DIEL RHYTHM IN SPECIES COMPOSITION AND DIVERSITY, DENSITY, AND CHLOROPHYLL CONTENT OF PHYTOPLANKTON IN OTTER CREEK, OKLAHOMA

By

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PREFACE

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CHAPTER I

INTRODUCTION

The presence of phytoplankton in the stream ecosystem has long been acknowledged. Butcher (1932) found the stream phytoplankton to be benthic algae dislodged from the stream bed by the current. In contrast, Fritsch (1902) concluded that the initial mass of phytoplankton is supplied by backwater areas and that these organisms will reproduce in flowing waters to maintain a true planktonic community. Hynes (1972) stated that phytoplankton is always present in larger rivers and true plankters often predominate. The importance of the true potamoplankton has been greatly underestimated or discounted in most published reports (Williams 1964).

In small streams, the phytoplankton often contains many dislodged benthic algae and may not be distinctive from the benthic community. In a small Michigan river, all of the common planktonic algae originated in impoundments or were of benthic origin (Blum 1957). The dislodged benthic algae that occur in the plankton have been referred to as tychoplankton. Shallow-water streams may develop rich tychoplankton communities which often consist largely of diatoms (Reid and Wood 1976). The term phytoplankton is generally used to refer to all algae suspended in the water column, regardless of origin (Lackey 1964).

Most of the early literature on stream phytoplankton was qualitative. Numerous lists of the species of phytoplankton present in a

stream have been published (Fritsch 1903, Butcher 1932, Lackey 1942, Brinley and Katzin 1942). Reports of seasonal changes in species composition of phytoplankton are also extensive (Prowse and Talling 1958, Blum 1957, Lakshminarayana 1965). Reif (1939) and Chandler (1937) showed species composition of stream phytoplankton to vary along the length of a river due to selective elimination of some plankters by aquatic vegetation and debris.

In recent years the use of quantitative measures, such as species diversity and density, of phytoplankton communities has increased. Patten (1962) reported diversity values of phytoplankton from the Raritan River and Bay, New Jersey. Staub et al. (1970) studied the species diversity of phytoplankton in the Wolf River and its tributaries in Memphis, Tennessee, and Carpenter (1971) reported diversity values for the phytoplankton of the Cape Fear River, North Carolina. Species diversity of phytoplankton in the Arkansas River, near Ponca City, Oklahoma, was measured (Wilhm et al. 1977). Pielou (1966) gave an equation for equitability of species in a community. Measurements of this component of species diversity were made for phytoplankton in the Arkansas River (Wilhm et al. 1977). Numerous authors have reported density values for stream phytoplankton (Williams 1964, Weber and Moore 1967, Carpenter 1971, Wilhm et al. 1977).

Other quantitative phytoplankton studies have shown diel periodicities. The phytoplankton of the Saline River, Michigan, exhibited a diel pulse in biomass (Blum 1954). Muller-Haeckel (1966) observed a diel pulse in downstream drift of certain benthic algae, apparently due to daytime oxygen production which makes them more buoyant and easily carried away by the current. Rhythms have also been reported in uptake

of nitrogen (Goering et al. 1964), photsynthetic activity (Lorenzen 1963), and chlorophyll content (Yentsch and Ryther 1957, Shimada 1958). Diel rhythm in species diversity of stream phytoplankton has not been studied.

The objectives of this study are to: (1) observe the diel rhythm of density, chlorophyll a and pheophytin a content, species diversity, and equitability of stream phytoplankton; and (2) measure the diel rhythm of water temperature, dissolved oxygen, pH, and conductivity.

CHAPTER II

REVIEW OF LITERATURE

The true phytoplankton of running waters, or potamoplankton, consists of algae that live and reproduce in flowing water. The existence of true phytoplankton was first noted by Zacharias (1898) from studies of German rivers and by Fritsch (1902, 1903) in the Thames River. Since these early reports there has been much controversy over whether these organisms exist as true phytoplankton or merely represent dislodged benthic algae. Blum (1956) stated that few euplankton organisms exist in streams and most algae in these waters are derived from the bottom. Similar views were given by Reid and Wood (1976) and Ruttner (1963) who concluded that river algae consist mostly of washed-in algae or those broken from the bottom. Butcher (1932) concluded that the numbers as well as the types of planktonic algae are quite similar to the benthic algae.

Many authors support the theory that true stream phytoplankton exists. From a study of major waterways of the United States, Williams (1964) concluded that the theory of the benthic origin of most phytoplankton is no longer tenable. Williams found most organisms in river samples were not broken-off or detached benthic algae, but were true planktonic forms. In a study of the Little Miami River, Ohio, particulate organic matter was largely of phytoplankton origin (Weber and Moore 1967). Hynes (1972) stated that some plankton is always present

in large rivers and true plankters often predominate. Swale (1964) concluded that most of the algae of the River Lee are strictly planktonic and suggested that Butcher's connection of benthic and planktonic algae may hold only for fairly shallow rivers where light penetrates to the bottom.

Numerous qualitative studies of stream phytoplankton have been made. Many of these studies have simply listed phytoplankton of various streams or have shown variation of phytoplankton along the length of a stream. Lists of stream phytoplankton were given by Fritsch (1902, 1903) for the Thames River, Butcher (1932) for the Rivers Tees and Lark in England, and by Lackey (1942) for the Cumberland and Duck Rivers, Tennessee. Greenberg (1964) showed the numbers of plankton increased downstream in the Sacramento River which suggests that older water has more time to acquire planktonic organisms, but Lackey et al. (1943) recorded over 250 species of plankters from Four Mile Creek, Ohio, in only 64 km. Aquatic vegetation in streams was found to remove many lake phytoplankters by filtration (Chandler 1937). Reif (1939) showed that large members of the Chlorophyceae and desmids were eliminated from the plankton more rapidly than diatoms and members of the Cyanophyta.

Other qualitative studies have shown seasonal variations of stream phytoplankton. Blum (1957) found the planktonic algae of the Saline River, Michigan, varied seasonally with high numbers of Oscillatoria and Nitzschia present in summer and minimal numbers of all phytoplankton in winter. Diatoms were found to dominate the phytoplankton of the River Ganges throughout most of the year except in summer when green and blue-green algae dominated (Lakshminarayana 1965). Phytoplankton in the Ohio River system was at a minimum in winter and consisted largely

of diatoms (Brinley and Katzin 1942). Maximum numbers and types of plankters were present in spring and summer. Prowse and Talling (1958) reported the phytoplankton of the Nile River was dominated by Melosira granulata and Anabaena flos aquae during periods of water storage due to the closure of the Gebel Aulia dam. In a study of the Logan River, Utah, Clark (1960) found no seasonal variation of phytoplankton composition, apparently due to local conditions within the canyon of the study area.

Qualitative characteristics of phytoplankton have been used as pollution indicators in many streams. Purdy (1930) listed two classes of phytoplankton from the Illinois River, those that thrived in polluted waters and those confined to clean waters. The presence in moderate or great abundance of members of the classes Chrysophyceae and Cryptophyceae was an indication of clean, unpolluted water in the Scioto River, Ohio (Lackey 1941). Algae that may be found in streams heavily polluted by sewage effluents include Microcystis, Anabaena, Euglena, Pandorina, Cladophora, Ankistrodesmus, and Rhizoclonium (Bartsch and Ingram 1959). Brinley (1942) found the presence of large numbers of Euglena, Trachelomonas, and Phacotus indicated heavy pollution in the waters of the Miami River, Ohio. Nitzschia palea dominated the plankton of polluted parts of the Saline River, Michigan (Blum 1957). From studies of rivers in the National Water Quality Network, Williams (1963, 1964) found diatoms were the largest planktonic group and concluded that these organisms were important indicators of water quality. Palmer (1969) proposed an index to indicate organic pollution based on the presence of certain pollution-tolerant algae.

