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Effects of burning on soil algae in a restored tallgrass prairie.

Sandra Lou Kragskow

EFFECTS OF BURNING ON SOIL ALGAE IN A RESTORED TALLGRASS PRAIRIE

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Sandra Lou Kragskow

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ProQuest LLC.
789 East Eisenhower Parkway
P.O. Box 1346
Ann Arbor, MI 48106 - 1346

THESIS ACCEPTANCE

Accepted for the faculty of the Graduate College, University of Nebraska, in partial fulfillment of the requirements for the degree Master of Arts, University of Nebraska at Omaha.

Thesis Committee

Name	Department
A Thomas Wolan	Biology
Larry J Stephens	Math/CS
Thomas B Bragg	Biology
Ann Antlfinger	Biology

Barbara A. Haythorne
Chairperson

29 November 1982
Date

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S.L.K.

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INTRODUCTION

Algae are present in almost every soil throughout the world, with the Chlorophytes and Cyanophytes the most common (Bold, 1970). Algal abundance and diversity in any particular soil seems to be dependent on, and respond to, changes in light, moisture, pH, nutrients and substrate (Shields and Durrell, 1964).

Algae are important constituents of the soil for they: 1) represent the primary colonizers in denuded areas, 2) bind soil particles and prevent erosion, 3) aerate and add organic matter to the soil, 4) fix nitrogen, and 5) serve as a food source for small animals (Durrell, 1959). Their succession on denuded areas is especially noteworthy. For example, Starks (1979), in a study of algal colonization on a surface mined area, described algal succession by an increase in abundance and diversity over time. He felt algae were able to colonize the area due to minimal plant cover, minimal litter and high solar radiation. Even though soil algae are widely distributed and occupy important positions in the ecology of terrestrial habitats, they have received relatively little attention. Particularly lacking is meaningful ecological research (Starks, Shubert and Trainor, 1981). The most extensive investigations, which have been carried out in Russia, unfortunately are not

readily available (Cameron, 1974).

The general tendency for algae to colonize denuded areas suggests that there is likely to be some relationship between burning and algal populations. However, information is extremely limited concerning the effects of burning on abundance and diversity of soil algae. Fritsch and Salisbury (1915) noted that the first organisms to colonize soil on burned English heath were algae, especially unicellular Chlorophytes. Cullimore and McCann (1973) noticed a decrease in algal abundance four weeks after burning a natural Canadian grassland.

The effects of burning on the grassland soil microclimate have been studied by many researchers including: Kucera and Ehrenreich (1962) and Ehrenreich and Aikman (1963). A major result of fire is the elimination of vegetative cover and litter. When these researchers compared burned and unburned areas, they found burned areas displayed: 1) decreased soil moisture, 2) increased light intensities, 3) increased pH, and 4) slightly increased or inappreciably changed nutrients, namely nitrate-nitrogen, phosphorous and potassium.

Since fire alters the soil microclimate, algae will very likely be affected and may exhibit detectable post-fire changes. One can understand the effect fire has on soil algae by studying how environmental changes affect soil algae and how burning alters a grassland soil microclimate.

Broady (1979) found algal flora to be richest when the soil was denuded of vegetation and exposed to the atmosphere. Starks and Shubert (1982) noted fluctuations in algal abundance correlated with fluctuations in precipitation and soil moisture; abundance increased during periods of high precipitation and soil moisture, and decreased during dry periods. In addition, moist soils have a more varied algal flora than do dry soils (Shields and Durrell, 1964). Cameron (1964) found exposed, well-lighted areas supported more abundant algal growths than grassy areas. MacEntee and Bold (1974) stated basic soils support a more abundant and diverse Cyanophyte flora than do acidic soils. Since fire may cause an increase in pH (Ehrenreich and Aikman, 1963), an increase in the Cyanophyte flora may occur.

The purpose of my thesis research was to: 1) record the soil algal flora present at Allwine Prairie Preserve, an eastern Nebraska reestablished grassland, and 2) study the effects of fire on the abundance and diversity of prairie soil algae over one growing season. Emphasis was placed on monitoring the changes in algal abundance and diversity in relation to precipitation, litter cover, soil pH, and soil nutrients such as nitrate-nitrogen, phosphorous and potassium.

MATERIALS AND METHODS

Study Site

My thesis research was conducted at Allwine Prairie Preserve, a 65 ha reestablished grassland research area located in Douglas County, in eastern Nebraska. Previously a cultivated, terraced cropland, the area was seeded with native grasses in 1970 (Bragg, 1978). The portion of the preserve used for this study was dominated by little bluestem (*Andropogon scoparius*), with some sideoats grama (*Bouteloua curtipendula*) and a dense layer of litter. The soil of the study site was classified as Marshall silty clay loam with a high available water capacity, and approximately a 3 % slope. Of the 75 cm annual precipitation, about 75 % falls during the six-month period from April to September (United States Department of Commerce, 1981).

Treatment of the Study Plots

Two 9 m x 6 m upland plots were established in the southwest portion of the prairie, one an experimental plot and the other a control plot (Figure 1). A controlled burn was carried out on the experimental plot 25 April 1981. Previous management of the study area consisted of mowing in 1970, 1971, 1972 and burning in late April of 1975, 1976 and 1978.

Climatological Measurements

Precipitation data were obtained from the Omaha (North), Nebraska, National Weather Service located approximately 11 km east of Allwine Prairie.

Soil Sampling Procedure

Within each plot three transects were established. Surface soil samples (1 - 2 cm deep) were removed from each transect at approximately 1 m intervals. Soil samples were pooled for each transect. A total of 30 samples were removed from each plot. Soil samples were collected by use of a small garden trowel which was washed in 70 % alcohol between transects in order to prevent cross contamination. Samples were placed in plastic bags for transport to the laboratory.

March evaluations were conducted to assess pre-burn conditions; subsequent evaluations were conducted in May, June, July, August and September at approximately five week intervals. For simplicity, reference in the text will be to March evaluations for pre-burn conditions, May for evaluations one week after burning, and June, July, August, and September evaluations for 7, 12, 17, and 22 weeks following burning.

Algal Analyses

Soil samples were passed through a 5 mm sieve to remove any vegetation, break up clods and achieve a general

mixing of the transect sample. If the soil was moist it was spread out on a tray to air dry. From an initial dilution of 1.0 g of soil in 9.0 ml of sterile Bold's Basal Medium (Nichols, 1973), serial 10-fold dilutions to 10^{-4} were made. One ml aliquots were spread using a sterile glass rod onto petri plates containing Bold's Basal Medium solidified with 1.5 % agar. To prevent drying of the growth medium, plates were poured 10 mm thick and sealed with masking tape. A mean number of 30 plates were prepared for each collection and treatment; each plate representing either a 10^{-2}, 10^{-3} or 10^{-4} dilution. Plates were incubated at 20°C on a 12:$\overline{12}$ photoregime for three to eight weeks until colonies appeared.

Algal abundance was assessed by colony counts from a pooled harvest for each transect. Separate counts of Cyanophyta, Chlorophyta and Chrysophyta were not made. Counts were determined from plates having between 10 and 300 colonies; each colony considered to represent the growth of one organism. Results were expressed as number of algae per gram of soil.

Algal diversity was assessed from a pooled harvest for each transect. Algae were harvested by flooding each plate with Transeau's solution (Tiffany, 1938) then gently scraping the agar surface with a glass slide. Wet-mount slides were prepared and examined. Algal diversity was assessed

by identification to genus using the taxonomic works of Weber (1971), Whitford and Schmacher (1973) and Prescott (1979). Slides were prepared and examined until no new genera were encountered. The diversity analysis was concerned only with the presence or absence of an alga and not with the number of individuals of a specific genus.

Soil Analyses

Soil pH, nitrate-nitrogen, phosphorous and potassium were determined by the Lincoln Agronomy Department Analytical Laboratory, University of Nebraska at Lincoln. Soil samples from each collection were pooled for each plot, passed through a sieve and spread out to air dry, then sent to the Analytical Laboratory.

Data Analyses

The number of colonies on each 10^{-3} and 10^{-4} plate were averaged to calculate the mean number of algae per gram of soil. The number of genera in each transect were averaged to calculate the mean number of genera in a treatment. Shannon-Wiener indices ($H' = -\sum_{i=1}^{s} P_i \log P_i$) of diversity and abundance were calculated using frequency values. Frequency was calculated by dividing the number of transects in which a given genus was observed at each collection time by the total number of transects evaluated. Statistical analysis of algal diversity was calculated using a two-way analysis of variance.

RESULTS

Algal Analyses

Algal Abundance Algal abundance in both treatment areas exhibited significant decreases in May (Figure 2). From May through July the abundance of the burned treatment remained low but stable, while abundance of the unburned area fluctuated. Following July, abundance of both treatment areas increased, with the burned area achieving first a slightly, then a substantially higher level of abundance. A comparison between treatment areas in September showed the burned area had a 34 % greater algal abundance than the unburned area. The response of the algae to precipitation was evident by an increase in abundance in both treatment areas. Precipitation between July and September (34.50 cm total) produced the greatest abundance, particularly in the burned area. In response to low precipitation during the period June to July (3.50 cm total), the abundance decreased. Changes in algal abundance without burning more closely paralleled changes in precipitation than did abundance in the burned area.

A comparison of the percent change in algal abundance between sampling dates shows somewhat different seasonal fluctuations in the two treatment areas (Figure 3). In May, abundance of the burned area decreased 46 %, while

abundance in the unburned area decreased 22 %. It was not until August that the burned area exhibited a significant 55 % increase in abundance.

General Algal Diversity Highly significant differences existed between collection dates ($F = 39.55$, $p < 0.0001$), suggesting that algal diversity exhibits seasonal variations. Similarly, highly significant differences also existed between the treatment areas on various collection dates ($F = 9.00$, $p < 0.0001$), suggesting that burning has an impact on soil algal populations. Differences between the treatment areas across dates were less significant ($F = 5.39$, $p < 0.10$). Algal diversity in the burned area did not show a significant change in May, while diversity significantly increased in the unburned area (Figure 4). By June, diversity of the burned area had increased to levels similar to those in the unburned area. Following June, diversity of the burned area gradually increased, while diversity of the unburned area fluctuated. A comparison between treatment areas in September showed the burned area had a 27 % greater algal diversity than the unburned area. Significant differences existed between transects within treatment areas ($F = 2.84$, $p < 0.0298$). Perhaps this indicates patchy discontinuous growth patterns of soil algae, which would obscure the effects of burning when individual transects are compared. However, the data analysis corrects for transect differences.

The percent change in algal diversity between sampling dates is shown in Figure 5. Diversity of the burned area in May increased 10 %, while diversity in the unburned area increased 34 %. In June, diversity in the burned area increased 31 % over the May sample, while that in the unburned area increased only 5 %.

To account for both abundance and richness a Shannon-Wiener index was calculated (Figure 6). Data in Figure 6 show a seasonal pattern similar to that in Figure 4. These data suggest that algal diversity has a definite seasonal pattern, which is different in burned and unburned treatments. Diversity of the burned area steadily increased throughout the study period, while diversity of the unburned area increased until June, then stabilized throughout the duration of the study.

