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Diatoms In The Des Moines River

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Diatoms were observed to be the dominant algal group in all seasons in the 860 km long Des Moines River, from April 1961 through September 1964. The 9 most abundant diatom taxa were: *Diatoma vulgare, Gomphonema olivaceum, Melosira granulata, Nitzschia dissipata, N. palea, Stephanodiscus hantzschii, Synedra acus* and *S. ulna*. Of the 60 most abundant diatom taxa in the Des Moines River, 36 are important components of diatom floras in other major United States Rivers. From over 600 samples collected year around and throughout the length of the river, 274 diatom taxa representing 38 genera were identified. No new diatom taxa were recognized. Diatoms and a water sample were collected weekly. Water samples were analysed for: temperature, pH, turbidity, sulfate, iron, phosphate, silica, nitrite, nitrate, methyl orange alkalinity, chloride, calcium hardness, total hardness, oxygen, and manganese.

The river basin climate produced 5 distinct positive growth periods for diatoms each year; these were characterized by heavy benthic, attached, and planktonic (except in winter) diatom growth; and delimited or terminated by one of 5 distinct respective "antigrowth periods" of highwater. The latter periods were typified by heavy silt loads, and removal of most diatoms from the river by flushing and scouring. Sources of diatoms for repopulating the river were the two headwater lakes, numerous tributaries, migratory animals, and impoundments in the upper and middle zones of the river itself. Motility is an important survival factor for diatoms settling out with silt in river impondments, and 80% of the Des Moines River diatoms are motile forms.

Flow (water volume) and available light were probably the most important limiting factors for diatom growth in all seasons in the Des Moines River, both in turn limited by precipitation in the drainage basin. Light penetration most probably was limited by ice and snow cover and turbidity; in addition to precipitation, high turbidity was also caused by effluents from commercial washing of sand and gravel. Seasonal temperature variation also regulated the kinds of dominant and abundant diatoms. Ample nutrients, especially nitrates and phosphates, for diatom growth were provided by inorganic fertilizers washed from farmlands and sewage and related effluents from over 500,000 people. The intrinsic fertility of the Des Moines River is insignificant under these conditions. It is estimated that during positive growth periods over 1000 tons per month of diatoms and other algae were produced in and carried out of the river; the vast amount of diatom primary production in the Des Moines River is probably utilized negligibly by other organisms.

Two large dams, at Saylorville and Red Rock, will alter the diatom growth patterns in the Middle and Lower portions of the river as well as providing the opportunity for a stratified sedimentary deposition of diatoms. The impoundments from these dams will probably result in a change in the kinds of dominant diatoms and increase the number of taxa collectable.

INDEX DESCRIPTORS: Bacillariophyceae, Des Moines river, Iowa diatoms

INTRODUCTION

Diatoms are generally the most important algal group in rivers with regard to numbers, biomass, and food for other aquatic organisms. This is especially true for major rivers in the United States (Williams and Scott, 1962). This study was an examination of diatom growth in the Des Moines River from April 1961 through September 1964. The diatom taxa found, relative abundance of major species, and an evaluation of various physical, chemical, and human factors which influence diatom growth are included here; more detailed water chemistry data and items of historical interest are recorded elsewhere (Drum, 1964).

STUDY AREA

The Des Moines River is the largest and longest river flowing through the state of Iowa. Its drainage basin climate is characterized by 76 cm annual precipitation, and cold winters and hot summers.

The physical morphology of the river provides a wide range of aquatic habitats, from impounded lakes to surging rapids, throughout a length of 860 km. The river in this study was divided into three distinct zones or reaches, which are easily defined and delimited geologically. The upper zone extends from the headwaters of both main forks to the first rock outcroppings which occur on each fork (Fig. 1). Both forks arise at the outlet of a large shallow lake, the West Fork from Lake Shetak and the East Fork from Tuttle Lake. Other lakes also drain into the river in this region, especially on the West Fork. In earlier times, many shallow lakes in the drainage basin of the upper zone were drained for agricultural enterprise. The river bottom in this zone is characterized by silt and sand to sand-gravel with few rapids. Several impoundments are formed by "lowhead" dams on the West Fork, and a few on the East Fork.

The upper and middle zones cut through deposits left by the last glacier, and here the river basin is "young" and the natural drainage incomplete. The soil covering the glacial till here is generally very fertile, and the topography adjacent to the river beyond often steep banks is level plain excepting occasional moraine deposits.

The middle zone begins on the West Fork about 20 km above the junction of the two forks. Here the river cuts down through 3-5 m of Kinderhook limestone and the river bed becomes rock rubble and bedrock. A similar transition occurs on the East Fork a few kilometers above the junction. Between the beginnings of the middle zone and the Great Coal Bank at Fort Dodge, almost the entire river bottom is rocky. About 15 km below the junction, the limestone tilts and disappears from the cliffs, which then become composed of massive irregular sandstone bluffs lying over Pennsylvania coal measures. An outstanding habitat feature in the middle zone is the occurrence of an alluvial fan or outwash deposit projecting into and often completely across the river bed wherever a creek or intermittent stream of the natural drainage system enters the river. These areas are usually composed of cobbles and boulders and cause rapids in many places (Figure 2). Most of the remainder of the river bottom here is sand or sand-gravel with a few backwater areas and impondments with silt to silt-sand bottom deposits. The middle zone ends at the mouth of the Raccoon River in Des Moines, Iowa, where that river empties into the Des Moines River, and which is also the southernmost extension of Wisconsin Glaciation in Iowa.

In the lower zone the character of the river basin changes abruptly. The flood plain is often several kilometers wide, the river meanders and doubles back on itself, and the bottom is usually silt or sand-silt. Occasional rapids, rock rubble areas, and bedrock form the river bottom in some places. High silt loads are generated and maintained in the lower zone by public works activities such as channel-straightening and bridge building; commercial washing of sand and gravel in and around Des Moines also contributes to the turbid condition of the water. The drainage basin has much less fertile soils, and the rolling plains have nearly complete natural drainage. The lower zone ends south of Keokuk, Iowa where the Des Moines River empties into the Mississippi River.

NUTRIENT SUPPLY

Prior to extensive settling and cultivation by white immigrants, the land in the Des Moines River drainage basin was very fertile (Owen, 1852). Rains washed nutrients into the streams and rivers, but information about the relative abundance of algal growth at that time is unknown. Extensive cultivation in the drainage basin has been accompanied by an increasing use of inorganic fertilizers (nitrates, phospate, potassium, and sulfate) to improve crop yields. Consequently, inorganic fertilizers are also washed into the river by rains and snow melt. Natural runoff is supplemented by the use of clay drainage tiles, especially in the upper and middle zones of the river where natural drainage is incomplete, and many former upland marshes have been drained and cultivated.

Sewage effluents from cities located on the river and its major tributaries especially the Boone and Raccoon Rivers, as well as untreated wastes from creameries, livestock feeding areas (cattle, pig, chicken, and turkey excreta), and meat-processing plants (butchering, rendering, and glue and hide works) all contribute additional nutrients to the Des Moines River. These sources are generally independent of local precipitation, especially the sewage effluents from cities, entering the river throughout the year.

