RELATIVE IMPORTANCE OF FLOWING WATER ON BIOMASS AND ALGAL TAXONOMY OF PERIPHYTON ASSEMBLAGES

BIOS 569 - Practicum in Aquatic Biology

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ABSTRACT

Periphyton growth on artificial substrata, which were deposited in Tenderfoot Stream, Gogebic County, Michigan, during the summer of 1995, were examined to characterize the effects of flowing water on the biomass and algal composition of the lotic environment. Biomass was analyzed via chlorophyll *a* concentrations of the periphyton assemblages. The assemblages were also identified to the genus level to determine algal composition.

Chlorophyll *a* concentrations at both Tenderfoot Creek and Lake roughly increased from the beginning to the end of the experiment. Stream chlorophyll concentrations were not consistently higher or lower than the lake site concentrations; the higher chlorophyll concentration alternated between both stream and lake sites throughout the experiment. Increases at the stream site could be attributed to the more rapid arrival of needed nutrients via water flow present at the creek site but absent in the lake site. In contrast, decreases at the stream site could be attributed to the scouring and removal of algae from their places of attachment. Little Cyanophyta were found on any of the substrata indicating the influence of grazer control: invertebrate grazers are more likely to consume other types of algae over the unpalatable cyanophytes. For stream tiles, diatoms were most abundant demonstrating a possible reliance on mechanical adaptations that allow them to tolerate the current. As for lake tiles, filamentous green algae were the most dominant, thereby showing that lake waters provided optimal physiological conditions that allowed growth. A transplant experiment, in which half of the tiles present at one site were placed in the opposite site, was performed to roughly illustrate these effects of flowing water on chlorophyll concentrations and algal composition.

Although this experiment itself could not determine whether or not flowing water was influential in altering the biomass content or algal generic composition, this project allowed one to explore whether or not flowing water was influential at all. The works and studies done in relation to current velocity in the past allow one to recognize that biomass and algal composition of a lotic environment are most likely to be influenced by flow in either a stimulatory or inhibitory way.

INTRODUCTION

All organisms need energy for growth, maintenance, reproduction, and for some organisms -- locomotion. At the most basic level, primary producers utilize light energy to make organic material, which may be used as a source of energy to make ATP. Through food webs, consumers obtain their organic fuels second hand, sometimes third or fourth hand. For example, carnivores that eat herbivores may be considered secondary consumers dependent on primary consumers. Hence, it is the extent of photosynthetic activity that sets the energy budget for the entire ecosystem. As an advantage for primary producers, only a small amount of solar radiation is needed for photosynthesis. Yet, they are known to convert this small amount of light energy into chemical energy by photosynthesis to create about 170 billion tons of organic material per year for the entire earth. (Hynes 1970)

About half of all the photosynthetic production of organic molecules is synthesized by algae. Thus, it is easy to see the extremely important role algae carry ecologically. Being aquatic organisms themselves, algae make up the most basic level of many aquatic food webs, which support other predatory animals as well as suspension feeding animals in the system. (Hynes 1970)

However, the amount of productivity for which algae are responsible varies from one ecosystem to the next. The factors that limit this productivity depend on the algae's ecosystem and the changes that occur within their ecosystem. Water, light, temperature, and inorganic nutrients are four important factors that may be significant in limiting algal productivity, in addition to the overall algal reproductions and growth (Hynes 1970) In particular, these four factors -- water, light, temperature, and nutrients -- are essential for algal growth in running water ecosystems. Yet, if all four factors were maintained at sufficient levels for growth and productivity, another crucial environmental factor could be current velocity.

In fact, phycologists have always noted that there existed algae that only grew best in running water. *Lemanea*, *Hildenbrandtia*, *Audouinella*, and species of *Cladophora* are only a few types of algae that fit this criterion. In previous years, these species of algae were thought to grow in running waters only because lower water temperatures or a better supply of oxygen and nutrients occurred there. (Whitford 1960) However, Ruttner (1926) was able to explain part of the significance of current velocity. In still water, plants and animals developed a layer of film lacking the vital materials at their surfaces. Flowing water caused this layer of film to be swept away to bring vital materials close to the surface of the organisms for absorption.

Whitford (1960) explained the phenomenon in relation to the laws of cohesion and diffusion. In quiet waters, the needed material diffusing through the cell surface is in lowest concentration at the surface of the organisms, and is in increasingly higher concentrations the further away from the cell surface. Running water will sweep away the water containing low concentrations of the needed material, and then bring water with high concentrations of the needed material closer to the surface of the organism. As a result, the diffusion distance is decreased and the gradient for diffusion inward is increased.

On the other hand, flowing water may have detrimental effects to the growth of algae. Raven (1992) described stream flow as one of the many "physical assaults" that algae must encounter. Breakage or a detachment of already growing communities of periphyton is one result of flowing water in streams. Another "assault" on stream algae is a result of the fact that flow is unidirectional. Upstream movements of their propagable parts are therefore restricted and prevented from anchoring onto a substratum. In addition, Reisen et. al. (1970) would also add to this list of "assaults" the impact of humans, which includes anything from aquatic pollution to the direct physical disturbance of walking along a streambed of algae. Furthermore, Welch et. al. (1992) would also add to this list the effect of invertebrate grazer abundance. One finding in their work was that water flow did not always enhance algal nutrient uptake due to the high density of grazers.

The enhancing and detrimental effects of flowing water obviously influences the growth of algae. The purpose of this study is to characterize the effects of flowing water on the biomass of a running water system. Since algae are primary producers and maintain the food web in the running water ecosystem, biomass was analyzed by an assay for chlorophyll *a* , which is a pigment that all algae possess. In particular, algae from periphyton assemblages (the growth of organisms from the free surfaces of submerged objects in water) were examined. At the same time, the periphyton were also used to characterize the effects of flowing water on the taxonomic composition of algae present in the stream. Furthermore, to elucidate the influential effects of flowing water, periphyton from a lotic environment were transplanted to a non-lotic environment and assayed for biomass content and algal taxonomy. It was predicted that flowing water would not significantly influence the biomass or algal taxonomy for a running water system. Therefore, between a still water system and a running water system that are both supplied with the same water temperature, light energy, and nutrient concentrations, there should be no difference in biomass content and algal taxonomic composition observed. Moreover, transplanting periphyton from one environment to the other should not alter the biomass or algal composition in its new environment.

MATERIALS AND METHODS

Experimental Design

The experiment was conducted at Tenderfoot Creek and Lake in Gogebic County, Michigan at the University of Notre Dame Environmental Research Center (Fig. 1). It was initiated on May 27, 1995 and continued for 49 days.

The experimental design involved depositing artificial substrata at the stream site and examining substrate colonization as it was affected by flowing water. This process was also done at a lake site -- the control site -- at which flow was absent. Moreover, colonization was studied by transplanting one half of the tiles at one site into the opposite site, thus providing a control and experimental group at each site. Biomass was monitored at both sites, while taxonomic structure of the algal assemblages was also studied. Current velocity was measured as well as controlling ecological factors such as the water temperature, the concentrations of nitrate, phosphate, and ammonium ions, and water depth.

Sampling

To allow quantitative sampling of periphyton, 15.3 x 15.3 cm clay tiles were used to provide a flat, smooth surface for colonization (Fig. 2). Eighteen clay tiles were deposited at the chosen stream and lake sites at the beginning of the experiment (Fig. 3-4, Table 1). Colonization was not apparent until day 17, which marked the be ginning of the sampling periods. After three sampling periods (day 33), one half of the tiles at each site was transferred to its opposite site. Therefore, each habitat contained a control and experimental group of tiles.

For the first three sampling periods (days 17, 25, and 33), two tiles were randomly obtained from both lake and stream sites. In the last two sampling periods, two tiles from each control and experimental of the particular habitat were collected (for a total of four tiles from each site). Again, sampling for the transplant part of the experiment was performed randomly. Each tile collected was subsampled three times for biomass and three more times for alga taxa composition.

For an estimate of biomass, the periphyton was prepared for an analysis of chlorophyll *a* on the same day that samples were collected. The procedure utilized was the monochromatic method as outlined by Lorenzen (1967). Periphyton assemblages were scraped off tiles using a 1- cm razor blade (Fig. 5). Samples were then extracted in 90% acetone, ground manually, and stored overnight in the dark in a refrigerator. The algal samples were spun at full speed at full speed for ten minutes with an *International Model HN* centrifuge. Absorption readings were taken with a *Bausch and Lomb Spectronic 88* spectrophotometer at a wavelength of 665 nm. Absorption readings were again taken after acidifying the samples with three drops of 3N HCl to account for the presence of phaeophytins. The chlorophyll *a* concentrations were expressed in ($\mu g / cm^2$) by using the following equation:

$$\text{Chl } a = \frac{(k)(F)(Ei\ 665 - Ef\ 665)(V)}{(A)(Z)}$$

where k = absorption coefficient of chlorophyll *a* = 11.0, F = factor to equate the reduction in absorbance to initial chlorophyll concentration = 2.43, Ei 665 = corrected absorption before acidification at 665 nm, Ef 665 = corrected absorption after acidification at 665 nm, A = area of the sample scraped, and Z = length of the light path through cuvette = 1 cm.

To analyze for alga taxa, periphyton assemblages were removed from each tile using a razor blade. The organisms were allowed to sit in 4 dram vials of habitat water, which also contained the fixative Lugol's solution for 2 to 3 days. Then, the periphyton assemblages were studied under 400 X power of an *Olympus phase contrast* compound microscope. Identifications were made to the genus level (Prescott 1954). Diatoms were quantitatively counted as individual cells or valves, if they were unicellular; otherwise, they were counted as individual filaments or colonies, if they were multicellular. Out of approximately 100 diatom cells, percent abundances were calculated for the common genera studied. For any other taxon outside the division Bacillariophyta, each one was identified and then qualitatively ranked in order of decreasing dominance.