Diversity of Algal Groups An analysis of the three major algal groups separately suggests that the diversity in each group was affected differently by burning. Highly significant differences existed among algal groups overall ($F = 198.71$, $p < 0.0001$), and also among the groups on various collection dates ($F = 5.71$, $p < 0.0001$). However, a comparison of differences among the groups in the two treatment areas showed that they were not significantly different ($F = 0.15$, $p < 0.8617$).

Chlorophytes accounted for 46 % of the total number of

genera. Diversity in the burned area did not show a significant change in May, while diversity significantly increased in the unburned area (Figure 7). In June, diversity in the burned area increased to levels similar to those in the unburned area. Following June, diversity of both treatment areas fluctuated, with the burned area maintaining a consistently higher level of diversity. A comparison between treatment areas in September showed the burned area had a 29 % greater Chlorophyte diversity than the unburned area.

Figure 8 illustrates a Shannon-Wiener index of Chlorophyte diversity. Large differences were seen between the treatment areas in May, in that the unburned area exhibited a larger diversity increase than that of the burned area. Following May, diversity of the burned area increased, then stabilized, while the unburned area decreased until August, then increased in September.

Cyanophytes accounted for 31 % of the total number of genera. Both treatment areas exhibited similar significant increases in diversity in May (Figure 9). Following May, diversity of the burned area steadily increased, while diversity of the unburned area fluctuated. Cyanophyte diversity in both treatment areas increased significantly over the study period. A comparison between treatment areas in September showed the burned area had a 32 % greater Cyanophyte diversity than the unburned area.

Figure 10, a Shannon-Wiener index of Cyanophyte diversity, also shows this trend. From March through July the diversity of both treatment areas remained relatively parallel of each other. It was not until August that the differences between the treatment areas became apparent, with the burned area exhibiting large increases in diversity, while diversity of the unburned area fluctuated.

Chrysophytes accounted for 20 % of the total number of genera. In May, neither treatment area exhibited significant changes in diversity (Figure 11). From March through July the diversity of both areas remained relatively stable, with the burned area exhibiting a very slight increase in diversity. Following July, diversity of both treatment areas increased; this increase in diversity corresponded to increases in precipitation. Chrysophyte diversity increased slightly over the study period. A comparison between treatment areas in September showed the burned area had a 8 % greater Chrysophyte diversity than the unburned area. Overall, the Chrysophytes did not show any pronounced differences between the treatment areas.

Figure 12 illustrates a Shannon-Wiener index of Chrysophytes diversity. Due to the small sample size used to calculate the index, the result did not closely resemble Figure 11. No pronounced differences were seen between the treatment areas.

A composite list of all algal genera collected is shown in Table I. Throughout the evaluation a total of 63 genera were observed from the unburned area, consisting of 31 Chlorophytes, 14 Chrysophytes, and 18 Cyanophytes. Eighty genera were observed from the burned area, 37 of these were Chlorophytes, 17 were Chrysophytes, and 26 were Cyanophytes. The higher diversity in the burned area was primarily due to increases in the number of Chlorophytes and Cyanophytes. The orders Chlorococcales and Chroococcales represented the largest number of genera with a maximum of 14 and 12, respectively. I was unable to identify at the genus level, two different isolates from both treatment areas.

Of the 82 genera collected in both treatment areas, 61 were common to both areas and of these 28 were found in at least 90 % of the samples examined (Table I). Ten of these were Chlorophytes, 7 were Chrysophytes, and 11 were Cyanophytes.

A total of 18 genera were unique to the burned area, consisting of 8 Chlorophytes, 2 Chrysophytes, and 8 Cyanophytes (Table I). Sixty-five percent of these genera were not collected before the August collection. Only two Chlorophyte genera were unique to the unburned area. These were the genera Quadrigula and Bulbochaete.

Changes in the number of genera common to both treatment areas and the number unique to the burned and unburned areas

for each collection are shown in Table II. The number of genera common to both areas remained relatively constant, exhibiting approximately a 10 % increase or decrease between successive collections. The number of genera unique to the burned area gradually increased throughout the study period, with the largest increase occurring in August, exhibiting approximately a 50 % increase in genera number as compared to the previous sampling. These increases were primarily due to increases in the number of Chlorophytes and Cyanophytes. The number of genera unique to the unburned area decreased throughout the study period, with approximately a 70 % decrease occurring between May and June. Diversity differences between the treatment areas thus were due to increases in the number of genera unique to the burned area.

Soil Analyses

A composite list of the soil analyses are shown in Table III. Soil pH did not appear to be affected by the burn. Nitrate-nitrogen levels in the treatment areas remained similar to one another, except for the June and July samples during which the burned area had a slightly higher level. Soil phosphorous and potassium decreased following the burn, but then increased and maintained levels near those found in the unburned area. Overall, the soil chemistry analyses were unaffected by burning.

DISCUSSION

The initial decrease in algal abundance with burning, similar to that found by Cullimore and McCann (1973), may have been caused by low to moderate precipitation, and a probable decrease in soil moisture induced by higher evaporation from the exposed soil surface (Fritsch and Salisbury, 1915; Alexander, 1977). An investigation of surface mined soils suggested a similar decrease in algal abundance as precipitation became low and soil moisture decreased (Starks and Shubert, 1982). Although soil moisture levels were not measured in this study, it was observed that the soil of the unburned area appeared to contain more moisture than soil of the burned area. Unburned areas are usually characterized by higher soil moisture levels, due to the insulating blanket of litter and vegetation (Ehrenreich and Aikman, 1963). This may account for the higher abundance of the unburned area during this same time period.

Throughout the remainder of the study, algal abundance in both treatment areas significantly increased with the burned area ultimately achieving a higher level of abundance than the unburned area. High precipitation between July and September was apparently responsible for the increase in algal abundance in both treatment areas. Stokes (1940) and Starks and Shubert (1982) observed increases in algal abundance following such periods of high precipitation.

When moisture was adequate, the greater abundance of the burned area than the unburned may have been due to higher light intensities, as suggested by Broady (1979). The effect of light intensity is reflected in the vertical distribution of soil algae, where there is an inverse relationship between algal abundance and soil depth (Willson and Forest, 1957; Nordin and Blinn, 1972; King and Ward, 1977). Dense litter layers and thick vegetation, such as that found in the unburned area, deprive photosynthetic organisms of light (Vogl, 1974; Starks, 1979). Even though the September vegetation was dense in the burned area, there was very little litter. From three to six years are required for the standing crop on a burned prairie to return to preburn conditions, and two to five years are necessary for litter layers on a burned prairie to return to preburn conditions (Ehrenreich and Aikman, 1963).

It was unlikely that any temperature differences between the treatment areas could have accounted for the dissimilarity in algal abundance. Although burned areas commonly have slightly higher soil surface temperatures than comparable unburned areas (Fritsch and Salisbury, 1915; Boerner, 1982), most algae can withstand extreme fluctuations of temperature. If soil temperatures go outside normal growth range many algae can survive as spores or cysts (Lund, 1967; Campbell, 1977).

Although the requirement for moisture and adequate

sunlight appear to be factors which greatly influence algal abundance, it must be stressed that many factors interact to cause changes in the population. Even when moisture or light intensity are correlated with changes in a community, only a few of the possible environmental factors have been examined. One or a combination of several unstudied factors may influence the sequence of populations. Causation is not easy to establish and rarely are the data obtained conclusive (Alexander, 1971).

A more diverse algal population in the burned area apparently was due to higher light intensities and the relatively litter-free environment. Starks (1979) observed an increase in algal diversity in areas characterized by minimal litter, minimal plant cover and high solar radiation. Exposed soil surfaces probably contain many unoccupied microhabitats suitable for colonization and support the development of a rich algal flora (Bristol, 1920; Broady, 1979). Some of the algae that colonized the burned area, particularly the 18 genera unique to the area, were probably transported by wind and animal vectors (Parsons, Schlichting and Stewart, 1966; Proctor, 1966; Starks, 1979). If conditions at the time of arrival were not conducive for growth, the alga could survive adverse conditions for long periods as a resistant cyst, resting spore, akinete or zygote. Sixty-five percent of the genera unique to the burned treatment were not encountered before the August collection. However, the time

of colonization was unknown. The high precipitation after the July collection may have produced an abundance of these genera, thus increasing the probability they would be encountered during subsequent samplings.

Algal diversity is influenced by moisture; damp soils having a more varied algal population than dry soils (Chapman, 1962; Shields and Durrell, 1964). This was not found in the present investigation since the unburned area supported a lower algal diversity and was observed to have a higher moisture level, while the burned area supported a higher algal diversity and was observed to have drier soils.

Over the study period, the variation in diversity and the Shannon-Wiener index (Figures 4 and 6) suggested both treatment areas exhibited seasonal successional patterns. Seasonal succession is defined as an increase in algal diversity over time (Atlas and Bartha, 1981); an increase in algal abundance is not indicative of succession (Shields and Durrell, 1964). Many environmental factors operating together and the complex effects of season have been suggested to determine the course of algal succession (Alexander, 1971). Successional differences which existed between the treatment areas apparently were due to environmental alterations produced by the fire. Seasonal succession of the unburned area occurred until June, followed by a stabilization throughout the duration of the study suggesting a steady state condition. Throughout

the study period the burned area exhibited gradual increases in diversity, which surpassed the unburned area. A steady state was not evident in the burned area.

A continuation of this Allwine Prairie study over several years would answer two questions: 1) does the unburned population exhibit a similar succession annually, and 2) are the present successional trends sustained in the burned population? Further increases in algal diversity could occur in the burned area since a steady state had not been achieved. And we might expect a diversity increase over several years, since an investigation of surface mined soils found that diversity increased two or three fold over a three year study period (Starks and Shubert, 1982).

A problem to consider in this study, is an artifact related to the dilution sampling technique. This technique fails to distinguish between algae actively growing in the soil and those present as resting stages (Pipe and Cullimore, 1980). However, others have suggested that any noticeable change in the duration of the incubation period is probably explained by dormant cells needing a long incubation period (six or more weeks), while actively growing organisms require a shorter incubation (MacEntee, Schreckenberg and Bold, 1972). I possibly observed this phenomena in my work as different collections were ready to harvest at different times after being plated. Pre-burn collections in both treatment areas

were ready to harvest between three and five weeks, indicating the presence of actively growing organisms. Subsequent collections from the unburned area were ready to harvest after incubation for three to five weeks. However, algal populations of the burned area in May were ready to harvest after incubation for eight weeks, suggesting the dominance of dormant cells. Subsequent collections from the burned area were ready to harvest after incubation for three to five weeks, suggesting the majority of the 80 algal genera were growing and thriving in the burned habitat.