With a constant supply of ample nutrients the Des Moines River is extremely fertile in all seasons for potential algal growth. Present indications are that the amount of available nutrients will continue to increase with the increasing human population of the river drainage area.

Sewage effluents and farmland fertilizers also keep other Iowa rivers fertile. Neel and Smith (1961), studying the taste and odor problem in the municipal water supply of Cedar Rapids (Cedar River), concluded that sewage effluents and fertilizers provide sufficient nutrients in the Cedar River to support massive algal growth at all times.

An endosymbiotic blue-green alga which fixes nitrogen for its diatom hosts has been described from two members of the genus *Rhopalodia* (Drum & Pankratz, 1965). Other diatom genera probably have nutritionally important endosymbionts, mistakenly regarded as oil bodies or food reserves. Endosymbionts may be an important factor for diatom growth in general and diatom community relationships in particular.

METHODS

The Des Moines River was observed and sampled in all seasons. Over 600 diatom collections were gathered from 23 stations on the river and from 46 tributaries and lakes whose overflows eventually reach the river. Regular weekly collections were made at the Fraser dam or upstream from the mouth of Pease Creek. The Fraser dam is about halfway between the headwaters and the mouth of the river (Starrett, 1950). Sporadic sampling of the other places began in April 1961 and continued through September 1964. Three surveys of the entire river from headwaters to mouth were completed in 3 days each, in order to determine the relative homogeneity of the diatom flora and the water chemistry. Most of the river is easily accessible by road, and collecting stations were chosen for both habitat variety and ease of access in all seasons. Only a few precise quantitative measurements of diatom abundance were made. Instead, primary emphasis was placed on field observations of relative diatom abundance as a group, and on wet mount examinations of all collections prior to cleaning, to ascertain that most cells were viable when collected.

Three types of diatom growths were collected: 1) suspended or planktonic; 2) attached; and 3) benthic or bottom. Suspended diatoms were collected with an extra-fine no. 25 bolting cloth plankton net, or by settling from 40-liter water samples. The first method permitted sampling of larger volumes of water, and resulted in a greater variety of taxa per collection, whereas the second method afforded collection of small diatoms which usually passed through the plankton net. Attached diatoms were scraped from the substrate with a large jackknife or something similar. Benthic diatoms were readily collected with a large plastic syringe, sold commercially as a "gravy baster."

Diatoms were prepared for permanent mounts by addition of 50-100 ml 30% hydrogen peroxide and 100-500 mg of potassium dichromate to each sample. Several drops of a suspension of diatom frustules from each collection were dried on a no. 1 cover glass, 484mm^2, which was then affixed to a regular glass slide with Hyrax. Taxonomic determinations were made from cleaned frustules only, and taxa identified are listed in Table 2. Standard works were used for most identifications, while especially difficult problems were solved while in residence at the Academy of Natural Sciences in Philadelphia. A complete set of slides from each collection, including ringed (circled) specimens used for identifications, is deposited in the Diatom Herbarium at the Botany Department, Iowa State Univ.

A 500 ml water sample was collected at the same time and place as each diatom collection. In all, 286 water samples were analyzed for: pH, turbidity, SO_4, Fe, PO_4, SiO_2, NO_2, NO_3, methyl orange alkalinity, Cl, calcium hardness, total hardness, usually O_2 and sometimes Mn; temperature was also measured. Plastic (polyethylene) bottles were used to carry the water. These chemical data are summarized in Table 1. Chemical determinations were made with a Hach Portable Water Testing Laboratory, model DR-EL (Hach Chem. Co., Ames, Ia.). Many of the methods have been discussed by Volker (1962).

RESULTS

Extensive field notes were kept and these are combined and projected with the fresh-mount observations into the following "typical river year," as regards diatom growth. A chronological summary of all field notes can be found elsewhere (Drum, 1964). The river year begins with the Spring Melt, a 1-2 week period usually occurring in March. Water from melted ice and snow reaches the river laden with silt. The amount of silt varies with the volume of ice and snow cover, rate of melting and mean daily temperature; the more rapid the melting and subsequent runoff, the higher the silt load. The winter diatom flora is generally scoured from the river during this period. Turbidity rises to 1000 ppm or more, and the concentrations of dissolved ions are reduced as much as 50% by dilution as shown in Table 1. However, this dilution is disproportionate to the increase in the volume of water, which may be many times as great. These effects may be prolonged for up to 2 months by spring rains and the high-water period may become continuous with the Spring Flood. Usually however, a 2-6 week growth period occurs when the river level subsides between the Spring Melt and the Spring Flood. During the Spring Growth Period *Gomphonema olivaceum* quickly repopulates the rocks and other fixed substrates in shallow water (1 m or less). After 2 weeks the massive growths of this species reach a maximum and begin to break away from their substrates, and are absent after about four weeks. *Diatoma vulgare* also becomes abundant, and usually outlasts *G. olivaceum*, by several weeks. *Nitzachia dissipata, N. palea, N. subcapitellata* and *N. linearis, Navicula tripunctata, Cymatopleura solea,* and *Surirella Brightwellii* are abundant in the brown layer covering the river bottom in depths of 1m or less. The Spring Growth Period diatom plankton is first dominated by *Stephanodiscus hantzschii,* which gradually diminishes in numbers as *Synedra acus, S. ulna,* and *Fragilaria crotonensis* become more abun-