Although numerous values of species diversity of phytoplankton have been reported for lacustrine and marine habitats, few have been reported for streams. Patten (1962) found that species diversity of the net phytoplankton of the Raritan River and Bay, New Jersey, varied seasonally with highest values in spring and lowest in fall and winter. Species diversity of phytoplankton from the Wolf River and its tributaries around Memphis, Tennessee, was reported by Staub et al. (1970). The authors proposed the following scale to relate values of diversity ($\bar{d}$) to varying degrees of pollution: 0.0 to 1.0 for heavy pollution, 1.0 to 2.0 for moderate pollution, 2.0 to 3.0 for light pollution, and 3.0 to 4.5 for slight pollution. In a study of the Cape Fear River and estuary, North Carolina, phytoplankton species diversity was highest at the estuary mouth and lower upstream (Carpenter 1971). Lowest diversities were observed in January and February. Species diversity and equitability were reported for phytoplankton from the Arkansas River, Oklahoma (Wilhm et al. 1977). Species diversity and equitability showed seasonal variation in the study, with lowest values during summer and early fall. Sager and Hasler (1969) concluded from studies of phytoplankton in three Wisconsin lakes that variability in the diversity index could largely be attributed to the equitability component.

Density has often been reported for stream phytoplankton. Williams (1964) observed densities of phytoplankton from most major rivers of the United States. These densities were used with percentages of total phytoplankton abundance comprised by four major diatom species to compute a "trophic index" which showed good correlation with areas of known clean and polluted waters. Berner (1951) found low densities of phytoplankton in the Missouri River which he attributed to high

turbidity. Phytoplankton populations in the Little Miami River, Ohio, exhibited wide seasonal variations in density, ranging from 75 cells/ml in February, to 114,900 cells/ml in July (Weber and Moore 1967). Carpenter (1971) reported greatest phytoplankton densities in the Cape Fear Estuary and lower densities upriver. Seasonal variation in phytoplankton density was noted in samples from the Arkansas River (Wilhm et al. 1977). Maximum densities occurred in early fall when phytoplankton was dominated by planktonic diatoms.

Measurements of chlorophyll content have been used to estimate algal biomass of various waters. McConnell and Sigler (1959) and Grzenda and Brehmer (1960) found biomass and chlorophyll content were closely correlated. In a study of a sea loch in Scotland, phytoplankton biomass was estimated by chlorophyll analysis and by a method based on cell concentration and volume (Wood et al. 1973). Considerable differences between the two methods were found, but the authors concluded that the chlorophyll-based estimates were better since they took into account the contribution of microflagellates to the phytoplankton biomass. Studies which report chlorophyll content of phytoplankton populations were made by Yentsch and Ryther (1957) at Woods Hole Harbor, Massachusetts; Ganf (1974) for Lake George, Uganda; Berman and Pollingher (1974) for Lake Kinneret, Israel; Jones et al. (1974) for the Upper Skunk River, Iowa; Wilhm et al. (1977) for the Arkansas River, Oklahoma; Duffer and Dorris (1966) for the Blue River, Oklahoma; and Baumgardner (1966) for Skeleton Creek, Oklahoma.

Diel periodicities occurred in various aspects of phytoplankton. A diel pulse in biomass of stream phytoplankton was observed in the Saline River, Michigan (Blum 1954). This was apparently due to

increased buoyancy of the benthic diatom Nitzschia palea, which occurred in the phytoplankton in large numbers during periods of maximum photosynthesis. Muller-Haeckel (1966) observed a diurnal drift rhythm of benthic diatoms in running water and concluded the drift activity of diatom cells was connected with photosynthetic activity and cell division of the organisms. In studies of photosynthesis by phytoplankters, Doty and Oguri (1957) found marine photoplankton exhibited a daily periodicity in photosynthesizing ability, and Lorenzen (1963) obtained similar results in a study of Senix Creek, New York. A diel periodicity in photosynthetic activity was observed for phytoplankton of the Eastern Pacific Ocean, which was closely correlated with a periodicity in chlorophyll a content (Shimada 1958). Yentsch and Ryther (1957) observed diel periodicities in photosynthesis and chlorophyll a content of phytoplankton from Woods Hole Harbor, Massachusetts, but the two rhythms were not directly correlated. In laboratory studies of some freshwater algae, chlorophyll a content showed considerable daily fluctuations. Variation in light intensity was ruled out as the sole cause of chlorophyll fluctuations (Gibor and Meehan 1961).

Certain physicochemical conditions of streams influence phytoplankton. Blum (1956) stated that temperature had little effect on phytoplankton of rivers because it is relatively uniform within a river, but turbidity limited phytoplankton growth since it reduces light penetration. Berner (1951) and Staub et al. (1970) found significant negative correlation between turbidity and plankton counts. Water temperature, pH, and silica content were positively correlated with total plankton and total diatom counts in the Wolf River, Tennessee (Staub et al. 1970). In the River Ganges, total phytoplankton varied indirectly with

seasonal changes of water level, transparency, temperature, silica, magnesium, and total nitrogen concentrations; while calcium and total hardness of the waters were directly correlated with phytoplankton counts (Lakshminarayana 1965). Williams (1964) found high stream-flow and low calcium hardness was limiting to plankton, and many diatom species were temperature limited. Temperature, stream flow, and biochemical oxygen demand accounted for about 60% of the variation in plankton numbers in the Sacramento River, and Greenberg (1964) concluded that many other factors were also involved in determining phytoplankton numbers.

CHAPTER III

DESCRIPTION OF OTTER CREEK

General Description

Otter Creek is an intermittent stream which flows through Garfield and Logan counties in Northcentral Oklahoma. The stream originates near Covington, flows 41.8 km southward, and empties into Skeleton Creek, a tributary of the Cimarron River. The elevation at the source is 363 m and 287 m at the mouth, with an average gradient of 1.8 m/km. Based on the degree of branching, Otter Creek is a sixth order stream where it empties into Skeleton Creek (Horton 1945). The stream has narrow, eroding valleys which reach a depth of 22.8 m along the sixth order stream.

