BIOLOGICAL AND PHYSICAL INVESTIGATIONS OF BODIES OF WATER BENEATH DENSE WATER HYACINTH POPULATIONS BEFORE AND AFTER CHEMICAL TREATMENT

By

William W. Brower

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1980

ACKNOWLEDGEMENTS

The author would like to thank Dr. Joseph S. Davis for his continued academic and research guidance, and Dr. William Haller for his financial support and research guidance.

The author would also like to thank his loving wife, Sharon. The completion of the author's education and this study would have been impossible without her constant understanding, guidance, financial support, and excellent typing.

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August 1980

Chairman: Joseph S. Davis

Major Department: Botany

Dense infestations of water hyacinths (*Eichhornia crassipes* Mart. Solms), or other free-floating, mat-forming aquatic weed species, dramatically affect the water quality below them. Dissolved oxygen concentrations, summer water temperatures, the annual range of water temperature, and light penetration are all reduced below actively growing hyacinth mats, while suspended organic material, CO_2, and HCO_3^- concentrations are increased. Phytoplankton populations were fairly abundant beneath actively growing hyacinth mats, and composed mostly of blue-green algae (e.g. *Oscillatoria limnetica*) and phytoplanktonic diatoms (e.g. *Fragilaria caepucina* var. *mesolepta*

and *Melosira granulata* var. *angustissima*). Under such conditions, surface periphyton diatom populations were highly variable and minimal while periphyton diatom densities at greater depths were very low. Zooplankton populations were large, being composed mostly of rhizopodal protozoans (such as *Arcella* spp. and *Centropyxis* spp.), and also various rotifers and crustaceans. Maximal hyacinth fresh weight biomass was found to be 57.7 kg/M^2, while the maximal dry weight biomass was 6.1 kg/M^2.

The hyacinth mats were chemically treated with 2,4-D, which proved to be an efficient means of aquatic weed control. After chemical treatment, floating mats of dying hyacinths were persistent on the pond surfaces for several months. Water quality under the decaying mats was worse than under actively growing hyacinths. Phytoplankton and zooplankton populations were much reduced while the periphyton diatom populations were variable. The zooplankton was mostly composed of rhizopodal protozoans which were feeding on the decaying vegetation.

Open water conditions were established approximately six months after herbicide application, and water quality slowly improved. Dissolved oxygen concentrations, pH, light penetration, water temperatures, and annual range of water temperatures all increased, while CO_2 and HCO_3^- concentrations, and suspended organic material decreased. Phytoplankton populations were large after hyacinth treatment and disappearance, being mostly composed of blue-green algae, but with occasional large seasonal green algae populations. Periphyton diatom populations increased in both the pond surfaces and depths. Zooplankton populations were reduced after open water conditions were established and were largely composed of various rotifers and crustaceans.

Sediment accumulation studies showed that the dry weight of sediments deposited below actively growing hyacinths averaged 0.218 kg/M^2 during an eight month period (3.6 percent of the original hyacinth biomass available), while that below chemically treated hyacinths was 0.626 kg/M^2 (20.9 percent of original biomass). Therefore, sedimentation was much greater (5.8 times) after herbicide application to hyacinths. However, the majority of the hyacinth biomass (79.1 percent) was not accounted for in the sediments.

INTRODUCTION

The water hyacinth, *Eichhornia crassipes* Mart. Solms, is a perennial, free-floating, mat-forming aquatic plant, which often accumulates to form dense infestations in tropical and subtropical areas (Holm et al. 1969).

The water hyacinth, an exotic species introduced into the United States of America circa 1890, is native to South America. Since its introduction, it has caused significant economic and environmental impact on Southeastern U.S. waterways. According to Penfound and Earle (1948), water hyacinths cause problems by (1) obstructing navigation, (2) impeding drainage, (3) destroying wildlife resources, (4) reducing water related recreation and (5) constituting a hazard to life. However, perhaps the most serious effect of dense water hyacinth infestations is their environmental impact upon the water quality and species composition of aquatic ecosystems. It is well known that water hyacinth infestations deteriorate water quality by reducing the pH, dissolved oxygen concentrations, nutrient availability, and light penetration of the underlying bodies of water (McVea and Boyd, 1975). But what effect do water hyacinths have upon the naturally occurring aquatic producer communities, which are the basis for the entire aquatic food web? How are the phytoplankton and periphyton communities affected, and what effect will this have upon the zooplankton communities? These are all questions which have not been adequately investigated in the past, and to which this study was partially addressed.

Control of aquatic weed populations has been thoroughly investigated in the last several decades. Mechanical harvesting of water hyacinths has been attemped time and time again, but has proved uneconomical. These failures are due to several factors, all of which continue to make mechanical harvesting unfeasible on a large scale basis. Firstly, elaborate and expensive harvesting machinery is needed. This machinery breaks down often, is difficult and costly to repair, and requires fairly skilled employees to operate. More importantly, aquatic vegetation is composed mostly of water. Therefore, most of the time and energy expended on mechanical harvesting is wasted on moving water, not plant material.

During the last two decades there have been extensive investigations into the use of various herbicide formulations as a means to control chemically dense growths of aquatic vegetation. This appears to be the most economically sound means of aquatic weed control available at this time.

The most commonly used herbicide to control water hyacinths is 2,4-D (2,4-Dichlorophenoxyacetic acid). This herbicide has been successfully used for many years throughout the Southeastern U.S., and especially Florida, where aquatic weed problems can become quite severe. However, little emphasis has been placed upon the *in vivo* conditions which arise due to herbicide application and the effects that they have upon water quality and aquatic biological communities.

PURPOSE

The objectives of this study were as follows:

1. Determine the effort required to eradicate water hyacinths from small farm ponds using a herbicide formulation of the oil soluble amine of 2,4-D (Emulsamine E-3).[1]
2. Study the aquatic biological communities (phytoplankton, periphyton diatoms, and zooplankton) associated with naturally occurring dense infestations of water hyacinths, populations of chemically treated hyacinths, and those in open water conditions after hyacinth treatment and disappearance.
3. Compare water quality parameters (chemical and physical) associated with natural hyacinth populations and open water conditions after hyacinth treatment and disappearance.
4. Investigate the interrelationships and interactions existing between aquatic producer (periphyton

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[1]Emulsamine E-3 is a registered product of Union Carbide Agricultural Products Incorporated. Emulsamine E-3 contains 50.7 percent of the dodecyl and 12.7 percent of the tetradecyl amine salts of 2,4-Dichlorophenoxyacetic acid. The product is formulated as an oil soluble salt and contains 359.5 gm acid equivalent per liter.

diatom and phytoplankton) and consumer (zooplankton) communities, along with the physical and chemical parameters which affect them.

5. Compare the environmental impact of herbicide application to water hyacinths, to the impact of naturally occurring populations of water hyacinths on the aquatic environment.

MATERIALS AND METHODS

Description of Study Area

The three ponds studied are located in Silver Springs Groves, a commercial citrus grove near MacIntosh, Florida. These three ponds are shallow bodies of water used for irrigation of the surrounding groves during dry periods and for frost protection during cold weather. The ponds were constructed in 1961. They originally had sand bottoms and clear water, being fed by several small springs and ground water runoff. Water hyacinths eventually invaded the area in the late 1960's, and totally covered the surface of all three ponds (Fig. 1).

The ponds are highly eutrophic, receiving an abundance of nutrients from springs and surface runoff of the fertilized citrus groves. The once sand-bottomed ponds developed thick deposits of dead and decaying organic material on the pond bottoms which originated from naturally dying water hyacinths and other vegetation. Water quality under these conditions was poor. The water contained much suspended and dissolved organic matter, little (if any) dissolved oxygen, abundant nutrients, and smelled strongly of hydrogen sulfide.

The three ponds will be referred to as Ponds One, Two, and Three, for convenience. All three ponds are interconnected, with the highest ponds (Pond One and Pond Two, respectively)

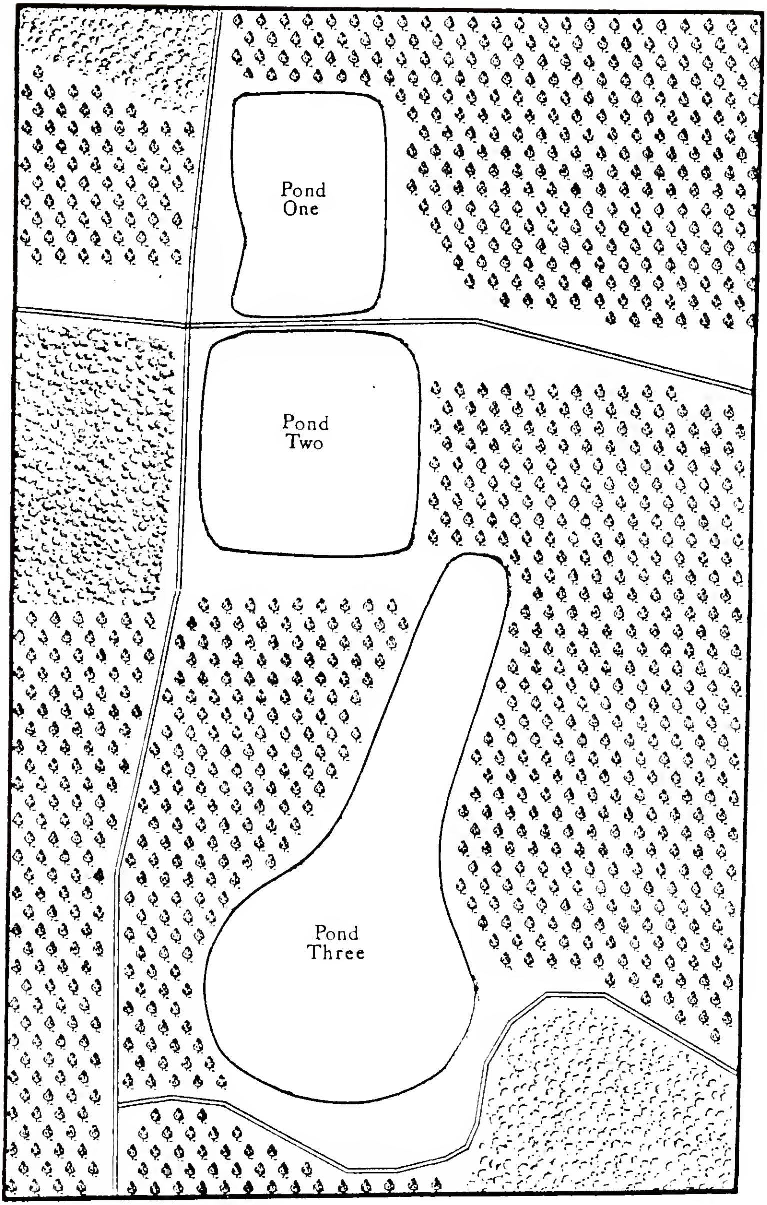

Figure 1. Map of Silver Springs Groves study area (♤ ♤ ♤ ♤ = citrus trees, = mixed hardwood forest).

feeding the lowest (Pond Three). Pond One is separated from Pond Two by a dike, through which runs a 30 cm culvert that allows water to flow from Pond One to Pond Two. Ponds Two and Three are connected by a standpipe which allows overflow from Pond Two to enter Pond Three. Overflow water from Pond Three exits through a similar standpipe, and drains into a small creek which eventually enters Orange Lake. Pond One has a surface area of 0.81 hectares, with depths to a maximum of 1.5 M.

Pond Two is located between Ponds One and Three and is the deepest of the three ponds, with depths up to a maximum of 3.4 M and a surface area of 0.99 hectares.

Pond Three with a surface area of 1.87 hectares has a fairly circular main body and a canal-like arm leading towards Pond Two. Pond Three has a maximum depth of 2.0 M.

Field Sampling Procedure

The ponds were studied during a thirty-four month time span from April 8, 1975, until January 18, 1978. Samples were taken every three or four weeks throughout the study period, except during a drawdown period (when the ponds were drained to remove nutrient-rich water and to consolidate and oxidize the sediments) in the summer and fall of 1976. Phytoplankton, zooplankton, and periphyton diatom samples were taken during each sampling period. Water samples and physical measurements were obtained as often as possible.

Before herbicide application, all sampling had to be done from a small jonboat towed across Ponds One and Two, or from a dock built out into Pond Three, due to dense hyacinth populations. A rowboat was used for sample collection after open water conditions were established.

The initial herbicide applications of 2,4-D were done by professional field crews from the State of Florida Game and Freshwater Fish Commission. Using an airboat and spraying equipment, 2,4-D was applied to Ponds Two (Fig. 2) and Three (Fig. 3) on May 15, 1975, at the rate of 3.34 kilograms of active ingredient/hectare. Respraying was necessary two and six months later (July 15, 1975, and November 19, 1975, respectively) to insure complete control of hyacinths. Due to regrowth, these ponds were resprayed after two months. At that time the pond surfaces were covered with mats of organic detritus and dead and dying hyacinths, many of which had started to reproduce vegetatively by sprouting. After six months the hyacinth mats were resprayed again, but by this time the mats only occupied approximately one-fourth of the pond surfaces.

Ponds Two and Three were the experimental ponds treated with 2,4-D, while Pond One was left untreated as an experimental control for the first twelve months of the study. Pond One was selected as the control pond since it is the highest pond, and received no flow from either of the two experimental ponds. Pond One was chemically treated with 2,4-D on April 15, 1976, using the same procedures as on Ponds Two and Three. Efficient

Figure 2. Pond Two during initial herbicide treatment on May 15, 1975.

Figure 3. Pond Three during initial herbicide treatment on May 15, 1975.


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hyacinth control was achieved with this first chemical treatment. Retreatment (with Diquat) was not necessary until March 1977, to control a marginal fringe of hyacinths, pennywort, and duckweed.

Chemical and Physical Measurements

The determination of chemical parameters was done from water samples collected during each field sampling. At least two samples were collected from each pond at a depth of 30 cm below the pond surface. Water samples were collected in clean, airtight, dark polyethylene bottles, which were labeled and immediately refrigerated in the field. Samples were transported back to the lab where they were analyzed within 24 hours to determine the following chemical parameter concentrations and physical parameters: pH, HCO_3^-, CO_2, turbidity, soluble salts, and specific conductivity. These samples were fixed with a preservative (phenyl mercuric acetate), and later analyzed at the University of Florida Soils Lab to determine the following chemical parameter concentrations: nitrate-nitrogen, potassium, total phosphate-phosphorus, available phosphate-phosphorus, calcium and magnesium.

Turbidity was measured using a Hach turbidimeter, Model 2100A, measuring turbidity in Nephelometric Turbidity Units (NTU's) which are equivalent to JTU's and FTU's. Specific conductivity was determined by a YSI conductivity bridge, Model 31, measuring specific conductivity in terms of micromhos/cm^2. The pH was measured with a Brinkmann pH meter, Model PH-102.

Light penetration was determined by Secchi disk disappearance and by a light meter. The Secchi disk used was 25 cm in diameter, and divided into four alternating black and white quadrants. The light meter (a LI-COR Model LI-185 Quantum/Radiometer/Photometer) was equipped with a quantum type light probe (Lambda Instrument Corp.), which measures quanta in the photosynthetically active radiation spectrum between 400 and 700 nannometers in microeinsteins $M^{-2}sec^{-1}$.