Each of the three major algal groups seemed to be affected differently by burning. This gives some insight into their variable abilities to adapt and survive various environmental conditions. The more diverse Chlorophyte population in the burned area apparently was due to higher light intensities and their ability to survive dry soil conditions as resistant cells, zygotes or resting spores. Also many Chlorophytes form mucilaginous colonies and sheaths which lose water slowly yet have a remarkable capacity to absorb water quickly (Starks, 1979). In fact, four of the eight Chlorophyte genera unique to the burned area have been reported by Fritsch (1922) and Trainor (1970) to survive extreme desiccation for long periods. Fritsch and Salisbury (1915), in a study on a burned heath, noted that the first organisms to colonize the burned area were Chlorophytes. However,

Chlorophytes were not considered to be the first to colonize the burned Allwine Prairie because the Chlorophytes did not show the largest Shannon-Wiener increase following the burn. Of the seven genera identified by Fritsch and Salisbury (1915), three were unique to the burned Allwine Prairie (Dactylococcus, Trochiscia, Zygogonium) and three were common to both treatment areas (Chlorhormidium, Gloeocystis, Trebouxia). From the results of this study over one growing season, Chlorophytes in both treatment areas exhibited seasonal succession, until May in the unburned area and June in the burned area (Figure 8). This was followed by a stabilization, suggesting a steady state, however, the burned area maintained a higher steady state level. Further increases in Chlorophyte diversity may not occur in the burned area since a steady state had been achieved, although a continuation of this study over several years would be necessary to confirm this hypothesis.

The more diverse Cyanophyte population in the burned area apparently was due to higher light intensities and the ability of Cyanophytes to withstand and grow under a wide variety of environmental conditions. Since Cyanophytes are usually the dominant algal component of a desert ecosystem, they can withstand high light intensities (Fogg, Stewart, Fay and Walsby, 1973). Cyanophytes are especially resistant to adverse conditions, due to many morphological and physiological mechanisms; such as, nitrogen fixation, resistant akinetes

or heterocysts, slime capsules and mucilaginous sheaths that can absorb large volumes of water (Durrell and Shields, 1961). Of the eight genera unique to the burned area, two have been reported to be capable of nitrogen fixation (Stewart, 1973) and all possess mucilaginous sheaths. Cyanophyes were considered to be the first to colonize the burned Allwine Prairie because they showed the largest Shannon-Wiener increase following the burn. Also, Cyanophytes have been reported to be the first to colonize natural grasslands, eroded soils, deserts and volcanic sites (Cameron, 1964; Cullimore and McCann, 1973; Alexander, 1977). Cyanophyte seasonal succession of the unburned area occurred until May, followed by a stabilization throughout the duration of the study suggesting a steady state, while the burned area exhibited seasonal successional trends which surpassed the unburned area (Figure 10). A steady state was not evident in the burned area. Further increases in Cyanophyte diversity could occur in the burned area since a steady state had not been achieved.

Overall, the Chrysophytes, 50 % of which were diatoms, appeared to be relatively unaffected by burning. In fact, it was surprising that burning did not produce a lower diversity as compared to the unburned area, since Chrysophytes are generally considered to be sensitive to dry or adverse conditions, such as in a burned area (Trainor, 1970). Precipitation apparently had a marked effect on the Chrysophyte

diversity. Increases in diversity corresponded to increases in precipitation (Figure 11). A similar relationship between diversity and precipitation was found by Loescher (1981), in a study on native prairie diatom floras. Of the eight Bacillariophyceae found at Allwine Prairie, seven belong to the order Pennales and five had a true raphe. This result supports the suggestion by Loescher (1981) that most terrestrial diatom taxa belong to the order Pennales and that most of these also have a true raphe. Because the diatoms that possess a raphe are motile, it is thought that they are able to move into moister areas as the soil dries and to return to the soil surface after being washed into deeper layers by rain. Thus, in soil habitats there is selection against species without raphes. Unfortunately, due to the small sample size used to calculate the Chrysophyte Shannon-Wiener index, no seasonal successional trends or steady state conditions were evident.

Overall, the soil chemistry analyses of pH, nitrate-nitrogen, phosphorous and potassium were unaffected by burning. These analyses were not correlated with changes or differences in algal abundance and diversity in the treatment areas.

SUMMARY

Even with seasonal variations, burning increased both algal abundance and diversity. However, different algal groups responded differently to burning. A comparison between the burned and unburned areas in September showed increases in both algal abundance and diversity in the burned area, with 34 % greater algal abundance, 27 % greater algal diversity, 29 % greater Chlorophyte diversity, 32 % greater Cyanophyte diversity and 8 % greater Chrysophyte diversity than that found in the unburned area. A total of 63 genera were observed from the unburned area, as compared to 80 genera from the burned area, with diversity differences primarily due to increases in the number of Chlorophytes and Cyanophytes. The Chrysophytes appeared to be relatively unaffected by burning. A total of 18 genera were unique to the burned area, representing 8 Chlorophytes, 8 Cyanophytes and 2 Chrysophytes. Cyanophytes were considered to be the first algae to colonize the burned Allwine Prairie. An increase in algal abundance appeared to be determined by an increase in precipitation and light. An increase in algal diversity apparently was due to higher light intensities and the relatively litter-free environment in the burned area. Overall, the soil chemistry analyses of pH, nitrate-nitrogen, phosphorous and potassium were unaffected by burning and did not correlate with changes in algal abundance and diversity.

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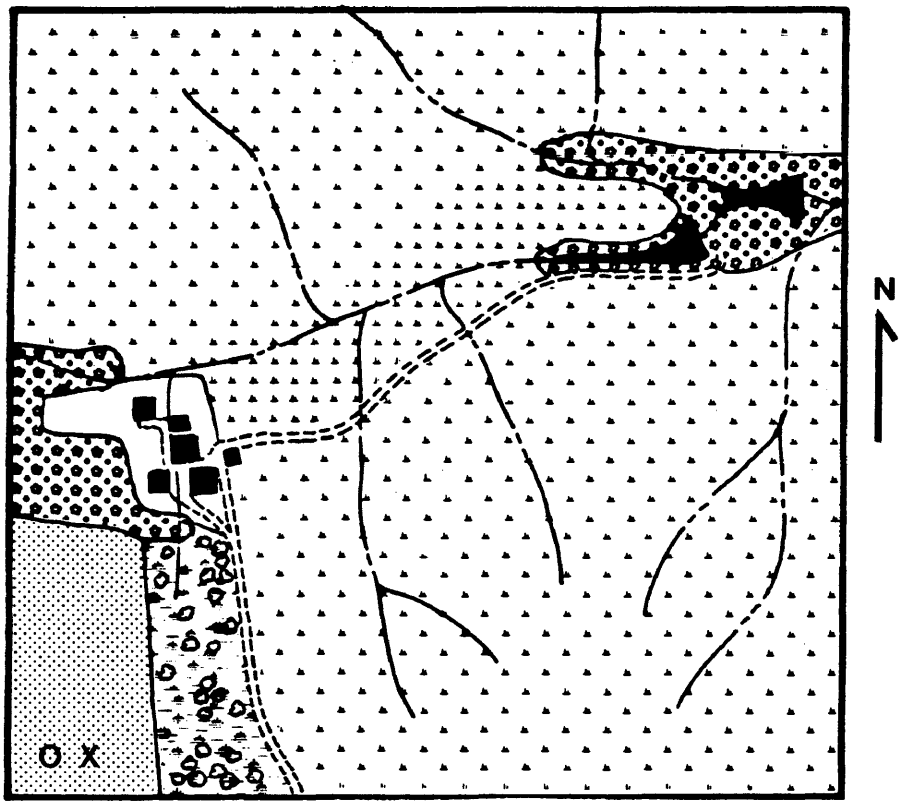

Fig. 1. Location of study plots at Allwine Prairie Preserve. O = unburned plot; X = burned plot.

Fig. 2. Mean algal abundance and precipitation data. Solid line = algal abundance; dashed line = precipitation; bar = mean $\pm$ 1 standard error; solid circle = burned area; open circle = unburned area; arrow = treatment date.

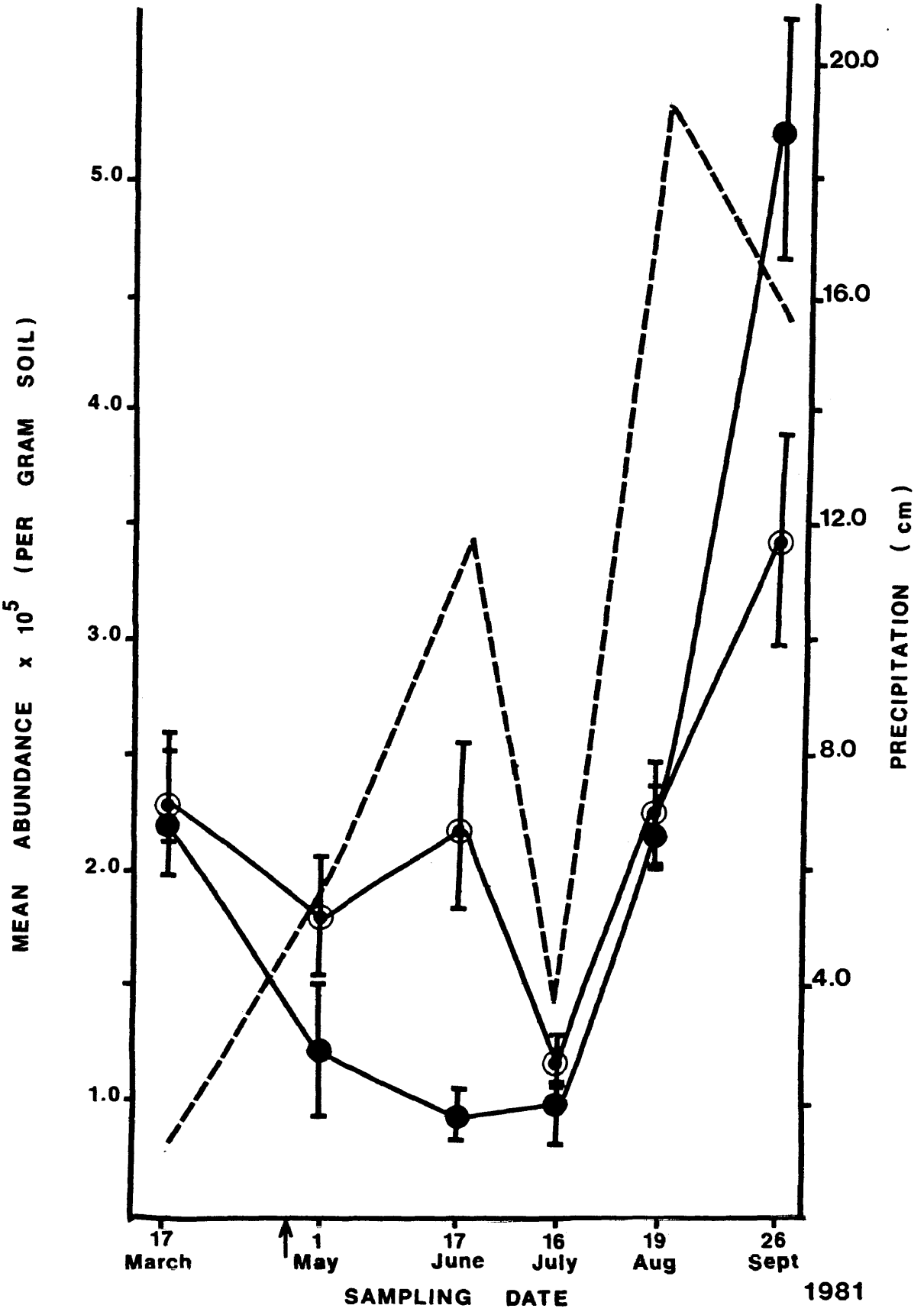
MEAN ABUNDANCE x 10^5 (PER GRAM SOIL)
5.0
4.0
3.0
2.0
1.0
20.0
16.0
12.0
8.0
4.0
PRECIPITATION (cm)
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 3. Percent change in algal abundance. Bar = percent change from the previous sampling date; solid bar = burned area; open bar = unburned area; arrow = treatment date.