Otter Creek drainage basin occupies an area of 302.1 km^2 and its perimeter is 106.2 km (Figure 1). Harrel (1966) concluded from stream order analysis that the Otter Creek basin is well drained. Formations in the area were laid down during the Permian period and, because of their color, are called the "Permian red beds" (Fitzpatrick et al. 1939). The formations exposed in the upper reaches of the basin are mostly shales with some gypsum and lenticular sandstone. The Garber formation, exposed in the rest of the basin, consists of alternating sandstones and shales with interstratified beds of limestone and gypsum (U. S. Geologic Survey 1945). Although this sandstone is considered to

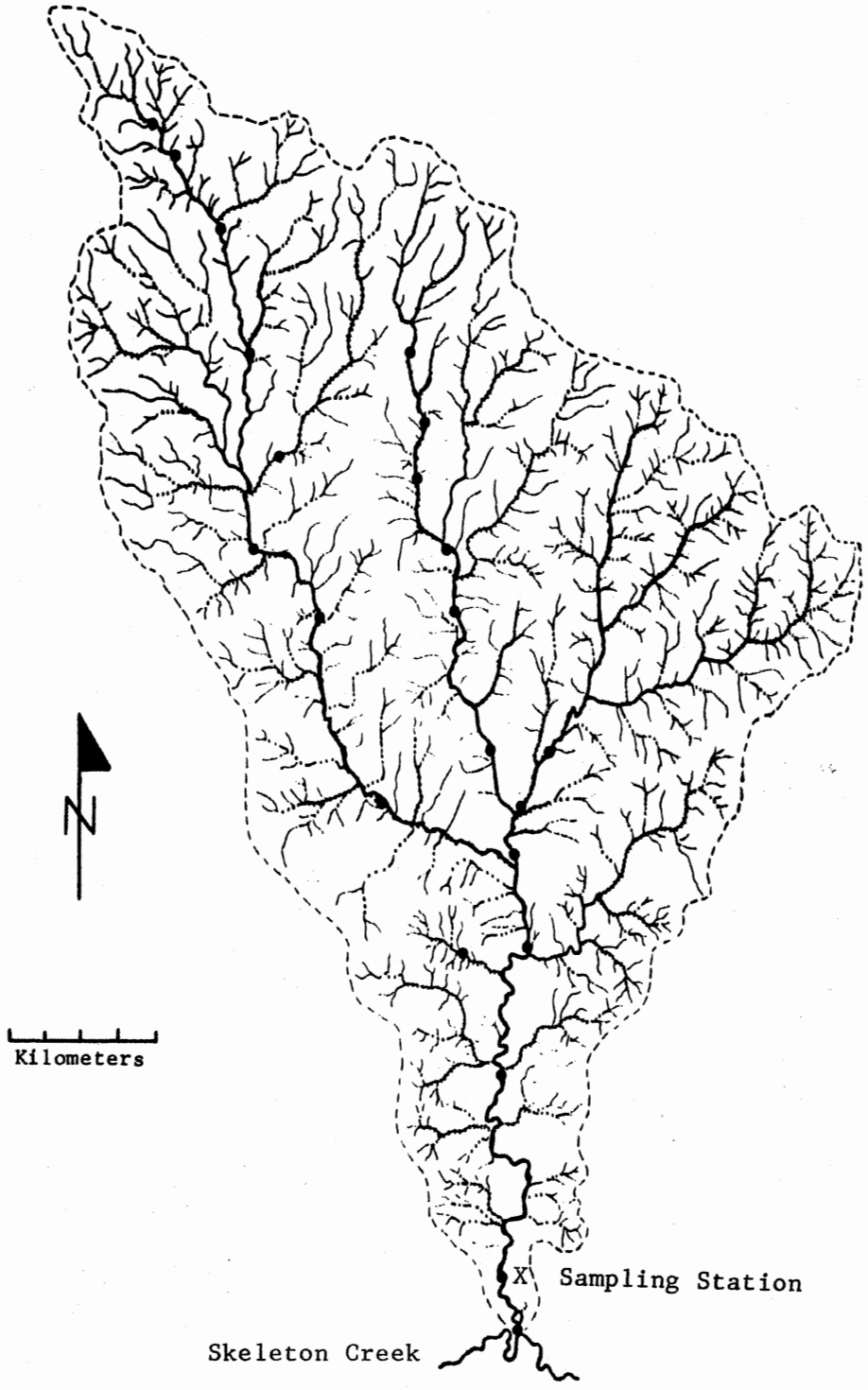

Figure 1. Otter Creek Drainage Basin and Sampling Station.

be one of the most important aquifers in the state, the water is hard and high in sulfates and chlorides (U. S. Geologic Survey 1945). Soils in the basin belong to the Renfrow-Zaneis-Vernon association and are clay, silt, or sandy loams (Gray and Galloway 1959). The area is in the mixed-grass prairie association and broad-leaf trees line the stream banks. Most land in the basin is cultivated or used for pasture.

The Otter Creek area has a long-summer continental climate. Summers are warm and winters are generally mild, with short cold periods. The mean annual temperature is 16C. The mean annual precipitation is 81 cm, but there are wide fluctuations (Fitzpatrick et al. 1939, Galloway 1960).

Sampling Station

A sampling station was selected for study which corresponds to that designated as station 1 by Harrel (1966) and by Seyfer (1976). At this station the stream bank is partially lined with trees. The stream is approximately 75 cm deep and 4 m wide at this location. The stream valley is approximately 7 m deep. Sediments are fine sand and silt in the pool. The gradient along this section of the sixth order stream is 0.42 m/km and the discharge is 0.08 m^3/sec (Harrel 1966).

CHAPTER IV

MATERIALS AND METHODS

Field Methods

Phytoplankton samples were collected on four dates: 28 June 1976, 11 June 1977, 11 July 1977, and 21 August 1977. Samples were taken every 3 h beginning at 0500 h on each date.

Four, 1 l phytoplankton samples were taken at each sampling time and preserved in Lugol's solution. Four, 1 l samples were taken at each sampling time for chlorophyll *a* determination and returned to the laboratory in an ice chest. All water samples were surface samples dipped with a jar near the water's edge.

Water temperature and conductivity were measured with a Yellow Springs Instrument Co. (YSI) Model 33 salinity-conductivity-temperature meter. Dissolved oxygen was measured with a YSI Model 54 oxygen meter. A portable Beckman pH meter was used for determining hydrogen-ion concentration. Three measurements of each physicochemical parameter were made at each sampling time.

Laboratory Methods

Samples for chlorophyll *a* and pheophytin *a* determinations were extracted in 20 ml of 90% aqueous acetone. Following storage in a refrigerator at 4 C for 24 h, the optical density of the liquid extract

was read before and after acidification with concentrated HCl on a Beckman DBG spectrophotometer. The optical density readings were used to calculate chlorophyll _a_ and pheophytin _a_ using the following equations:

$$\text{Chlorophyll } \underline{a} \text{ (mg/m}^3\text{)} = \frac{26.7\ (665_b - 665_a)\ E}{V \times L}$$

$$\text{Pheophytin } \underline{a} \text{ (mg/m}^3\text{)} = \frac{26.7\ (1.7 \times 665_a - 665_b)\ E}{V \times L}$$

where 665_b is the corrected optical density at 665 nm before acidification, 665_a is the corrected optical density at 665 nm after acidification, E is the volume of acetone used for the extraction (ml), V is the volume of water filtered (liters), and L is the path length of the cuvette (cm) (Lorenzen 1967).

Phytoplankton species identification samples were examined on a cleared 0.45 μ membrane filter. The first 200 organisms in each sample were counted. Species diversity was determined for each sample by the equation of Patten (1962):

$$\bar{d} = -\sum(n_i/n)\ \log_2\ (n_i/n)$$

where n_i is the sample estimate of the number of individuals in the i'th species and n is the total number of individuals sampled. Equitability was calculated by the equation of Pielou (1966):

$$J = \bar{d}/\log_2\ S$$

where S is the number of species per sample. Density was computed for each phytoplankton sample by the following equation:

$$\text{Density (cells/ml)} = \frac{200 \times 177}{V \times F_n \times A_f}$$

where 200 represents the number of organisms counted, 177 is the area

(mm^2) of the membrane filter, V is the sample volume (ml), F_n the number of microscope fields examined, and A_f the area of the microscope field (Millipore Corp. 1974).