The photosynthetic response of plants for which data are available approximates this 400 to 700 nannometer range. Readings obtained from this light meter must be multiplied by 1.40 when used in water to correct for the immersion effect (since the light entering the diffuser scatters in all directions). Light penetration readings using the quantum sensor were made at 10 cm depth intervals throughout the water column, and also above the water surface at different levels within the plant cover (when present).

Visual estimates of the percentage of pond surface area covered by water hyacinths, pennywort (*Hydrocotyle* spp.), and duckweed (*Lemna* spp.), were made on each sampling date. These estimates, when added together, approximate the total percentage of pond surface areas covered by floating aquatic vegetation.

Phytoplankton and Zooplankton Collection and Counting

Surface quantitative phytoplankton and zooplankton samples were collected on most sampling dates from the deepest accessible portion of each pond. These quantitative samples were obtained by pouring measured amounts of surface pond water through a plankton net (#25-standard nylon with 83 meshes/cm). Precautions were taken to insure that all of the plankton poured into the net was collected in the tube attached to the bottom of the net. This was done by lowering the net into the water (leaving the mouth of the net above water), and then letting the water drain out several times.

Immediately after collection, all phytoplankton and zooplankton samples were labeled and preserved with 10 percent formalin. Rose bengal solution (prepared according to Standard Methods, 1965) was added to the samples to facilitate the counting of zooplankters, especially rotifers and crustaceans.

The phytoplankton samples were thoroughly mixed before counting. A subsample was removed with a Pasteur pipette and placed into a Palmer counting cell. Phytoplankton was then counted using a binocular microscope at a magnification of 312X. Ten to fifty random fields within the Palmer cell were then counted. The number of fields counted depended on the density of phytoplankton within the sample.

Phytoplankters were counted and identified to genus, and to species when possible. This identification was facilitated by G.W. Prescott's *Algae of the Western Great Lakes Area* (1962), and Whitford and Schumacher's *Fresh-Water Algae in North Carolina* (1969). Planktonic diatoms were usually identified only to genus (unless the species names were obvious), since the diatom samples were not "cleaned" to aid in identification. These planktonic species were usually similar to the members of the periphytonic diatom populations.

The average number of the individual phytoplankters per field and total phytoplankton were calculated. Phytoplankters were counted and recorded in terms of cells per liter of original pond water. Whole colonies and broken colonies (*Microcystis, Volvox, Eudorina, Synura, Dinobryon,* etc.) were observed and counted in terms of individual cells to determine an average number of cells per colony. This average was then used to convert from colonies to individual cells per liter.

Zooplankton samples were similarly counted in a Sedgewick-Rafter Counting Cell at a magnification of 156X. Zooplankton included protozoans, rotifers, rotifer larvae, crustaceans, crustacean larvae, and crustacean eggs. Colonial forms were counted in terms of individuals. The total zooplankton counts were in terms of total zooplankton individuals per liter of original pond water.

Zooplankters were usually identified only to genus, except in the case of certain cosmopolitan rotifers and crustaceans which were identified to species. This identification was aided by Ward and Whipple's *Freshwater Biology* (1959).

The Sedgewick-Rafter counting cell serves for counting and estimating population sizes of microzooplankton (e.g.

rotifers, protozoans, nauplii larvae), but biases the estimations of macrozooplankton (e.g. *Cyclops*, *Diaptomus*, chironomids) populations. For this reason, macrozooplankton was also determined on the basis of individuals per liter of original pond water. These macrozooplankton counting wheel determinations were found to be more realistic than counts made with the Sedgewick-Rafter counting cell when used for macrozooplankters. All zooplankters larger than nauplii larvae are reported in terms of the counting wheel population estimations, while nauplii larvae and smaller organisms are reported in terms of the Sedgewick-Rafter counting cell population estimations.

Periphyton Diatoms

Periphyton diatoms were collected on artificial substrate by using diatometers (Biomonitor Inc., Ripon, Wisconsin) containing glass microscope slides. These diatometers are plastic frames each holding eight glass slides which are held in place by a wire frame with attached styrofoam floats. The glass slides are held in a vertical position in the water column and are exposed to the water and available sunlight. The floats keep the submerged diatometers in a horizontal position. The slides within remain vertical to reduce sediment accumulation, which would bury attached diatoms.

Diatometers were installed in each of the three ponds on April 22, 1975. Surface and one meter depth diatometers were placed in Ponds One and Three, while Pond Two (the deepest) received surface, one meter and two meter depth diatometers. The diatometers were secured by weights to the pond bottoms.

Slides were exposed to the water column for periods of three or four weeks, after which time they were removed and clean slides reinserted. Removed slides were then labeled and allowed to air-dry. No special preserving technique was necessary for such dried slides since the siliceous frustules of diatoms will not desiccate or deteriorate in air. Slides so obtained can be stored indefinitely.

Periphyton Diatom Density Counts

Diatom density counts were made to estimate the total number of diatom valves per cm^2 in the three ponds (surface and depths) throughout the study period. This was done by counting all the diatom valves observed in a vertical strip 2.54 cm long and 46 microns wide down a dried slide from the diatometers. The several density counts obtained for each sample were averaged and numerically converted to diatom valve density per cm^2 of artificial substrate.

Periphyton Diatom Slide Preparation

The diatoms on one of the dried diatom slides from each collection were "cleaned" to oxidize all organic matter. This organic matter, if not removed, would interfere with the identification of the diatoms. "Cleaning" (Van der Werff, 1958) was accomplished by adding 100 ml of 30 percent H_2O_2

to the air-dried diatometer slide in a 1000 ml beaker. The slide was allowed to remain in this solution for 24-48 hours. A small amount of $K_2Cr_2O_7$ was then added to the beaker initiating an exothermic reaction. After the boiling subsided, this solution was poured into a 200 ml beaker which was then filled to the top with distilled water. After four hours, the top 150 ml of solution in the beaker was decanted. The beaker was then refilled with distilled water. This step was repeated until the solution in the beaker became colorless, indicating that the $K_2Cr_2O_7$ was now absent from the solution and the diatoms were ready to mount on slides.

The cleaned samples were then pipetted onto coverslips, using clean Pasteur pipettes and allowed to air dry. This process was repeated until visual observation indicated an adequate accumulation of diatom frustules on the coverslips. Microscopic investigation of the coverslips was necessary to determine whether enough diatoms were on the coverslips, especially in samples where sand or other siliceous deposits were present. The remaining cleaned diatom mixture left over after making the slides was put into vials and stored for future reference.

After they were air-dried, the coverslips were placed diatom-side up on a hot plate, and heated at approximately 540°C for 30 minutes to evaporate moisture and to oxidize any remaining organic matter. After 30 minutes, slides were removed from the hot plate with forceps and inverted onto a drop of Hyrax mounting medium on a clean glass slide. The slide (with coverslip and

Hyrax) was then placed on the hot plate to drive the solvent from the Hyrax. The slides were then removed from the hot plate and labeled.

Diatom Species Proportional Analysis

The prepared diatom slides were then examined to obtain a species proportional analysis of the diatom populations inhabiting the three ponds throughout the sampling period. This was done by counting 200 diatom valves per slide, and at least 100 valves on those slides which were thinly populated with diatoms. Counting and identification of the diatom valves was done under the oil immersion objective (1162.5 magnifications). Identification was aided by several taxonomic keys such as Patrick and Reimer (1966) and Hustedt (1930).

Water Hyacinth Length

The length (meters) of water hyacinths was measured in Pond One (control pond) and Pond Two (treatment pond) for the first three months of the study (April 8, 1975, to June 29, 1975). The length of hyacinth plants was measured *in situ*, from petiole tips to root tips. Several such measurements were similarly obtained from each pond and averaged.

Sediment Accumulation

The investigation of sediment accumulation beneath actively growing hyacinth populations, and chemically treated populations was not a prime objective of this study, but an attempt was made to study this phenomenon.

Submerged pans, each with an exposed surface area of 0.09 M^2, were suspended from buoys in Ponds One and Two, one meter below the pond surfaces. Two sediment pans were placed in Pond One (control pond), and three in Pond Two (treatment pond). These sediment pans were placed in the ponds on May 14, 1975, before herbicide application, and carefully removed on January 12, 1976, after all floating debris had disappeared.

The sediment-water slurry taken from the pans was then filtered to separate the organic material from the water. This organic material was then dried in an oven at 60°C for 48 hours and the dry weight determined.

Statistical Analysis

The data of this study were statistically analyzed using the facilities of the Northeast Regional Data Center located on the University of Florida Campus in Gainesville, Florida. The procedures and programs of SAS 76-78 (Statistical Analysis System) were used to sort and analyze all data.

Correlation coefficients were determined between all variables using the SAS CORR procedure. This procedure determines the correlation coefficient between two variables and approximates the significance probability of the correlation coefficient. The significance probability of a correlation coefficient is the probability that a value of the correlation coefficient as large or larger in absolute value than the one calculated would have arisen by chance, if the two random variables were truly uncorrelated (Barr et al. 1976).

Only those correlations which had a significance probability of 10 percent or less are reported and are noted as being either positively or negatively correlated.

The SAS STEPWISE procedure was then used to determine which of the collection of independent variables that showed significant correlations should most likely be included in a regression model. This procedure is useful for determining the relative strengths of the relationships between proposed independent variables and a dependent variable and involves the use of stepwise multiple regressions.

This procedure first finds the single-variable model which produces the largest R^2 statistic (R^2 is the square of the multiple correlation coefficient). For each of the other independent variables, STEPWISE calculates an F-statistic reflecting that variable's contribution to the model, if it were to be included. If the F-statistic for one or more variables has a significance probability greater than the specified "significance level for entry" (50 percent in this study), then the variable with the largest F-statistic is included in the model. In this way, variables may be added one by one to the model. However, after a variable is added, STEPWISE looks at all the variables already included in the model. Any variable no longer producing a parial F-statistic significant at the specified significance level for staying in the model (50 percent) is then deleted from the model. Only after this check is made and any required deletions accomplished, can another variable be added to the model (after F-statistics are again calculated for the variables still remaining outside the model, and the evaluation process is repeated). Variables are thus added one by one to the model until no variable produces a significant F-statistic. The process terminates when no variable meets the conditions for inclusion in the model, or when the variable to be added to the model is one just deleted from it (Barr et al. 1976). The previously described procedure includes the STEPWISE option of the STEPWISE procedure.

Using the above mentioned statistical procedures, the best possible models for specific parameters were determined from lists of selected independent variables until the largest variance in the dependent variable was accounted for. The lists of independent variables from which the STEPWISE procedure selected the best possible regression models were as follows:

A. Total phytoplankton and phytoplankters: pH, bicarbonate, turbidity, soluble salts, potassium, available phosphate-phosphorous, calcium, magnesium, specific conductivity, water temperature, percent total vegetation cover, Secchi disk disappearance, light penetration, and nitrate-nitrogen.

B. Total zooplankton, zooplankters, etc.: percent total vegetation cover, water temperature, dissolved oxygen, pH, and total phytoplankton.

C. Periphyton diatoms, etc.: pH, bicarbonate, turbidity, soluble salts, potassium, available phosphate-phosphorous, calcium, magnesium, specific conductivity, water temperature, percent total vegetation cover, Secchi disk disappearance, light penetration, nitrate-nitrogen, and total phytoplankton.

Only those models which showed a significance probability of 10 percent or less are reported in this study.

RESULTS

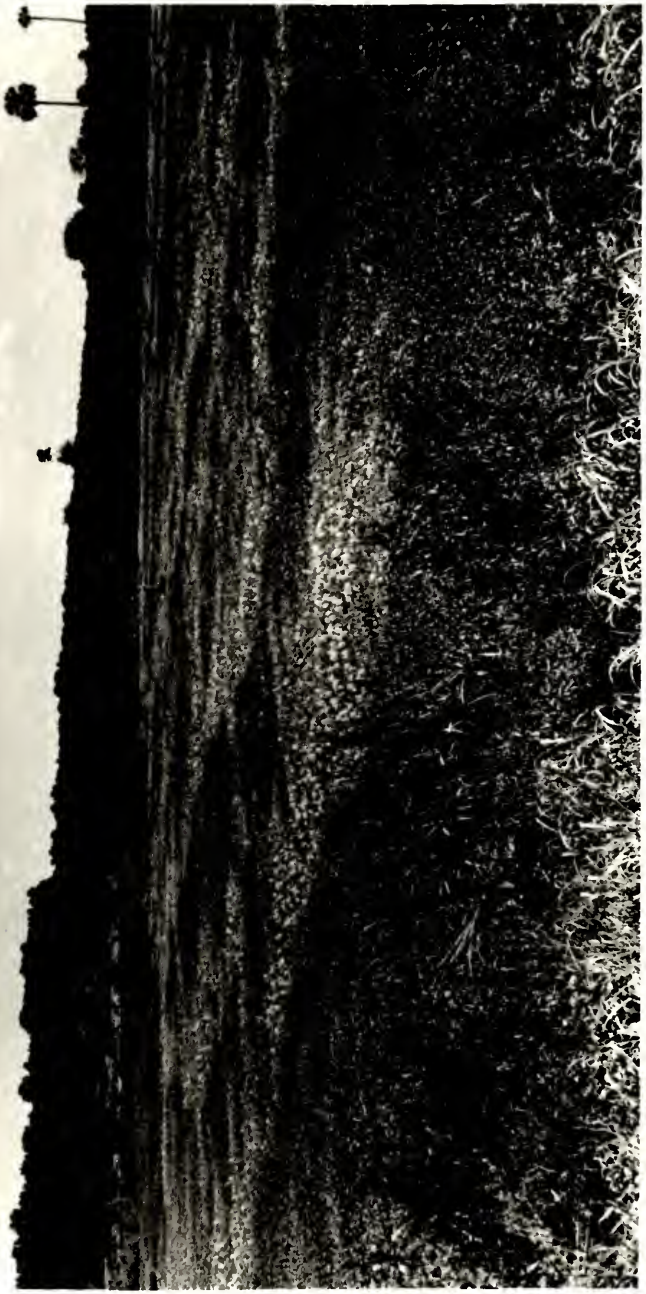
Water Hyacinth Control

The application of 2,4-D by airboat spray crews to dense growths of water hyacinths proved to be a very efficient means of control. The hyacinth plants began to wither and curl within hours after herbicide application to Ponds Two and Three on May 15, 1975. A swathlike pattern of dying hyacinths was visible within three days after treatment (Fig. 4). This swath pattern is typically found after airboat application of herbicides to dense growths of water hyacinths due to propeller dispersion.

A thick cover of decaying water hyacinths remained on the surface of the treatment ponds six weeks after treatment (June 29, 1975), with approximately 75 percent of the plants dead. However, many small patches of live juvenile and seedling plants were present and the underwater portions of many apparently dead plants were still green and viable. Sprouting (vegetative reproduction) of new small plants was also occurring from many of the old "dead" plants.

At this time it was apparent that respraying of the treatment ponds was necessary even though the initial treatments had been effective (75 percent control). If respraying had not been done soon, undesirable regrowth would have eventually

Figure 4. Pond Two one week after initial herbicide treatment on May 22, 1975, showing swathlike pattern of dying hyacinths.



resulted in complete pond coverage. Retreatment took place on July 15, 1975. Herbicide application was much simpler and more thorough, due to the increased maneuverability of the airboat through the dead hyacinth mats.