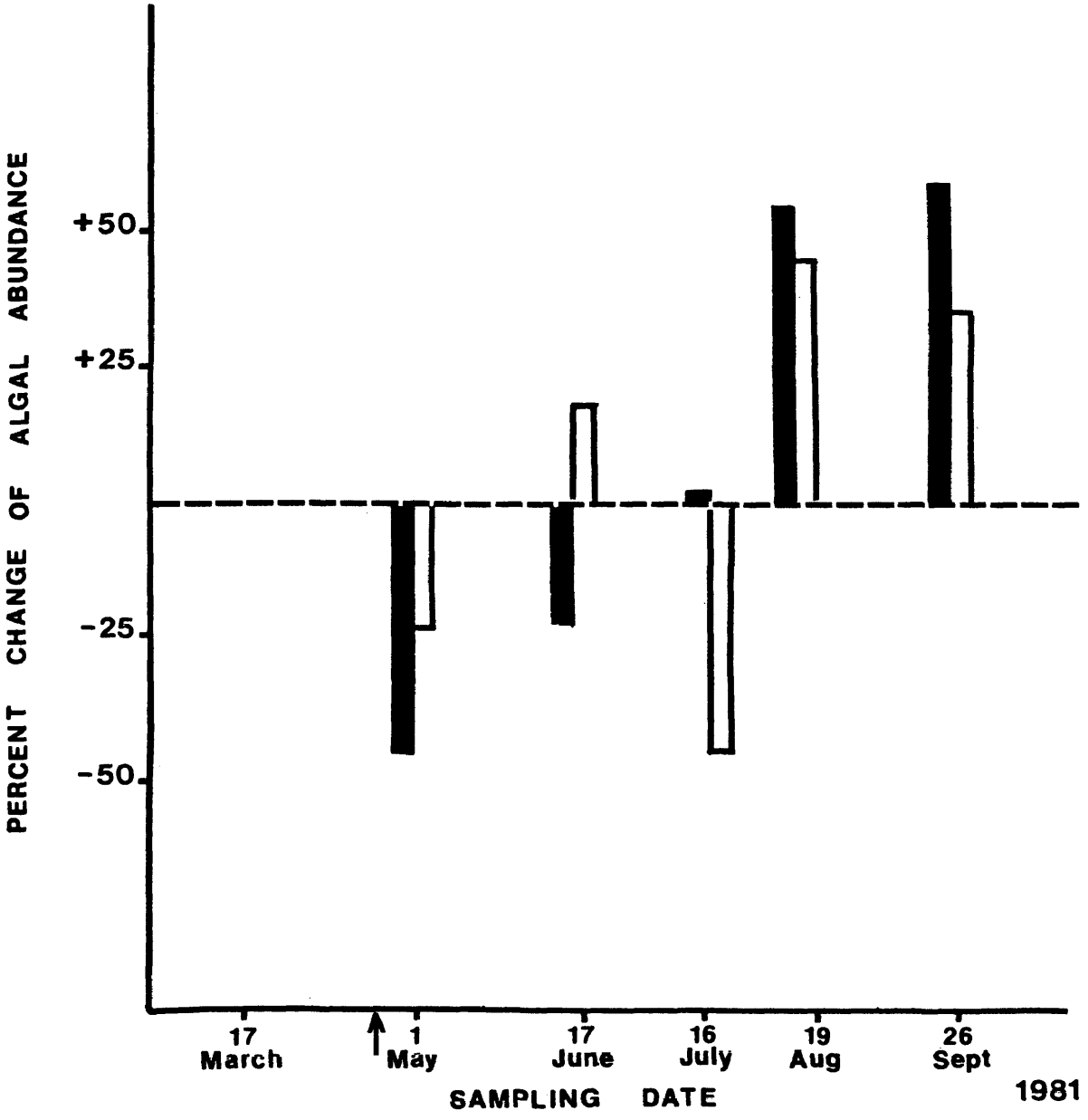
PERCENT CHANGE OF ALGAL ABUNDANCE
+50
+25
-25
-50
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 4. Mean number of algal genera. Bar = mean $\pm$ 1 standard error; solid circle = burned area; open circle = unburned area; arrow = treatment date.

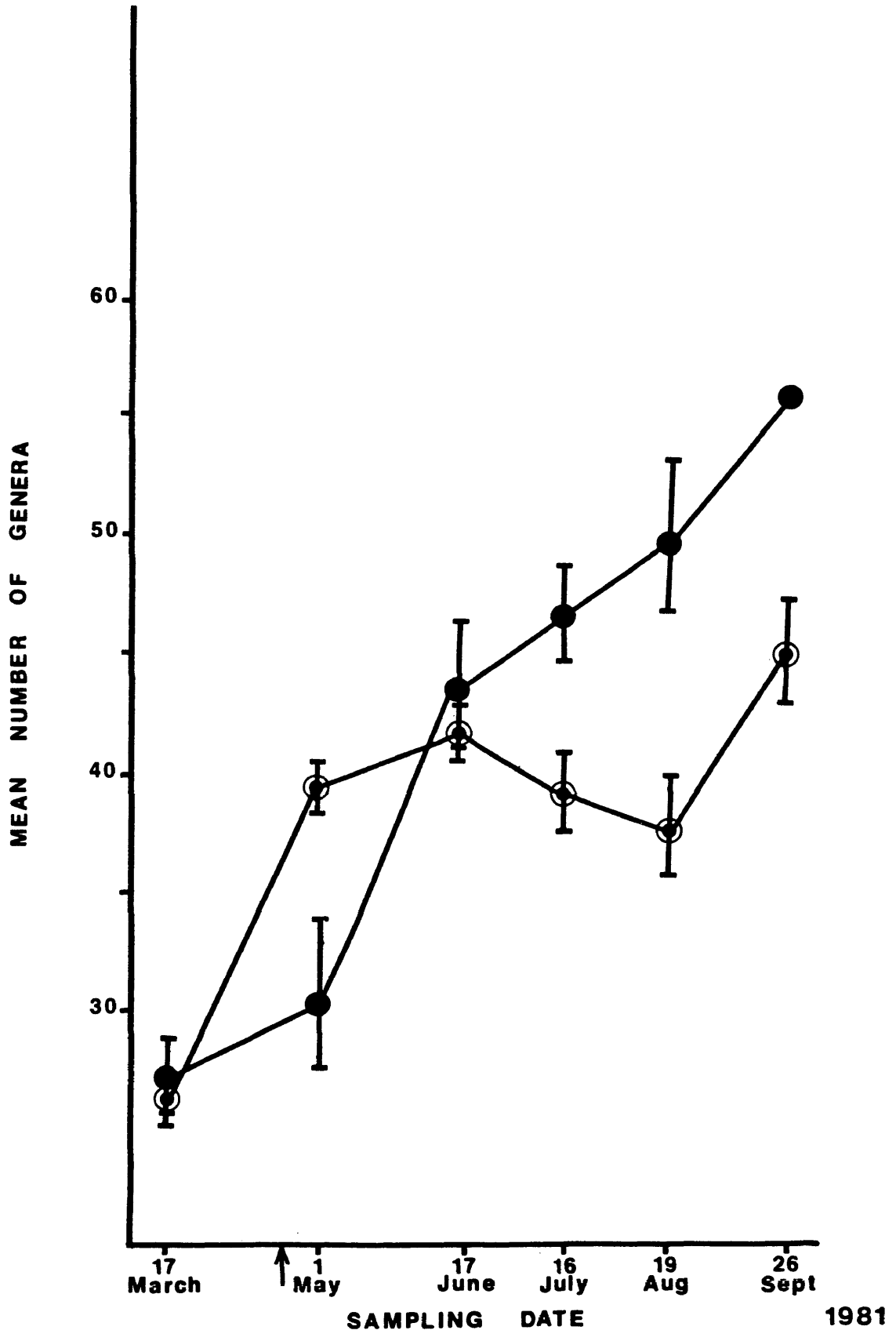
MEAN NUMBER OF GENERA
60
50
40
30
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 5. Percent change in number of algal genera. Bar = percent change from the previous sampling date; solid bar = burned area; open bar = unburned area; arrow = treatment date.