An algal genus pollution index was calculated for pooled samples based on a list of the 20 most pollution-tolerant algal genera (Palmer 1969). The index was developed for use in evaluating organic pollution in water samples. In this study, the index can be used to determine whether organic pollution influences the algae more than diel changes in light or water conditions. The list was prepared based on the reports of 165 authors. The 20 most pollution-tolerant genera are assigned a number from one to five (Table 1). Each genus in a sample whose density exceeds 50 cells/ml contributes that number to the index of the sample. Palmer stated that a score of 20 or more for a sample indicates evidence of high organic pollution, and a score of 15 - 19 indicates probable evidence of high organic pollution.

Statistical Design

Data for each biological parameter on each date was analyzed for significant differences over time. The following Analysis of Variance (AOV) was used:

Source	Degrees of Freedom
Total	31
Replicates	3
Times	7
Reps x Times	21

Parameters found to differ significantly over time were plotted against time and examined for diel rhythms. Murphy's Studentized Range/Maximum Gap test was used to show where significant differences occurred (Murphy 1973).

Table 1. Tolerance values for the algal genus pollution index (Palmer 1969).

Genus	Value	Genus	Value
Anacystis	1	Micractinium	1
Ankistrodesmus	2	Navicula	3
Chlamydomonas	4	Nitzschia	3
Chlorella	3	Oscillatoria	5
Closterium	1	Pandorina	1
Cyclotella	1	Phacus	2
Euglena	5	Phormidium	1
Gomphonema	1	Scenedesmus	4
Lepocinclis	1	Stigeoclonium	2
Melosira	1	Synedra	2

Each biological parameter was further analyzed by pooling data over all sampling dates. The following AOV was used:

Source	Degrees of Freedom
Total	127
Days	3
Replicates in Days	12
Replicates	3
Reps x Days	9
Times in Days	28
Times	7
Times x Days	21
Reps x Times in Days	84

Significance of the "Times x Days" interaction indicated a different diel pattern occurred on each day.

CHAPTER V

RESULTS

Physicochemical

The concentration of dissolved oxygen and surface water temperature showed regular diel fluctuations on all sampling dates (Table 2). Maximum dissolved oxygen was measured at 1700 h and minimum values occurred during early morning. Diel variation was 5.9 mg/l on 28 June 1976 and was less than 3 mg/l on all sampling dates in 1977. Highest values were measured on 28 June 1976. Diel variation in temperature generally was 6 or 7 C. Maximum temperature was measured at 1700 h on all dates except on 11 July 1977 when it occurred at 1400 h. Minimum temperatures occurred at either 0500 h or 0800 h. Temperatures equalled or exceeded 30 C during the afternoon in June and July.

Although diel variation in conductivity exhibited no consistent trends, minimum values were measured during the morning collections (Table 2). Diel variation of conductivity was 145 µmhos in 1976 and 100 µmhos or less during summer 1977. Values ranged from 1245 - 1390 µmhos on 28 June 1976 and from 260 - 300 µmhos on 11 July 1977. Values were also low on 21 August 1977.

Values of pH ranged from 7.3 - 8.5 during the study (Table 2). Maximum values were measured on 28 June 1976. The diel variation on this date was 0.7, which was the largest measured. Diel variation in pH was 0.5 or less during 1977.

Table 2. Physicochemical Conditions* in Otter Creek.

Date	Time	Dissolved Oxygen (mg/l)	Temperature (C)	Conductivity (μmhos)	pH
28 June 1976	0500	4.2	25.0	1270	8.3
	0800	4.0	24.5	1245	8.3
	1100	5.6	26.0	1250	7.8
	1400	8.4	30.0	1343	7.9
	1700	9.9	31.5	1390	8.0
	2000	6.6	28.5	1320	8.2
	2300	5.0	27.4	1298	8.5
	0200	4.6	26.0	1293	8.5
11 June 1977	0500	4.2	24.5	900	7.7
	0800	4.4	25.5	850	7.6
	1100	4.1	27.0	850	7.7
	1400	6.4	30.0	925	7.6
	1700	7.1	30.0	900	7.9
	2000	6.2	29.0	900	7.8
	2300	5.0	27.0	900	7.9
	0200	4.3	25.5	950	7.6
11 July 1977	0500	3.8	25.5	300	7.8
	0800	4.3	26.0	260	7.6
	1100	4.2	28.0	270	7.7
	1400	4.0	31.5	275	7.8
	1700	4.3	30.0	280	7.7
	2000	4.3	28.0	282	7.8
	2300	4.2	27.5	290	7.8
	0200	4.1	27.0	290	7.8
21 August 1977	0500	4.2	23.0	340	7.8
	0800	4.0	23.0	345	7.8
	1100	4.1	25.0	355	7.5
	1400	5.1	29.0	370	7.6
	1700	5.2	29.0	380	7.4
	2000	5.2	27.0	360	7.5
	2300	4.7	25.0	358	7.4
	0200	4.5	23.5	350	7.3

* Values are means of three measurements.

Biological

Chlorophyll a content varied from 1.3 mg/m^3 on 21 August 1977 to 45.2 mg/m^3 on 28 June 1976 and 55.4 mg/m^3 on 11 June 1977 (Table 3). Values were generally highest in June. On all sampling dates chlorophyll a was highest during the late morning or afternoon and lowest at night or early morning. Significant differences occurred among sampling times on all dates except 11 July 1977 (Observed Significance Level [OSL] $<$ 0.005). Murphy's Studentized Range/Maximum Gap test was used to determine where differences occurred (α = 0.05). The largest diel variation was 48.1 mg/m^3 on 11 June 1977. The values measured at 0800, 1100, and 1400 h were significantly greater than all others. On 28 June 1976 and 21 August 1977 the maximum values were significantly greater than all others and night-time measurements were significantly smaller. The smallest diel variation in chlorophyll a was 4.9 mg/m^3 on 11 July 1977. Although no significant differences occurred on this date, the same trend of high afternoon values was shown.

On 11 June and 11 July 1977, pheophytin a concentrations increased in the afternoon with maximum values measured 3 h after maximum chlorophyll a values occurred (Table 3). Significant differences occurred only on 11 June 1977 (OSL $<$ 0.005) when values ranged from 13.4 - 55 mg/m^3. Murphy's Studentized Range/Maximum Gap test showed measurements at 1400 h and 1700 h differed from all others (α = 0.05). Diel variation was less than 10 mg/m^3 on other dates. Lowest concentrations were measured in July and August.