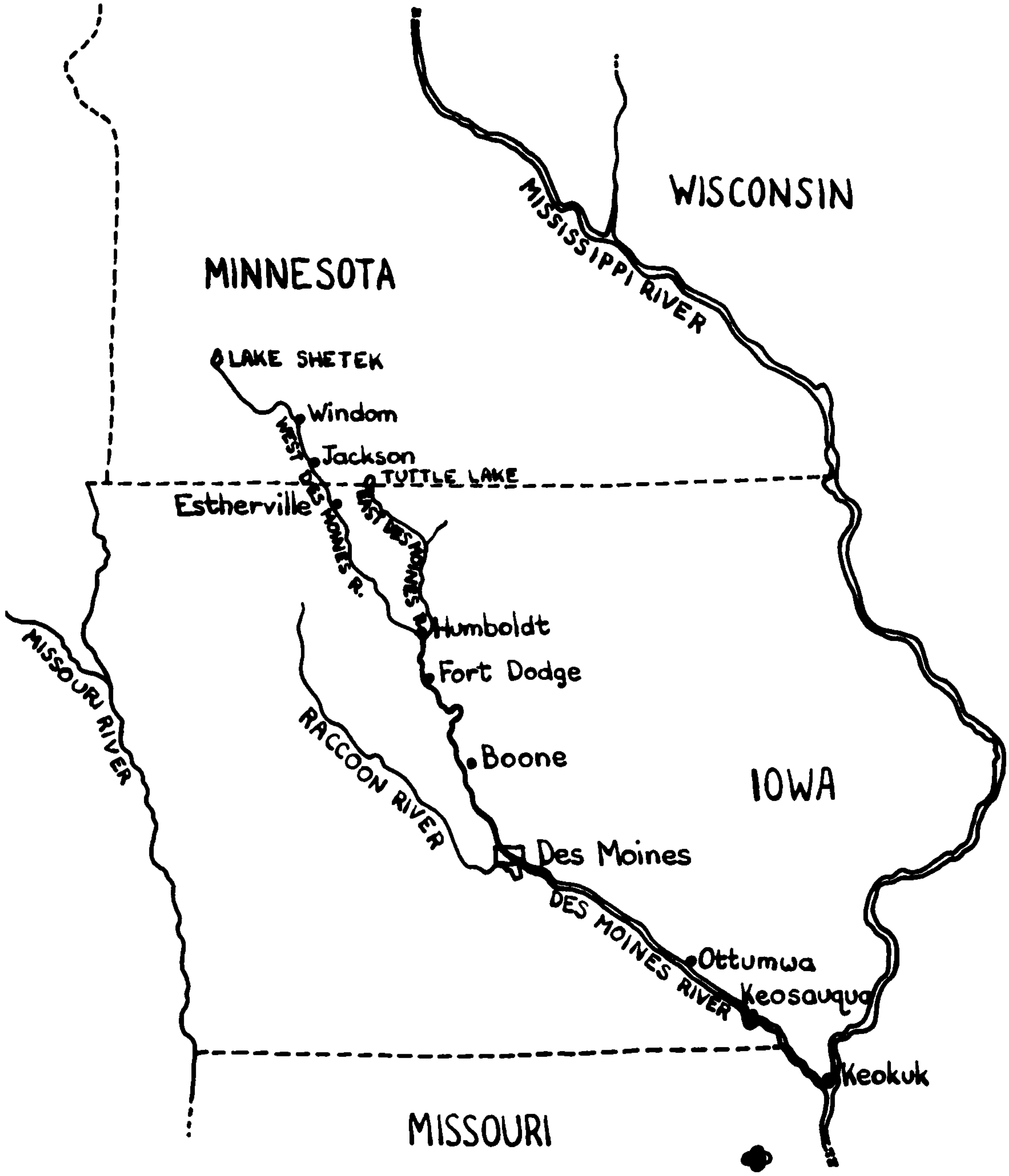

Fig. 1. *This map shows the entire course of the Des Moines River, from the two main headwater lakes, Shetek and Tuttle, to the confluence with the Mississippi River. The upper zone of the river terminates near Humboldt, the middle zone at Des Moines, and the lower zone at Keokuk.*

dant. At the end of this period however, *Melosira granulata* dominates the plankton. It is well to note that at the beginning of the period when *Stephanodiscus hantzschii* dominates the benthos as well as the plankton, its cells still have the long slender spines which are characteristic of one growth form of this species. This observation must be made from living material since the spines are dislodged or destroyed by usual cleaning methods. Contrary to the observations of Starrett (Starrett and Patrick, 1952) *Asterionella formosa* was not a "typical spring plankter in the Des Moines River" during my study.

The Spring Growth Period can last from 2 weeks to 2 months. It may be terminated by a Spring Flood or an Early Summer Flood, but in years of low spring rainfall it may be continuous with the Early Summer Growth Period.

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During the Early Summer Growth Period the river diatom assemblage is dominated by *Melosira granulata*, accompanied by *Stephanodiscus astraea* and several species of *Cyclotella*. Other algae,

Fig. 2. *This drawing illustrates the "alluvial fan or outwash deposit" which is formed when a stream entering the Des Moines River washes boulders and cobbles from the glacial deposits into the river.*

especially greens and blue-greens, also become abundant in the plankton. Benthic diatoms are sparse and attached diatoms are seldom observed. A large growth of *Amphora veneta* was observed in the splash zones around the floodgates in the Fraser dam each June (4 years in succession) which formed auxospores after attaining maximum growth. This growth period lasts 2-6 weeks. It may be terminated by a Summer Flood which lasts 1-6 weeks, or be continuous with the Summer Growth Period.

During the Summer Growth Period the river has a massive diatom plankton growth dominated by *Melosira granulata* with *Cyclotella atomus, C. Kuetzingiania, C. striata, Stephanodiscus astraea,* and some *S. hantzschii* (spineless form). These taxa often dominate the benthos, probably as a result of their settling from the plankton. *S. astraea* cells often have 1-10 epiphytic cells of *Epipyxis sp.*, a loricate chrysophyte, growing on them. Epiliths are not evident during this 4-10 week growth period which may end with either the brief Autum Flood or be continuous with the Autumn Growth Period. In the summer months *Anacystis cyanea,* a blue-green alga, was occasionally present in the plankton, but was never observed to be a dominant plankter which it was 15 years previous (Starrett and Patrick, 1952).

More diatom biomass develops in the Des Moines River during the Autumn Growth Period than at any other time. Macroscopically abundant diatom growth develops in plankton, benthos and on all stable substrates (especially rocks). Gumtow (1955) recorded greatest attached stream algal growth in Autumn, dominated by diatoms. First, a massive diatom growth develops in the plankton, dominated by *M. granulata.* In the upper reaches of the river *Diatoma vulgare* begins to colonize stable substrates about the end of September, and *Gomphonema olivaceum* follows about 2 weeks later after the water temperature remains below 10 C. As noted by Blum (1954, 1956) these two attached diatoms grow separately but in similar habitats. Colonization of stable substrates by these diatoms moves slowly downstream, especially in the middle zone where macroscopic colonies of *G. olivaceum* may not appear until late in November, although sometimes by mid-October. The benthic layer is composed of scores of common and abundant diatoms, mostly motile, pennate forms. When *M. granulata* disappears from the plankton, some of the green and blue-green algae also disappear and the river color changes from greenish-brown to light brown as *Synedra ulna* becomes the dominant plankter. The latter is then replaced by *Stephanodiscus hantzschii* (spiny form) and the river water is colored dark brown. The Autumn Growth Period lasts 2-3 months and is terminated when the water temperature falls below 1 C.