During September 1975, four months after the initial treatment, the majority of hyacinths were dead, forming large floating mats of decaying organic material. Such floating mats are commonly referred to as "sudds" (Fig. 5). During this time foul water conditions existed which included strong H_2S odors, very little dissolved oxygen, an abundance of floating and suspended organic material in the water, and dark brownish-gray colored water. During this period water quality was even worse than that occurring under actively growing hyacinth mats. Prevailing winds often swept the sudds across the pond surfaces, from end to end. Various grasses, sedges, and other plants had colonized these sudds by October and November of 1975.

These floating mats of organic material (sudds) had disappeared by December 1975, six months after the initial treatment. This cleared most of the pond surfaces, leaving open water conditions (Fig. 6). The remaining plants included a minimal surrounding marginal fringe of pennywort (another surface mat-forming species) and water hyacinths. These fringes were retreated with 2,4-D as before.

This retreatment of the marginal hyacinth and pennywort fringe with 2,4-D killed almost all of the water hyacinths but had little effect upon the pennywort population. This pennywort fringe remained viable in several large patches, but was dormant during winter.

Figure 5. Pond Two four months after initial herbicide treatment, and two months after retreatment. Floating mats of organic material ("sudds") are found on the pond surface.

Figure 6. Pond Two in April 1976, after open water conditions have been established (before pond drawdown).

The pennywort fringe, which began actively growing in early spring, was sprayed in March and April of 1976 with Silvex (2,4 Trichloropropionic acid) according to label instructions with a portable sprayer operated from a sixteen foot jonboat. This final spraying killed and controlled the marginal fringes. Marginal fringes reappeared at times, but they did not constitute a major problem in either treatment pond during the remainder of the study.

Although herbicide application controlled the water hyacinths and pennywort, other aquatic weeds appeared in the treatment ponds. Duckweed had always been present in all three ponds occurring in small numbers among the members of the actively growing hyacinth and pennywort communities. Treatment of the mat-forming species permitted duckweed to eventually dominate the pond surfaces (treatment Ponds Two and Three). Heavy phytoplankton blooms were also prevalent during this time. Duckweed was first noticed on Pond Two in May and June 1976, and by the end of July 1976, covered most of the pond surface area.

Most likely, the control of the duckweed populations could have easily been achieved using herbicide application but this was not done for two reasons. Firstly, the duckweed was being harvested in rather small amounts (a pickup truckload from time to time) to feed experimental populations of the aquatic weed eating fish, the white amur (*Ctenopharyngodon idella* Val.), which were being grown at a different location. Secondly, the effect of duckweed mats on water quality could be investigated. The duckweed populations disappeared when the pond drawdowns occurred.

A drawdown of Ponds Two and Three was started on June 20, 1976. The water level in Pond Three dropped quickly. The pond was almost drained by July 18, 1976. Pond Two drained more slowly, and was only down one meter on September 28, 1976. Pond Two was totally drained by October 1976.

The water levels in the treatment ponds were drawn down during this study to remove the nutrient-rich water contained in the ponds after chemically treating the aquatic vegetation, to consolidate and oxidize the abundant sediments on the pond bottoms, and to study sediment thickness and nutrient composition in conjunction with another study.

Before the ponds were totally drained, 2.0 ppm of Rotenone was added to kill all the fish living in the remaining water of each pond. No fish were found in either treatment pond.

The water levels in Ponds Two and Three were re-established in January 1977, by which time the sediments in both ponds had consolidated significantly (Fig. 7). During the remainder of the study period, only small marginal fringes of hyacinths, pennywort, alligatorweed (*Alternanthera philoxeroides*), and duckweed appeared in the treatment ponds. These small marginal fringes occasionally arose, but were easily controlled by herbicide application from a hand sprayer or by manual removal.

Pond One was left untreated (as a control) for the first twelve months of the study so that comparisons between actively

Figure 7. Pond Three in January 1978, after open water conditions have been established following pond drawdown.

growing hyacinth and chemically treated hyacinth ponds could be made (Fig. 8). However, on April 15, 1976, Pond One was treated with 2,4-D as Ponds Two and Three had been treated one year before. Thus, Pond One acted as an experimental control pond during year one of the study, and then as another experimental treatment pond (lagging one year behind Ponds Two and Three). Treatment of hyacinths in Pond One showed the same results as in the treatment of Ponds Two and Three. Hyacinth control was considerable after three to four weeks. Very efficient control was evident after six to eight weeks. After nine weeks (June 23, 1976) foul water conditions existed, with stong H_2S odors, and floating or suspended organic matter in the water. The water was a cloudy brownish-gray color, and contained little dissolved oxygen. Herbicide treatment of hyacinths does not create foul water conditions, for such water quality conditions are also commonly found beneath actively growing hyacinth populations, before herbicide treatment. However, herbicide treatment does temporarily worsen water quality.

In Pond One, approximately 70 percent of the hyacinths were controlled by the middle of July 1976. Pond One was retreated on July 15, 1976, to control the remaining hyacinths, which were beginning to vegetatively reproduce (Fig. 9). The large decaying, floating mats of organic material (sudds) remaining after hyacinth control supported populations of pennywort and various grasses. These decaying mats (being similar to those found in Ponds Two and Three) persisted through October, after

Figure 8. Pond One (control pond) in April 1975, showing intact, untreated floating mats of aquatic vegetation.

Figure 9. Pond One (control pond) on July 15, 1976, during herbicide retreatment.

which time they had all eventually broken up, and aerobically oxidized or sunk. Pond One then had open water conditions except for a large marginal fringe of hyacinths, pennywort, and duckweed.

This fringe was sprayed with Diquat (Chevron Chemical Co.) according to label instructions in March 1977. This spraying controlled most of the marginal fringe but did not eradicate it. A small fringe (one to three feet in width) grew back during early summer, and was prevalent during the rest of that season.

In general, the treatment of Ponds One, Two, and Three showed that very dense infestations of water hyacinths can be controlled (75 to 90 percent control is fairly easy to achieve), and eventually eradicated by chemical treatment. However, under high nutrient conditions (such as in these citrus ponds), regrowth and the appearance of other aquatic weed infestations can be expected. Only by monthly monitoring, and occasional herbicide applications or hand removal of fringe or regrowing plants, can control of floating aquatic plant populations be achieved under such conditions.

Chemical and Physical Measurements

Hydrogen Ion Concentration (pH)

The pH during the study period ranged from 6.20 to 9.04 in Pond One, 6.20 to 9.30 in Pond Two, and 6.00 to 9.80 in Pond Three (Fig. 10). The lowest pH's (6.0 to 7.3) were found

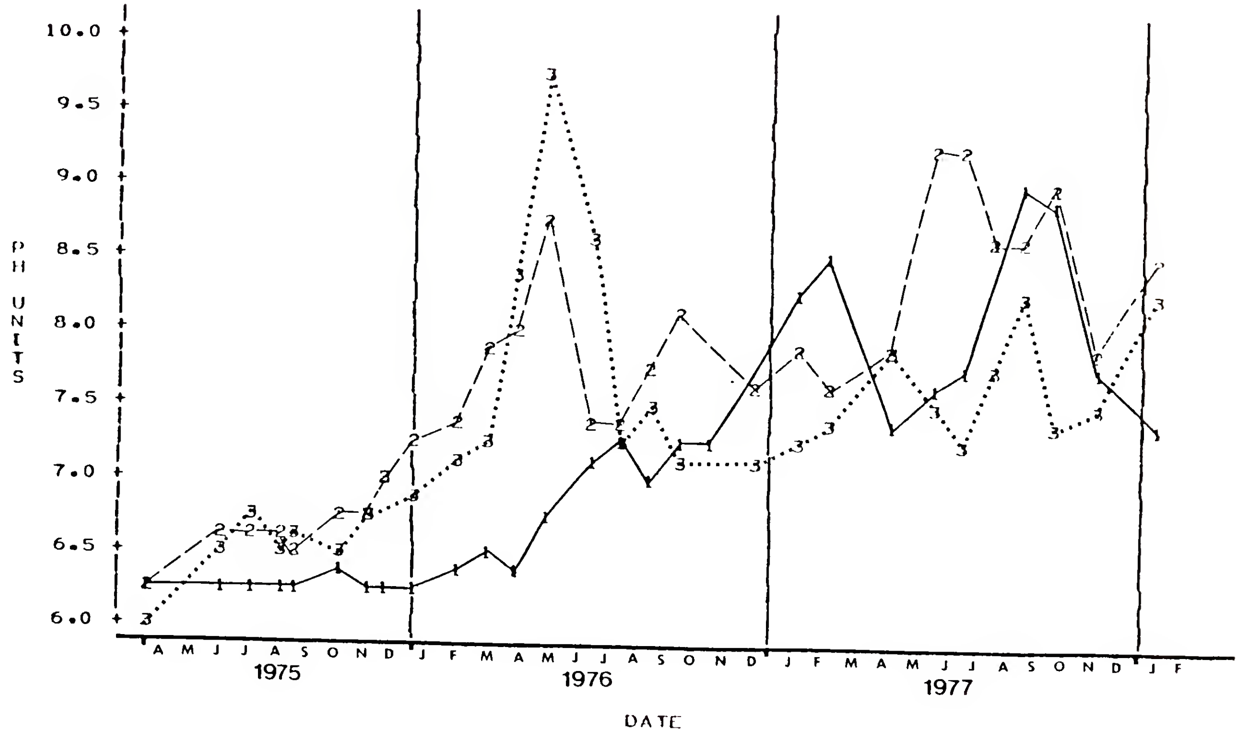


Figure 10. Citrus Ponds surface pH
(——— = Pond One, – – – = Pond Two, ······· = Pond Three).

under actively growing, or dying hyacinth mats, due to the high levels of CO_2 found during these periods. Higher pH's (7.3 to 9.8) occurred after disappearance of the hyacinth mats (open water conditions), while CO_2 concentrations were lower. After hyacinth disappearance, higher pH's occurred during spring and summer, while lower pH's occurred during fall and winter.

Bicarbonate (HCO_3^-)

The concentration of bicarbonate ion (HCO_3^-) during the study period ranged from 33.4 to 89.2 ppm in Pond One, 37.3 to 104.6 ppm in Pond Two, and from 5.8 to 95.7 ppm in Pond Three (Fig. 11). In general, the concentration of HCO_3^- was higher under actively growing or dying hyacinth mats, and lower after hyacinth disappearance (open water conditions). Higher HCO_3^- concentrations were found during summer, while lower concnetrations occurred during winter.

Carbon Dioxide (CO_2)

The concentration of carbon dioxide (CO_2) during the study period ranged from 0.7 to 47.8 ppm in Pond One, 1.2 to 34.7 ppm in Pond Two, and from 0.2 to 39.0 ppm in Pond Three (Fig. 12). The concentration of CO_2 was high under actively growing or dying hyacinth mats (18 to 48 ppm), when respiration far exceeded

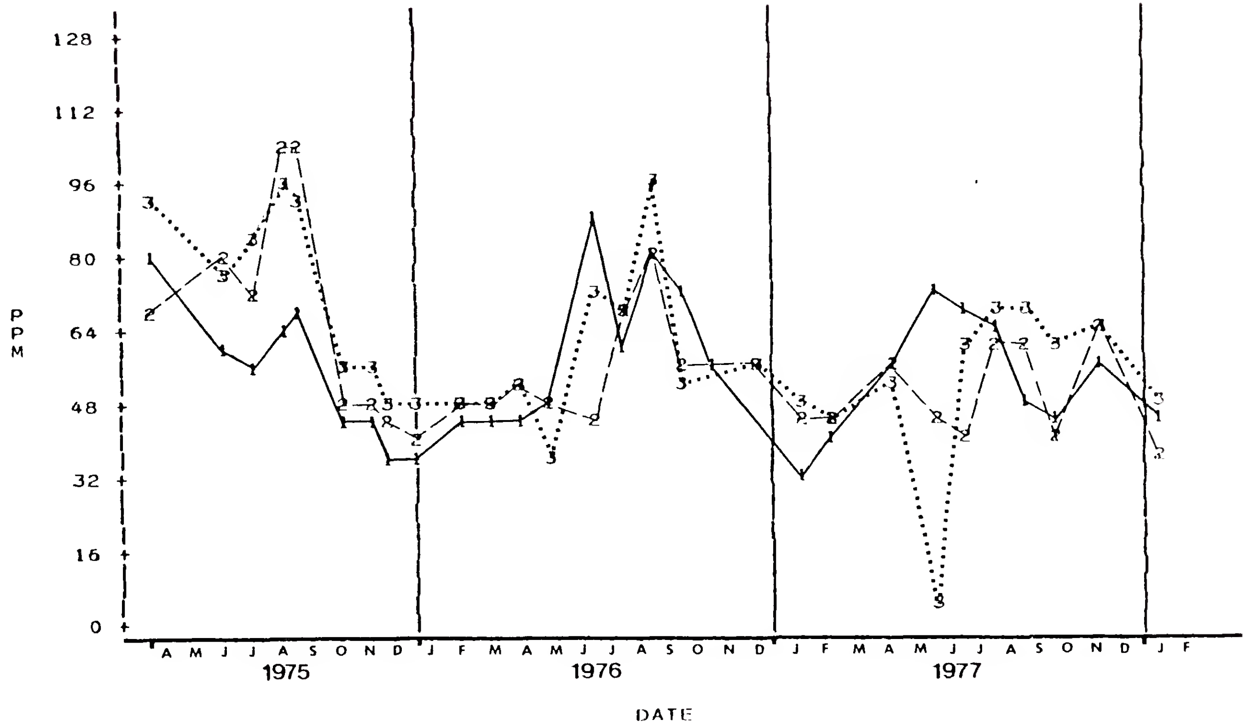


Figure 11. Citrus Ponds surface bicarbonate ion concentrations in ppm (——— = Pond One, – – – = Pond Two, ······ = Pond Three).