Additionally, for every work day -- days 1, 8, 17, 25, 33, 41, and 49 -- growth determinants were measured and recorded despite whether or not tiles were sampled. Current velocity was measured with a *Kahl Scientific Instrument Corporation* current meter. Water temperature was monitored by using a *HACH Conductivity / TDS Meter.* Water concentrations of nitrate, phosphate, and ammonium ions were determined by using a *HACH DREL / 2000 Direct Reading Spectrophotometer*. Lastly, water depth was recorded using a meter stick.

RESULTS

a) Chlorophyll a *and generic composition for Tenderfoot Creek and Lake*

Although the current velocity, water temperature, and water depth data were not helpful in analyzing the results, it is still possible to see the trends in the other data obtained. In general, chlorophyll *a* for both Tenderfoot Creek and Lake exhibited a gradual increase from the beginning to the end of the experiment (Fig. 6). However, from 28 June to 14 July, the stream and lake did show changes in opposite directions: whereas the concentration at one site increased or decreased, the concentration at the opposite site decreased or increased respectively.

Equally important were how the nutrient concentrations of $N\text{-}NH_3$, PO_4^{3-}, and $N\text{-}NO_3^-$ changed over time. In the graph of $N\text{-}NH_3$ versus time and PO_4^{3-} versus time (Fig. 7-8), the stream and lake concentrations changed in directions opposite to each other. For instance, when the concentration of the nutrient increased in one site, the concentration in the opposite site experienced a decline. The third nutrient concentration graph of NO_3^- versus time (Fig. 9) revealed parallel changes in concentrations for stream and lake between almost every sampling period of the experiment. For example, whenever lake concentrations of NO_3^- increased, stream concentrations of NO_3^- likewise increased.

The periphytic algae studied in this experiment included the Bacillariophyta, Chlorophyta, and Cyanophyta (Table 2). In general, the diatoms and green algae constituted the majority of the algae found on the substrata throughout the experiment while the blue green algae occurred rarely and in small numbers in comparison to the diatoms and green algae. From Table 3, one sees a definite pattern at the stream site in contrast to the lake site: diatoms were more numerous than the green algae in the stream, whereas the green algae were more numerous than the diatoms in the lake.

On the whole, both creek and lake sites shared many of the same algal genera (Table 2). However, unique to the stream site were the green alga *Vaucheria* and the diatom *Rhopalodia*. Moreover, the stream site displayed different trends in diatom dominance as opposed to the lake site (Figs. 10-14). For the first two sampling periods, *Fragilaria*, *Epithemia*, *Eunotia*, and *Tabellaria* were the most dominant diatoms. *Fragilaria* and *Epithemia*, for the most part, continued to be the most dominant diatoms, while *Eunotia* and *Tabellaria* became less dominant as other various algae took their places from the third sampling period until the end of the experiment. Similarly, the lake contained *Fragilaria* as well as *Epithemia* as two dominant diatoms throughout the experiment. However, more *Fragilaria* were found in the lake than in the stream for almost every sampling period excluding the third one. Percent abundance for *Epithemia* fluctuated between the two the sites. In addition, Tenderfoot Lake tended to have *Synedra* and *Cymbella* as reoccurring diatoms throughout most of the experiment.

Again, it is apparent from Table 4 that the lotic environment varied from the nonflowing site in terms of filamentous green algae composition. On one hand, the stream showed to have *Stigeoclonium* as its most common genus, as well as *Vaucheria*, *Mougeotia*, and *Ulothrix* as three other dominant green algae (Figs. 10-14). On the other hand, the lake contained *Spirogyra* in all sampling periods and was the most common green alga. *Mougeotia*, *Desmidium*, and *Hyalotheca* were three other common genera in the lake (Figs. 10-14).

b) Chlorophyll a *and generic composition for transplant experiment*

Since the transplant experiment was performed for only two sampling periods, an analysis for any statistical trends was not possible.

Of primary importance is the resulting data during the second sampling period (14 July) during which the transplant experiment was employed.

Figure 15 shows the chlorophyll*a* concentrations for both the control and the experimental groups in stream and lake sites. Looking at this graph, one sees that the difference between the S->L (stream explanted tiles) chlorophyll concentration and the stream control group chlorophyll concentration during 14 July was not significant. Moreover, the difference between the S->L concentration and that of the lake control group for the last sampling period was insignificant for the same reason. However, it was noted that there was a significant decrease between the chlorophyll *a* concentration for S->L on 6 July and its concentration for the following sampling period.

As for lake explanted tiles that were placed into the stream (L->S), it was noted that there was a slight decrease between the L->S chlorophyll *a* concentration and that of the lake control group for 14 July. However, compared to the stream control group for 14 July, L->S concentration was not very different as seen by the overlap in error.

Algae from the Chlorophyta, Bacillariophyta, and the Cyanophyta were found on the explanted tiles in the experiment (Table 5). The chlorophytes and bacillariophytes made up most of the growth on all the experimental tiles compared to the few cyanophytes, which only occurred on the stream explants (S->L). Between the two, Chlorophytic algae were more abundant than the Bacillariophytic algae for both sampling periods for S->L. The opposite seemed to be true for the lake explants that were placed in the stream (L->S). Initially, the tiles were colonized by more Chlorophyta than Bacillariophyta. However, by 14 July, the Bacillariophyta dominated over the Chlorophyta.

The S->L tiles showed immediate colonization by*Spirogyra* (Table 6). *Desmidium* was another dominant filamentous green alga. As far as the diatoms were concerned,*Fragilaria* and*Epithemiia* were most prevalent (Figs. 10-14).

In contrast, common diatoms that grew on lake explanted tiles that were placed in the stream (L->S) included*Brebissonia* and *Anomoeoneis*. (Figs. 10-14). Apart from all other groups of tiles, L->S tiles also showed the greatest percentage of *Rhopalodia* during the last sampling period. As for the filamentous green algae, this transplant group exhibited dominance by*Stigeoclonium.*,*Spirogyra*, and *Desmidium* (Table 6) .

DISCUSSION

a) Chlorophyll a *and generic composition for Tenderfoot Creek and Lake*

The primary reason that the data recorded were highly fluctuating and thus had no significance was that a faulty current meter was used. Although it was wisely suggested by the faculty advisor to utilize a different mode of measuring current velocity, this advice was not taken and meaningless results were thus obtained. Nevertheless, despite the lack of current velocity data, the significant point at hand is to explore the possibilities of how flowing water *might* have affected the two main variables of the project: biomass and the generic algal composition of the aquatic system.

As shown by Figs. 6 and 9, chlorophyll*a* and NO_3^- concentrations at both Tenderfoot Creek and Lake were proportional to each other. This proportionality between the two sites emphasizes a crucial point: Tenderfoot Creek flows out from Tenderfoot Lake. Hence, the properties of the stream should be viewed as a function of the properties of the lake (Hynes 1970). For chlorophyll*a*, not only were concentrations at both sites proportional to each other, but they also showed a rough trend of increasing throughout the experiment. Since chlorophyll concentrations were used as an indicator of the biomass of the system, then it is most likely that the biomass of the system increased throughout the experiment as well.

Even though the changes in concentrations for chlorophyll*a* and nitrate ions were proportional to each other, one could point out that the absolute concentrations of either chlorophyll *a* or nitrate ions from each site were not identical to each other. The same holds true for the ammonia, phosphate, and nitrate ion concentrations (Figs. 7-9). Consequently, all four graphs appear to defy the strong interrelationship between a lake and its outflowing stream. Theoretically, both stream and lake concentrations should be similar for each given time period. There are four sources of error that can be attributed to the discrepancies that the opposing changes between the stream and lake illustrate: 1) sampling error, 2) environmental heterogeneity, 3) contamination of the sample, and 4) analytical error. Since people were often observed fishing and boating in Tenderfoot Lake during the summer, then perhaps such water movement could have influenced algal growth, and therefore the chlorophyll concentrations in the lake as opposed to the stream. Even Horner et al. (1981) reinforced the importance of flow as a result of human impact on algal growth. He mentioned that stream channel reconstruction, water diversions for irrigation purposes, and other factors strongly affect the physical and chemical environments of algae. The point is that human impact largely affects the growth of algae. In this experiment, such human impact could have been a source of error.

At the same time, it could be possible that these sources of error were not involved in the experiment at all. Perhaps then, the concentrations of chlorophyll*a* for the stream and lake actually did oppose each other and fluctuated throughout the experiment. Thus enters the factor of central importance and is the focus of this project: flowing water or current velocity. The current velocity present in the stream and absent in the lake could account for the differences in chlorophyll *a* concentrations, and hence biomass. Whitford (1960) demonstrated that water current could actually sweep material from the cell surfaces of algal cells. As a result, a diffusion gradient allowed a recycling of nutrients and the removal of excretion of products from the cell surface. Such factors stimulated algal growth. The chance that any one nutrient will become limiting is much less due to this diffusion gradient. Perhaps the water current in Tenderfoot Creek swept nutrients off the cell surfaces of stream algae to produce this desirable diffusion gradient. This idea could explain how chlorophyll *a* was sometimes higher in the stream than in the lake.