Phytoplankton density ranged from 913 cells/ml on 21 August 1977 to 12,545 cells/ml on 11 June 1977 (Table 3). Regular diel fluctuations

Table 3. Mean chlorophyll a, pheophytin a, density, number of taxa, species diversity, and equitability of phytoplankton in Otter Creek.*

Variable	Date	Time 0500	0800	1100	1400	1700	2000	2300	0200
Chlorophyll a (mg/m^3) (Std. error = 7.56)	28 June 1976	23.7	27.2	31.1	33.0	45.2	36.8	32.4	24.0
	11 June 1977	7.3	41.1	44.1	55.4	17.7	15.0	11.7	9.7
	11 July 1977	6.7	6.2	8.0	9.4	7.6	5.4	4.5	4.9
	21 August 1977	1.3	5.3	33.8	19.6	12.9	4.5	3.1	1.3
Pheophytin a (mg/m^3) (Std. error = 7.55)	28 June 1976	8.5	7.0	6.6	4.4	9.6	8.4	7.1	6.9
	11 June 1977	14.5	16.8	21.6	44.8	55.0	29.9	20.4	13.4
	11 June 1977	0.6	7.5	5.4	5.7	9.0	8.4	4.0	0.6
	21 August 1977	3.3	5.6	4.0	3.6	4.4	3.7	6.9	4.0
Density (cells/ml) (Std. error = 2215.29)	28 June 1976	**	**	**	**	**	**	**	**
	11 June 1977	4749	9630	11697	12310	12545	7698	7347	6590
	11 July 1977	2804	2870	2817	2964	5903	3664	2146	2620
	21 August 1977	1113	2026	2990	1720	1315	1276	1039	913
No. of Taxa (Std. error = 2.94)	28 June 1976	10	10	14	10	12	10	11	12
	11 June 1977	16	16	16	16	16	17	16	17
	11 July 1977	19	20	19	18	16	19	20	19
	21 August 1977	18	19	16	19	21	21	20	20
Species Diversity ($\bar{d}$) (Std. error = 0.58)	28 June 1976	2.3	1.9	2.4	2.0	2.4	1.7	1.9	1.9
	11 June 1977	3.2	3.2	3.0	3.3	3.0	3.2	3.0	3.1
	11 July 1977	3.7	3.8	3.7	3.6	2.9	3.2	3.7	3.6
	21 August 1977	2.8	2.6	2.6	3.0	3.4	3.2	3.1	3.0
Equitability (Std. error = 0.11)	28 June 1976	0.70	0.57	0.65	0.62	0.66	0.51	0.57	0.53
	11 June 1977	0.79	0.81	0.77	0.81	0.76	0.78	0.75	0.76
	11 July 1977	0.87	0.87	0.87	0.87	0.73	0.76	0.86	0.86
	21 August 1977	0.65	0.60	0.64	0.71	0.78	0.72	0.71	0.70

* Values are means of four measurements except densities on 11 June 1977 are means of two measurements.
** Values not measured.
___ Values underscored by the same number of lines are not significantly different (Murphy 1973).

in density occurred on all dates. Maximum densities were measured at 1700 h in June and July and at 1100 h in August. Lowest densities were found at night or early morning. Maximum densities coincided with maximum chlorophyll a concentrations in June and August, but in July maximum density occurred 3 h later than maximum chlorophyll a. The largest diel variation in density was 7796 cells/ml on 11 June 1977 when chlorophyll a variation was greatest.

Ninety-four taxa of phytoplankters were collected during the study; 54 diatoms, 24 green algae, and nine euglenophytes (Table 4). Both planktonic and benthic diatoms were identified (Hynes 1972). Genera found during the study that are planktonic were Cyclotella, Fragilaria, Melosira, and Stephanodiscus. Benthic forms included Navicula, Nitzschia, Surirella, and Synedra. In general, largest numbers of the planktonic forms were found.

Species composition during sampling days was compared by determining the four most abundant species in pooled counts of four replicate samples (Table 5). Little variation in species composition occurred on 28 June 1976. The euglenophyte Trachelomonas volvocina generally comprised over 50% of the total sample at all times. T. kelloggii and the green alga Tetrastrum elegans made up 13 - 28% of the total sample in 1977. Green algae were generally the dominant forms on 11 June 1977. Actinastrum hantzschii, planktonic diatoms in the genus Cyclotella, and the blue-green alga Chroococcus limneticus were common on this date. On 11 July 1977 the green alga Kirchneriella obesa was the dominant form at 1700 h and 2000 h. At other times the planktonic diatom Stephanodiscus astrea was dominant. Benthic diatoms were also common. The

Table 4. Algae collected in Otter Creek, 1976, 1977.*

Chlorophyta
- Actinastrum hantzschii Lagerheim
- Ankistrodesmus convolutus Corda
- Ankistrodesmus sp.
- Chlorella vulgaris Beyerinck
- Chlorococcum humicola (Naeg.) Rabh.
- Closteriopsis longissima Lemm.
- Crucigenia apiculata (Lemm.) Schmidle
- Crucigenia quadrata Morren
- Crucigenia tetrapedia (Kirch.) West
- Kirchneriella contorta (Schmidle) Bohlin
- Kirchneriella obesa (W. West) Schmidle
- Micractinium sp.
- Pediastrum duplex Meyen.
- Scenedesmus abundans (Kirch.) Chodat
- Scenedesmus dimorphus (Turp.) Kutz.
- Scenedesmus opoliensis Richter
- Scenedesmus quadricauda (Turp.) Breb.
- Scenedesmus sp.
- Schroederia setigera (Schroed.) Lemm.
- Selenastrum minutum (Naeg.) Collins
- Spirogyra sp.
- Tetraedron regulare Kutz.
- Tetrastrum elegans Playf.
- unidentifiable filament

Euglenophyta
- Euglena sp.
- Phacus pleuronectes (Muell.) Dujardin
- Phacus sp.
- Trachelomonas acanthostoma (Stokes) Deflandre
- Trachelomonas girardiana (Playf.) Deflandre
- Trachelomonas Kelloggii (Skv.) Deflandre
- Trachelomonas lacustris Drez.
- Trachelomonas schauinslandii Lemm.
- Trachelomonas volvocina Ehr.

Pyrrhophyta
- Cryptomonas sp.
- Glenodinium sp.

Cyanophyta
- Chroococcus limneticus Lemm.
- Cylindrospermum sp.
- unidentifiable filament

Table 4. (Continued)

Bacillariophyta

- Achnanthes lanceolata (Breb.) Grun.
- Achnanthes minutissima Kutz.
- Bacillaria paradoxa Gmel.
- Caloneis bacillum (Grun.) Cl.
- Caloneis lewisii Patr.
- Caloneis ventricosa (Ehr.) Meist.
- Cyclotella atomus Hust.
- Cyclotella meneghiniana Kutz.
- Cyclotella stelligera Cl. & Grun.
- Cymbella affinis Kutz.
- Cymbella minuta Hilse ex Rabh.
- Cymbella ventricosa Kutz.
- Cymbella sp.
- Diploneis smithii (Breb. ex. W. Smith) Cl.
- Eunotia pectinalis Rabh.
- Fragilaria sp.
- Frustulia vulgaris (Thwaites) DeT.
- Gomphonema parvulum Kutz.
- Gyrosigma spencerii (Quek.) Griff. & Henfr.
- Melosira italica (Ehr.) Grun.
- Melosira sp.
- Navicula bacillum Ehr.
- Navicula capitata Ehr.
- Navicula cryptocephala Kutz.
- Navicula cuspidata (Kutz.) Kutz.
- Navicula elginensis (Greg.) Ralfs
- Navicula exigua Greg. ex Grun.
- Navicula minima Grun.
- Navicula pelliculosa (Breb. ex Kutz.) Hilse
- Navicula pupula Kutz.
- Navicula pygmaea Kutz.
- Navicula radiosa Kutz.
- Navicula tripunctata (O. Mull.) Bory
- Navicula sp.
- Nitzschia acicularis W. Sm.
- Nitzschia amphibia Grun.
- Nitzschia angustata (W. Sm.) Grun.
- Nitzschia apiculata (Greg.) Grun.
- Nitzschia filiformis (W. Sm.) Hust.
- Nitzschia hungarica Grun.
- Nitzschia linearis W. Sm.
- Nitzschia palea (Kutz.) W. Sm.
- Nitzschia parvula Lewis
- Nitzschia sigma (Kutz.) W. Sm.
- Nitzschia sigmoidea (Ehr.) W. Sm.
- Nitzschia tryblionella Hantz.
- Pleurosigma delicatulum W. Sm.
- Rhoicosphenia curvata (Kutz.) Grun. ex. Rabh.