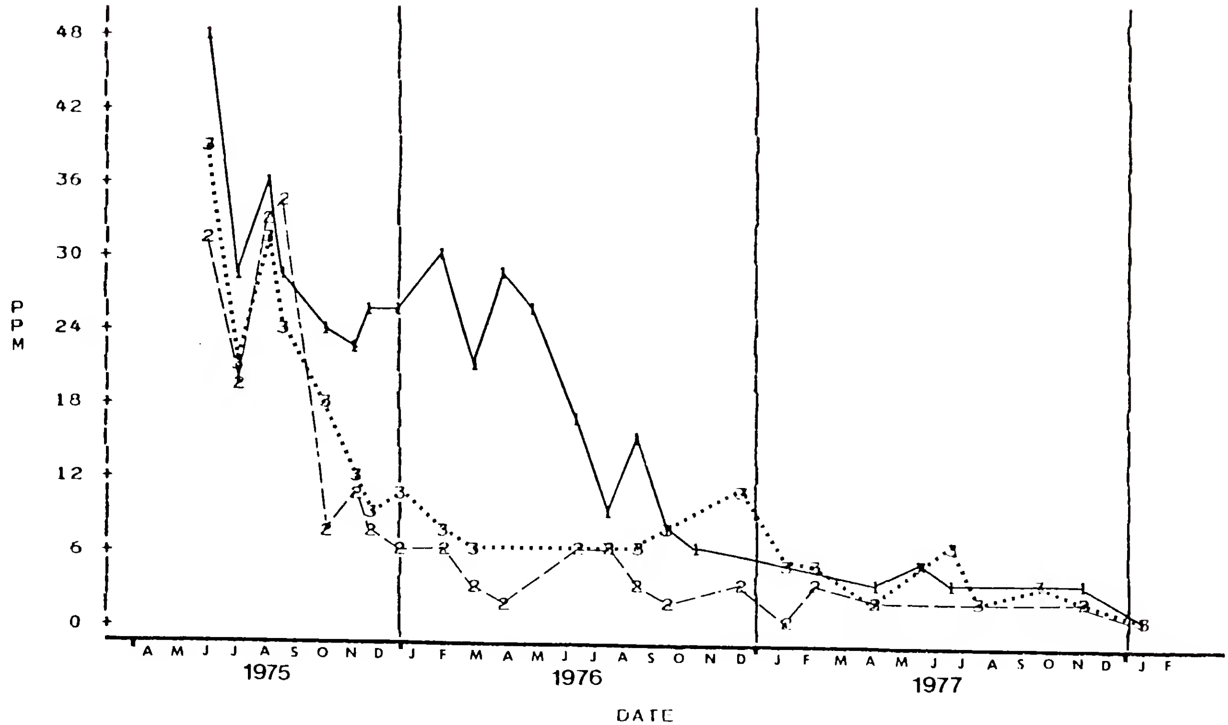


Figure 12. Citrus Ponds surface carbon dioxide concentrations in ppm (——— = Pond One, — — — = Pond Two, ·········= Pond Three).

photosynthesis due to decomposition and lack of light. The concentration of CO_2 was low after hyacinth disappearance (10 ppm or less), when photosynthesis had increased, and equalled or exceeded respiration.

Turbidity

Turbidity readings ranged from 2.4 to 55.5 NTU's in Pond One, 1.6 to 130.0 NTU's in Pond Two, and from 1.2 to 106.8 NTU's in Pond Three (Fig. 13). Turbidity readings decreased in the years after hyacinth treatment. Turbidities were largest during warm water periods, and smallest during cool water periods. Turbidities increased during hyacinth treatment and while the hyacinth populations were dying in Ponds Two and Three.

Soluble Salts

The concentration of soluble salts during the study period ranged from 142.5 to 324.5 ppm in Pond One, 138.0 to 397.0 ppm in Pond Two, and from 160.0 to 409.0 ppm in Pond Three (Fig. 14). Soluble salts were lowest under actively growing hyacinth populations and highest in the years following hyacinth disappearance.

Specific Conductivity

Specific conductivity determinations were only done after herbicide treatment of the ponds. The specific conductivity of Pond One ranged from 301.0 to 405.5 micromhos/cm^2, 275.0 to 397.0

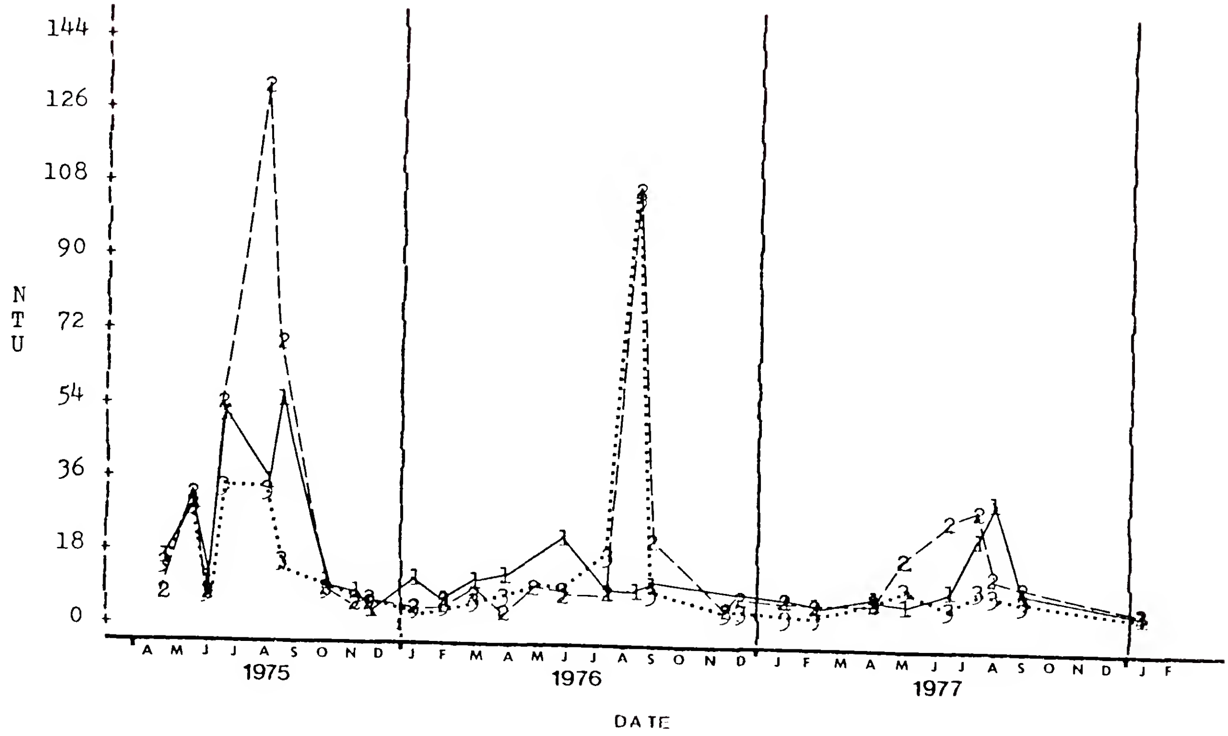


Figure 13. Citrus Ponds surface turbidity in nephalometric turbidity units (——— = Pond One, – – – = Pond Two, ······· = Pond Three).

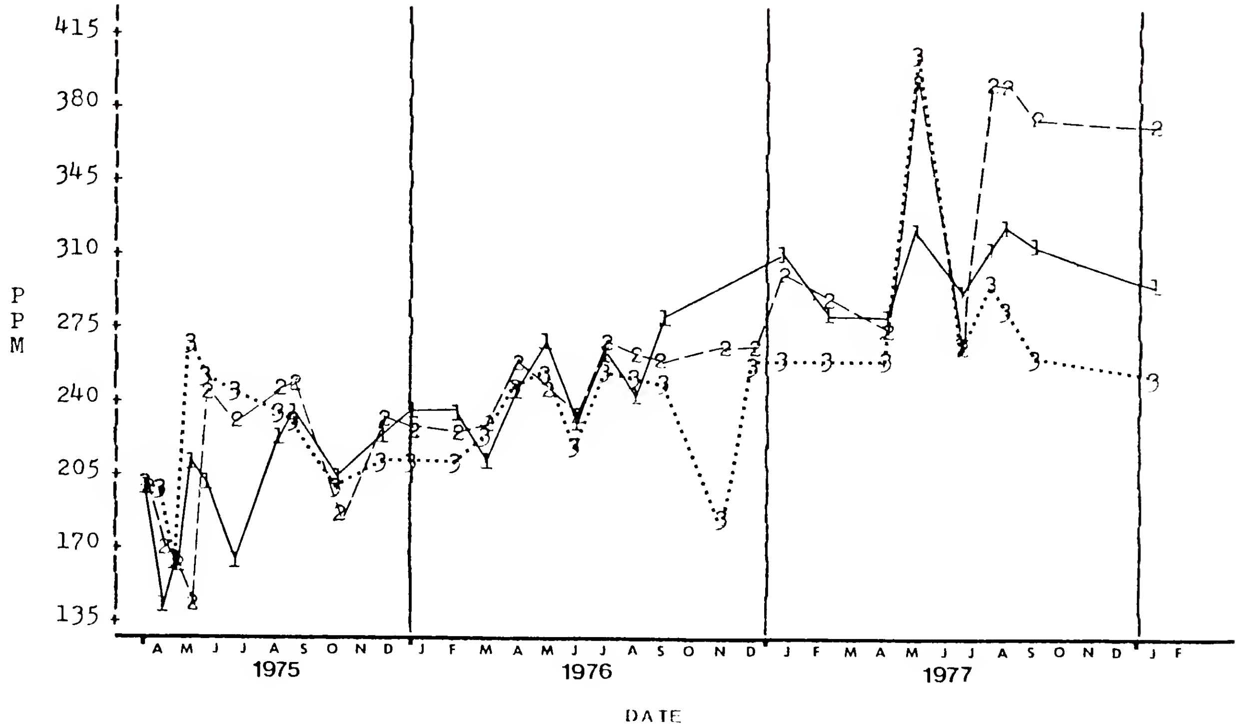


Figure 14. Citrus Ponds surface soluble salts concentrations in ppm (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

micromhos/cm^2 in Pond Two, and from 230.0 to 409.0 micromhos/cm^2 in Pond Three (Fig. 15). In general, the highest specific conductivities were found after hyacinth disappearance, and after open water conditions had become firmly established, when nutrients liberated from decomposing hyacinths were abundant. The specific conductivities of all three ponds were similar during the spring and summer of 1976. This is the period after hyacinth disappearance on Ponds Two and Three, and during which time herbicide application was occurring on Pond One. The specific conductivities of all three ponds were similar during the summer of 1977. However, during the fall and winter months of 1976-1977 and 1977-78, the specific conductivity values varied greatly. After hyacinth disappearance, Pond One always had the highest specific conductivity, and Pond Three had the lowest, while Pond Two was usually intermediate. This is as expected, since water flowed from Pond One, to Pond Two, to Pond Three; and nutrients were removed by the growing vegetation in each pond. Therefore, the nutrient levels (and therefore, specific conductivity) decreased in each successive pond.

Nitrate-Nitrogen

Nitrate-nitrogen concentrations were determined only for the first two years of the study. Since these procedures proved to yield variable, and apparently unreliable data, these determinations were discontinued in 1977.

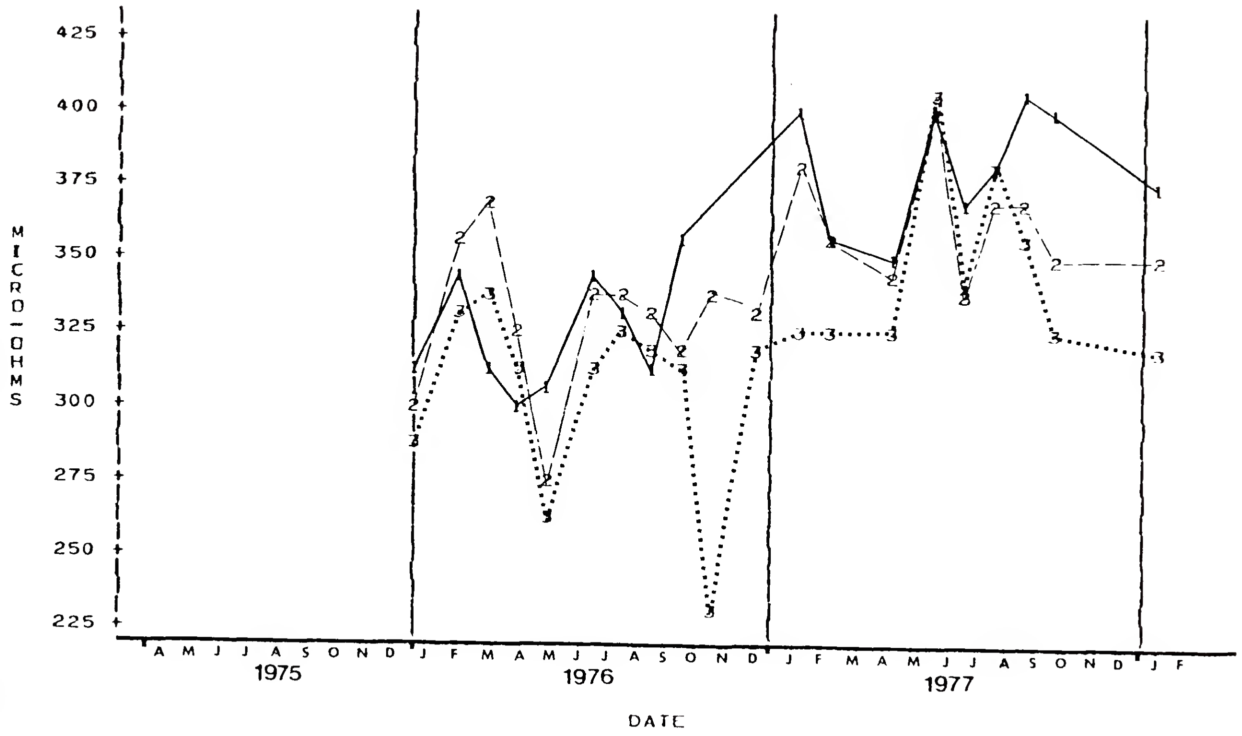


Figure 15. Citrus Ponds surface specific conductivity in micromhos/cm^2 (——— = Pond One, – – – = Pond Two, ······· = Pond Three).

Overall, the nitrate-nitrogen concentrations in all three ponds usually fluctuated between 0.0 and 0.8 ppm. One large peak of nitrate-nitrogen was found in each pond during the study (Fig. 16).

Potassium

The concentration of potassium ranged from 2.3 to 19.4 ppm in Pond One, 0.8 to 21.6 ppm in Pond Two, and from 2.7 to 22.2 ppm in Pond Three (Fig. 17). Initially, potassium levels were very low in Ponds Two and Three (treatment ponds) before herbicide application. The potassium levels in these ponds increased greatly after herbicide application while hyacinths were dying and decaying, apparently as a result of potassium released from decomposing hyacinths. A similar pattern was observed in Pond One during its treatment in 1976. After open water conditions existed, the potassium levels of all three ponds seemed to stabilize between 7 and 14 ppm.