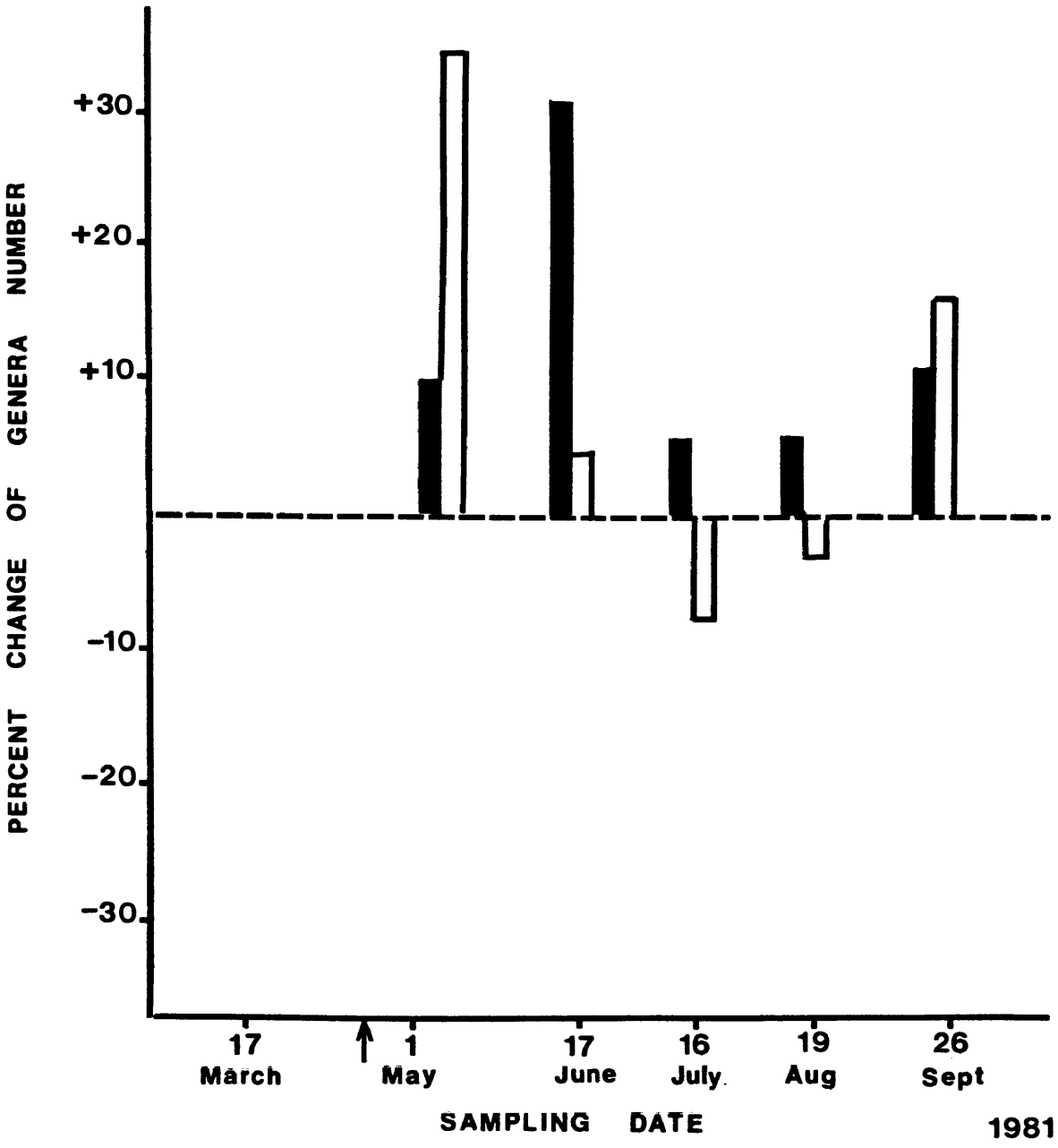
+30
+20
+10
-10
-20
-30
PERCENT CHANGE OF GENERA NUMBER
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 6. Shannon-Wiener index (H') of algal diversity; high H' values indicate greater diversity. Solid circle = burned area; open circle = unburned area; arrow = treatment date.

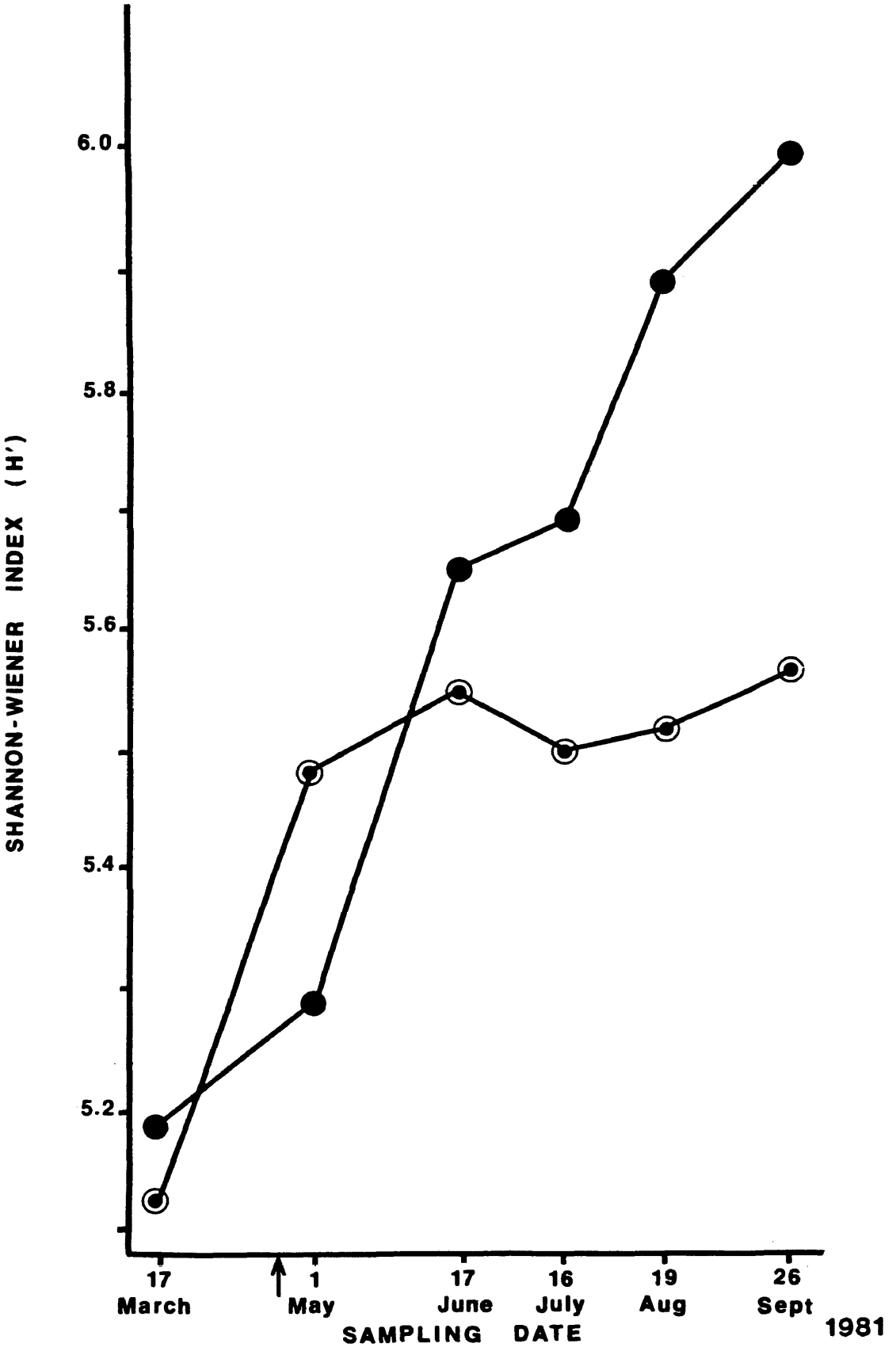
SHANNON-WIENER INDEX (H')
6.0
5.8
5.6
5.4
5.2
17 March
1 May
17 June
16 July
19 Aug
26 Sept
1981
SAMPLING DATE

Fig. 7. Mean number of Chlorophyte genera. Bar = mean ± 1 standard error; solid circle = burned area; open circle = unburned area; arrow = treatment date.

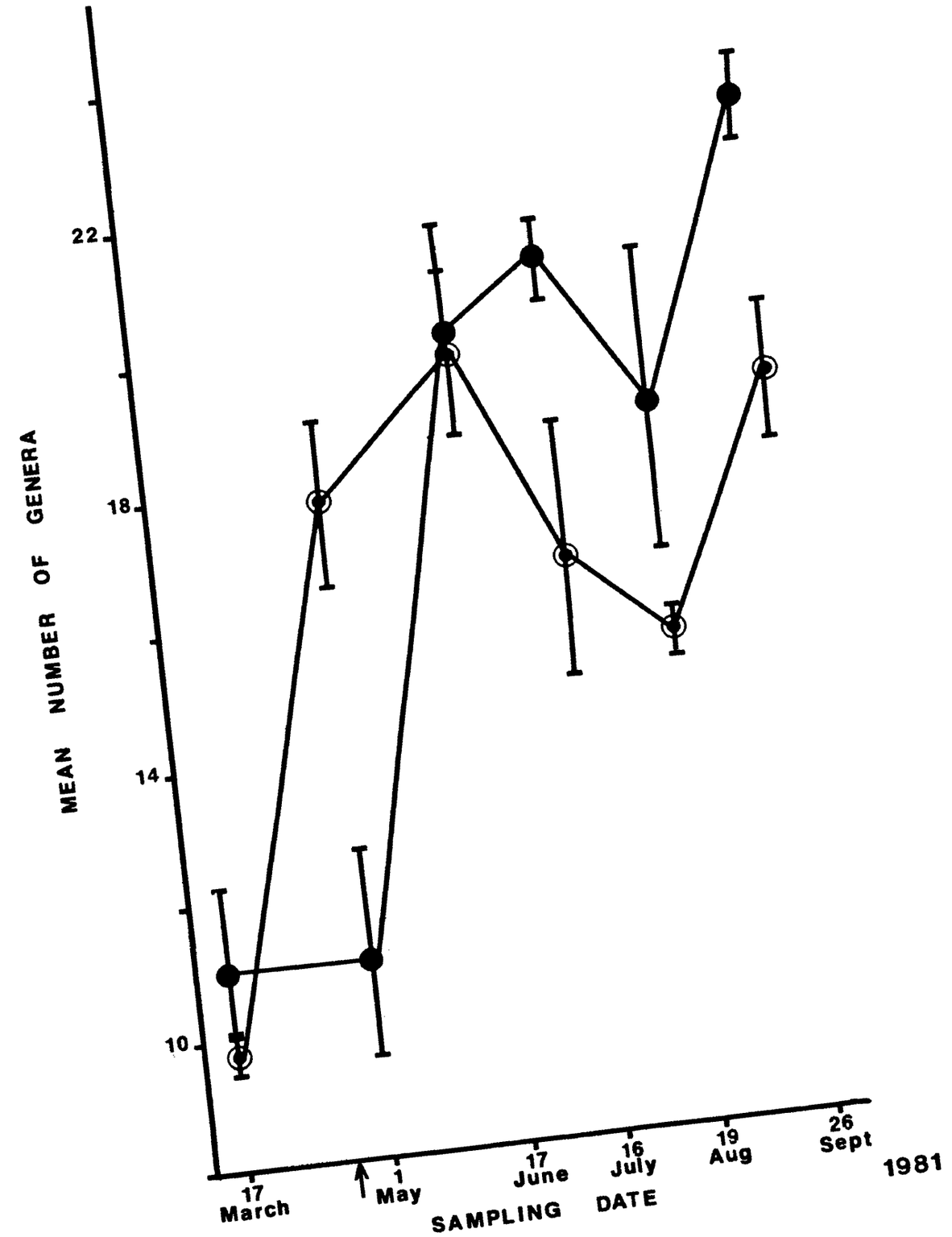
MEAN NUMBER OF GENERA
22
18
14
10
17 March
1 May
17 June
16 July
19 Aug
26 Sept
1981
SAMPLING DATE

Fig. 8. Shannon-Wiener index (H') of Chlorophyte diversity; high H' values indicate greater diversity. Solid circle = burned area; open circle = unburned area; arrow = treatment date.