The next question to ask is why would stream concentrations be lower than lake concentrations of chlorophyll? One possible answer to this question deals with strength of the current velocity. Too strong of a current may wash algae away. Thus, the removal of algae from the ecosystem would lead to a decrease in chlorophyll *a* concentration. Work done by Bergey et. al. (1995) showed that *Cladophora* fragmentation was greatest when current velocity was increased. It was thus concluded that *Cladophora* loss should be greatest in pools as opposed to riffles because pools were more susceptible to increases in current velocity.

The fact that very little Cyanophyta were found on any of the substrata in the experiment suggests the influence of grazer control (Biggs et. al. 1994). Due to the fact that periphyton produces the majority of organic material in many aquatic food webs, invertebrate grazers depend upon algae as source of energy. However, because many cyanophytes are unpalatable, they tend to compete less successfully for colonization against the more tasteful bacillariophytes and chlorophytes. (Fogg et. al. 1973)

The differences found in the relative abundance in Tenderfoot Creek and Lake reiterate a vital point: the algae in streams are different from algae in lakes. One possible difference between diatoms in the stream versus those in the lake involves the mechanical adaptations that allowed stream diatoms to tolerate the stress of current in the first place. Stevenson (1984) ran experiments and personally observed that diatoms held themselves firmly with either a raphe, stalk, or mucilaginous pad even when subjected to increasing current velocities. With such adaptations, it could be possible that stream diatoms such as *Fragilaria*, *Epithemia*, *Eunotia*, and *Tabellaria* were numerous enough to dominate over the chlorophytes such as *Stigeoclonium*, *Vaucheria*, *Mougeotia*, and *Ulothrix*.

The fact that the green alga *Spirogyra* was the most dominant genus for every sampling period in Tenderfoot Lake also emphasizes how different lake algae is from stream algae. This successful trait of *Spirogyra* supported the work of Borchardt (1994) who hypothesized that a certain species of *Spirogyra* were only found in slow moving waters because such waters were physiologically optimal. Thus, perhaps the reason why *Spirogyra* was so successful in Tenderfoot Lake was that it absorbed nutrients best at the concentration levels and water velocities existing in the lake. Thus, it would make sense to find more Chlorophyta than Bacillariophyta in the lake.

b) Chlorophyll a *and generic composition for transplant experiment*

The chlorophyll *a* data obtained for the transplant experiment indicated no significant change for either stream or lake explanted tiles as compared to either the stream or lake control groups. Nevertheless, it would be just as beneficial to explore the possibilities of how flowing water affected the biomass and generic composition for the transplanted tiles.

If the transplant experiment were to be carried out for more sampling periods, the S->L tiles might be expected to show a decrease in chlorophyll *a* concentration compared to the stream control group because stream algae accustomed to receiving a flux of chemical resources via moving waters would no longer be receiving them at the more rapid rate required by the algae. Thirb et. al. (1982) demonstrated this point when they found that a certain algae (*Lemanea*) was unable to survive for more than 14 days in non-lotic waters. Compared to lake control group of tiles, the algae on the S->L tiles would most likely exhibit lower concentrations of chlorophyll. The stream explanted algae would already be at a disadvantage by not receiving their needed resources at the correct rate; therefore, they would not have concentrations of chlorophyll that would exceed the chlorophyll concentrations for lake algae. Algae dwelling in lakes are already successful because they are surrounded by optimal concentrations of nutrients in water that has an optimal rate of flow for these lake specific algae (Borchardt 1994).

On the contrary, it is more difficult to predict the outcome of lake explanted tiles that are to be placed in a stream. On one hand, one may argue that chlorophyll *a* concentrations would increase for L->S tiles. Algal growth would be enhanced if current velocity consistently brought the vital materials to the surface of algal cells for absorption and removed the unneeded excreted products (Whitford 1960). On the other hand, one may also argue that increased flow might even decrease nutrient uptake because the lake algae were not accustomed to an uptake of resources at this increased flow rate. Hence, chlorophyll *a* concentrations would decrease. Moreover, current velocity imposes new stresses on the transplanted algae that would cause them to fragment or to be scoured from their point of attachment (Raven 1992).

As seen by the lake control group, the S->L group of tiles showed very little Cyanophyta present. Again, this observation reinforces the importance of grazer control: because the cyanophytes are unpalatable by invertebrates, they tend to be disregarded. As their numbers increase, they will most likely compete less and less successfully for space on the substrata. (Fogg. et. al. 1973)

Colonization by S->L tiles showed more dominance by Chlorophyta than Bacillariophyta. This dominance is similar to that of the control lake group, which was also dominated by chlorophytes. However, this order of dominance is the exact opposite of the control stream group, which had more Bacillariophyta than Chlorophyta. Thus, S->L tiles stress again how lake algae differs from stream algae. Evidence is not strong enough to say that the diatom abundance from its previous habitat decreased; rather, it is more important to say that the optimal resource concentrations and water velocity of the lake allowed the flourishment of common lake algae such as*Spirogyra* and *Desmidium* than the diatoms *Fragilaria* and *Epithemia.*

In contrast, the L->S transplant tiles displayed algal growth by mostly Bacillariophyta over Chlorophyta. Again, it is more likely that the lake diatoms, such as *Brebissonia* and *Anomoeoneis*, on the tiles were most likely able to cope with their new environment consisting of lotic waters than the green algae like*Stigeoclonium*, *Spirogyra*, and *Desmidium*. Diatom success could also be attributed to their ability to form mechanical adaptations that increase their adherence potential (Stevenson 1984).

Although this experiment itself could not determine whether or not flowing water was influential in altering the biomass content or algal generic composition, it was possible to at least explore the possibilities to see whether flow could have been influential. The works and studies done in relation to current velocity in the past allow one to say that the proposed hypothesis is incorrect. Biomass and algal composition of a lotic environment are most likely to be influenced by flow in either a stimulatory or inhibitory way.

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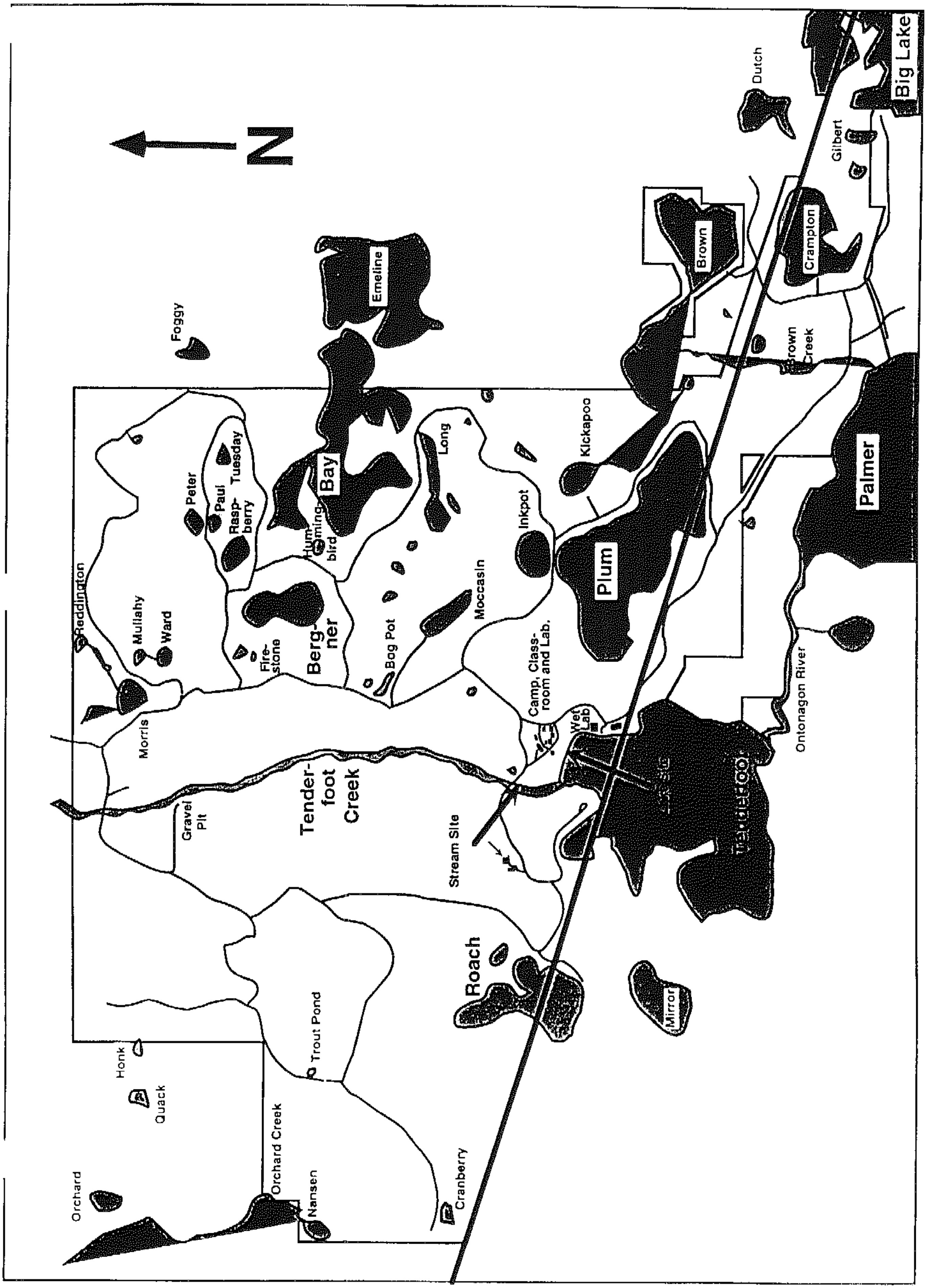
Fig. 1. Map of the property of the University of Notre Dame Environmental Research Center indicating where tiles were deposited in Tenderfoot Creek and Tenderfoot Lake for the experiment initiated on 27 May and ending on 14 July (UNDERC unpublished).