The Winter Growth Period begins almost abruptly as water turbidity falls to near zero, water level drops noticeably as many smaller tributaries freeze solid and ion concentrations increase (Table 1). Most portions of the river covered by 20 cm or less of water freeze solid, and ice in more sluggish areas is often 50 cm or more thick. The diatom plankton diminishes until only a few cells of *S. hantzschii* and occasionally some *Synedra acus* and *S. ulna* remain. Algae other than diatoms are seldom found in the plankton, benthic or attached habitats during the winter months. Epilithic growths of *Gomphonema olivaceum* continue to flourish in rapid water if the ice cover is not

Table 1. *Guide to expected perennial conditions in the Des Moines River during an average year (as extrapolated and summarized from field observations and chemical data).*

Growth period.	Expected duration and time of occurence.	Length (weeks)	Temp O° C	Turb ppm	pH	SO_4 ppm	PO_4 ppm	NO_3 ppm	NO_2 ppm	SiO_2 ppm	Cl ppm	Alk ppm	Ca ppm	Hard ppm	Period of positive growth?
Spring Melt	3/15-3/31	1-2	5	2000	8.0	35	.5	6.0	.05	12	15	160	150	225	no
Spring Growth Period	3/31-5/31	2-12	16	75	8.4	90	.2	3.0	.005	10	19	220	250	380	yes
Spring Flood	3/15-5/15	2-8	10	2000	8.2	40	.4	7.0	.025	13	12	180	150	260	no
Early Summer Flood	5/15-6/21	2-4	22	1000	8.0	80	.25	6.5	.01	20	12	270	260	400	no
Early Summer Growth period	6/1 -7/15	2-6	27	60	8.5	120	.2	4.0	.01	15	18	250	260	380	yes
Summer Flood	6/30-7/30	1-4	27	1000	8.0	50	.4	5.0	.05	25	12	230	200	320	no
Summer Growth Period	6/30-9/15	4-10	23	100	8.3	125	.3	2.4	.006	9	22	235	230	370	yes
Autumn Flood	8/21-10/21	1-2	20	200	8.0	70	.3	4.5	.02	10	20	275	250	390	no
Autumn Growth Period	9/15-12/15	12	7	40	8.4	110	.24	4.3	.016	16	23	290	280	420	yes
Winter Growth Period.	12/15-3/15	12	0	10	7.8	100	.5	4.0	.026	14	32	350	335	480	yes

prohibitive. Colonies which become frozen solid did not yield viable cells upon thawing, nor did experimentally frozen colonies. The brown benthic layer is composed mainly of *Nitzschia* species but other motile pennate diatoms are common. *S. hantzschii* is also frequently abundant in the benthic layer (as spiny form), especially in the lower zone where it is more abundant in the plankton than upstream. The Winter Growth Period usually lasts about 3 months and is terminated by the Spring Melt.

Diatom Taxa Identified from the Des Moines River

From the samples collected, 274 diatom taxa were identified, representing 38 genera. They are listed in Table 2 with indication of abundance for 85% (225). In Table 2, "A" denotes a taxon abundant enough in one or more growth periods to comprise 1-20% of the diatoms in one or more growth periods; "D" denotes a taxon which comprised more than 20% of the diatoms in one or more growth periods; "O" denotes taxa regularly found once or twice in several collections, or common in only one collection; "R" denotes a taxon found only once or a few times from all collections. Taxa denoted by "D" or "A" were found in most collections. As noted in detail below, the occurrence of many of the less common diatoms in the Des Moines River may be temporary as well as insignificant. Consequently, ecological discussion is confined to dominant and abundant taxa where pertinent. An earlier list of diatoms from the Des Moines River was published by Starrett and Patrick (1952). Patrick identified 82 taxa representing 23 genera from samples collected by Starrett from 3 stations along the river in Boone County, Iowa, including the Fraser dam. As noted in Table 2, I found 66 of the taxa identified by Patrick. After examining the slides from which she made her determinations, I have concluded that their study was not intended to be exhaustive.

Biomass Measurements

In an attempt to obtain diatom data similar to that used by Hohn and Hellerman (1963), glass slides were left suspended in the river in specially-designed holders, but these were recovered only twice. The river is heavily fished and the entire basin well-hunted; field equipment has a continuous open season. A large concrete block (50 kg), with detachable concrete hemispheres placed on the surface, was moored in a riffle area, but water froze solid around it in the winter, and high water repeatedly dragged it up onto the outwash shoal. Further attempts to use artificial substrates for determination of diatom biomass were also unsuccessful.

Measurement of diatom biomass from natural substrate in the Des Moines River is reported elsewhere (Drum, 1963). In that study epilithic colonies of *Gomphonema olivaceum* were removed from flat rocks, the area of each rock surface determined with a planimeter, the colonies from each rock weighed, and the live weight determined to be 0.7 grams per square centimeter. This equals 28 US tons per acre. These colonies contained 3% dry weight organic matter and 16% ash.

One determination of plankton biomass was made by centrifuging 4 samples of fresh river water (2-500 ml samples and 2-1000 ml samples), extracting the pigments from the collected cells with 25 or 50 ml of methyl alcohol and measuring the absorption at 635 and 665mu in a Beckman DU spectrophotemeter. The results are shown in Table 3; the collection or sample contained about 98% diatoms, with about 1% green algae and 1% blue-green algae; the ratio of absorption peaks for chlorophyll A to chlorophyll C is only 0.15 greater than the same ratio obtained from pure cultures of *Surirella ovalis*. In the table, the expansion of chlorophyll per liter was based on the curve drawn by McConnell and Sigler (1959), who determined that the average photosynthetic cell contains about 1% chlorophyll, dry weight. The wet weight was based on the assumption that the diatoms were about 90% water, as lost by heating at 110 C. This transient biomass was moving downstream a ton or more per hour, from headwaters to the river's mouth at Keokuk, in a similar manner for 5 months (1963). A tremendous quantity of living biomass developed in the river, entering the Mississippi River at a rate of over 1000 tons per month (since discharge was greater than 90 cubic feet per second at the confluence). Perhaps even more astounding, is the fact that there was 2.5 times as much organic matter as live cells. This is based on a determination of suspended organic matter made at the same time as the chlorophyll extractions. Ten 20 ml samples of fresh river water were dryed in crucibles, brought to constant weight at 110 C, and then brought to constant weight again after ignition at 900 C.

Hemispherical *Gomphonema olivaceum* colonies 1-2 cm in diameter were sectioned when frozen, and viable cells (prior to the freezing) were observed nearly evenly distributed throughout. Since the polysaccharide stalks generated by these cells appeared to have some