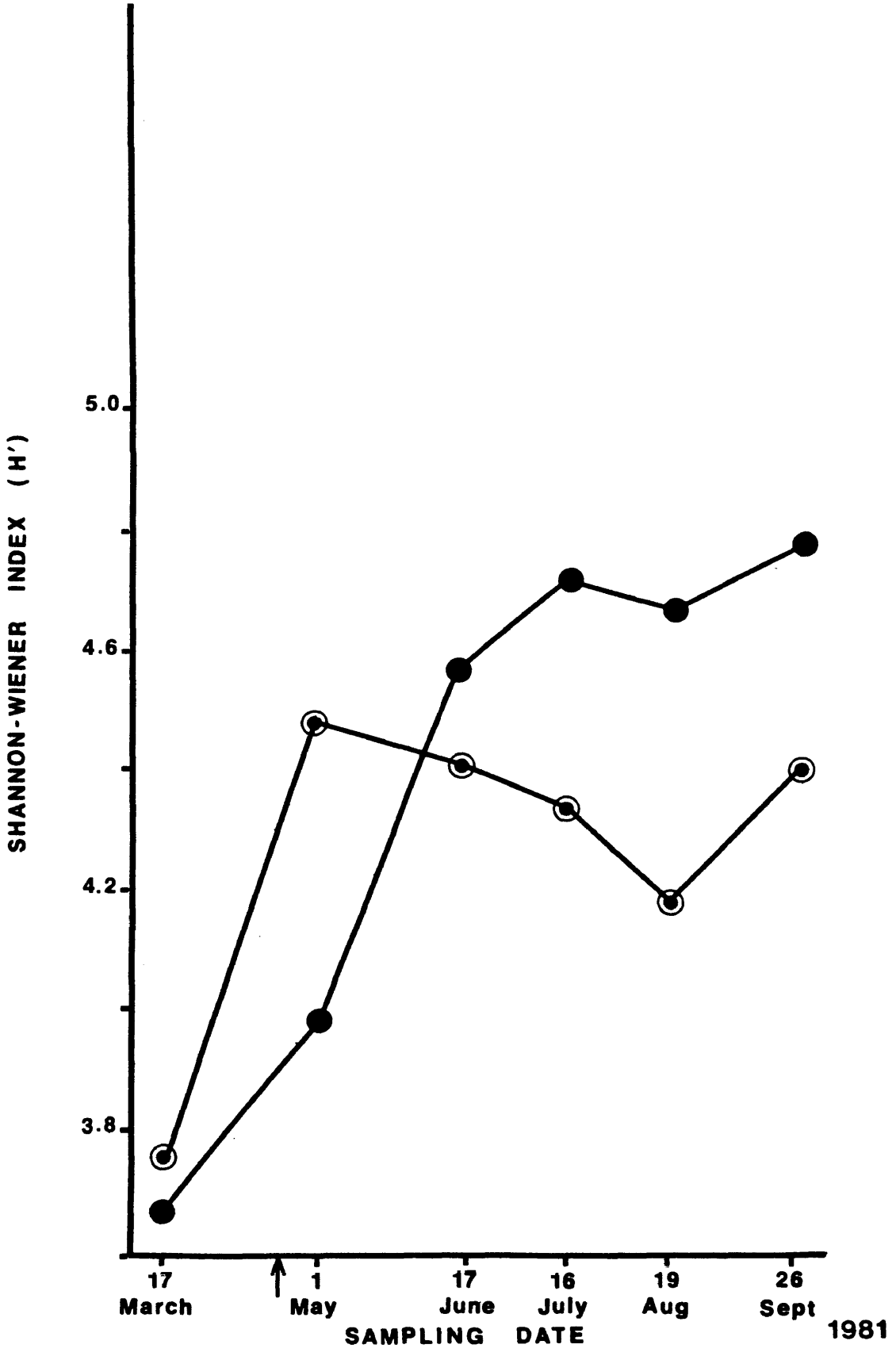
SHANNON-WIENER INDEX (H')
5.0
4.6
4.2
3.8
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 9. Mean number of Cyanophyte genera. Bar = mean $\pm$ 1 standard error; solid circle = burned area; open circle = unburned area; arrow = treatment date.

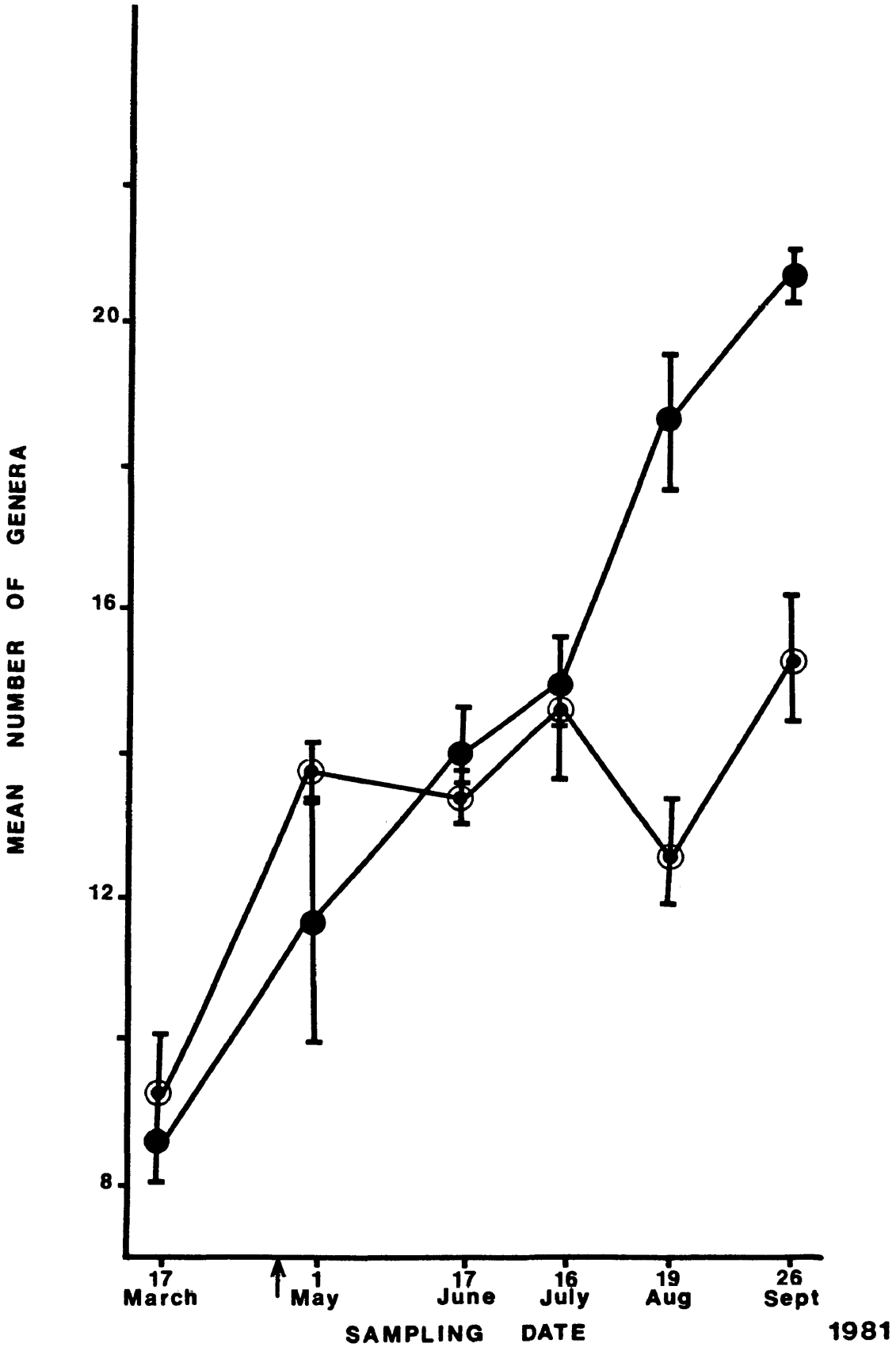
MEAN NUMBER OF GENERA
20
16
12
8
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 10. Shannon-Wiener index (H') of Cyanophyte diversity; high H' values indicate greater diversity. Solid circle = burned area; open circle = unburned area; arrow = treatment date.

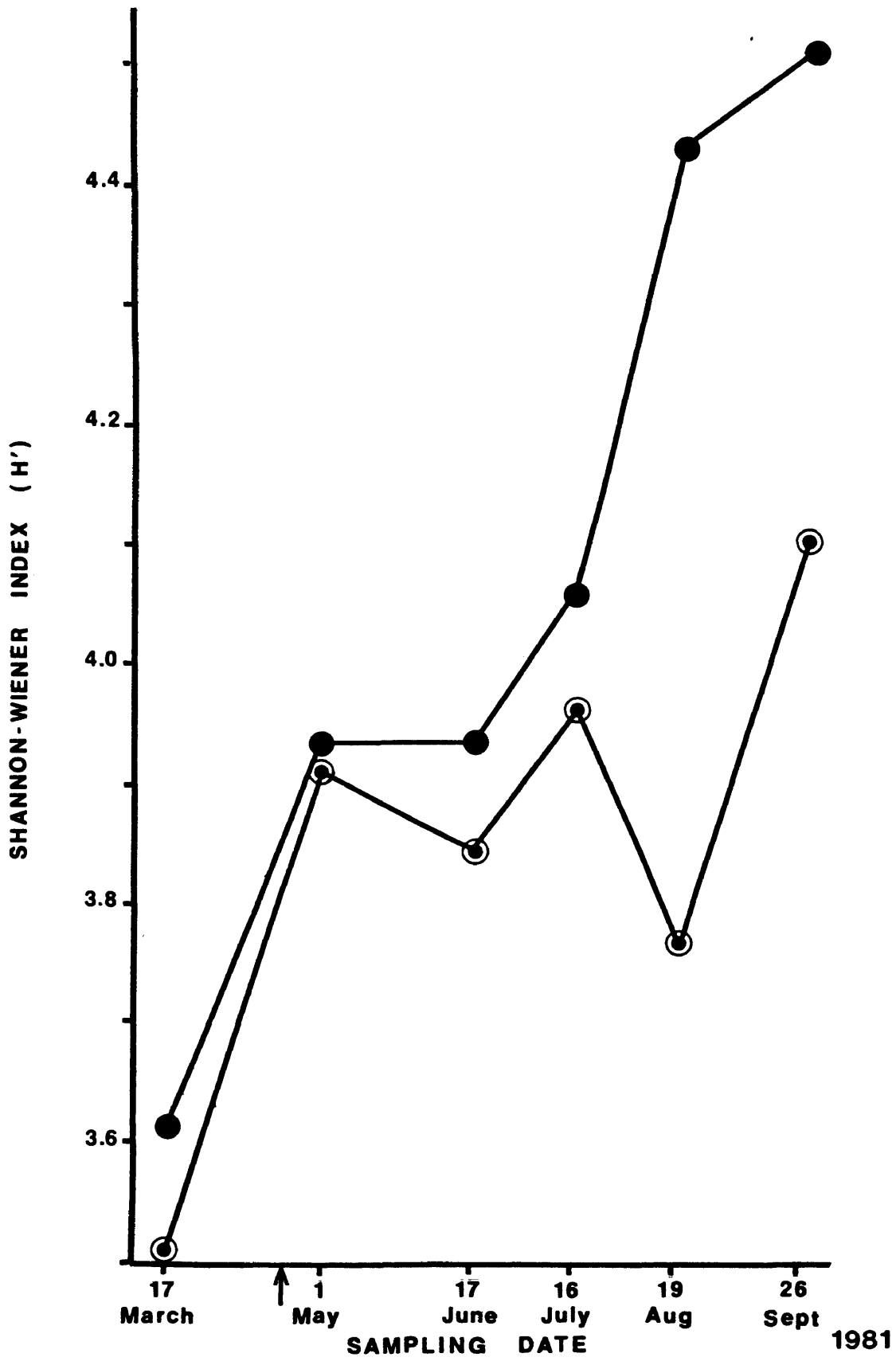
SHANNON-WIENER INDEX (H')
4.4
4.2
4.0
3.8
3.6
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 11. Mean number of Chrysophyte genera and precipitation data. Solid line = Chrysophyte diversity; dashed line = precipitation; bar = mean $\pm$ 1 standard error; solid circle = burned area; open circle = unburned area; arrow = treatment date.