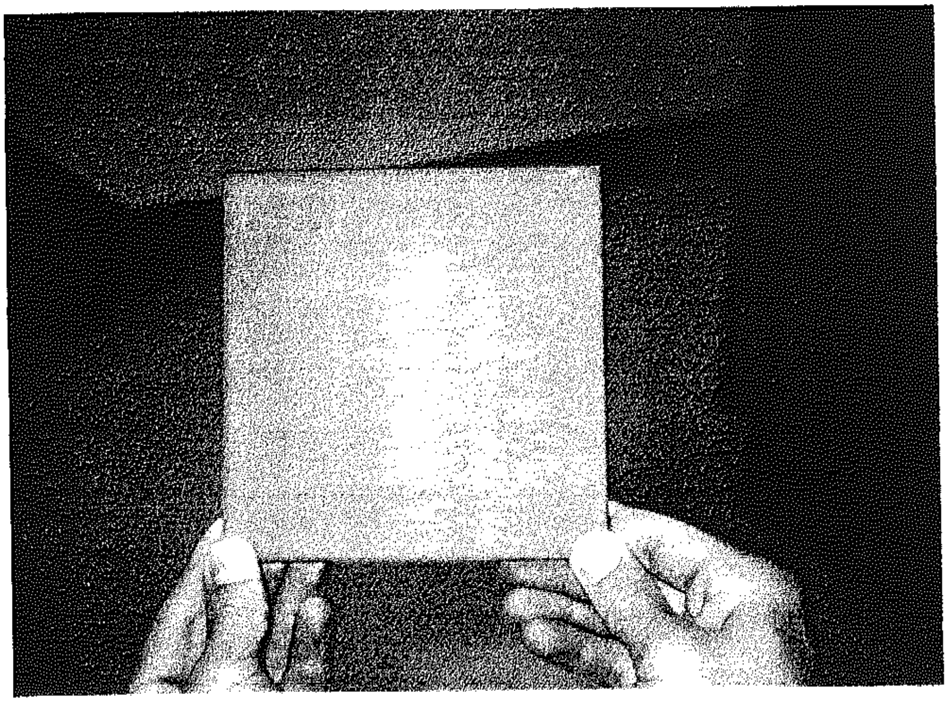


Fig. 2. Clay tile used for quantitative sampling of periphyton from 27 May to 14 July.

Fig. 3. Deposited clay tiles in Tenderfoot Creek. (Photo taken 27 May)

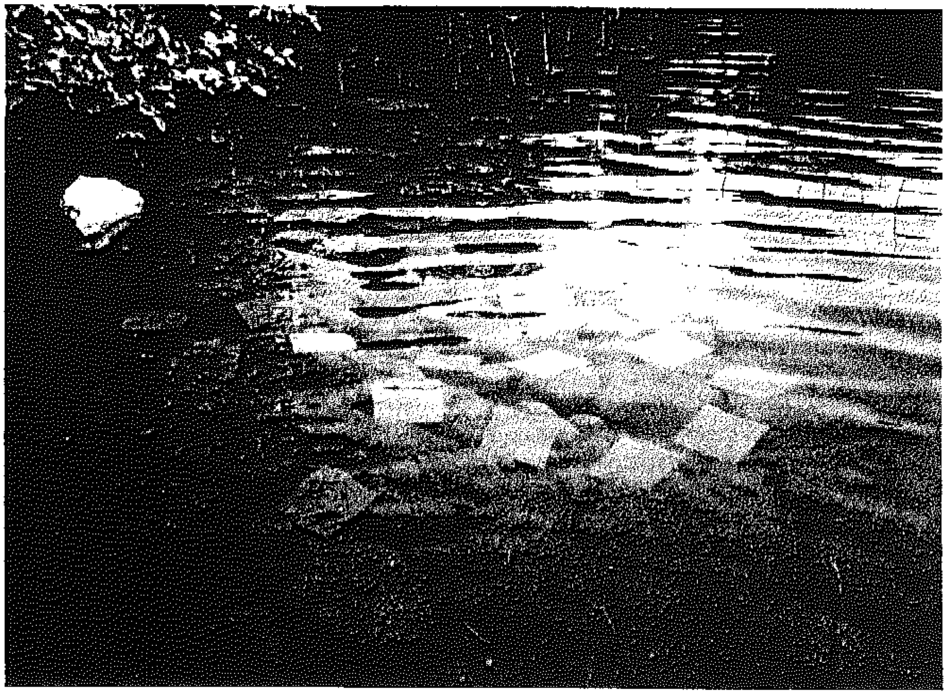


Fig. 4. Deposited clay tiles in Tenderfoot Lake. (Photo taken 27 May)

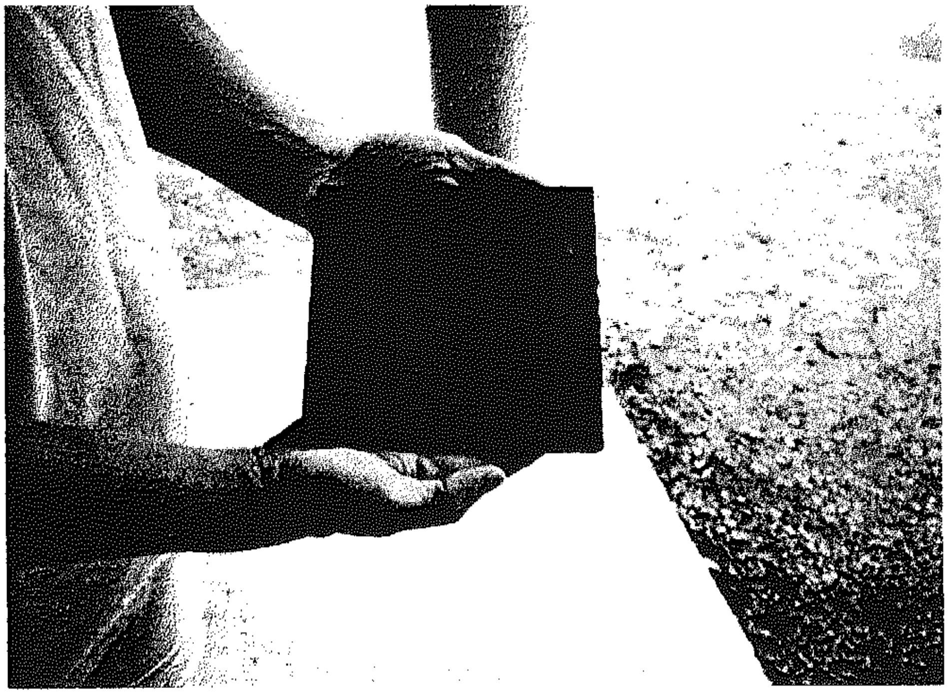


Fig. 5. Periphyton assemblages scraped in three random areas from clay tile for laboratory analyses.

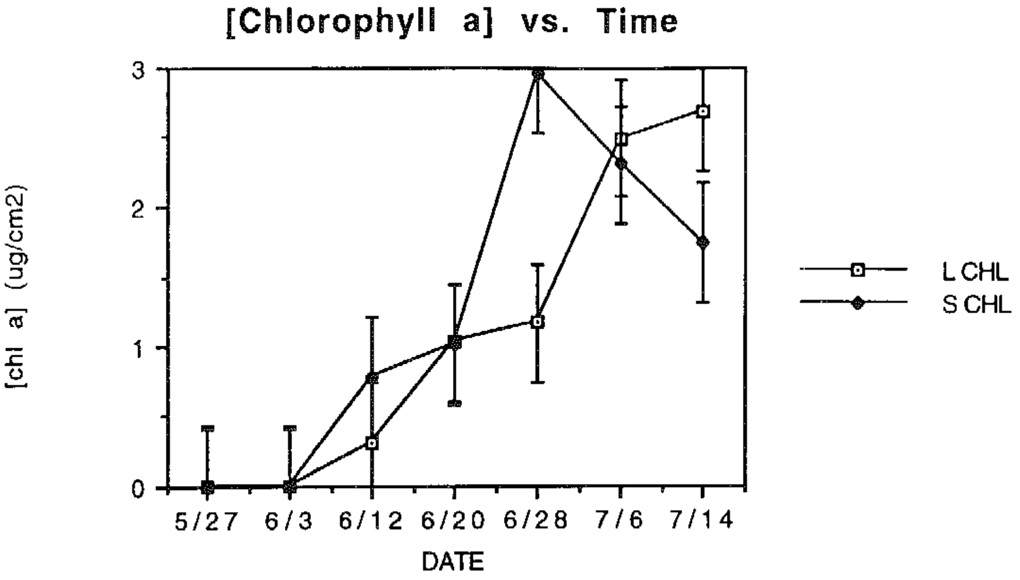


Fig. 6. Chlorophyll *a* concentrations from 27 May to 14 July in Tenderfoot Creek (S Chl) and Tenderfoot Lake (L Chl). Each error bar is one standard error from the mean.