Total Phosphate-Phosphorus

The concentration of total phosphate-phosphorus ranged from 0.0885 to 0.8200 ppm in Pond One, 0.1425 to 0.8330 ppm in Pond Two, and from 0.1165 to 1.3095 ppm in Pond Three (Fig. 18). In the treatment ponds (Ponds Two and Three), total phosphate-phosphorus increased greatly after chemically treating the hyacinths, apparently due to release of phosphate-phosphorus by decomposing vegetation. Total phosphate-phosphorus eventually

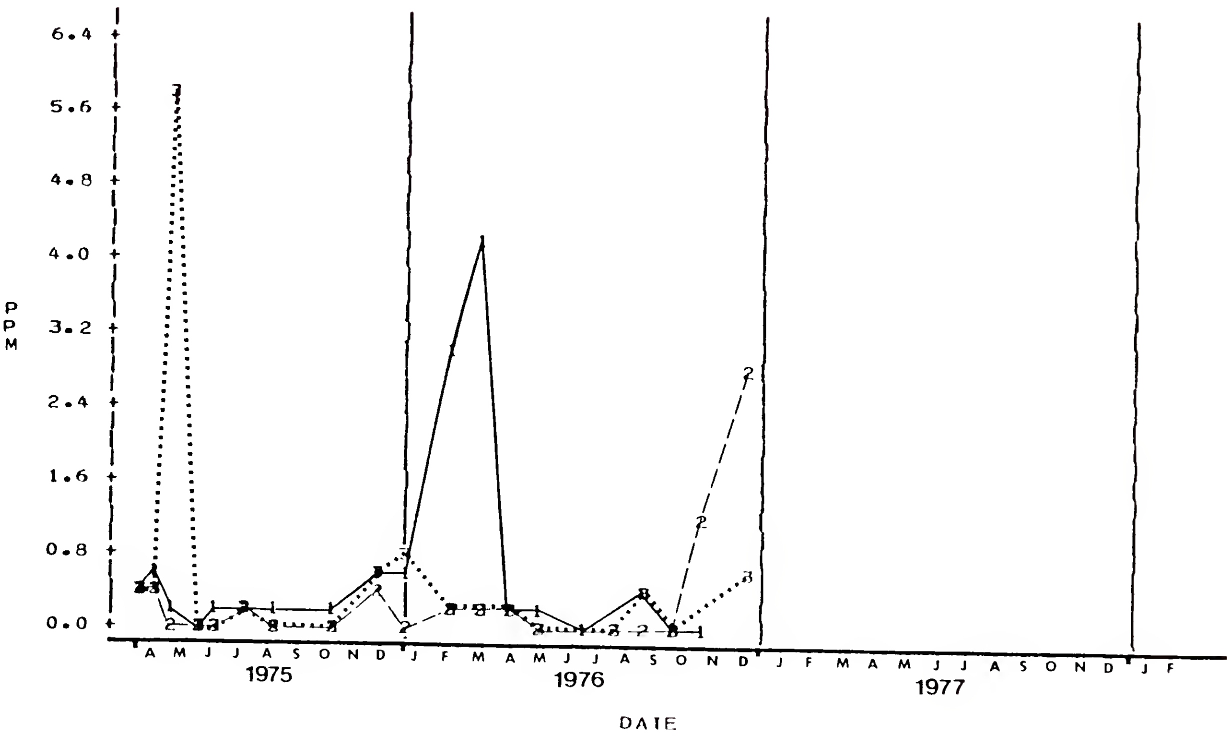


Figure 16. Citrus Ponds surface nitrate-nitrogen concentrations in ppm (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

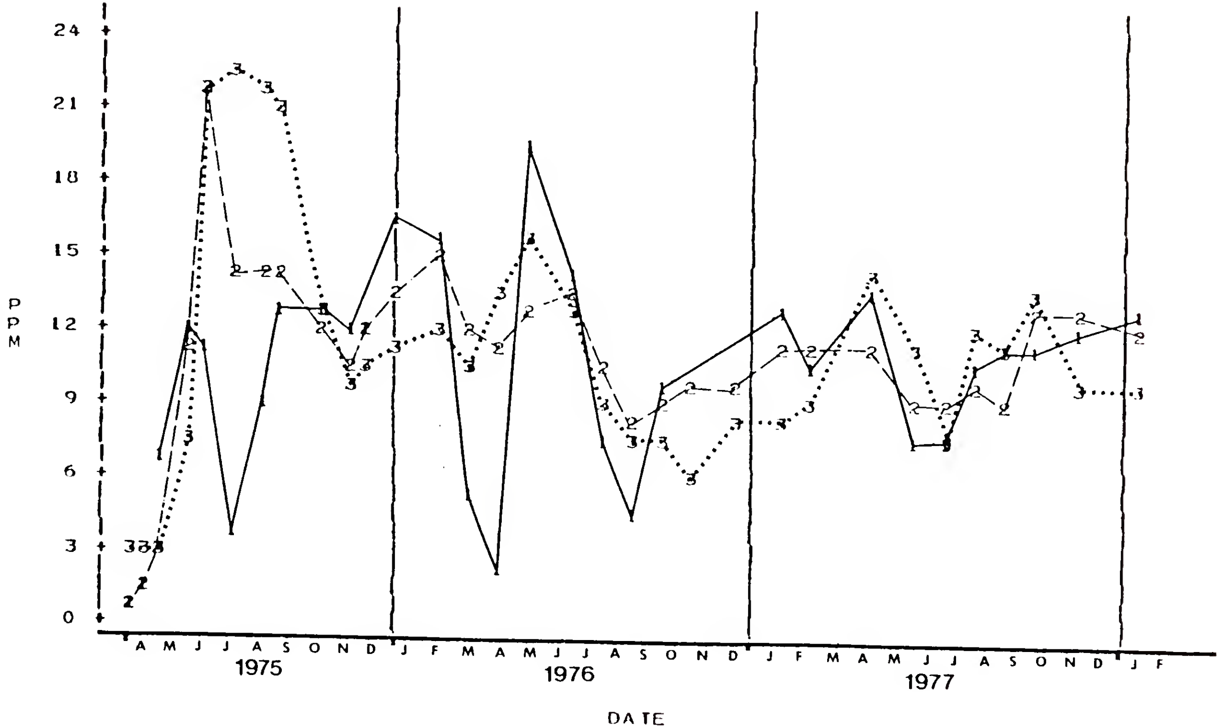


Figure 17. Citrus Ponds surface potassium concentrations in ppm (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

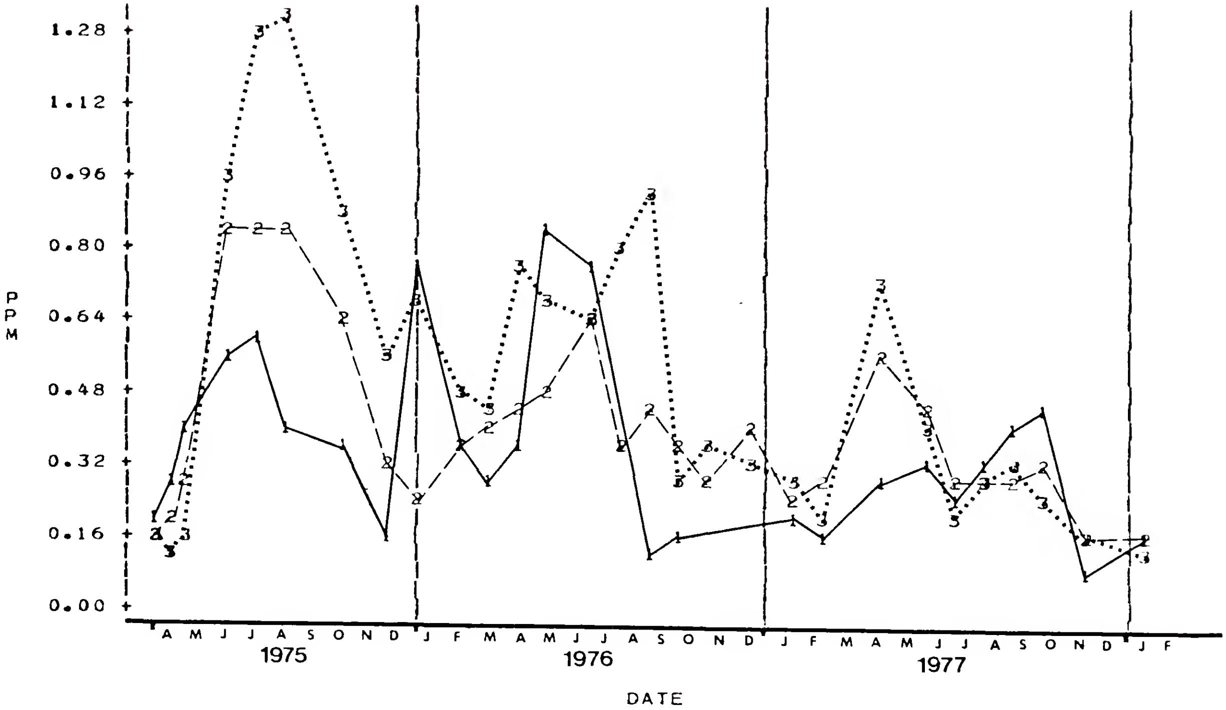


Figure 18. Citrus Ponds surface total phosphate-phosphorus concentrations in ppm (——— = Pond One, — — — = Pond Two, ... = Pond Three).

decreased to the lower levels found under open water conditions (0.15 to 0.50 ppm) in 1977 due to removal of phosphate-phosphorus by phytoplankton, and the flushing-out of excess nutrients by incoming spring and runoff water. A similar large increase occurred after chemical treatment in Pond One in 1976. As this nutrient-enriched water moved downstream it would also elevate the nutrient levels of Ponds Two and Three. Lower levels of total phosphate-phosphorous were found in Pond One after open water conditions were established.

Available Phosphate-Phosphorus

The concentration of available phosphate-phosphorus ranged from 0.0115 to 0.6920 ppm in Pond One, 0.0055 to 0.9120 ppm in Pond Two, and from 0.0010 to 1.3085 ppm in Pond Three (Fig. 19). During the study period, the concentrations of available phosphate-phosphorus followed the same tendencies as total phosphate-phosphorus.

Calcium

The concentration of calcium ranged from 17.25 to 49.00 ppm in Pond One, 16.50 to 48.40 ppm in Pond Two, and from 16.75 to 45.00 ppm in Pond Three (Fig. 20). Except for a low concentration of calcium in the three ponds during the winter of 1975-1976, all the ponds normally showed calcium concentrations

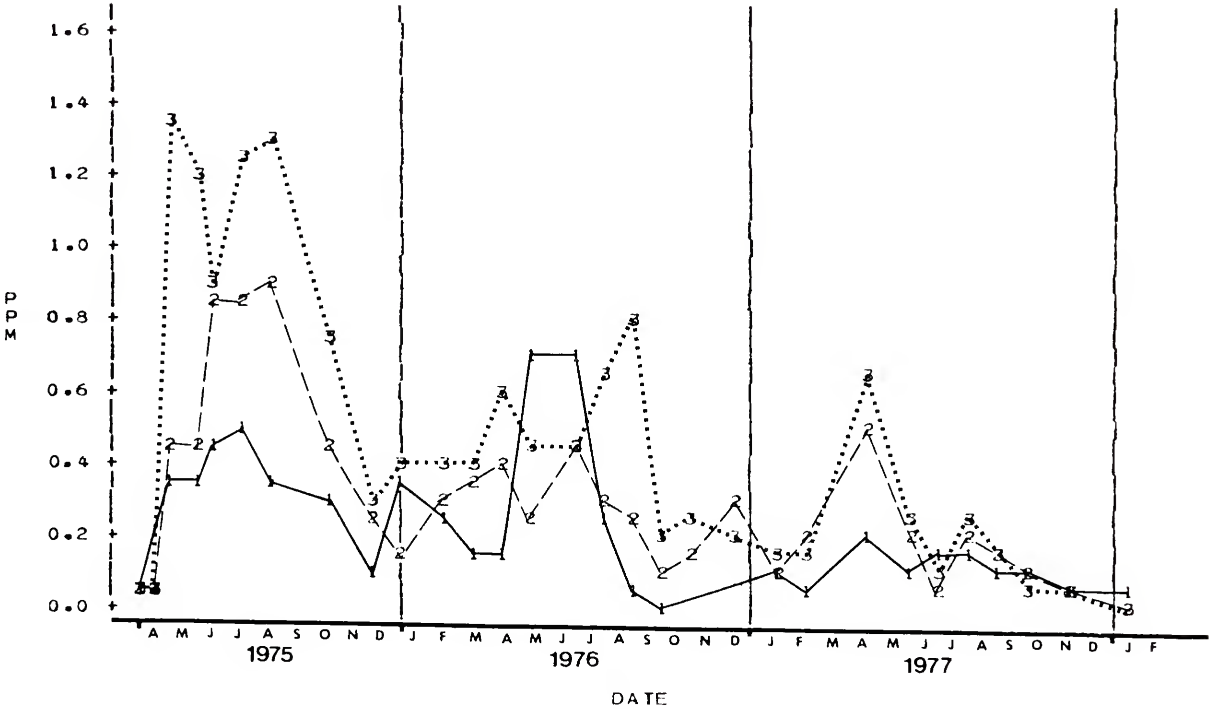


Figure 19. Citrus Ponds surface available phosphate-phosphorus concentrations in ppm (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

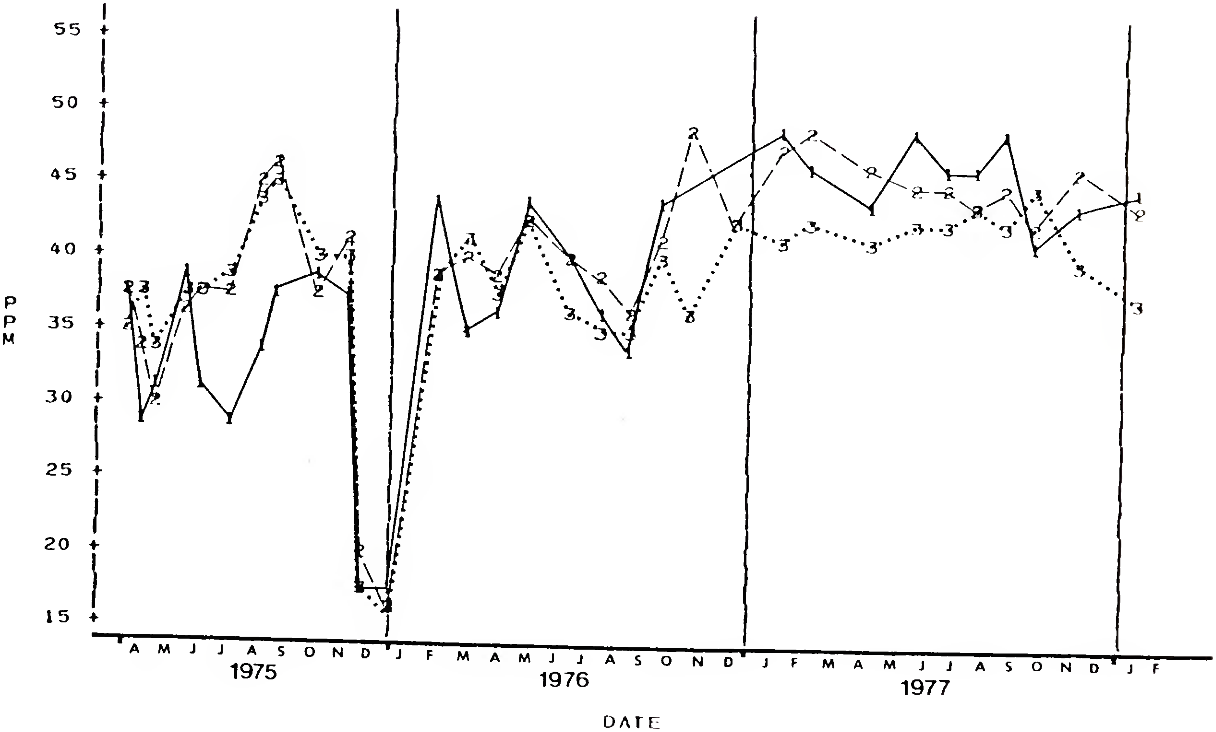


Figure 20. Citrus Ponds surface calcium concentrations in ppm (——— = Pond One, — — — = Pond Two, ... = Pond Three).

ranging from 28 to 49 ppm. The concentration of calcium in all three ponds seemed to be quite stable, and showed only a slight increase during open water conditions.