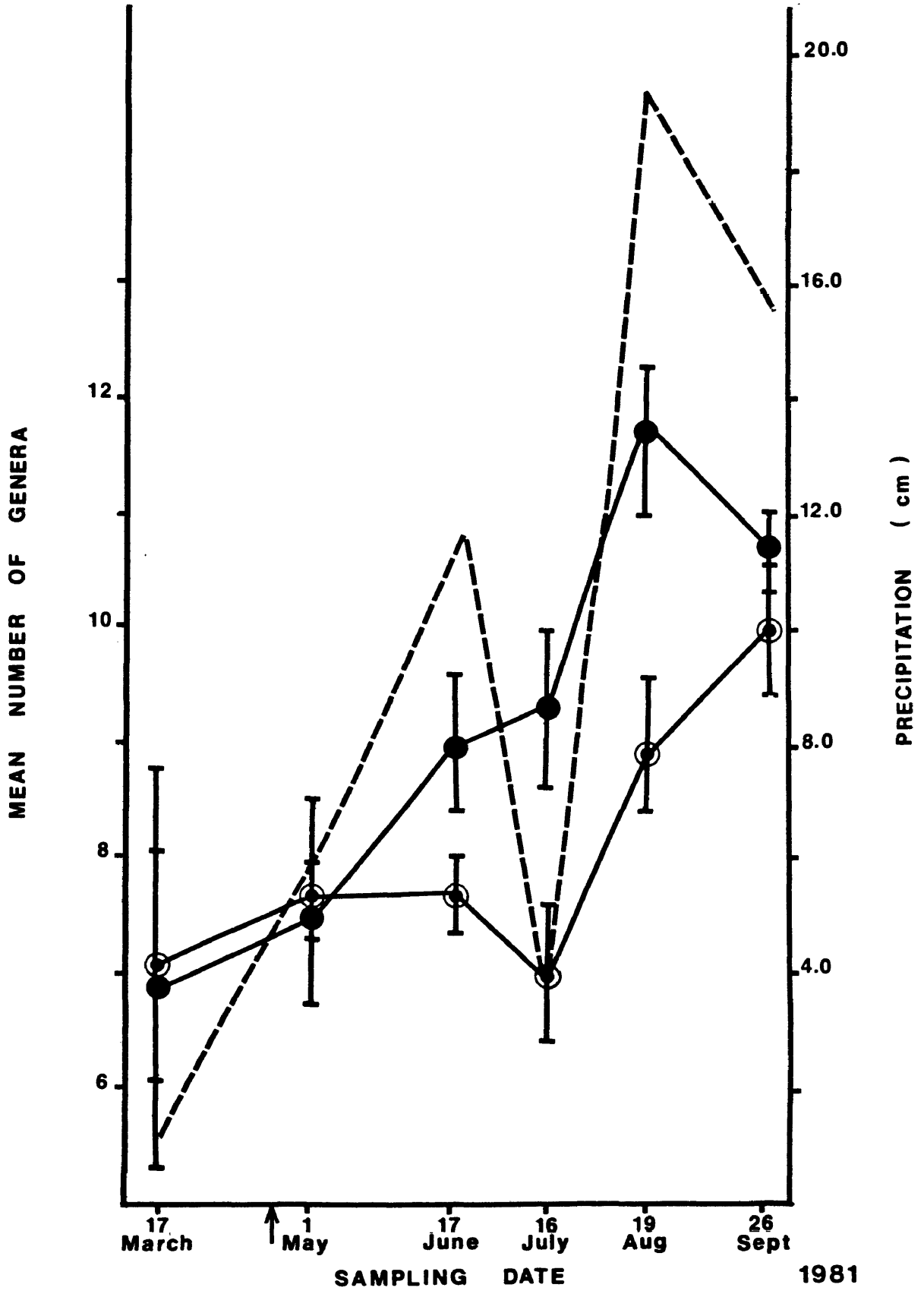
MEAN NUMBER OF GENERA
PRECIPITATION (cm)
20.0
16.0
12.0
8.0
4.0
12
10
8
6
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

Fig. 12. Shannon-Wiener index (H') of Chrysophyte diversity; high H' values indicate greater diversity. Solid circle = burned area; open circle = unburned area; arrow = treatment date.

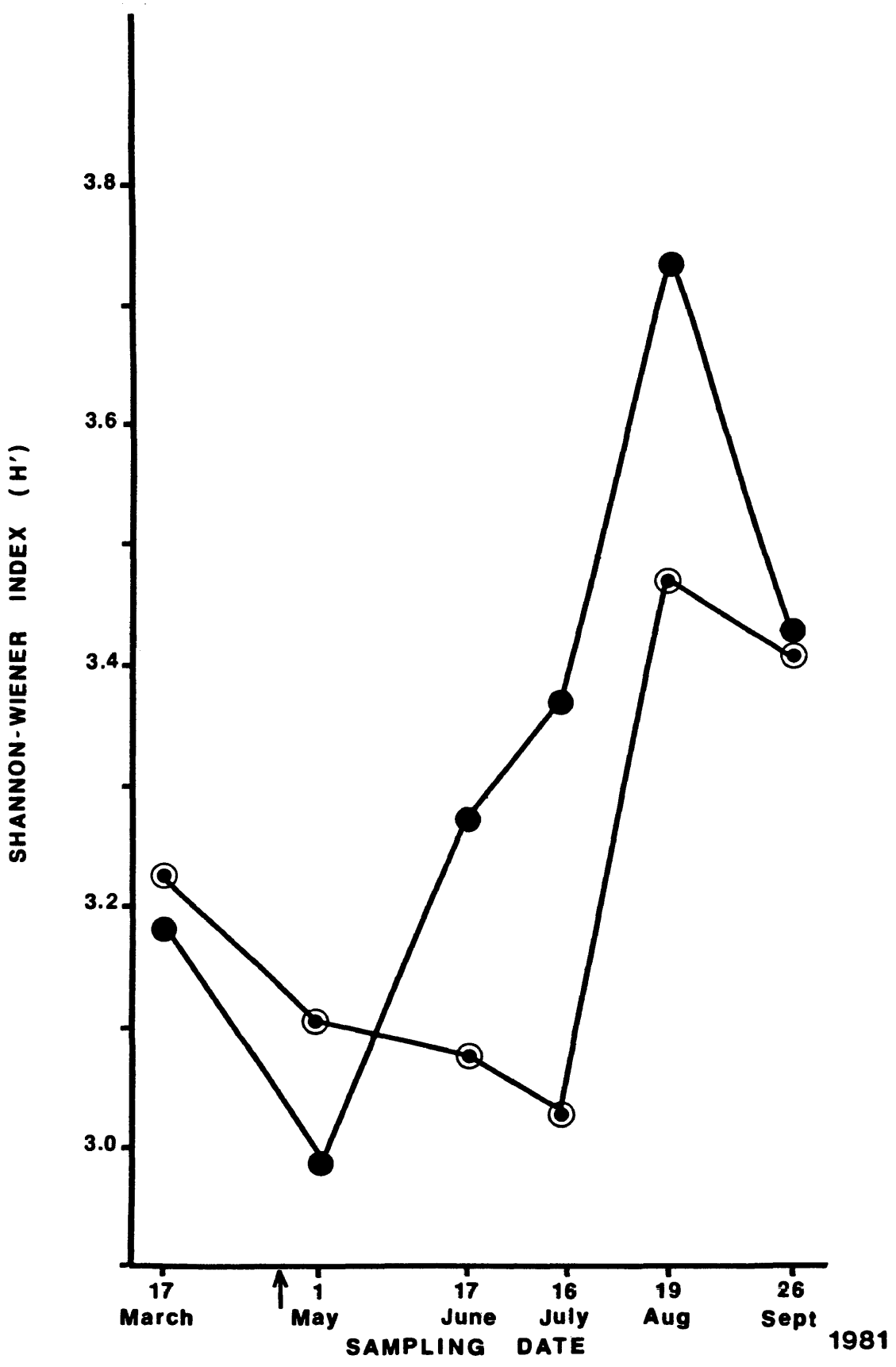
SHANNON-WIENER INDEX (H')
3.8
3.6
3.4
3.2
3.0
17 March
1 May
17 June
16 July
19 Aug
26 Sept
SAMPLING DATE
1981

TABLE I

Algal genera identified in soils of Allwine Prairie Preserve.

GENUS	SAMPLING DATE 1* B	1* U[a]	2* B	2* U	3* B	3* U	4* B	4* U	5* B	5* U	6* B	6* U
Chlorophyta												
Chlorophyceae												
Volvocales												
Chlamydomonas®	+	+[b]	+	+	+	+	+	+	+	+	+	+
Pandorina	o	o	+	+	+	+	+	+	+	o	+	+
Pascherina	o	o	+	o	+	+	+	+	+	o	+	o
Unidentified Volvocales	o	o	o	+	+	+	+	+	+	+	+	+
Tetrasporales												
Tetraspora	+	+	+	+	+	+	+	o	+	o	+	+
Gloeocystis	o	o	+	+	+	+	+	+	+	+	+	+
Chlorococcales												
Bracteacoccus	o	o	+	+	+	+	+	+	+	+	+	+
Characium	+	+	o	+	+	o	o	o	o	+	+	o

GENUS	SAMPLING DATE											
	1		2		3		4		5		6	
	B	U	B	U	B	U	B	U	B	U	B	U
Chlorococcum	o	o	o	+	+	+	+	+	+	+	+	+
Fasciculochloris●	o	o	o	o	o	o	o	o	+	o	+	o
Trebouxia◉	+	+	+	+	+	+	+	+	+	+	+	+
Palmella◉	+	+	+	+	+	+	+	+	+	+	+	+
Sphaerocystis	o	o	o	o	o	+	+	+	o	o	+	o
Palmodictyon	+	+	o	o	o	o	o	o	+	o	o	o
Ankistrodesmus◉	+	+	o	+	+	+	+	+	+	+	+	+
Chlorella◉	+	+	+	+	+	+	+	+	+	+	+	+
Dactylococcus●	o	o	o	o	o	o	o	o	o	o	+	o
Eremosphaera●	o	o	o	o	o	o	o	o	o	o	+	o
Quadrigula⚙	o	o	o	o	o	o	o	o	o	o	o	+
Trochiscia●	o	o	o	o	+	o	+	o	+	o	+	o
Ulotrichales												
Chlorhormidium◉	+	+	+	+	+	+	+	+	+	+	+	o
Pseudoschizomeris◉	+	+	+	+	+	+	+	+	+	+	+	+