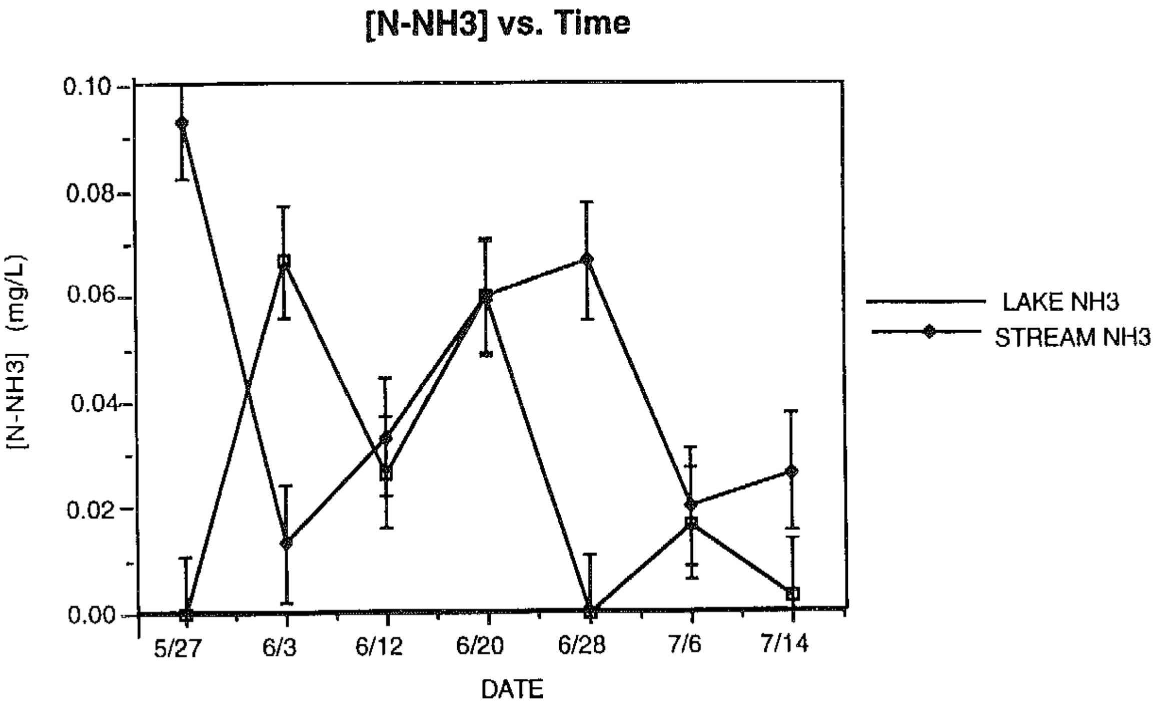


Fig. 7. Ammonia concentrations from 27 May to 14 July in Tenderfoot Creek (Stream NH3) and Tenderfoot Lake (Lake NH3). Each error bar is one standard error from the mean.

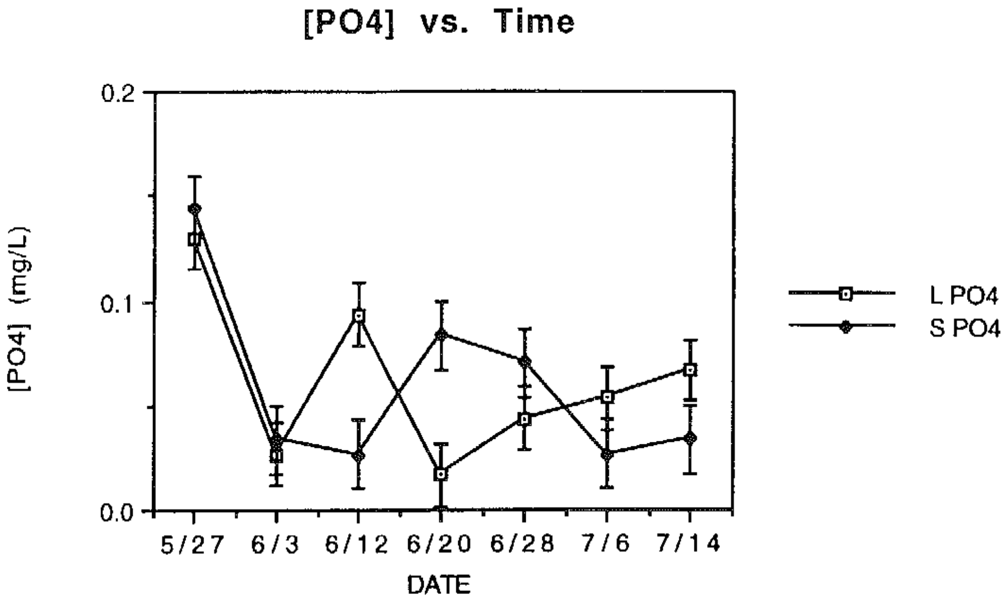


Fig. 8. Phosphate concentrations from 27 May to 14 July in Tenderfoot Creek (S PO4) and Tenderfoot Lake (L PO4). Each error bar is one standard error from the mean.

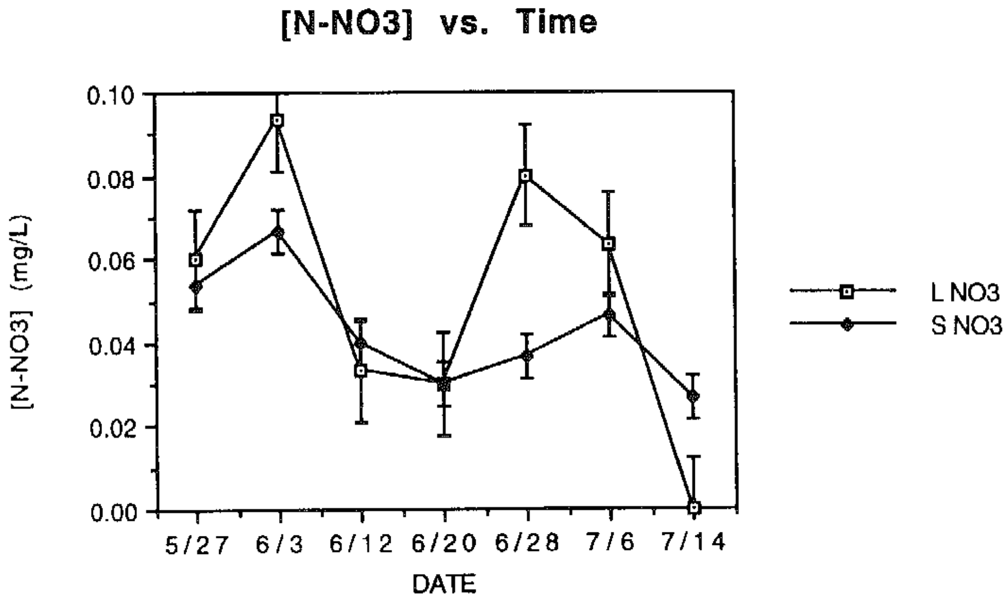


Fig. 9. Nitrate concentrations from 27 May to 14 July in Tenderfoot Creek (S NO3) and Tenderfoot Lake (L NO3). Each error bar is one standard error from the mean.

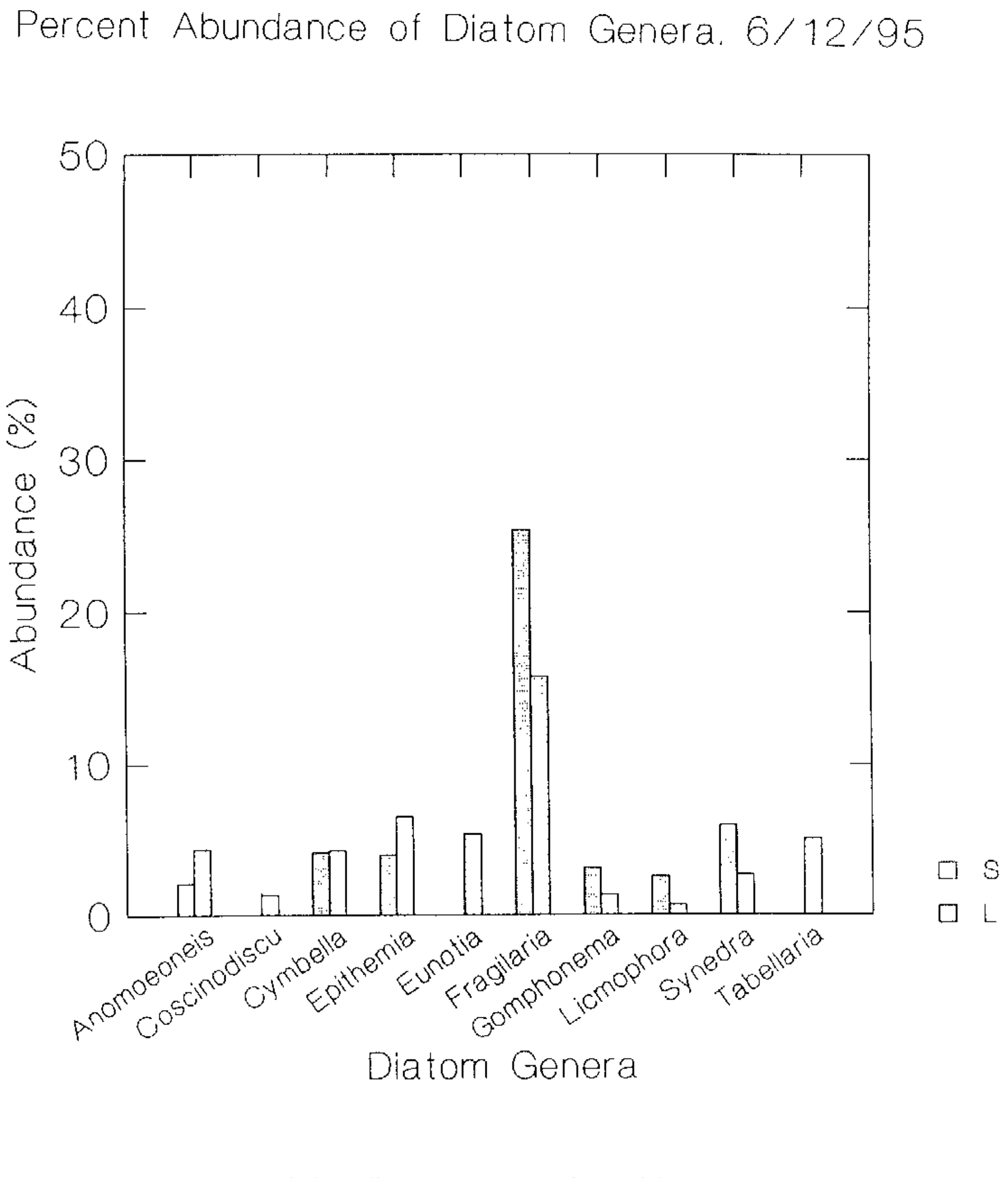


Fig. 10. Percent abundance of the diatom genera found in Tenderfoot Creek (S) and Tenderfoot Lake (L) for 12 June sampling period. Miscellaneous diatom genera (not shown) accounted for the remaining 50% of the percent abundance.