Magnesium

The concentration of magnesium ranged from 3.2 to 17.3 ppm in Pond One, 4.9 to 17.2 ppm in Pond Two, and from 2.3 to 16.5 ppm in Pond Three (Fig. 21). The concentration of magnesium was similar to that of calcium, but concentrations of magnesium appeared to be fairly constant throughout the study (with the exception of winter 1975-1976).

Dissolved Oxygen

The concentration of dissolved oxygen in the pond surfaces during periods of dense hyacinth cover varied with the seasons (due to changing air and water temperatures). Dissolved oxygen concentrations under actively growing hyacinth mats were less than 3.0 ppm in spring, less than 1.5 ppm in summer, and less than 9.0 ppm during winter and fall (Fig. 22). Changing water temperatures considerably influenced this, since the solubility of oxygen in water increases with decreasing water temperature. Air temperature, and its effect on the hyacinth mat, also influences the amount of dissolved oxygen. During fall and winter, air temperatures are lower, thus slowing down plant growth. Winter frosts also cause natural killing of the hyacinths, thus reducing the size of the hyacinth mat. Lower air temperatures

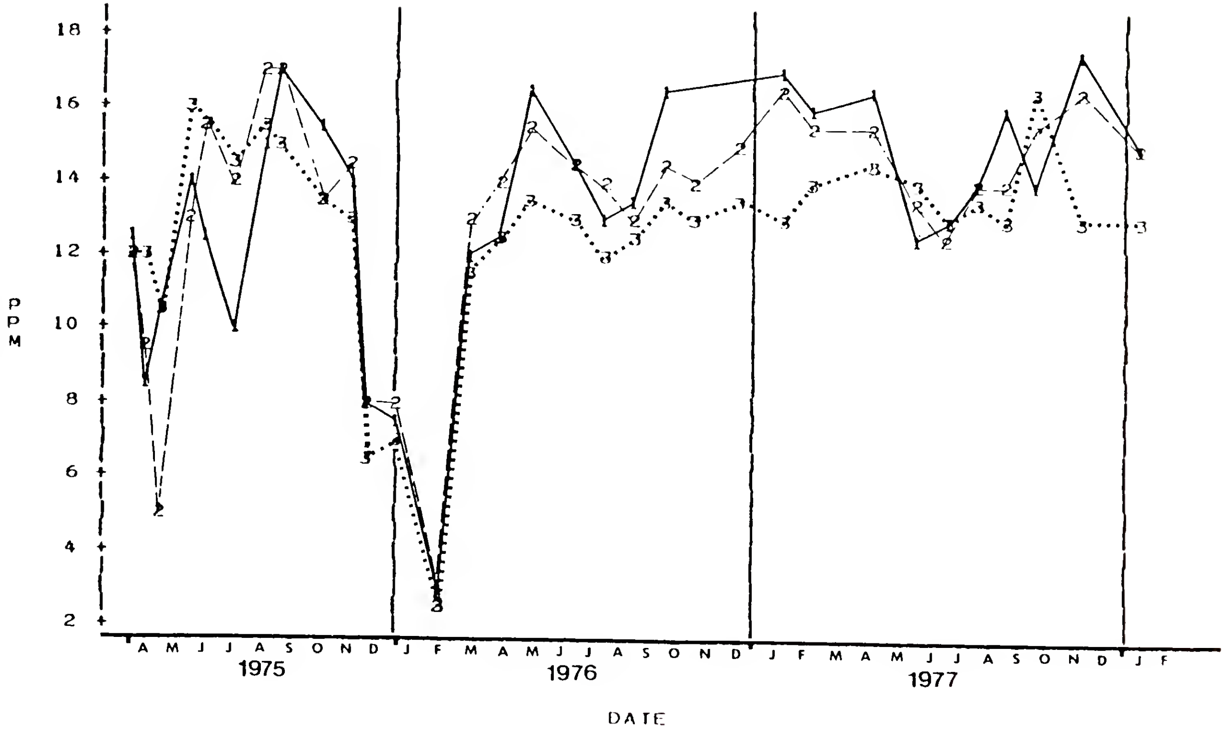


Figure 21. Citrus Ponds surface magnesium concentrations in ppm (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

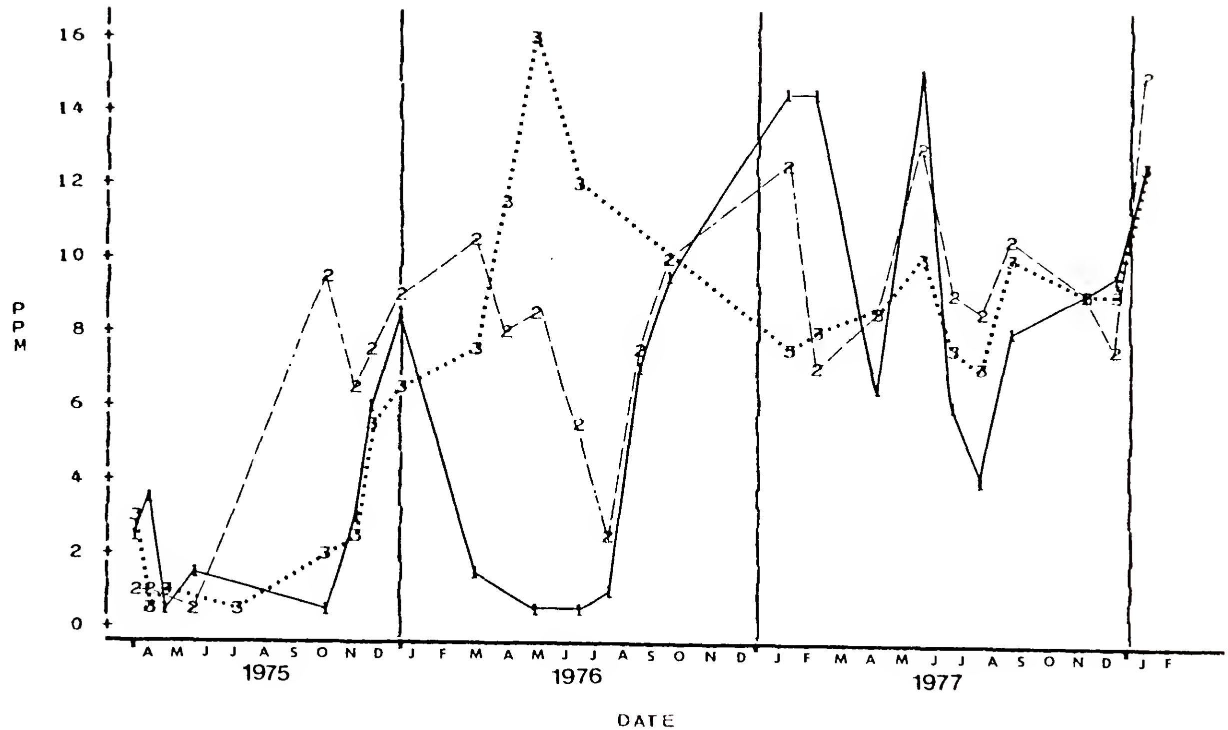


Figure 22. Citrus Ponds surface dissolved oxygen concentrations in ppm (——— = Pond One, — — — = Pond Two, ······· = Pond Three).

were generally associated with large open spaces developing in the mat, allowing more oxygen to enter the water column. Furthermore, less oxygen is removed from the water for plant respiration by the hyacinth roots since less biomass is found during the winter.

Surface dissolved oxygen concentrations dropped to less than 1.0 ppm during chemical treatment of hyacinths. Within six months after the initial herbicide applications in each pond, the surface dissolved oxygen concentrations had increased considerably. Surface dissolved oxygen concentrations were much higher (normally four to sixteen ppm) and fluctuated greatly (due to changes in water temperature, solar radiation, phytoplankton populations, etc.) after open water conditions existed.

The concentration of dissolved oxygen at one meter depths below the pond surfaces is shown in Fig. 23. The highest oxygen concentrations in all ponds were found during the cool water periods (fall and winter). Little oxygen was found at one meter depths during warm water periods (usually less than 0.5 ppm) under actively growing mats. Dissolved oxygen levels at a one meter depth improved yearly after hyacinths disappeared and open water conditions existed.

In summary, dissolved oxygen concentrations were minimal under actively growing dense hyacinth mats and chemically treated dying hyacinth mats, and were maximal during cool water periods when the vegetation cover was reduced. Figures 24-28 show oxygen-temperature profiles for specific sampling dates during the study.

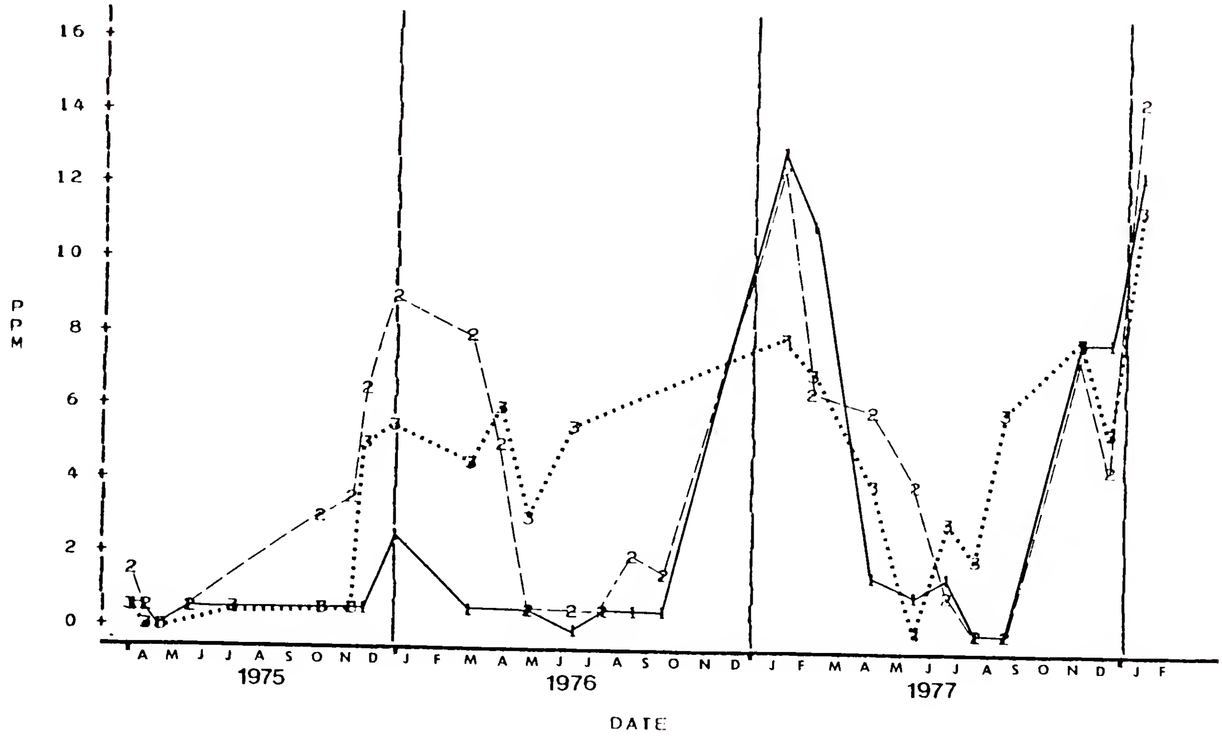


Figure 23. Citrus Ponds one meter depth dissolved oxygen concentrations in ppm (———— = Pond One, — — — = Pond Two, ········= Pond Three)

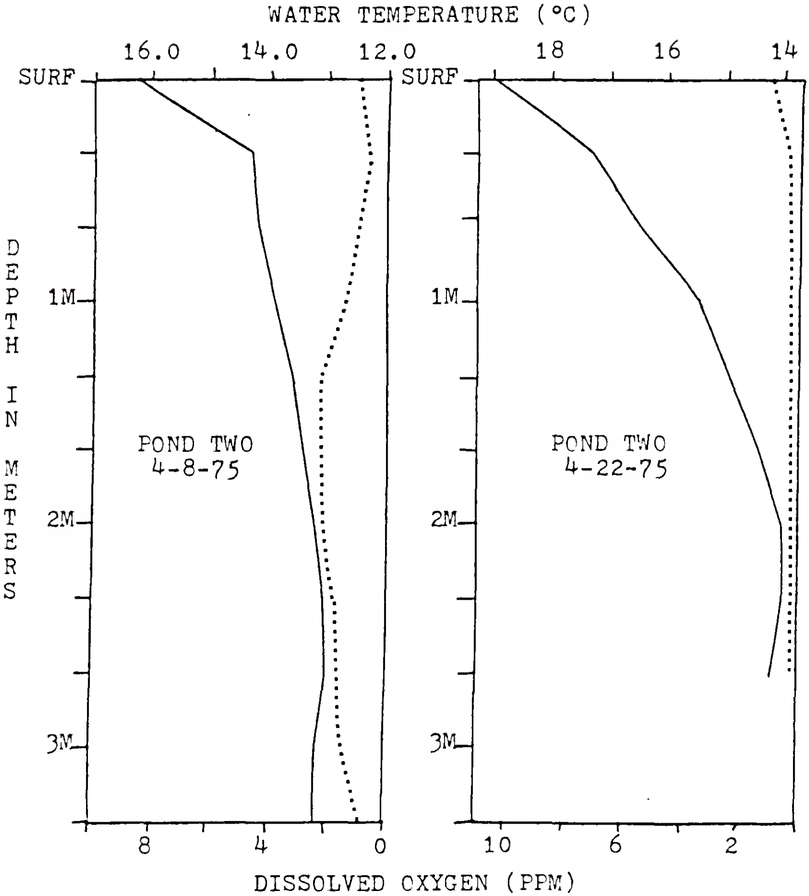


Figure 24. Pond Two dissolved oxygen and temperature profiles beneath actively growing water hyacinth populations before chemical treatment.

a) April 8, 1975 b) April 22, 1975

(——— =water temperature in degrees centigrate, ········ =dissolved oxygen concentration in ppm).

Figure 25. Pond Two dissolved oxygen and temperature profiles beneath chemically treated water hyacinth populations.

a) June 4, 1975, three weeks after chemical treatment (a thick cover of dead and decaying water hyacinths remained on the pond surface).

b) October 20, 1975, five months after chemical treatment (large floating mats of decaying organic material, or "sudds", were found on the pond surface).

(——— = water temperature in degrees centigrade,
------ = dissolved oxygen concentration in ppm.)