Table 2. *Diatom taxa found in the Des Moines River.*

Taxon	Relative abundance	Reported by Starrett and Patrick?
Anchnanthes exigua Grun.	C	
Achnanthes exigua v. *heterovalva* Krasske	C	
Achnanthes hauckiana v. *rostrata* Schutz	O	
Achnanthes hungarica Grun.	A	
Achnanthes lanceolata Bréb.	A	
Achnanthes lanceolata v. *elliptica* Cl.	C	
Achnanthes minutissima Kütz.	C	
Amphipleura pellucida Kütz.	C	
Amphiprora ornata J.W. Bail.	C	
Amphora montana Krasske.	A	
Amphora ovalis Kütz.	C	Yes
Amphora ovalis v. *pediculus* Kütz.	C	
Amphora thermalis Hust.	R	
Amphora veneta Kütz.	A	
Anomoeoneis sphaerophora (Kütz.) Pfitz.	C	
Asterionella formosa Hass.	C	Yes
Bacillaria paradoxa Gmel.	O	
Caloneis amphisbaena (Bory) Cl.	C	
Caloneis bacillum (Grun.) Mereschk.	C	
Caloneis Lewisii Patr.	C	Yes
Caloneis Schumanniana v. *biconstricta* Grun.	C	
Caloneis silicula v. *truncatula* Grun.	O	
Cocconeis pediculus Ehr.	A	Yes
Cocconeis placentula Ehr.	C	
Cocconeis placentula v. *euglypta* (Ehr.) Cl.	C	
Coscinodiscus pygmaeus v. *micropunctatus* M. Perag. & Herib.	R	
Cyclotella atomus Hust.	A	
Cyclotella catenata Brun	O	
Cyclotella Kuetzingiana Thw.	A	
Cyclotella Menghiniana Kütz.	A	Yes
Cyclotella nana Hust.	A	
Cyclotella pseudostelligera Hust.	C	
Cyclotella stelligera Cl. & Grun.	C	
Cyclotella striata (Kütz.) Grun.	A	
Cyclotella striata v. *bipunctata* Fricke.	A	
Cylindrotheca gracilis (Bréb.) Grun.	R	
Cymatopleura cochlea Brun.	C	
Cymatopleura elliptica (Bréb.) W. Sm.	C	
Cymatopleura solea (Bréb.) W. Sm.	A	
Cymbella affinis Kütz.	A	
Cymbella cistula (Hempr.) Grun.	C	
Cymbella helvetica Kütz.	C	
Cymbella hybrida Grun.	O	
Cymbella lanceolata (Ehr.) V.H.	O	
Cymbella mexicana (Ehr.) Cl.	C	Yes
Cymbella norvegica Grun.	O	
Cymbella perpusilla A. Cl.-Eul.	R	
Cymbella prostrata (Berk.) Cl.	A	
Cymbella rhomboides Boyer.	C	Yes
Cymbella sinuata Greg.	C	
Cymbella tumida (Bréb.) V.H.	A	
Cymbella minuta Hilse ex Rabh.	A	Yes
Diatoma vulgare Bory.	D	Yes
Diploneis elliptica v. *pygmea* A. Cl.-Eul.	O	
Eunotia formica Ehr.	R	
Eunotia curvata (Kütz.) Lagerst.	0	
Eunotia monodon v. *major* f. *bidens* W. Sm.	R	
Eunotia valida Hust.	R	
Epithemia sorex Kütz.	O	
Epithemia turgida (Ehr.) Kütz.	0	
Epithemia zebra v. *saxonica* (Kütz.) Grun.	O	
Fragilaria capucina Des Mazieres.	C	
Fragilaria capucina v. *mesolepta* (Rabh.) Grun.	C	
Fragilaria construens (Ehr.) Grun.	C	
Gragilaria crotonensis Kitton.	A	
Fragilaria Harrissonii v. *dubia* Grun.	O	
Fragilaria intermedia Grun.	A	
Fragilaria lapponica Grun.	0	
Fragilaria pinnata Ehr.	O	
Frustulia vulgare Thw.	C	Yes
Gomphonema affine Kütz.	C	
Gomphonema angustatum v. *obesa* Lauby.	O	
Gomphonema accuminatum Ehr.	C	
Gomphonema accuminatum v. *Brebissonii* (Kütz.) Cl.	O	
Gomphonema accuminatum v. *coronata* (Ehr.) W. Sm.	O	
Gomphonema bohemicum Reichelt & Fricke.	O	
Gomphonema brasiliense Grun.	R	
Gomphonema constrictum Ehr.	C	
Gomphonema gracile Ehr.	C	
Gomphonema intricatum v. *pumila* Grun.	C	
Gomphonema lanceolatum Ehr.	C	
Gomphonema lanceolatum v. *insignis* (Greg.) Cl.	C	
Gomphonema longiceps v. *subclavata* f. *gracilis* Hust.	C	
Gomphonema olivaceum (Lyngb.) Kütz.	D	Yes
Gomphonema parvulum Kütz.	A	Yes
Gomphonema parvulum v. *micropus* (Kütz.) Cleve.	C	Yes
Gomphonema sphaerophorum Ehr.		
Gomphonema ventricosum Greg.	C	
Gyrosigma accuminatum (Kütz.) Rabh.	C	Yes
Gyrosigma attenuatum (Kütz.) Cl.	C	Yes

Gyrosigma scalproides (Rabh.) Cl.	C	Yes
Hantzschia amphioxys (Ehr.) Grun.	C	Yes
Melosira ambigua (Grun.) O. Müll.	C	Yes
Melosira granulata (Ehr.) Ralfs.	D	Yes
Melosira granulata v. *angustissima* Müll.	A	Yes
Melosira granulata v. *muzzanensis* Meister.	C	
Melosira granulata v. *procera* (Ehr.) Grun.	C	
Melosira italica v. *valida* (Ehr.) Kütz.	A	
Melosira varians Ag.	A	Yes
Melosira italica v. *tenuissima* (Grun.) O. Müll.	C	
Meridion circulare Ag.	C	
Navicula accommoda Hust.	O	
Navicula americana v. *bacillaris* Herib. & Perag.	R	
Navicula bacilloides Hust.	O	
Navicula biconica Patr.	O	
Navicula canalis Patr.	O	
Navicula cincta (Ehr.) Kütz.	C	
Navicula cincta v. *rostrata* Reim.	O	
Navicula circumtexta Meister	R	
Navicula citrus Krasske.	A	
Navicula cocconeiformis Greg.	C	
Navicula confervacea (Kütz.) Grun.	O	
Navicula contenta f. *biceps* Arn.	O	
Navicula cryptocephala Kütz.	A	
Navicula cryptocephala v. *veneta* (Kütz.) Grun.	C	
Navicula cuspidata Kütz.	C	Yes
Navicula cuspidata v. *ambigua* (Ehr.) Cl.	A	Yes
Navicula cuspidata v. *Heribaudi* Perag.	C	
Navicula decussis Østr.	C	
Navicula demissa Hust.	O	
Navicula dicephala (Ehr.) W. Sm.	O	
Navicula dicephala v. elginensis (Greg.) Cl.	O	
Navicula disjuncta Hust.	O	
Navicula explanata Hust.	C	
Navicula gastrum Ehr.	C	
Navicula germainii Wallace.	C	
Navicula tripunctata (Müll.) Bory.	A	Yes
Navicula Grimmei Krasske.	O	
Navicula hassiaca Krasske.	O	
Navicula hungarica Grun.	A	Yes
Navicula hungarica v. *capitata* (Ehr.) Cl.	O	Yes
Navicula hungarica v. *linearis* Østr.	O	
Navicula integra (W. Sm.) Ralfs	O	
Navicula lanceolata (Ag.) Kütz.	C	Yes
Navicula lapidosa Krasske.	O	
Navicula longa (Greg.) Ralfs	O	
Navicula menisculus Schum.	C	
Navicula minima Grun.	C	
Navicula mucicoloides Hust.	A	
Navicula mutica v. *binodis* Hust.	0	
Navicula mutica v. *Cohnii* (Hilse) Grun.	O	
Navicula mutica v. *tropica* Hust.	A	
Navicula paanaensis Cl.-Eul.	O	
Navicula paludosa Hust.	R	
Navicula pelliculosa (Bréb.) Hilse.	A	
Navicula peregrina (Ehr.) Kütz.	O	Yes
Navicula placentula v. *latiuscula* (Grun.) Meister.	C	
Navicula pupula Kütz.	A	Yes
Navicula pupula v. *capitata* Hust.	C	Yes
Navicula pupula v. *mutata* (Krasske) Hust.	C	
Navicula pupula v. *pseudopupula* (Krasske) Hust.	O	
Navicula pygmaea Kütz.	C	Yes
Navicula radiosa v. *tenella* (Bréb.) Grun.	C	
Navicula Reinhardti Grun.	O	
Navicula rynchocephala Kütz.	A	Yes
Navicula scutelloides W. Sm.	R	
Navicula seminuloides v. *sumatrana* Hust.	R	
Navicula subhamulata v. *undulata* Hust.	O	
Navicula symmetrica Patr.	A	
Navicula tenera Hust.	O	
Navicula texana Patr.	O	
Nitzschia hungarica Grun.	A	Yes
Nitzschia ignorata Krasske.	O	
Nitzschia Kuetzingian Hilse.	C	
Nitzschia linearis W. Sm.	D	Yes
Nitzschia Lorenziana v. *subtilis* Grun.	R	
Nitzschia microcephala Grun.	O	
Nitzschia microcephala v. *elegantula* V. H.	O	
Nitzschia palea Kütz.	D	Yes
Nitzschia paleaformis Hust.	O	
Nitzschia parvula Lewis.	C	
Nitzschia punctata (W. Sm.) Grun.	C	
Nitzschia recta Hantz.	A	
Nitzschia reversa W. Sm.	A	
Nitzschia romana Grun.		
Nitzschia sicula (Castr.) Hust.	O	
Nitzschia sigma (Kütz.) W. Sm.	A	Yes
Nitzschia sigmoidea (Ehr.) W. Sm.	A	Yes