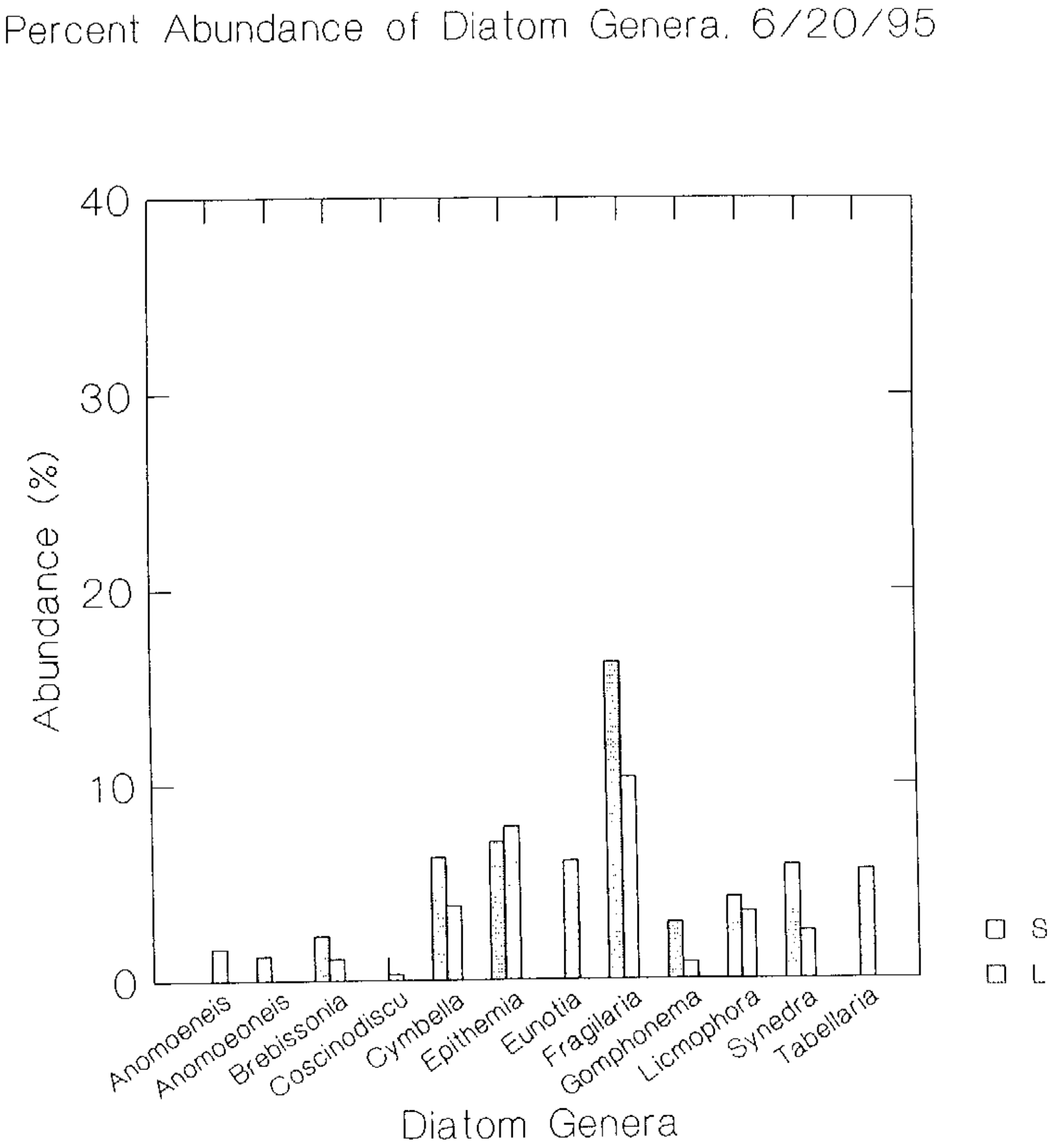


Fig. 11. Percent abundance of the diatom genera found in Tenderfoot Creek (S) and Tenderfoot Lake (L) for 20 June sampling period. Miscellaneous diatom genera (not shown) accounted for the remaining 60% of the percent abundance.

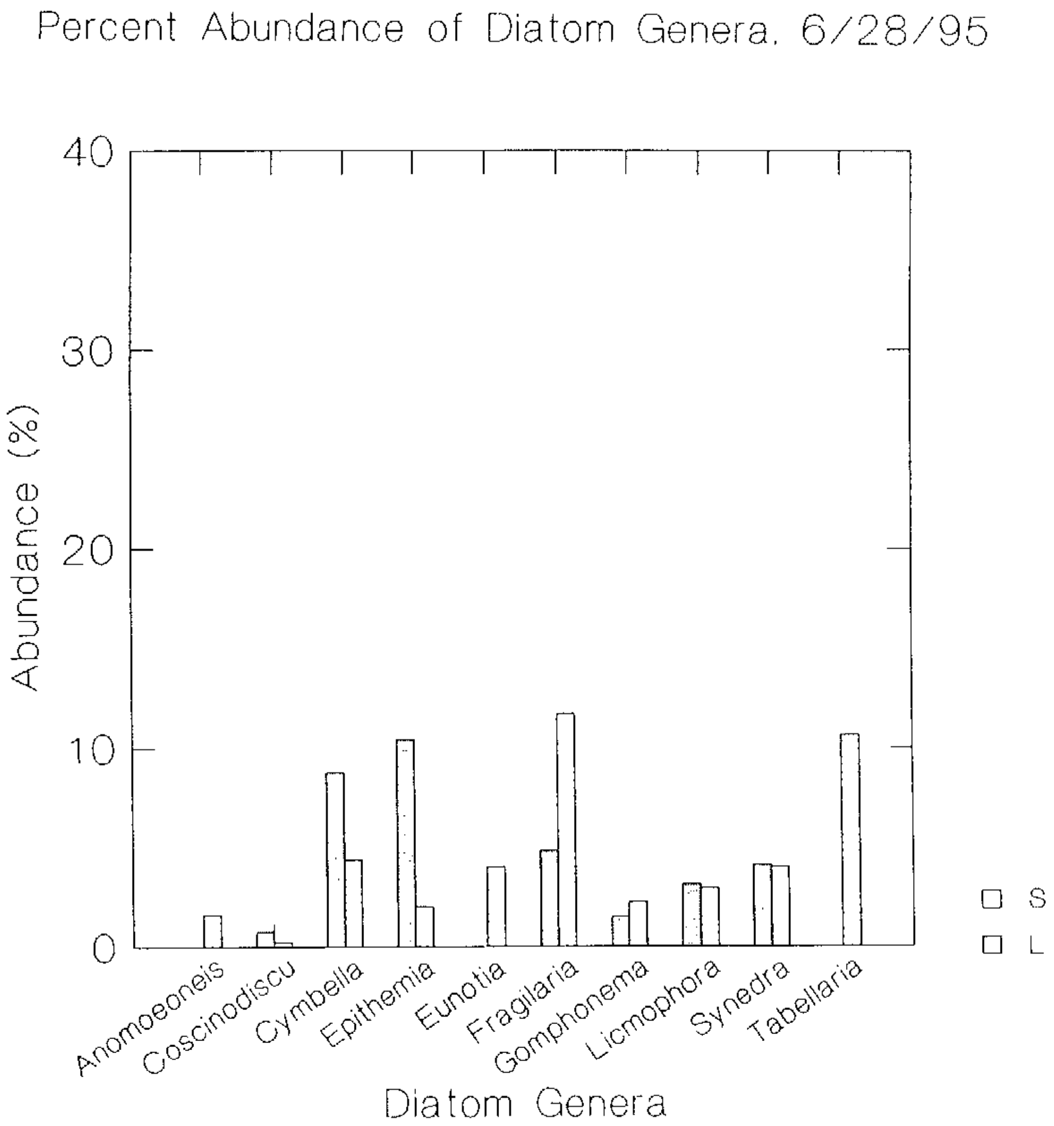


Fig. 12. Percent abundance of the diatom genera found in Tenderfoot Creek (S) and Tenderfoot Lake (L) for 28 June sampling period. Miscellaneous diatom genera (not shown) accounted for the remaining 60% of the percent abundance.