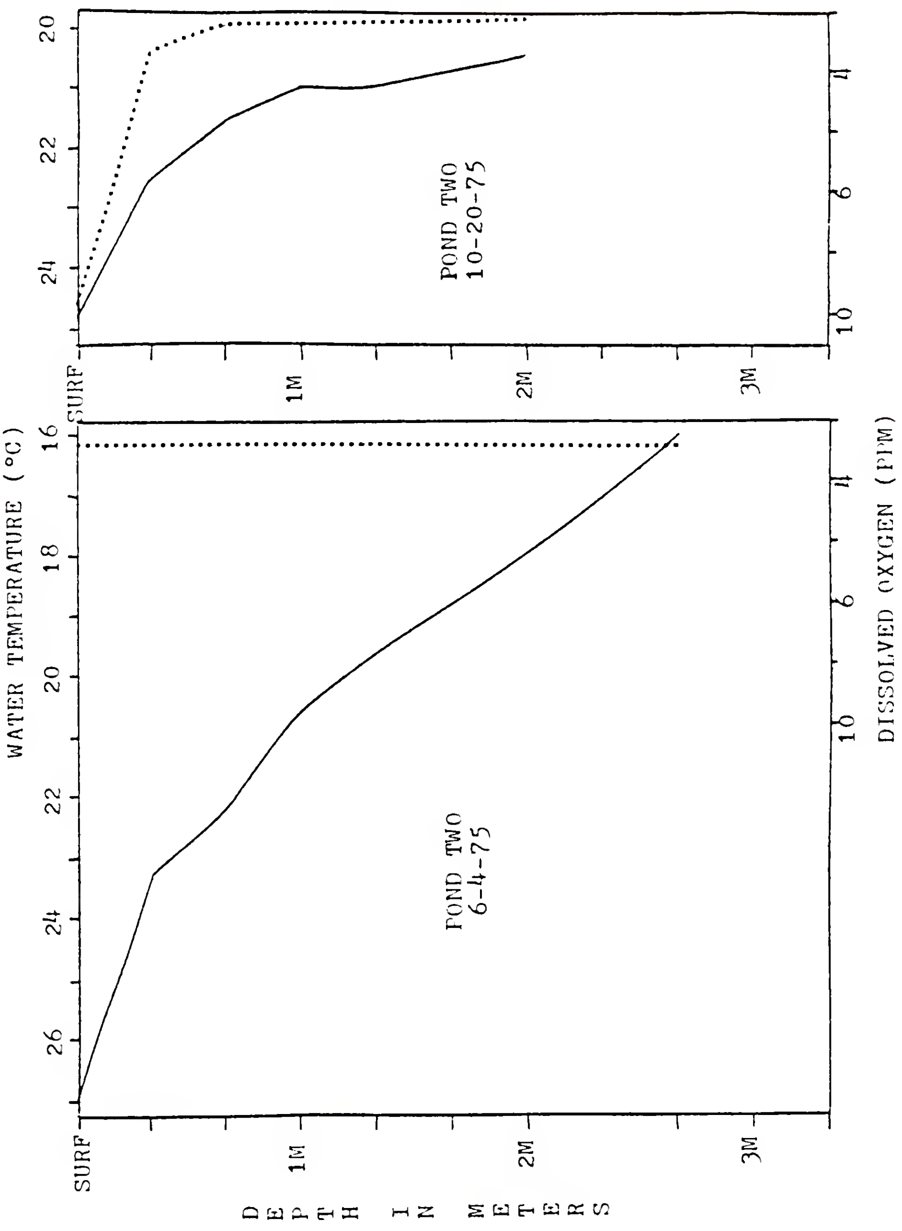

WATER TEMPERATURE (°C)
20
22
24
POND TWO
10-20-75
4
6
10
SURF
1M
2M
3M
16
18
20
22
24
26
POND TWO
6-4-75
DISSOLVED OXYGEN (PPM)
4
6
10
SURF
1M
2M
3M
DEPTH IN METERS

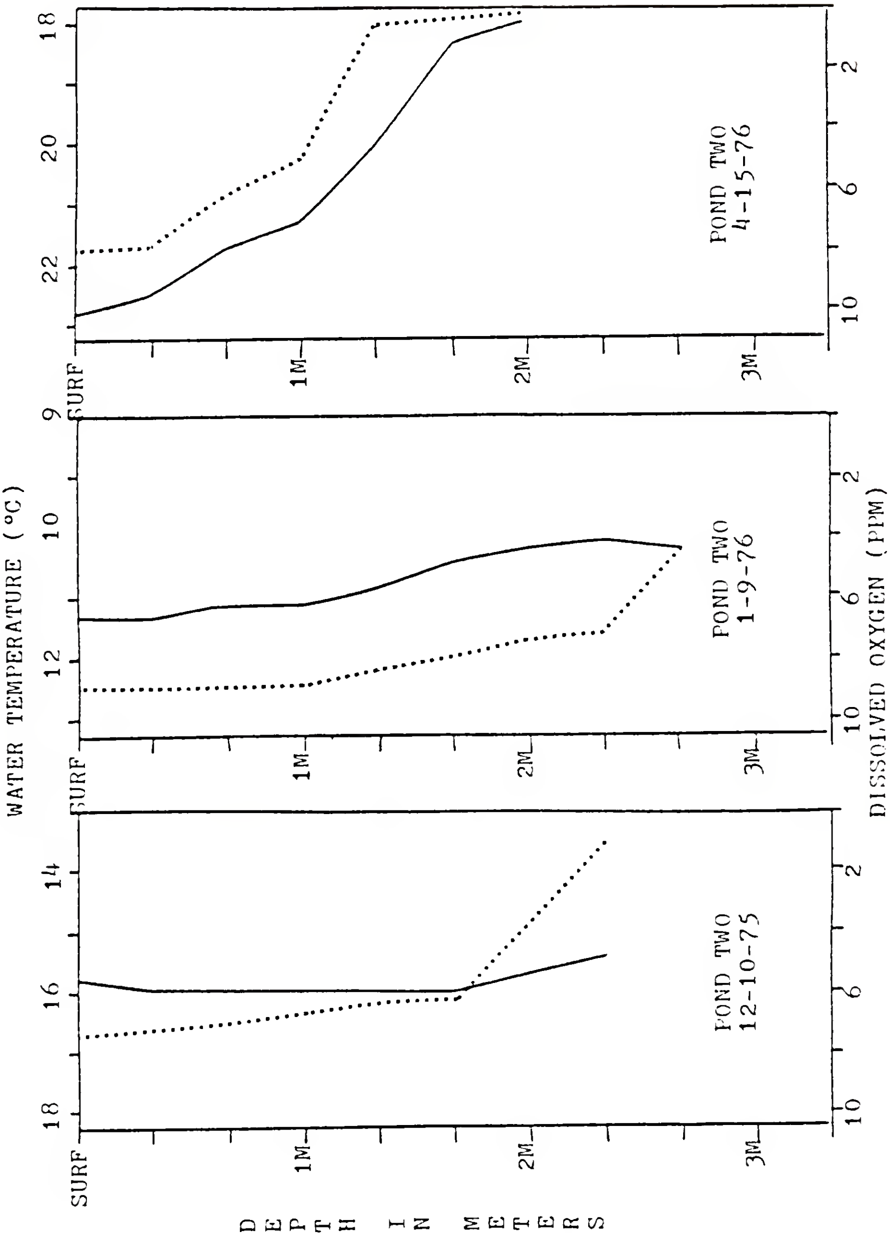
Figure 26. Pond Two dissolved oxygen and temperature profiles after removal of water hyacinth populations by chemical treatment, and establishment of open water conditions.

a) December 10, 1975, seven months after chemical treatment, and one month after open water conditions were established.

b) January 9, 1975, two months after open water conditions were established.

c) April 15, 1975, five months after open water conditions were established.

(——— = water temperature in degrees centigrade,
------ = dissolved oxygen concentration in ppm.)



WATER TEMPERATURE (°C)
DISSOLVED OXYGEN (PPM)
DEPTH IN METERS
POND TWO 4-15-76
POND TWO 1-9-76
POND TWO 12-10-75
18
20
22
9
10
12
14
16
18
2
6
10
SURF
1M
2M
3M

Figure 27. Pond Two dissolved oxygen and temperature profiles after establishment of open water conditions.

a) July 27, 1976, eight months after open water conditions were established (fourteen months after chemical treatment).

b) September 28, 1976, ten months after establishment of open water conditions.

c) January 22, 1977, fourteen months after open water conditions were established.

(——— = water temperature in degrees centigrade,
------- = dissolved oxygen concentration in ppm.)

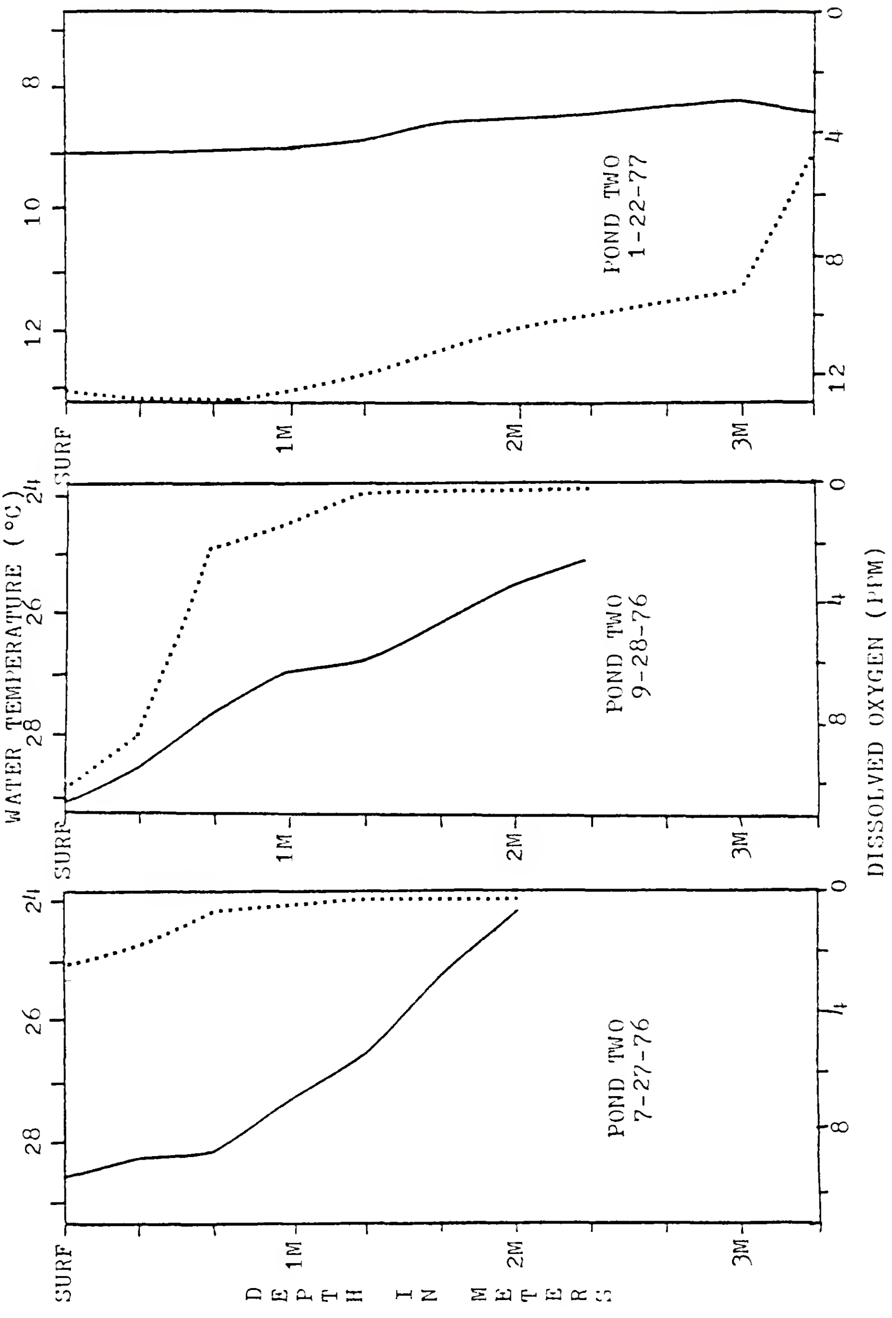

POND TWO
1-22-77
POND TWO
9-28-76
POND TWO
7-27-76
WATER TEMPERATURE (°C)
DISSOLVED OXYGEN (PPM)
DEPTH IN METERS
SURF
1M
2M
3M
8
10
12
24
26
28
0
4
8
12

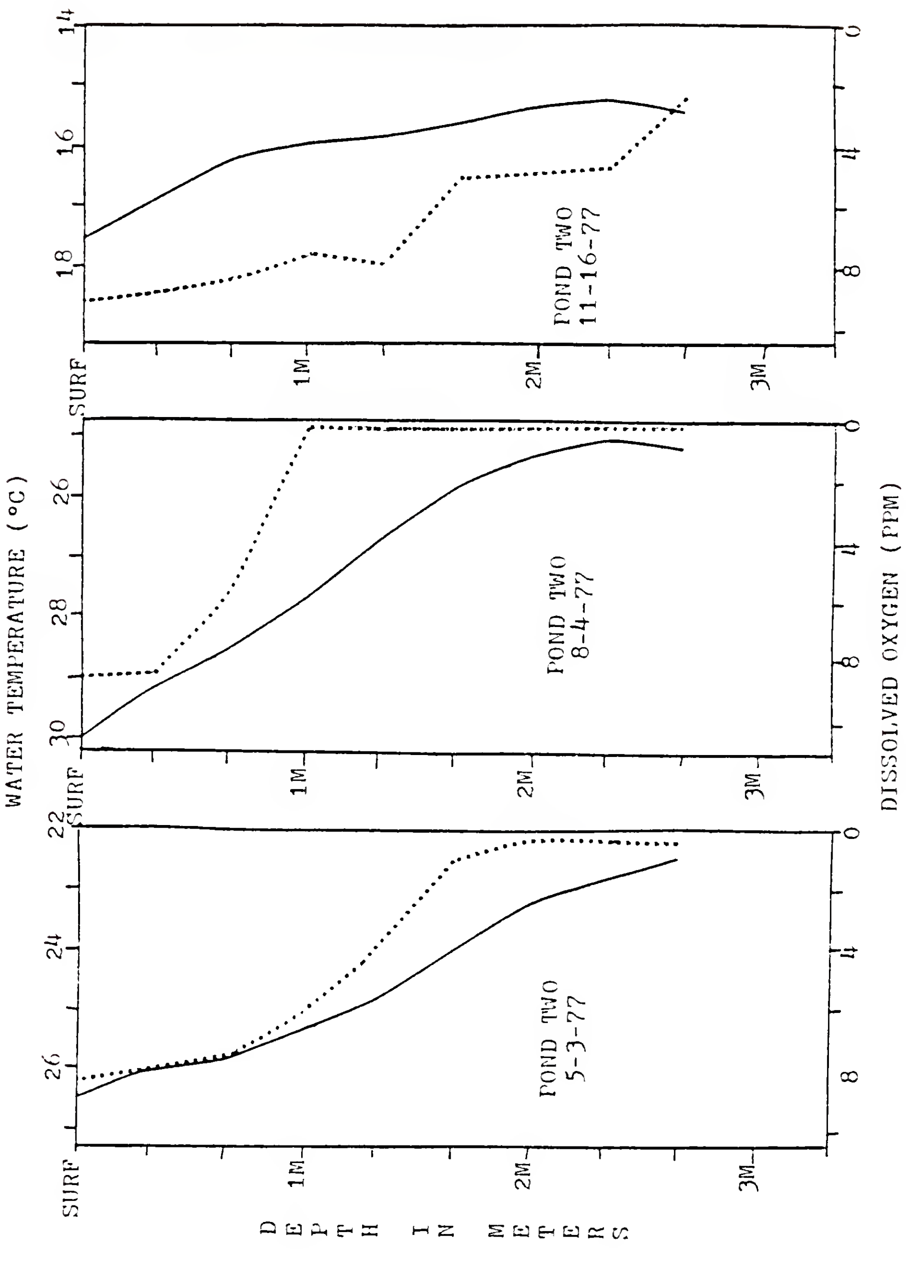
Figure 28. Pond Two dissolved oxygen and temperature profiles after establishment of open water conditions.

a) May 3, 1977, eighteen months after open water conditions were established (two years after chemical treatment).

b) August 4, 1977, twenty-one months after open water conditions were established.

c) November 16, 1977, two years after open water conditons were established (two and a half years after chemical treatment).