Nitzschia sinuata v. *tabellaria* Grun.	R	
Nitzschia spiculoides Hust.	O	
Nitzschia subacicularis Hust.	C	
Nitzschia subcapitellata Hust.	A	
Nitzschia tarda Hust.	O	
Nitzschia thermalis Kütz.	C	
Nitzschia tryblionella Hantz.	C	
Nitzschia tryblionella v. *debilis* (Arn.) Mayer.	O	
Nitzschia tryblionella v. *levidensis* (W. Sm.) Grun.	O	
Nitzschia tryblionella v. *victoriae* Grun.	C	
Nitzschia valida Cl.	C	
Nitzschia vermicularis (Kütz.) Hantz.	C	
Opeophora Martyi Herib.	R	
Pinnularia acrosphaeria Bréb.	O	
Pinnularia borealis Ehr.	O	
Pinnularia Braunii v. *amphicephala* (Mayer) Hust.	O	
Pinnularia intermedia (Lagerst.) Cleve.	O	
Pinnularia interrupta W. Sm.	O	Yes
Pinnularia karelica Cl.	O	
Pinnularia microstauron (Ehr.) Cl.	A	
Pinnularia obscura Krasske.	O	
Pinnularia viridis (Nitzsch) Ehr.	O	Yes
Pleurosignma delicatulum. W. Sm.	A	
Rhoicosphenia curvata (Kütz.) Grun.	C	
Rhopalodia gibba (Ehr.) Müll.	C	Yes
Rhopalodia gibba v. *ventricosa* (Kütz.) V. H.	O	
Rhopalodia gibberula (Ehr.) Müll.	C	
Stauroneis anceps Ehr.	O	
Stauroneis palustris Hust.	O	
Stauroneis phoenicenteron Ehr.	O	
Stauroneis smithii Grun.	C	Yes
Stauroneis Wislouchii Poretzky & Anisimowa	O	
Stephanodiscus astraea (Ehr.) Grun.	A	Yes
Stephanodiscus astraea v. *minutula* (Kütz.) Grun.	A	Yes
Stephanodiscus dubius (Fricke) Hust.	O	
Stephanodiscus hantzschi Grun.	D	
Stephanodiscus niagarae Ehr.	C	Yes
Surirella angusta Kütz.	O	
Surirella bidens Hust.	C	Yes
Surirella biseriata Bréb.	C	
Surirella brightwellii W. Sm.	A	
Surirella gracilis (W. Sm.) Grun.	O	
Surirella Kittonii. A. S.	O	
Surirella ovalis Bréb.	A	Yes
Surirella ovata Kütz.	C	
Surirella ovata v. *pinnata* W. Sm.	C	
Surirella ovata v. *salina* W. Sm.	C	
Surirella robusta v. *splendida* (Ehr.) V. H.	C	Yes
Surirella spiralis Kütz.	R	
Surirella striatula Turp.	O	
Surirella tenera v. *nervosa* A. S.	O	Yes
Synedra acus Kütz.	D	Yes
Synedra amphicephala Kütz.	A	
Synedra amphicephala v. *fallax*. Grun.	O	
Synedra berolinensis Lemmerm.	C	
Synedra gaillonii (Bory) Ehr.	O	
Synedra nana Meister.	C	
Synedra parasitica W. Sm.	O	
Synedra parasitica v. *subconstricta* Grun.	C	
Synedra rumpens Kütz.	O	
Synedra tabulata (Ag.) Kütz.	C	
Synedra tabulata v. *accuminata* Grun.	O	
Synedra ulna (Nitzsch) Ehr.	D	Yes
Synedra ulna v. *aequalis* (Kütz.) Hust.	C	
Synedra ulna v. *danica* (Kütz.) Grun.	A	
Synedra ulna v. *oxyrhynchus* f. *contracta* Hust.	C	
Synedra vaucheriae Kütz.	A	
Synedra vaucheriae v. *capitellata* Grun.	C	
Thalassiosira fluviatilis Hust.	O	

Table 3. *Colorimetric measurement of plankton biomass and gravimetric determination of plankton organic matter from the Des Moines River, October 1963.*

Milliliters in sample after methyl alcohol extraction of centrifuged plankton pellet	25
Absorption at 635 mu	0.097
Absorption at 665 mu	0.354
Ratio 665/635	3.6
Milligrams of chlorophyll/liter	0.06
Grams of dry weight of cells/m^3	6.0
Pounds of cells/hr at 90ft^3/sec discharge	2430
Tons/month	875
Milliliters of river water	20
Weight of residue	5.3 mg
Weight of organic matter	3.2 mg
Percent organic matter	60%
Grams of organic matter/liter	0.15
Tons/month at 90ft^3/sec discharge	2190

function in nutrient supply and transport, the stalk material was separated from frustules and debris after boiling water and hot methyl alcohol extractions, at a chloroform-water interface after 3000 rpm centrifugation for 10 min. Dilute HCl, H_2SO_4, HNO_3, and HF all destroyed the material. However, it was insoluble in both hot and cold treatments of: 8 N KOH, 1-25% NaOH, H_2O, 20% NH_4OH, 10% phenol, petroleum ether, methanol, chloroform, ethyl alcohol, alkaline hypochlorite and formamide. Enzyme digestion by pectinase and lysozyme also gave negative results. The stalk material was mucoidal in appearance and texture prior to drying. After drying, a white powder resulted which did not regain the former mucoidal texture when water was added (distilled or river water). Staining first with ruthenium red, and then methylene blue, showed that the stalk material as such occurs only extracellularly. This implies that a polymerisation of sugar units takes place at the cell surface as the secretion enters the surrounding water.