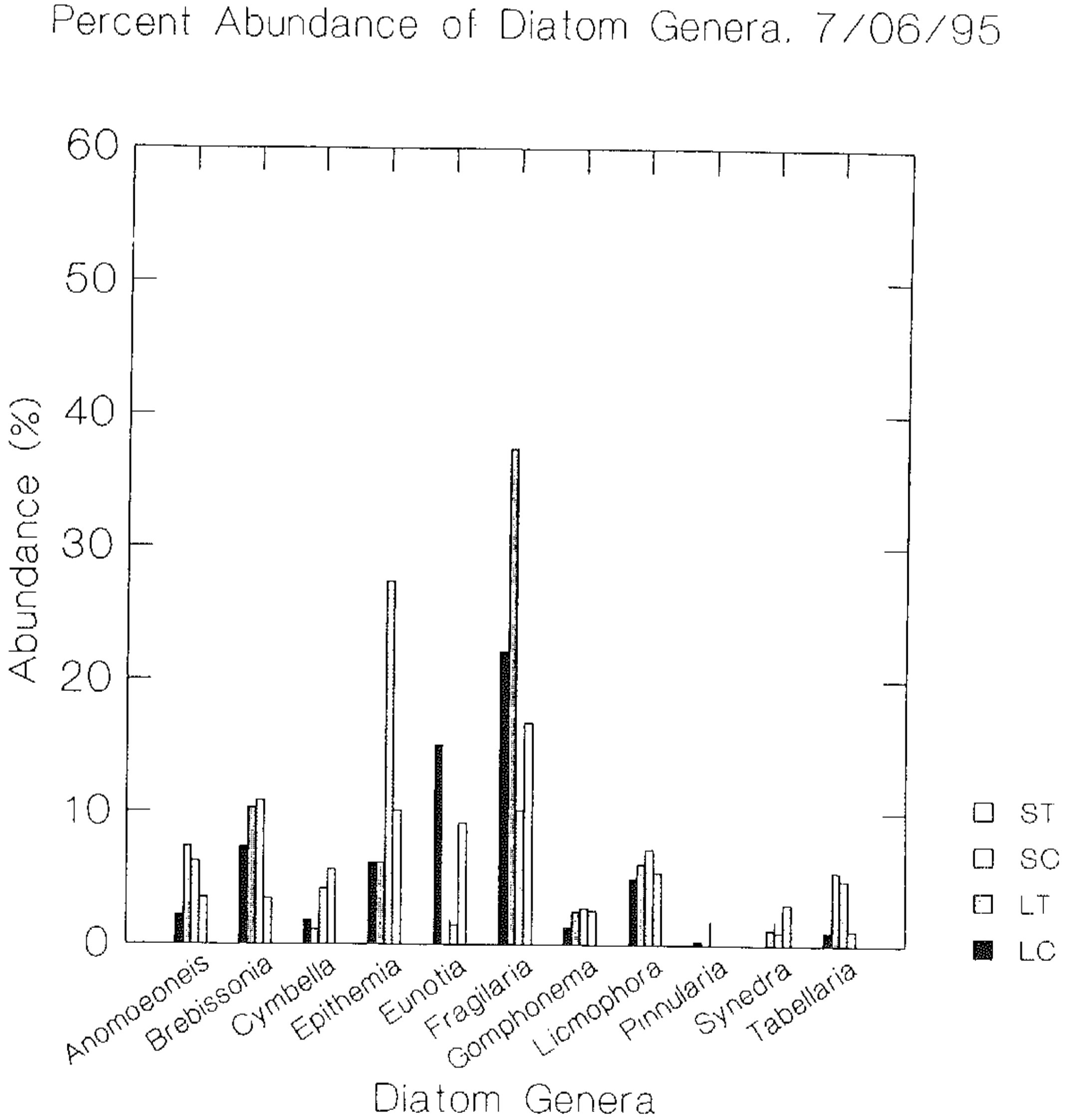


Fig. 13. Percent abundance of the diatom genera for control groups in Tenderfoot Creek (SC) and Tenderfoot Lake (LC) for 6 July sampling period. Percent abundance of the diatom genera for Tenderfoot Creek explanted tiles (S->L or ST) and Tenderfoot Lake explanted tiles (L->S or LT) for 6 July sampling period also shown. Miscellaneous diatom genera (not shown) accounted for the remaining 40% of the percent abundance.

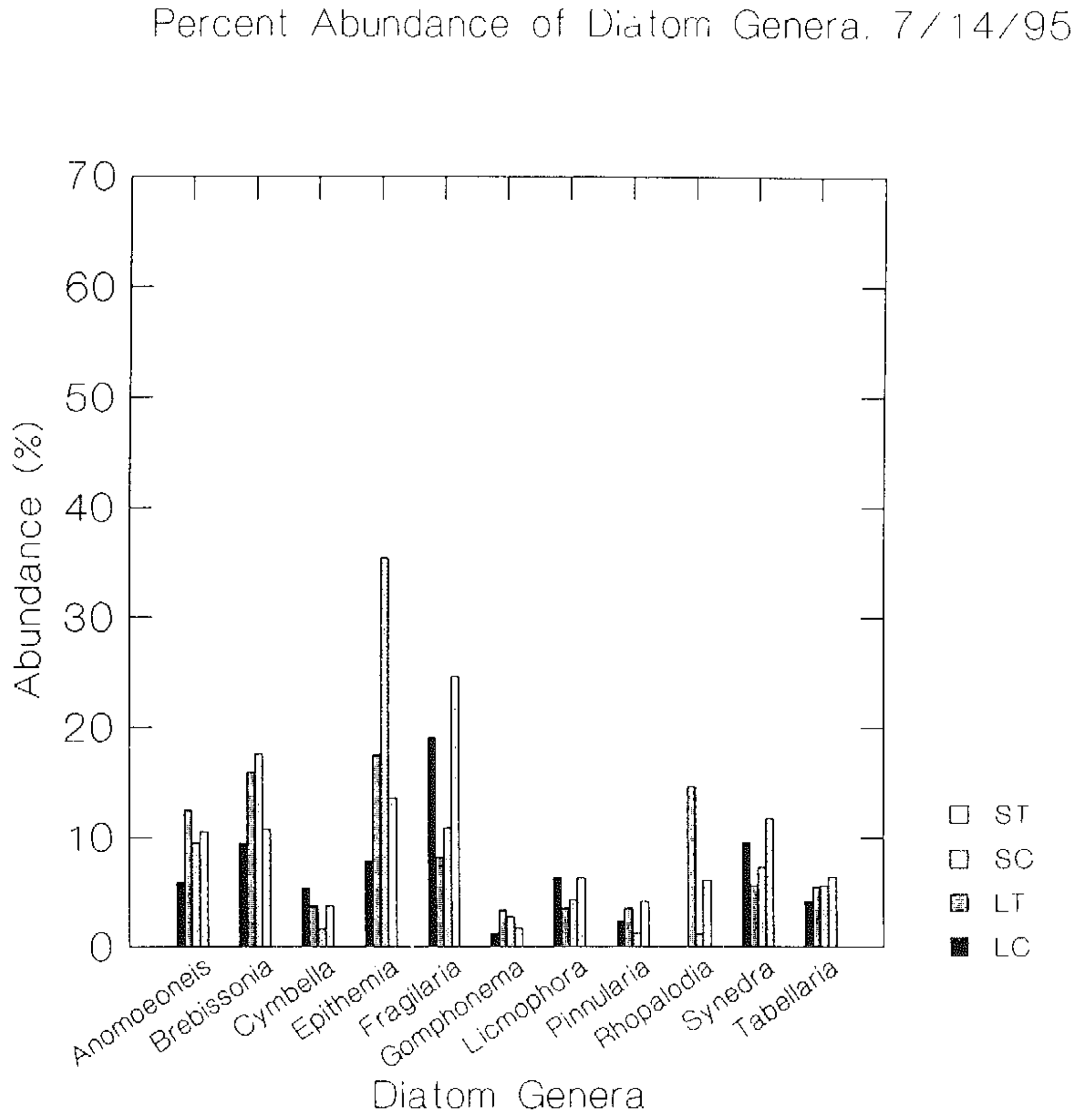


Fig. 14. Percent abundance of the diatom genera for control groups in Tenderfoot Creek (SC) and Tenderfoot Lake (LC) for 14 July sampling period. Percent abundance of the diatom genera for Tenderfoot Creek explanted tiles (S->L or ST) and Tenderfoot Lake explanted tiles (L->S or LT) for 14 July sampling period also shown. Miscellaneous diatom genera (not shown) accounted for the remaining 40% of the percent abundance.