Table 4. (Continued)

Bacillariophyta (continued)
Rhopalodia gibberula (Ehr.) O. Mull.
Stephanodiscus astrea (Ehr.) Grun.
Surirella angustata Kutz.
Surirella ovata Kutz.
Synedra rumpens Kutz.
Synedra ulna (Nitz.) Ehr.

*Nomenclature follows Patrick and Reimer (1966, 1975), Prescott (1962), and Tiffany and Britton (1971).

Table 5. Four most abundant species in pooled samples and percent composition of each.

Time	28 June 1976	11 June 1977
0500	Trachelomonas volvocina 46	Cyclotella stelligera 21
	Tetrastrum elegans 17	Actinastrum hantzschii 18
	Trachelomonas Kelloggi 11	Stephanodiscus astrea 12
	Scenedesmus dimorphus 10	Chroococcus limneticus 12
0800	Trachelomonas volvocina 64	Actinastrum hantzschii 15
	Trachelomonas Kelloggii 10	Cyclotella stelligera 14
	Tetrastrum elegans 7	Chroococcus limneticus 14
	Kirchneriella contorta 6	Cyclotella atomus 12
1100	Trachelomonas volvocina 49	Actinastrum hantzschii 24
	Tetrastrum elegans 11	Chroococcus limneticus 11
	Trachelomonas Kelloggi 9	Cyclotella stelligera 11
	Scenedesmus dimorphus 9	Cyclotella atomus 10
1400	Trachelomonas volvocina 58	Actinastrum hantzschii 16
	Trachelomonas Kelloggii 13	Cyclotella stelligera 16
	Tetrastrum elegans 10	Chroococcus limneticus 15
	Scenedesmus dimorphus 6	Cyclotella atomus 10
1700	Trachelomonas volvocina 53	Chlorella vulgaris 25
	Trachelomonas Kelloggii 14	Chroococcus limneticus 14
	Tetrastrum elegans 7	Cyclotella stelligera 13
	Phacus sp. 3	Actinastrum hantzschii 8
2000	Trachelomonas volvocina 69	Actinastrum hantzschii 24
	Tetrastrum elegans 8	Cyclotella stelligera 13
	Trachelomonas Kelloggii 5	Chroococcus limneticus 11
	Scenedesmus dimorphus 3	Cylindrospermum sp. 10
2300	Trachelomonas volvocina 61	Chroococcus limneticus 29
	Trachelomonas Kelloggii 12	Cyclotella stelligera 14
	Tetrastrum elegans 7	Actinastrum hantzschii 11
	Scenedesmus dimorphus 6	Cyclotella atomus 7
0200	Trachelomonas volvocina 63	Kirchneriella obesa 22
	Trachelomonas Kelloggii 12	Cyclotella stelligera 19
	unidentifiable filament 5	Cyclotella atomus 12
	Tetrastrum elegans 4	Actinastrum hantzschii 11

Table 5. (Continued)

Time	11 July 1977	21 August 1977
0500	Stephanodiscus astrea 18	Cryptomonas sp. 52
	Nitzschia palea 10	Stephanodiscus astrea 6
	Chroococcus limneticus 10	Diploneis smithii 5
	Diploneis smithii 8	Nitzschia palea 4
0800	Stephanodiscus astrea 19	Cryptomonas sp. 56
	Nitzschia palea 11	Phacus sp. 10
	Chroococcus limneticus 8	Chlorella vulgaris 5
	Navicula tripunctata 7	Diploneis smithii 4
1100	Stephanodiscus astrea 20	Phacus sp. 45
	Nitzschia palea 12	Cryptomonas sp. 20
	Diploneis smithii 11	Euglena sp. 10
	Navicula tripunctata 8	Trachelomonas Kelloggii 5
1400	Stephanodiscus astrea 18	Phacus sp. 43
	Nitzschia palea 11	Cryptomonas sp. 10
	Navicula tripunctata 8	Trachelomonas Kelloggii 9
	Diploneis smithii 7	Euglena sp. 8
1700	Kirchneriella obesa 24	Phacus sp. 34
	Chroococcus limneticus 22	Cryptomonas sp. 10
	Stephanodiscus astrea 12	Trachelomonas Kelloggii 9
	Navicula tripunctata 5	Chlorella vulgaris 6
2000	Kirchneriella obesa 38	Cryptomonas sp. 28
	Stephanodiscus astrea 22	Chroococcus limneticus 14
	Navicula tripunctata 8	Chlorella vulgaris 9
	Nitzschia palea 7	Stephanodiscus astrea 6
2300	Stephanodiscus astrea 18	Cryptomonas sp. 40
	Kirchneriella obesa 10	Kirchneriella obesa 11
	Nitzschia palea 10	Stephanodiscus astrea 8
	Navicula tripunctata 8	Nitzschia palea 6
0200	Stephanodiscus astrea 19	Cryptomonas sp. 42
	Nitzschia palea 15	Chroococcus limneticus 7
	Diploneis smithii 10	Stephanodiscus astrea 7
	Navicula tripunctata 6	Diploneis smithii 6

dominant species varied on 21 August 1977. A dinoflagellate in the genus Cryptomonas was dominant at night and in the early morning. At 1100, 1400, and 1700 h the dominant species was the euglenophyte Phacus sp. Dominance of Phacus sp. accompanied high chlorophyll a concentrations.

Using the method of Palmer (1969), the algal genus pollution index was calculated for pooled samples from 1977 (Table 6). The values obtained show pollution-tolerant genera were present in greater numbers during the day. On 11 June 1977 the index shows evidence of high organic pollution at all hours from 0800 h through 2000 h. At these times Euglena, the most tolerant genus listed by Palmer, and Scenedesmus, another highly tolerant genus, were present in large numbers. Indices for 11 July 1977 show evidence or probable evidence of high organic pollution between 0800 h and 1700 h. The abundance of Scenedesmus, Navicula, Nitzschia, and Chlorella accounted for the high values of the index. Probable evidence of high organic pollution was shown at 0800 h and 1700 h on 21 August 1977. Index values were large at these hours due to the presence of Chlorella.

The mean number of taxa per sample ranged from 10 - 21 (Table 3). On 11 June 1977 the diel variation in number of taxa per sample was 1, the smallest variation measured. Diel variation was four or greater on all other sampling dates. Fewer taxa per sample were identified in 1976 than in 1977.

Mean species diversity values ranged from 1.7 - 3.8 (Table 3). The largest diel variation in species diversity was 0.9 on 11 July 1977, while the smallest was 0.3 on 11 June 1977. On both of these dates minimum diversity occurred at 1700 h; the time when phytoplankton

Table 6. Algal genus pollution index values from phytoplankton in Otter Creek.+

Date	Time 0500	0800	1100	1400	1700	2000	2300	0200
11 June 1977	13	20**	20**	23**	20**	20**	13	10
11 July 1977	12	15*	22**	18*	19*	12	12	15
21 August 1977	6	16*	13	13	16*	11	6	6

+ Values are based on pooled counts of two replicate samples on 11 June and four replicate samples on 11 July and 21 August (Palmer 1969).