DISCUSSION

Diatoms of Rivers

Diatoms are an abundant algal group in the Des Moines River and other major rivers of the United States as well (Williams and Scott, 1962). After several years of sampling these rivers certain patterns of river diatom plankton became evident (ibid). Most of my observations with regard to most abundant diatom taxa agree with the nationwide data. All nine most-abundant diatoms in the Des Moines River (*Diatoma vulgare, Gomphonema olivaceum, Melosira granulata, Nitzschia dissipata, N. Linearis, N. palea, Stephanodiscus hantzschii, Synedra acus,* and *S. ulna)* have "occurred one or more times among the first four most abundant species in plankton samples" collected by the Water Quality Network (ibid). In addition, 27 of the 51 taxa in my study which occurred in the 1-20% abundance range were also listed in the above-quoted category of the Network. However, many of the more abundant diatoms in the Des Moines River occur in benthic or attached habitats, which makes comparison with the planktonic data of the Network strictly valid only for taxa characteristic of the plankton such as *Melosira granulata, Stephanodiscus hantzschii* and *Synedra acus.*

The Des Moines River is part of the Mississippi River drainage basin. In other rivers of this system, including the Upper Mississippi itself, *Melosira granulata* and *Stephanodiscus hantzschii* are two of the most abundant diatoms, just as they are in the Des Moines River. Furthermore, according to the Network data, *S. hantzschii* is perhaps the most prolific river diatom in the United States. Two more of the 9 most abundant diatoms in the Des Moines River, *Diatoma vulgare* and *Synedra ulna,* are major components of Great Plains rivers, including the Missouri. The permanent and non-permanent hardness of the Des Moines River is sufficient to permit abundant growths of *Surirella Brightwellii, Pleurosigma delicatulum* and *Caloneis amphisbaenia* which are species characteristic of hardwater rivers of the southwest such as the Arkansas River (Williams and Scott, 1962).

The wide range in water chemistry of different rivers in which the same diatoms are dominant lends credence to the idea that there is a group of "river diatoms," for which some aspect of the river environment is more important than concentration of dissolved ions. Whether these diatoms are necessarily "rheophilic" or "current-loving" is obscured by the fact that many of them are also dominant forms in lakes and ponds. Little information is available which could be used to establish the various genotypic and phenotypic characteristics of the more important diatoms. Meaningful information is unobtainable unless lineage is known. Thus, we can only surmise at the metabolic or physiological differences between diatoms producing the same type of frustule in widely differing types of water, and the importance of these differences in controlling diatom growth. If there are no genetic differences, then some diatoms are prolific in a wide range of habitats. For them, gross differences in total ionic strength of the environment are readily tolerated. This implies a tonicity-adjustment facility or perhaps osmotic indifference within certain limits. Other workers (Lewin and Guillard, 1963, Hendey, 1964) have reached the latter conclusion, but cannot explain it. Perhaps the subfrustular zone (Drum and Pankratz, 1964) as well as other extracellular polysaccharides control ion movement to the cell membrane. The amount of extracellular diatom polysaccharides in the form of tubes, sheaths or stalks is often greater than the amount of viable cells. These structures may aid in the capture of nutrients as suggested by Bennett (1963) for other types of cells.

Protozoans and many invertebrates were usually found living within the Benthic layer of diatoms and immeshed in colonial growths attached to fixed substrates. Ciliate and amoeboid cells were frequently stuffed with diatom cells. Nematodes were not observed to eat diatoms or to pass frustules with their feces. Insect larvae, notably shore flies and caddis flies, were often full of frustules when sectioned or squashed. But, at no time did grazing by an animal population appear to limit or reduce diatom biomass in detectable amounts. This condition is probably true of other rivers as well (Van Landingham, 1964). Consumption or use by other organisms in the immediate environment of river diatom productivity is negligible as most of it eventually empties into the sea. Since diatom cells remain viable for several months in cultures after ceasing to divide, it is reasonable to presume that most of the cells produced in plankton remain viable for as long as stable conditions exist.

The amount of substrate surface area was limiting during the growth periods where massive epilithic growths occurred, so that replacement proceeded only as old colonies were torn off rather than by death. The resulting bare patches were usually recolonised within 7-10 days. Invasion by animals occurred as soon as new growth began, but with no apparent diatom depletion.

Physical factors and Diatom Growth

Water is generally the most important limiting factor for the growth and distribution of land plants in the presence of a sufficient nutrient supply. In the Des Moines River light and flow are probably the most important limiting factors for submerged algal growth in the presence of sufficient nutrients. The two abiotic factors regulating light penetration of river water are silt load, and ice and snow cover. These are all in turn largely controlled by annual precipitation in the river drainage basin. In effect, "dry years" on land may be "light years" in the river, with maximum algal growth during the latter; "wet years" on land may be "dark years" in the river, as heavy rains or prolonged rains remove diatom populations by highwater scouring and subsequently prevent renewed growth by maintaining turbidity at levels which restrict light penetration. Nelson and Scott (1962) concluded that river discharge was the limiting physical factor for the biomass of a river community at any one time, due to both scouring and increased silt load which prevented growth of vascular aquatic plants as well as algae. Douglas (1958) also concluded that periodicity of diatoms depends on flow in a small stony stream.

The fact that more diatom cells were collected from the Plankton during the Winter of 1963-64, when snowfall was very light, than in the two previous winters may show that light penetration was affected by precipitation in all seasons. The thin and incomplete ice cover and low turbidity in the lower zone possibly permitted the massive growth of planktonic and benthic populations of *Stephanodiscus hantzschii* during the winter in that zone of the river.

With plenty of light and nutrients available, temperature appears to regulate the kinds of diatoms common during a particular growth period. Seilheimer and Eichelberger (1962) also concluded that temperature and available light were the most important factors regulating algal growth in the Ohio River, based on daily samples, in which they found diatoms to generally be the dominant algal group.

There seem to have been no seasonal pulses of diatoms as a group in the Des Moines River, although some diatoms were more prevalent or dominant during certain seasons each year. Patrick (1948) reports that diatoms frequently have a Spring and also an Autumn "pulse." Presumably as a result of similar light and temperature conditions at those times in the temperate zones. As noted in the above chronology of annual diatom growth in the Des Moines River, some diatoms produced maximum growth in the Spring and also in the Fall; others occurred only during the Summer; some peaked during the Winter; and some grew steadily throughout the year apparently unaffected by seasonal changes.