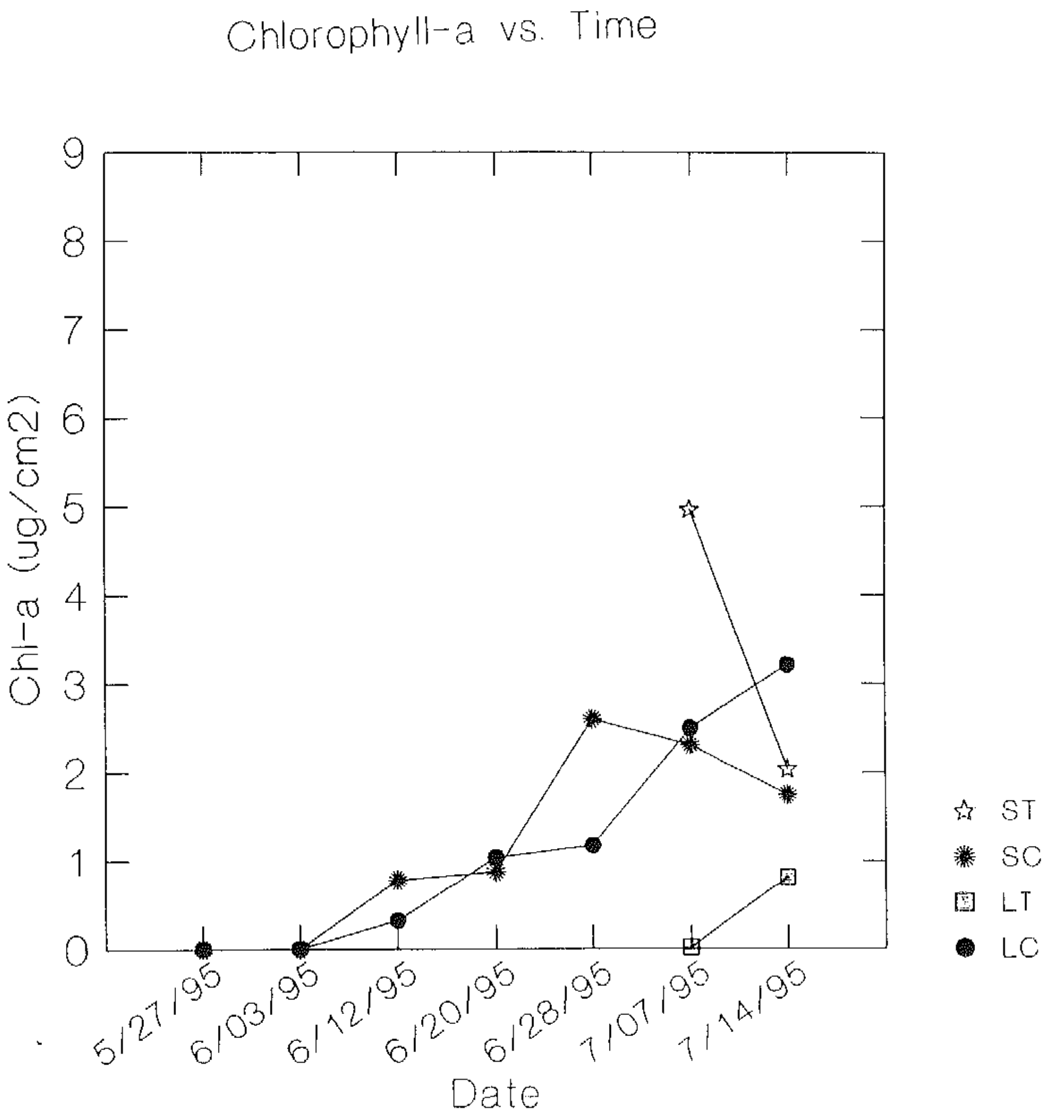


Fig. 15. Chlorophyll *a* concentrations for Tenderfoot Creek explanted tiles (S->L or ST) and Tenderfoot Lake explanted tiles (L->S or LT) from 6 July to 14 July. Chlorophyll *a* concentrations for control groups in Tenderfoot Creek (SC) and Tenderfoot Lake (LC) from 27 May to 14 July also shown. Each error bar is one standard error from the mean.

Table 1. Work schedule indicating the number of tiles remaining at each site and the procedures employed for sampling periods beginning on 27 May and ending on 14 July.

Date	Day	Tiles in Stream	Tiles in Lake	Procedure
5/27/95	1	18 S	18 L	Deposited tiles; daily measurements taken
6/3/95	8	18 S	18 L	Daily measurements taken
6/12/95	17	16 S	16 L	Sampled tiles (1); daily measurements taken
6/20/95	25	14 S	14 L	Sampled tiles (2); daily measurements taken
6/28/95	33	6 S, 6 L	6 L, 6 S	Sampled tiles (3); daily measurements taken; transplanted one half of tiles to opposite habitat
7/6/95	41	4 S, 4 L	4 L, 4 S	Sampled tiles (4); daily measurements taken
7/14/95	49	2 S, 2 L	2 L, 2 S	Sampled tiles (5); daily measurements taken; ended experiment

Table 2. Total genera of periphytic algae observed from substrata in Tenderfoot Creek and Tenderfoot Lake. (*) = unique genus at the respective site

Tenderfoot Creek	**Tenderfoot Lake**
Bacillariophyta:	Bacillariophyta:
Anomoeoneis	*Anomoeoneis*
Brebissonia	*Brebissonia*
Coscinodiscus	*Coscinodiscus*
Cymbella	*Cymbella*
Epithemia	*Epithemia*
Eunotia	*Eunotia*
Fragilaria	*Fragilaria*
Gomphonema	*Gomphonema*
Licmophora	*Licmophora*
Pinnularia	*Pinnularia*
**Rhopalodia*	*Synedra*
Synedra	*Tabellaria*
Tabellaria	
Chlorophyta:	Chlorophyta:
Bulbochaete	*Bulbochaete*
Cladophora	*Cladophora*
Desmidium	*Desmidium*
Hyalotheca	*Hyalotheca*
Mougeotia	*Mougeotia*
Rhizoclonium	*Rhizoclonium*
Spirogyra	*Spirogyra*
Stigeoclonium	*Stigeoclonium*
Ulothrix	*Ulothrix*
**Vaucheria*	
	Cyanophyta:
	* *Anabaena*
	* *Lyngbya*

Table 3. A comparison of the relative abundance of algal divisions found on substrata in Tenderfoot Creek and Tenderfoot Lake for five sampling periods.

	Stream	Lake
Date	**Ranking of Relative Abundance of Algae**	**Ranking of Relative Abundance of Algae**
6/12/95	Bacillariophyta > Chlorophyta	Chlorophyta > Bacillariophyta >> Cyanophyta
6/20/95	Bacillariophyta > Chlorophyta	Chlorophyta > Bacillariophyta
6/28/95	Bacillariophyta > Chlorophyta	Chlorophyta > Bacillariophyta
7/6/95	Bacillariophyta > Chlorophyta	Chlorophyta > Bacillariophyta
7/14/95	Bacillariophyta > Chlorophyta	Chlorophyta > Bacillariophyta >> Cyanophyta

Table 4. Dominant Chlorophytes and Cyanophytes found on Tenderfoot Creek and Tenderfoot Lake substrata for five sampling periods.

Date	**Stream Algae Genera**	**Ranking in order of decreasing dominance**	**Lake Algae Genera**	**Ranking in order of decreasing dominance**
6/12/95	*Desmidium*	1	*Spirogyra*	1
	Hyalotheca	2	*Mougeotia*	2
	Vaucheria	2	*Hyalotheca*	3
	Ulothrix	2.5	*Ulothrix*	4
	Mougeotia	5	*Desmidium*	5
	Cladophora	6	*Bulbochaete*	6
			Lyngbya	7
			Anabaena	7
			Rhizoclonium	8
			Cladophora	9
6/20/95	*Stigeoclonium*	1.5	*Spirogyra*	1
	Mougeotia	2	*Mougeotia*	2
	Vaucheria	2	*Ulothrix*	3
	Bulbochaete	4	*Hyalotheca*	3
	Desmidium	5	*Cladophora*	4
			Stigeoclonium	4.5
			Desmidium	5
			Rhizoclonium	7
6/28/95	*Stigeoclonium*	1	*Spirogyra*	1
	Vaucheria	2	*Rhizoclonium*	2
	Spirogyra	3	*Mougeotia*	3
	Ulothrix	3	*Desmidium*	4
	Mougeotia	4	*Cladophora*	5
	Rhizoclonium	4		
7/6/95	*Stigeoclonium*	1	*Spirogyra*	1
	Spirogyra	2	*Rhizoclonium*	2
			Desmidium	2.5
			Hyalotheca	3.5
7/14/95	*Stigeoclonium*	1	*Spirogyra*	1
	Spirogyra	2.5	*Mougeotia*	2
	Ulothrix	2.5	*Anabaena*	3
	Desmidium	4		

Table 5. A comparison of the relative abundance of algal divisions found on substrata explanted from one site and placed into its opposite site of the Tenderfoot area for 6 July and 14 July sampling periods.

	Stream Tiles Transplanted into Lake (S-L)	**Lake Tile Transplanted into Stream (L-S)**
Date	**Ranking of Relative Abundance of Algae**	**Ranking of Relative Abundance of Algae**
7/6/95	Chlorophyta > Bacillariophyta	Chlorophyta > Bacillariophyta
7/14/95	Chlorophyta > Bacillariophyta >> Cyanophyta	Bacillariophyta > Chlorophyta

Table 6. Dominant Chlorophytes and Cyanophytes found on substrata explanted from one site and placed into its opposite site of the Tenderfoot area for 6 July and 14 July sampling periods.

Date	**Genera of Algae from Tiles Transplanted from Lake to Stream (L-S)**	**Ranking in order of decreasing dominance**	**Genera of Algae from Tiles Transplanted from Stream to Lake (S-L)**	**Ranking in order of decreasing dominance**
7/6/95	*Spirogyra*	1	*Spirogyra*	1
	Mougeotia	2.5	*Bulbochaete*	2
	Bulbochaete	3.5	*Stigeoclonium*	2.5
	Ulothrix	3.5	*Desmidium*	4
	Desmidium	4.5	*Mougeotia*	4
	Stigeoclonium	6		
7/14/95	*Spirogyra*	1	*Spirogyra*	1
	Anabaena	2	*Stigeoclonium*	2
	Desmidium	2	*Desmidium*	3
	Rhizoclonium	3	*Ulothrix*	4
			Mougeotia	5
			Cladophora	6
			Hyalotheca	7