schallgruber, F. 1944. Das Plankton des Donaustromes bei Wien in qualitativen und quantitativen Hinsicht. Arch. Hydrobiol., 39: 685-689.

Scheele, M. 1954. Die Diatomeenflora der Schleusebwande in der unteren Felda und die Lichtabhangigkeit einiger Diatomeenarten. Ibid., 49: 581-589.

Schorler, B. 1907. Mitteilungen über das Plankton der Elbe bei Dresden im Sommer 1904. Ibid., 2: 355-357.

Schroeder, B. 1879. Planktologische Mitteilungen. Biol. Zentralbl., 18: 525-535.

Shelford, V. E., and Eddy, S. 1929. Methods for the study of stream communities. Ecology, 10: 382-391.

Sioli, H. 1954. Beiträge zur regionalen Limnologie des Amazonasgebietes. Arch. Hydrobiol., 49: 441-518.

Smith, G. M. 1920, 1924. Phytoplankton of the inland lakes of Wisconsin. Vol. I, II. Wis. Geol. & Nat. Hist. Surv. Bull. 57, Madison, Wis.

__________ 1938. Cryptogamic botany. Vol. I. McGraw Hill Book Co.

__________ 1950. Freshwater algae of the United States. McGraw Hill Book Co.

Sorensen, I. 1948. Biological effects of industrial defilements in the River Billeberaan. Acta Limnol., 1. 73 pp.

Starrett, W. C., and Patrick, R. 1952. Net plankton and bottom microflora of the Des Moines River, Iowa. Acad. Nat. Sci. Philadelphia, 104: 219-243.

Strickland, J. C. 1940. The Oscillatoriaceae of Virginia. Amer. Jour. Bot., 27(8): 628-633.

Ström, K. M. 1924. Studies in ecology and geographical distribution of fresh water algae and plankton. Rev. Algol., 1: 127-155.

Strom, K. M. 1927. Norwegian mountain algae. Skr. Norsk. Vid. Akad. Oslo I. Mat. Nat. Kl., 2: 1-264.

Summerhayes, V. S., and Elton, C. S. 1923. Contributions to the ecology of Spitsbergen and Bear Island. Jour. Ecol., 11: 214-286.

Swirenko, D. 1926. Plankton of the lower Dniester. Ber. Wiss. Forsch Inst. Odessa, 2(4): 21-40.

Tiffany, L. H. 1937. The Oedogoniales. North American flora. Vol. 11.

____________. 1952. The ecology of freshwater algae. In: G. M. Smith, Manual of phycology. (pp. 293-341).

Tiffany, L. H., and Transeau, E. N. 1931. Oedogonium periodicity in the north central states. Trans. Amer. Microsc. Soc., 46: 166-174; Figs. 1-3.

Tilden, Jodephine E. 1910. Minnesota algae. Vol. 1. Minneapolis.

____________. 1938. Algae and their life relations. Minneapolis, Minn.

Torrey Botanical Society. 1902. Memoirs. Vol. 11.

Transeau, E. N. 1913. The periodicity of algae in Illinois. Trans. Amer. Microsc. Soc., 32: 31-40; Figs. 1-8.

____________. 1916. The periodicity of fresh water algae. Amer. Jour. Bot., 3: 121-133.

____________. 1951. The Zygnemataceae, Columbus, Ohio. State University Press.

Wade, W. 1949. Some notes on the algal ecology of a Michigan Lake. Hydrobiologia,2(2): 109-117.

Waser, E., Blochliger, G., and Thomas, E. A. 1943. Untersuchungen am Rhein von Schaffhausen bis Kaiserstuhl 1938-1939 und 1940-1941. Zeits. Hydrol., 9: 225-309.

Wehrle, E. 1942. Algen in Gebirgsbachen am Sudostrande des Schwarzwaldes. Beitr. Naturk. Forsch. gberrheingebeit., 7: 128-286.

Welch, P. S. 1952. Limnology. 2 ed. xi, 558 pp.

West, G. S. 1927. British freshwater algae. Cambridge.

West, G. S., West, W., and Carter, N. 1923. British Desmidaceae. Roy. Society, London.

Whipple, Geo. C., and Parker, H. N. 1902. On the amount of oxygen and carbon dioxide in neutral waters and effect of these gases upon the occurrence of microscopic organisms. Trans. Amer. Microsc. Soc., 23: 103-144.

Wiebe, A. H. 1928. Biological survey of Upper Mississippi with special reference to pollution. Bull. U. S. Bur. Fish., 43(2): 137-167.

Wilson, L. R. 1937. A quantitative and ecological study of the larger aquatic plants of Sweeney Lake, Oneida County, Wisconsin. Bull. Torr. Bot. Club, 64: 199-208.

___________. 1941. The larger aquatic vegetation of Trout Lake, Vilas County, Wisconsin. Trans. Wis. Acad. Sci., Arts and Letters, 33: 135-146.

Wolle, F. 1887. Freshwater algae of the United States, Bethlehem, Pa.

________. 1892. Desmids of the United States, Bethlehem, Pa.

Wood, R. D. 1949. The Characeae of Woods Hole region Massachusetts. Biological Bull., 96: 174-203.

__________. A review of the genus Nitella (Characeae) of North America. Farlowia, 3: 317-323.

Wood, R. O., and Straughan, Jeanett. 1953. Time-intensity tolerance of Lemanea fucina to salinity. Amer. Jour. Bot., 40: 381-384.

Woronochin, N. 1930. Algen des Polar-und des Nord-Urals. Trud. Leningradsk. Obshchest. Estestv., 60: 3-77. Pl. 1-3.

_____________. 1932. Zur kenntnis der Algenflora und Algenvegetation in den Süsswasser becken der krim. Jour. U.R.S.S. 17(3): 265-325.

Zacharow, N. D. A., and Henckel, P. 1924. Beobachtungen uber den Einfluss einiger ausseren Umstanden auf Cladophora glomerata. Bull. Inst. Res. Biol. Sta. Univ. Perm, 2: 343-348. 1 pl.