Melosira granulata was the most important "warm water" diatom and seemed to be restricted to the plankton. It grew best when the water temperature was above 20 C and apparently little or no growth occurred below 15 C.

Gomphonema olivaceum was the most important attached diatom in the Des Moines River, and massive colonies developed only when the water temperature was 10 C or less. It was thus abundant from late Fall through Spring (6-7 months) and almost non-existent in collections made during the warmer months. Marked growth peaks for this organism were recorded in late Autumn and early Spring by Blum (1954, 1956) and Jørgensen (1957). Thermal control here may involve both the physiology of stalk secretion by this diatom and destruction of these stalks by bacterial or fungal activity. Downstream from the Center Street dam at Des Moines, Ia., no colonies of *G. olivaceum* were ever observed or collected from the Des Moines River (Lower Zone). This may indicate that a toxic or inhibitory substance entered the river at the city of Des Moines. Other diatoms, planktonic and benthic, did not appear to be affected. This corresponded directly with the absence of diatoms, in the lower zone only, from ectoparasitic copepods collected from fish downstream from the Center Street dam; copepods upstream were usually covered with a brown layer of diatoms, primarily *Gomphonema* species attached to the parasites by short stalks (Fee and Drum, 1965).

Stephanodiscus hantzschii occurred abundantly throughout the year, but grew best when the water temperature was below 5 C; an apparent concurrent development of slender spines, hair-like and up to 40 microns long, projecting from the valve mantle, was observed at 0-5 C. Spines such as these did not occur during the warmer half of the year. The physiological cause for their development is probably due to the need for increased surface area for the absorption of nutrients, less available in the lower energy situation.

Diatom Population Replenishment.

In a river, as long as it is a flowing body of water moving downhill, everything including the bedrock is transient. Thus replenishment is the keynote to the establishment and maintenance of river diatom communities. This means not only water and essential nutrients, but also the diatoms themselves.

There appear to be 3 sources of diatom inoculum for the Des Moines River following high water scouring: 1) lakes and ponds; 2) impoundments behind dams across the river; 3) permanent springs, seeps, quarries and pools in open pit coal or gypsum mines. The two headwater lakes, Shetek and Tuttle, support rich diatom floras, and most of the taxa listed in Table 2 could be found in collections taken from the overflows of these two lakes. They are 2 relatively permanent sources of inocula. Other lakes in the upper zone are mostly smaller, but their collective diatom floras are rich. This may in part be due to the wide range in their water chemistry. Many of these smaller lakes overflow only intermittently into the river; sometimes overflow may be interrupted for several years. This could cause concurrent or sporadic appearances of some diatom taxa in the river and also in my collections.

Impoundments behind lowhead dams in the upper and middle zones of the river are slowly filling up with silt and fine sand. Some have fringes of rooted aquatic vegetation. Siltation occurs when silt settles out of river water faster than it is washed away. Scouring or washing away of benthic diatom growths does not occur in the impoundments with the completeness observed in other portions of the river. Diatoms from small tributaries and the main river upstream, especially in times of highwater and flooding, settle out with the silt and fine sand particles. Eventually, motile pennate diatoms migrate to the surface of the mud and resume benthic, attached or planktonic growth (Van Heurck, 1896). The phenomenon of diatom migration up through several centimeters of overlying mud and fine sand can be observed in collections brought back to the laboratory and allowed to stand undisturbed for 6-10 hours in either light or dark conditions. Diatoms seem to react with a negative geotropism when agitated or surrounded by particles 1-20 microns in diameter, which may be a survival response. This relates to the fact that 40 of the 60 most abundant diatoms in the river are motile pennate forms, as are 219 of the 274 diatom taxa found in the river; motile forms are better able to withstand and recover from occasional burial.

Springs and seeps, especially those located on steep hillsides or on bluffs overlooking the river, can provide not only many of the common pennate diatoms, but also are sources of some rarer forms such as *Eunotia formica, Pinnularia borealis, Nitzschia Lorenziana v. subtilis* and *Surirella spiralis.* Water from pools in open-pit coal and gypsum mines and quarries is occasionally drained into the river, but this does not seem to be a stable source of diatoms.

Different kinds of diatoms can be introduced into the river by the following means: viable airborne cells; migratory waterfowl [since the Des Moines River is on a migratory waterfowl flyway (Schlicting, 1960: 1964)]; migratory amphibians, especially the snapping turtle which has diatoms as well as *Basicladia* growing on its carapace; aquatic rodents, particularly the muskrat (Errington, 1963).

Because of the transient factor, taxa may be brought to the river occasionally, where they thrive and pass on downstream never to reappear during the course of any one investigation. This may explain the appearance of *Gomphonema brasilense* in just 1 collection from one place; although many frustules were found in this collection, no other frustules were ever found in the river, even in samples taken the same morning upstream and downstream from the place. Another case is *Bacillaria paradoxa,* which occurred abundantly in two collections, 200 km and 18 months apart.

Some diatoms became important numerically in just the last year of study, after no known previous occurrence in the river. *Caloneis amphisbaena* was one of these. It was originally found in a spring in the lower zone of the river for two years. It appeared suddenly in large numbers in the benthos during the Spring Growth period in 1963, and was common thereafter throughout the river in all seasons. This points out the advantage enjoyed by those who study diatoms in lakes, where a permanent record of diatom growth may lie at the bottom, where sediments accumulate over the years without being washed away each time it rains heavily. The construction of two large dams, the Redrock and the Saylorville, will presumably provide semi-stable sediments which will be suitable for "core sample" studies in the future.

Conclusions

1. The Des Moines River exhibits a predictable yearly cycle of diatom growth phases which are generally regulated by precipitation and temperature. Benthic and attached diatom growth is further regulated by localised physical factors, particularly substrate stability. Planktonic diatom assemblages tend to be similar throughout the river during any particular growth period.

2. Abundant nutrients for massive diatom growth, provided by sewage and agricultural fertilizers, are always present in the Des Moines River. The massive diatom growths which did occur were terminated by flushing and scouring due to increased water flow.

3. The major sources of diatoms to replenish the river after water flow subsided were the two headwater lakes.

4. The one distinct river diatom habitat in this study was the rock riffle, which had two types: one type results from the river running over local limestone bedrock rock rubble; the second type is produced from alluvial outwash fans deposited at the mouths of most streams entering the Des Moines River.

5. The only diatom distribution anomaly observed was the apparent inability of *Gomphonema spp.* to grow as attached colonies anywhere in the lower zone (below the city of Des Moines and the confluence of the Raccoon and Des Moines Rivers) of the river.

6. The future growth and distribution of diatoms in the Des Moines River will be increasingly regulated by human activities as both human population and development increase. The biggest immediate changes will probably result from the influence of the two large impoundments at Saylorville and Red Rock respectively, created by dams finished after the completion of this study.

7. The Des Moines River is a marvelous system for diatom study.

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