GENUS	SAMPLING DATE 1 B	1 U	2 B	2 U	3 B	3 U	4 B	4 U	5 B	5 U	6 B	6 U
Stichococcus	+	+	o	+	o	o	+	o	o	o	o	o
Ulothrix	+	+	+	+	+	o	+	o	o	o	o	o
Microspora◉	+	+	+	+	+	+	+	+	+	+	+	+
Unidentified Ulotrichales	o	o	+	+	+	+	+	+	+	+	+	+
Chaetophorales												
Chlorosarcina	o	o	o	o	+	+	+	+	+	o	+	+
Chlorosarcinopsis	o	o	+	+	+	+	+	+	+	o	+	+
Apatococcus◉	+	+	+	+	+	o	+	+	+	+	+	+
Desmococcus◉	+	+	+	+	+	+	+	+	+	+	+	+
Fritschiella	o	o	o	o	o	+	+	+	+	+	+	+
Hazenia●	o	o	o	o	+	o	+	o	o	o	o	o
Coleochaete	o	o	o	o	o	o	o	o	o	+	+	+
Oedogoniales												
Bulbochaete۞	o	o	o	+	o	o	o	o	o	o	o	o
Oedocladium	+	+	o	+	o	o	o	o	o	o	o	o

GENUS	SAMPLING DATE 1 B	1 U	2 B	2 U	3 B	3 U	4 B	4 U	5 B	5 U	6 B	6 U
Siphonocladales												
Cladophora	o	o	o	+	+	+	+	+	+	+	+	+
Rhizoclonium●	o	o	+	o	o	o	+	o	+	o	o	o
Siphonales												
Protosiphon●	o	o	o	o	o	o	o	o	+	o	+	o
Zygnematales												
Zygogonium●	o	o	o	o	o	o	+	o	+	o	+	o
Chrysophyta												
Xanthophyceae												
Heterogloeales												
Heterogloea●	o	o	o	o	o	o	o	o	+	o	o	o
Mischococcales												
Botrydiopsis◉	+	+	+	+	+	+	+	o	+	+	+	+
Chlorobotrys◉	+	+	+	+	+	+	+	+	+	o	+	+

GENUS	SAMPLING DATE 1 B	1 U	2 B	2 U	3 B	3 U	4 B	4 U	5 B	5 U	6 B	6 U
Dichotomococcus●	o	o	o	o	o	o	+	o	o	o	o	o
Tribonematales												
Heterothrix◉	+	+	+	+	+	+	+	+	+	+	+	+
Heterococcus	o	o	o	o	o	o	o	o	+	+	+	+
Monocilia	+	+	o	o	+	o	o	o	o	o	o	o
Vaucheriales												
Vaucheria●	+	o	o	o	o	o	o	o	o	o	o	o
Botrydium	+	+	o	+	o	+	o	o	+	+	o	+
Bacillariophyceae												
Centrales												
Melosira	o	o	o	o	+	+	+	+	+	+	+	+
Pennales												
Diatoma	+	+	+	o	o	o	+	+	+	+	+	o
Fragilaria	o	o	o	o	o	o	o	o	+	+	+	+
Cocconeis	+	+	o	+	+	o	+	+	+	+	+	o

GENUS	SAMPLING DATE 1 B	1 U	2 B	2 U	3 B	3 U	4 B	4 U	5 B	5 U	6 B	6 U
Navicula◉	+	+	+	+	+	+	+	+	+	+	+	+
Hantzschia◉	+	+	+	+	+	+	+	+	+	+	+	+
Nitzschia◉	+	+	+	+	+	+	+	+	+	+	+	+
Surirella◉	+	+	+	+	+	+	+	+	+	+	+	+
Cyanophyta												
Chroococcales												
Anacystis◉	+	+	+	+	+	+	+	+	+	+	+	+
Aphanothece◉	+	+	+	+	+	+	+	+	+	+	+	+
Chroococcus◉	+	+	+	+	+	+	+	+	+	+	+	+
Dactylococcopsis●	o	o	o	o	o	o	o	o	+	o	+	o
Glaucocystis●	o	o	+	o	o	o	o	o	o	o	o	o
Gloeocapsa◉	+	+	+	+	+	+	+	+	+	+	+	+
Gloeothece	o	o	+	+	+	+	+	+	+	+	+	+
Merismopedia●	o	o	o	o	o	o	o	o	+	o	+	o

GENUS	SAMPLING DATE											
	1		2		3		4		5		6	
	B	U	B	U	B	U	B	U	B	U	B	U
Microcystis◉	+	+	+	+	+	+	+	+	+	+	+	+
Rhabdoderma●	o	o	o	o	o	o	o	o	+	o	+	o
Synechococcus	o	o	+	o	+	o	+	o	+	o	+	+
Synechocystis◉	+	+	+	+	+	+	+	+	+	+	+	+
Chamaesiphonales												
Xenococcus	+	+	o	+	o	+	+	+	+	o	+	+
Oscillatoriales												
Lyngbya◉	+	+	+	+	+	+	+	+	+	+	+	+
Microcoleus◉	+	+	+	+	+	+	+	+	+	+	+	+
Oscillatoria◉	+	+	+	+	+	+	+	+	+	+	+	+
Spirulina●	o	o	o	o	o	o	o	o	+	o	+	o
Nostocales												
Anabaena◉	+	+	+	+	+	+	+	+	+	+	+	+
Cylindrospermum●	o	o	o	o	o	o	o	o	o	o	+	o
Nodularia●	o	o	o	o	o	o	o	o	o	o	+	o

GENUS	SAMPLING DATE											
	1		2		3		4		5		6	
	B	U	B	U	B	U	B	U	B	U	B	U
Nostoc	o	o	+	+	+	+	+	+	+	+	+	+
Stigonema	o	o	+	+	+	+	+	+	+	+	+	+
Diplocolon	+	+	+	o	o	o	o	o	o	o	+	o
Plectonema●	o	o	o	o	o	o	o	o	+	o	+	o
Scytonema	o	o	o	+	+	o	+	+	+	+	+	+
Raphidiopsis◉	+	+	+	+	+	+	+	+	+	o	+	+

* 1 = 17 March 1981 (pre-burn sampling date); 2 = 1 May 1981; 3 = 17 June 1981; 4 = 16 July 1981; 5 = 19 August 1981; 6 = 26 September 1981.

[a] B = burned plot; U = unburned plot.

[b] + = present; o = absent.

◉ = prevalent genera (>90 % occurence); ● = unique to burned; ⚙ = unique to unburned.

TABLE II

Changes in the number of algal genera common to both plots and the number unique to the burned and unburned plots for each collection.

ALGAL GROUP	SAMPLING DATE																	
	1*	2*	3*	4*	5*	6*	1	2	3	4	5	6	1	2	3	4	5	6
	COMMON						UNIQUE BURNED						UNIQUE UNBURNED					
Chlorophytes	16	16	20	22	17	21	0	2	5	7	11	10	0	8	2	0	2	1
Chrysophytes	11	7	8	9	12	10	1	1	2	2	2	2	0	2	1	0	0	1
Cyanophytes	13	14	14	16	14	17	0	3	2	1	8	8	0	2	1	0	0	0
Total genera	40	37	42	47	43	48	1	6	9	10	21	20	0	12	4	0	2	2

* 1 = 17 March 1981 (pre-burn sampling date); 2 = 1 May 1981; 3 = 17 June 1981; 4 = 16 July 1981; 5 = 19 August 1981; 6 = 26 September 1981.

TABLE III

Soil analyses of Allwine Prairie Preserve.

SOIL PARAMETER	SAMPLING DATE											
	1*		2*		3*		4*		5*		6*	
	B	U[a]	B	U	B	U	B	U	B	U	B	U
pH	6.3	6.2	6.3	6.2	6.6	6.6	6.2	6.5	6.3	6.5	6.4	6.4
Nitrate-nitrogen (ppm)	1.5	1.1	0.8	0.8	2.5	1.1	2.1	1.2	1.4	1.2	3.8	3.0
Phosphorous (ppm)	12.0	13.0	2.1	15.0	18.0	16.0	15.0	24.0	18.0	13.0	24.0	16.0
Potassium (ppm)	336	293	80	335	353	359	351	363	353	383	478	444

* 1 = 17 March 1981 (pre-burn sampling date); 2 = 1 May 1981; 3 = 17 June 1981; 4 = 16 July 1981; 5 = 19 August 1981; 6 = 26 September 1981.

[a] B = burned plot; U = unburned plot.

APPENDIX

APPENDIX TABLE A

Colony counts for raw data used to determine algal abundance.

DATE	TREATMENT											
	BURNED Transect						UNBURNED Transect					
	1 dilution		2 dilution		3 dilution		1 dilution		2 dilution		3 dilution	
	10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-3}	10^{-4}	10^{-3}	10^{-4}
3/17/81	352	31	139	39	169	10	131	24	192	18	313	42
	226	28		36	223	19	161	11	231	27	331	19
				9			278	13	284	25		20
								9	244			21
5/1/81	33	13	52	16	55	17	137	11	127	31	161	41
	28	3	62	54	67	8	104	31	158	9	130	22
	49		67		57		94		96		99	
	32				133				88			
6/17/81	81	11	92	10	114	9	224	49	199	13	99	11
	91	10	80	15	93	6	332		317	14	93	6
	76		97		66		320		187		71	
7/16/81	25	14	90	9	73	8	43	25	82	10	87	14
	28	1	48	9	96	4	79	13	74	6	91	15
	33	4	86	38	81	8	115	14	69	12	85	12
	54	6	153	12	86	11	115	21	194	13	118	14
	79	5	147	13		33		12		18		
8/19/81	161	10	102	29	145	24	104	9	72	18	118	36
	137	15	168	12	144	21	96	10	87	9	215	18
	120	23	169	27	148	12	283	56	95	131	156	19
	227	12	395	120	132	11	113	17	374	9	125	18
9/26/81	433	62	479	44	277	86	168	33	162	43	220	10
	223	34	428	61	273	73	200	25	397	58	157	12
	396	139	148	70		71	135	70	452	59	526	65

APPENDIX TABLE B

Analysis of Variance.

SOURCE	df	F	p
Burn	1	5.39	0.10
Transect(Burn)	4	2.84	0.0298
Date	5	39.55	0.0001
Burn*Date	5	9.00	0.0001
Group	2	198.71	0.0001
Burn*Group	2	0.15	0.8617
Date*Group	10	5.71	0.0001
Total	107		