* Probable evidence of high organic pollution.

** Evidence of high organic pollution.

density was greatest. On 21 August 1977 species diversity was significantly lower in the morning that at other times. The minimum value was 2.6 at 0800 h, when phytoplankton density was high. Lowest species diversity values were calculated on 28 June 1976. Values ranged from 1.7 - 2.4. These low diversities were due to the large number of Trachelomonas volvocina.

Equitability varied from 0.51 - 0.87 (Table 3). Diel variation in equitability was smallest on 11 June 1977 when values ranged from 0.75 - 0.81. Diel variation was 0.14 or greater on other dates. Significant differences occurred among equitability values on 28 June 1976 and 21 August 1977.

CHAPTER VI

DISCUSSION

Dissolved oxygen and water temperature showed regular diel variations. The maximum variation in dissolved oxygen, 5.9 mg/l, is generally less than diel variations reported for other streams. Variations of 10 mg/l were observed in the unpolluted River Yare (Owens and Edwards 1964) and over 6 mg/l in Buffalo Creek, a small, unpolluted stream in Pennsylvania (McDiffet et al. 1972). Diel oxygen variation was more than 14 mg/l in Skeleton Creek, Oklahoma (Baumgardner 1966). Organic enrichment of Skeleton Creek caused high photosynthetic oxygen production during the day and high respiratory oxygen consumption at night (Baumgardner 1966). The smaller oxygen variation in the present study was probably due to high turbidity in Otter Creek which would decrease the oxygen production by benthic algae and phytoplankton in deep water. The maximum diel range in water temperature was 24.5 - 31.5 C which is similar to the diel range of 24 - 34 C in Skeleton Creek (Baumgardner 1966) and 23 - 34 C in the Blue River, Oklahoma (Duffer and Dorris 1966).

Chlorophyll _a_ values of Otter Creek phytoplankton ranged from 1.3 - 45.2 mg/m^3 which is within the range of 1.0 - 177.5 mg/m^3 reported from the Upper Skunk River, Iowa (Jones et al. 1974). Highest concentrations in the Skunk River were measured below two municipal sewage effluents. Chlorophyll concentrations ranged from 39 - 154 mg/m^3 in

polluted portions of a Russian river (Winberg and Sivko 1962), and from 8 - 338 mg/m^3 in Skeleton Creek (Baumgardner 1966). Higher concentrations resulted from organic enrichment by several sewage effluents that enter these streams. Chlorophyll a concentrations were considerably lower in the Arkansas River, ranging from 0.04 - 0.4 mg/m^3 (Wilhm et al. 1977); and in the Blue River, where concentrations of 4 mg/m^3 were measured at various sites (Duffer and Dorris 1966). Greater current velocity in these rivers was the probable cause of the lower concentrations. Jones et al. (1974) found chlorophyll concentrations decreased as flow increased in the Skunk River.

Chlorophyll a showed regular diel fluctuations with highest values measured in the late morning or afternoon. Yentsch and Ryther (1957) observed highest concentrations of chlorophyll in marine phytoplankton during the morning and afternoon with lower values at midday and at night. This midday depression, probably due to photoinhibition, was not observed in phytoplankton from Otter Creek. Shimada (1958) reported maximum chlorophyll concentrations in the morning in marine phytoplankton. In laboratory studies of several freshwater algae, Gibor and Meehan (1961) found little diel variation in chlorophyll a content of Ankistrodesmus sp. or Chlorella sp. However, chlorophyll a in Euglena gracilis showed more than a two-fold increase during illumination. The variation in Euglena was apparently due to rapid pigment formation when exposed to light and photo-oxidation of pigments when photosynthesis is inhibited. A species of Euglena was abundant at various times during the present study, but not always when chlorophyll variation was high. Other plankton species undoubtedly influence chlorophyll concentrations.

Pheophytin a is a degradation product of chlorophyll a. High pheophytin a concentrations indicate phytoplankton populations are old or in poor physiological condition. During 1977 pheophytin a exceeded chlorophyll a concentrations, generally in the afternoon and at night. Wilhm et al. (1977) described similar situations in the Arkansas River and concluded the presence of a senescent phytoplankton population was indicated. Pheophytin a values in the Arkansas River were smaller than those reported in the present study, again due to the reduction in phytoplankton population by the current velocity in the river.

The range in mean phytoplankton density was 913 - 12,545 cells/ml, which is similar to ranges reported for other streams. Wilhm (personal communication) measured phytoplankton densities of 3211 - 10,828 cells/ml in the Red River, Oklahoma. Phytoplankton density varied from 100 to over 100,000 cells/ml in the Arkansas River at Ponca City, Oklahoma (Williams 1963). Wilhm et al. (1977) reported densities in the Arkansas River ranging from 42 - 419 cells/ml. These lower densities may have reflected a decrease in organic enrichment in the river since Williams' study. Anderson et al. (1965) reported phytoplankton densities from less than 100 to over 200,000 cells/ml in the Kanawha River, Ohio, and Weber and Moore (1967) measured densities from 75 - 114,900 cells/ml in the Little Miami River, Ohio. Mean phytoplankton densities in 16 major U. S. rivers ranged from 1376 - 6745 cells/ml (Palmer 1961). The generally low phytoplankton densities in Otter Creek indicate little organic enrichment.

Phytoplankton density and chlorophyll a content were correlated on 11 June ($r = 0.77$) and 21 August 1977 ($r = 0.86$). Chlorophyll content

was shown to be correlated with dry-weight estimates of biomass for algae in the Logan River, Utah (McConnell and Sigler 1959) and in the Red Cedar River, Michigan (Grzenda and Brehmer 1960). In a study of a sea loch in Scotland, phytoplankton biomass was estimated by chlorophyll analysis and by cell counts (Wood et al. 1973). Chlorophyll-based estimates were considered more accurate since they took into account the contribution of microflagellates that might be omitted in cell counts. Some differences in chlorophyll and density variations in the present study may also be attributable to the omission of microflagellates from cell counts. Low correlation between chlorophyll a content and density was shown on 11 July 1977 ($r = 0.31$), largely due to poor correlation of values at times when Kirchneriella obesa was the dominant species. Low chlorophyll content of this species may be responsible for low chlorophyll and high density at these times.

Chlorophyll concentration and phytoplankton density increased in the morning indicating an increase in phytoplankton numbers. Since little change in number of benthic forms in the phytoplankton was observed, this increase was apparently due to rapid reproduction of plankton forms. Margalef (1958) observed high rates of reproduction, up to two cell divisions per day, in many small-celled planktonic diatoms and green algae. Lower chlorophyll concentrations and density in the afternoon and evening indicated a decrease in phytoplankton numbers. Natural mortality and increased grazing by zooplankton may have accounted for this decrease. Wetzel (1975) stated that zooplankton grazing rates increase with darkness due to rapid diurnal migration of zooplankton to the trophogenic zone. Saunders (1971) found a greater assimilation rate of algae by Daphnia at night.

Benthic and planktonic genera were identified in the Otter Creek phytoplankton with largest numbers of planktonic forms occurring. Benthic algae include the genera Diatoma, Navicula, Nitzschia, Surirella, and Synedra (Hynes 1972). All of these except Diatoma were identified during the study. The planktonic diatoms include the genera Cyclotella, Fragilaria, Melosira, and Stephanodiscus. These may be joined by planktonic green algae, such as Scenedesmus, Ankistrodesmus, and Pediastrum, as well as flagellates including Cryptomonas, Trachlomonas, and Euglena (Hynes 1972). These planktonic forms generally made up the majority of the phytoplankton in Otter Creek. Hynes (1972) predicted that the proportion of truly planktonic species increases in small, sluggish streams on the plains. The planktonic genera Cyclotella and Stephanodiscus, as well as the benthic genus Nitzschia, were abundant in the present study and were also reported in large numbers in the Arkansas River by Williams (1963) and by Wilhm et al. (1977). The dominant genera in the phytoplankton of Skeleton Creek included Euglena and Navicula (Baumgardner 1966), which were abundant at various times in Otter Creek. In the Saline River, Michigan, Blum (1954) reported the presence of large numbers of Nitzschia palea in the phytoplankton during the afternoon caused by increased buoyancy of this benthic diatom due to midday oxygen production. In the present study, N. palea was abundant at various times in July and August, 1977, but no significant diel change in number was shown.

Planktonic algae were the most abundant species in all pooled samples during the study. The euglenophyte Trachelomonas volvocina generally comprised over 50% of all samples on 28 June 1976. Prescott (1962) described this genus as tychoplanktonic; found in shallow waters

where temperature and organic matter are high. Trachelomonas was not among the 20 most pollution-tolerant genera listed by Palmer (1969). Dominant algae varied on 11 June 1977. All dominant forms were planktonic green algae, blue-green algae, or diatoms. On 11 July 1977 the dominant species was Stephanodiscus astrea or Kirchneriella obesa. Stephanodiscus is a planktonic diatom (Hynes 1972) and Kirchneriella is a planktonic green alga (Prescott 1962). Cryptomonas sp. and Phacus sp. were dominant forms on 21 August 1977. Cryptomonas is a flagellate that is found in the plankton of streams when the water is warm (Hynes 1972). Phacus is a euglenophyte that may be euplanktonic or tychoplanktonic in various shallow waters (Prescott 1962). The general dominance of planktonic algae may have resulted from high turbidity, which would limit the growth of benthic algae. Baumgardner (1966) found greater numbers of planktonic algae in regions of Skeleton Creek, near the confluence with Otter Creek, which he attributed to reduced light intensity penetrating to the stream bed.

Values of the algal pollution index exceeded 15 during the day on all sampling dates in 1977, which indicates "probable evidence of high organic pollution" (Palmer 1969). Values exceeded 20 in June and July, which indicates "evidence of high organic pollution." Palmer reported an index value of 25 from a sewage stabilization pond. Values never exceeded 15 in the Kiamichi and Red Rivers, Oklahoma (Wilhm, personal communication). The presence of one or more of the benthic genera, Navicula, Nitzschia, Euglena, Scenedesmus, or Chlorella accounted for the high values of the pollution index. During the day, sufficient numbers of these algae entered the tychoplankton to cause the pollution index to indicate organic pollution. An actual diel change in water

quality was not indicated by physicochemical measurements or phytoplankton species diversity. The pollution index was effected more by diel variation in the phytoplankton population than by water quality, thus indicating the importance of sampling time when using the index.

The range in species diversity in Otter Creek phytoplankton (1.7 - 3.8) is similar to that reported in other streams. Species diversity values in the Wolf River, Tennessee, ranged from 1.6 - 4.0 (Staub et al. 1970). Wilhm et al. (1977) reported phytoplankton species diversity from the Arkansas River, near Ponca City, Oklahoma, ranging from 2.3 - 3.8. Values from Cypress Creek, Tennessee, a shallow, heavily polluted stream, were generally lower (0.1 - 2.4) (Staub et al. 1970). Staub et al. (1970) proposed a relationship between phytoplankton species diversity and water quality. The scale was: 0.0 - 1.0 for heavy pollution, 1.0 - 2.0 for moderate pollution, 2.0 - 3.0 for light pollution, and 3.0 - 4.5 for slight pollution. Using these categories, phytoplankton diversity in Otter Creek suggests a moderately to lightly polluted condition in 1976, and lightly to slightly polluted in 1977.

Species diversity values generally did not indicate a diel change in water quality as was observed with the algal pollution index. One significant change occurred on 21 August 1977 when light pollution was indicated in the morning and slight pollution was indicated at other times. This change is probably due to the presence of greater numbers of a single species in the morning rather than a significant change in water quality. Seyfer (1976) concluded from a study of periphyton that Otter Creek showed signs of nutrient enrichment. Runoff from pastureland and cattle feedlots were suggested as possible sources of this enrichment. Results of the present study concur with this conclusion.

Lowest species diversity occurred on 28 June 1976. The low values reflected an abundant species, Trachelomonas volvocina, which generally comprised over 50% of the samples. On other dates, minimum species diversity values accompanied high phytoplankton densities. High density and low diversity were generally caused by the abundance of one or two species. On 11 July 1977 species diversity was lowest at 1700 h and 2000 h, the times when density was highest. The two most abundant species comprised over 45% of the sample at these times and less than 34% at other times. On 21 August 1977 species diversity was lowest in the morning, when the two most abundant species made up over 55% of the sample. Density was high at these times.

Equitability values showed diel fluctuations and generally reflected the same abundance of one or two species that caused low diversity and high density. Lowest equitability was measured on 28 June 1976 and other times when a few species were dominant. The range in equitability values (0.51 - 0.87) exceeded the range reported for the Arkansas River (0.57 - 0.76) near Ponca City, Oklahoma (Wilhm et al. 1977).

CHAPTER VII

SUMMARY

1. Physicochemical measurements and phytoplankton were collected every 3 h during four, 24 h sampling periods in summer, 1976 and 1977, from Otter Creek, Oklahoma. Diel variations in physicochemical conditions, phytoplankton species composition, species diversity, equitability, density, chlorophyll content, and pheophytin content were studied.
2. Diel variations in dissolved oxygen and surface water temperature occurred on all dates. Dissolved oxygen variations were generally less than diel variations reported for other streams and temperature variations were similar to other reports. Conductivity was lowest in the morning, but no consistent trends were shown.
3. Chlorophyll _a_ concentration showed diel variation with highest values occurring during the late morning or afternoon. Chlorophyll concentrations were less than those reported for heavily polluted streams and greater than those in larger rivers. Pheophytin concentration exceeded chlorophyll at times, indicating senescent phytoplankton populations.
4. Phytoplankton density showed diel fluctuations with maximum values measured in the late morning or afternoon. Values were within ranges reported for other streams. Density was correlated with chlorophyll content.

5. Ninety-four taxa of phytoplankters were collected, most were planktonic diatoms, green algae, or euglenophytes.
6. The algal pollution index showed evidence of organic pollution during the day due to the presence of certain benthic algae in the plankton. An actual diel change in water quality was not indicated by physicochemical conditions or species diversity.
7. Species diversity and equitability showed little diel variation and generally reflected changes in one or two dominant species. Species diversity values were similar to those reported for other streams and suggested slight to moderate levels of pollution in Otter Creek.

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