(———— = water temperature in degrees centigrade,
-------- = dissolved oxygen concentration in ppm.)


WATER TEMPERATURE (°C)
DISSOLVED OXYGEN (PPM)
DEPTH IN METERS
SURF
1M
2M
3M
14
16
18
26
28
30
22
24
26
0
4
8
POND TWO
11-16-77
POND TWO
8-4-77
POND TWO
5-3-77

Dissolved oxygen was found to be negatively correlated with percent total vegetation cover, and positively correlated with light penetration in the pond surfaces and depths. Therefore, the greater the amount of vegetative cover, the less the light penetration, and the less dissolved oxygen was found. Dissolved oxygen was also negatively correlated with water temperature in the pond depths.

Water Temperature

Water temperatures fluctuated between 8.5 and 32.6°C during the study period. Surface water temperatures (Fig. 29) showed a slightly greater range than did one meter depth water temperatures (Fig. 30). The yearly range of water temperatures increased after water hyacinths were removed (1976), and open water conditions became established (1976-1977). The smallest yearly range of water temperature occurred when the ponds had a thick cover of water hyacinths (1975). The hyacinth mats apparently acted as an insulative barrier which kept the pond water temperatures cooler than air temperatures in summer and warmer than air temperatures during winter.

The average difference between surface and one meter depth water temperatures was 2.6°C before and during treatment of hyacinths, and 1.3°C after hyacinth disappearance in Pond One (control pond). The average difference was 4.2°C before and during hyacinth treatment in Pond Two (treatment pond), and 1.7°C after hyacinth disappearance. The average difference was

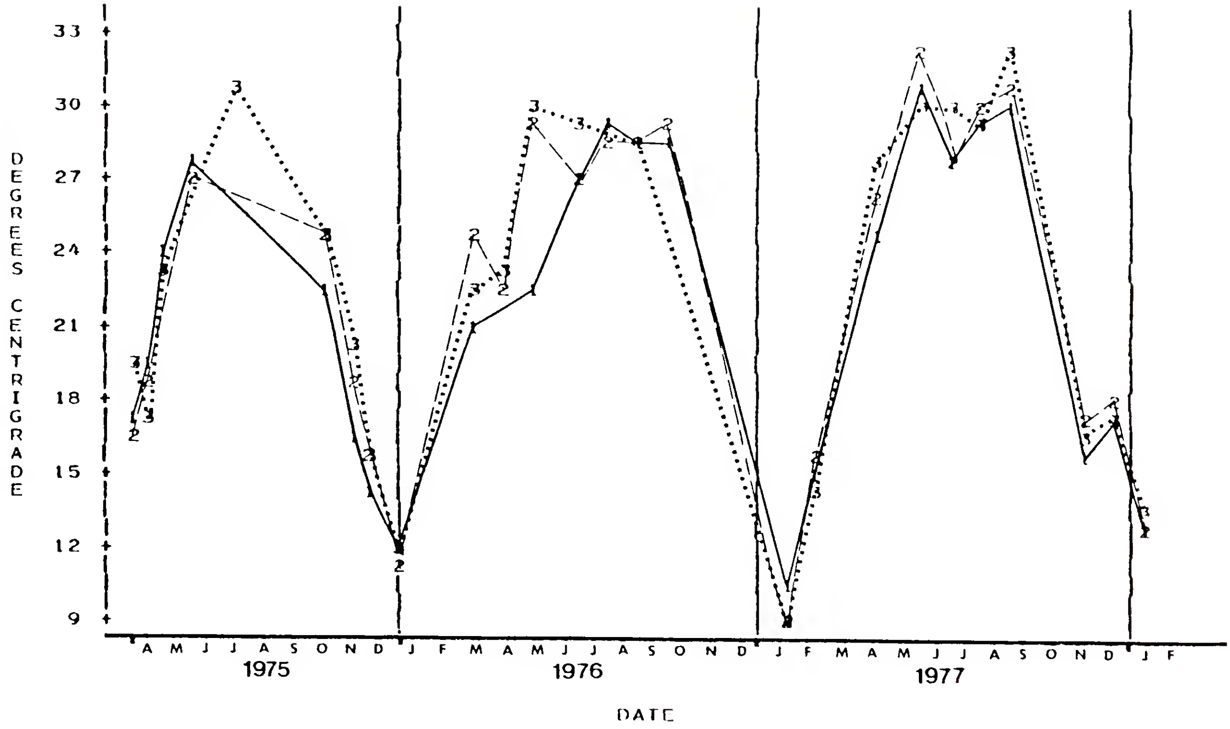


Figure 29. Citrus Ponds surface water temperature in degrees centigrade (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

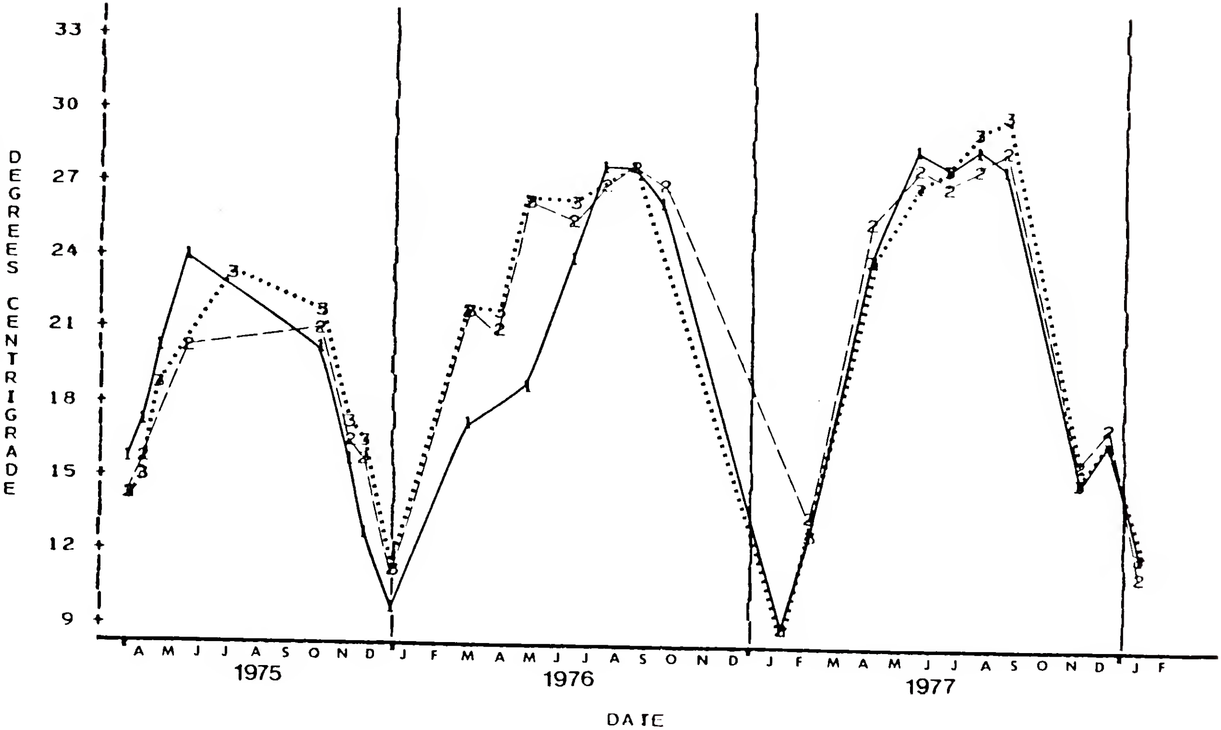


Figure 30. Citrus Ponds one meter depth water temperature in degrees centigrade (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

4.7°C before and during treatment in Pond Three, and 1.7°C after hyacinth disappearance. There was a larger temperature difference between pond surfaces and one meter depths when the ponds were covered by dense hyacinth mats. Less difference in water temperature occurred with depth after mat disappearance.

Secchi Disk

Light penetration was determined by the depth of Secchi disk disappearance (Fig. 31). Secchi disk readings were minimal during periods of dense hyacinth cover and during periods of heavy phytoplankton growth (summers) after hyacinth disappearance. Secchi disk readings were maximal during cool water periods (late fall and winter) before and after hyacinth disappearance when phytoplankton populations were minimal.

Secchi disk disappearance in the pond surfaces was negatively correlated to total phytoplankton, total blue-green algae, and water temperature.

Light Penetration

Light penetration was also measured by means of a light meter using a quantum type probe. Surface light penetration was measured at a depth of one centimeter below the pond surfaces (measuring the amount of light entering the water column). Surface light penetration readings were fairly variable, depending on the amount of vegetation present, which caused shading effects on the ponds beneath (Fig. 32). In general, surface readings

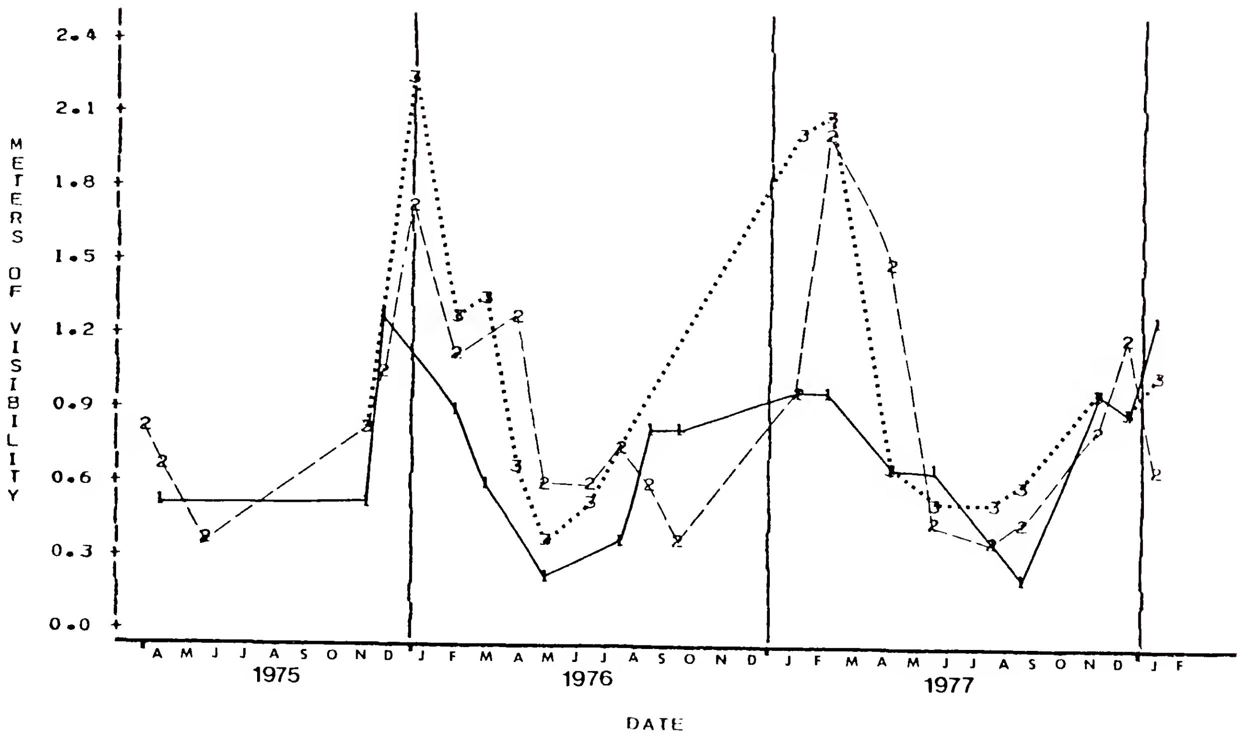


Figure 31. Citrus Ponds depth of light penetration, measured as the depth (in meters) of Secchi disk disappearance (——— = Pond One, — — — = Pond Two, ... = Pond Three).

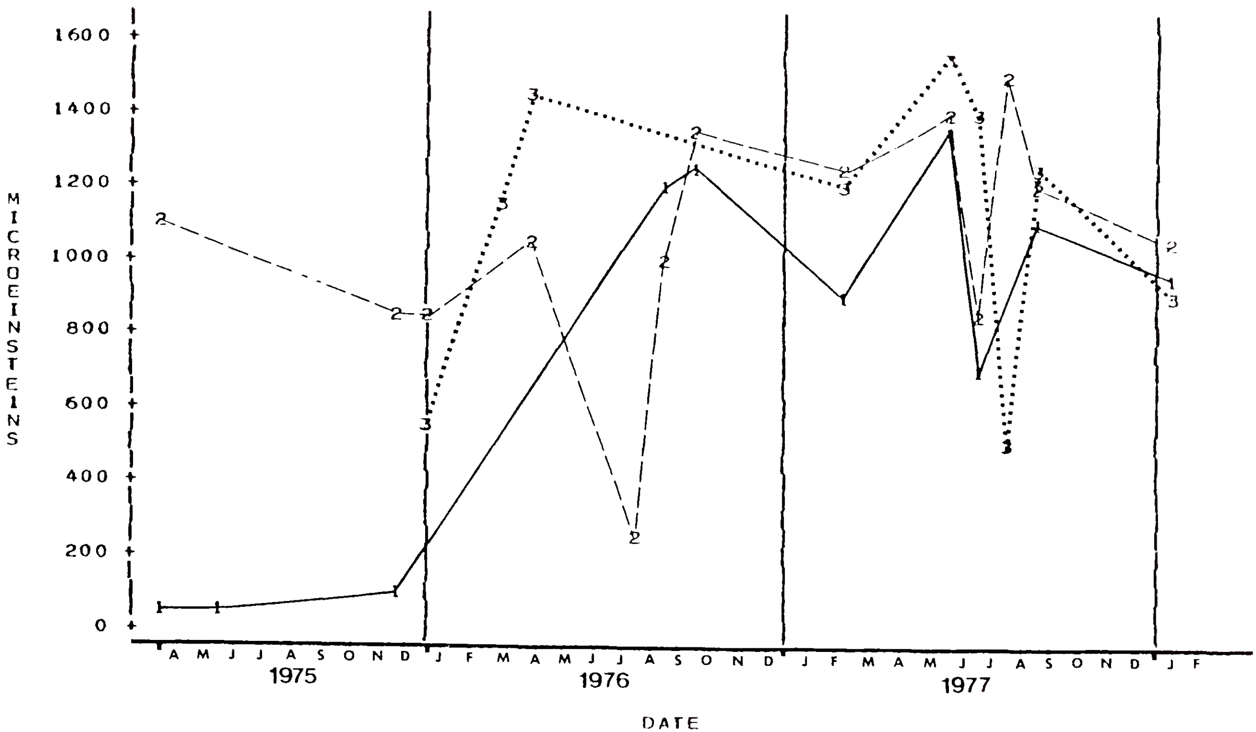


Figure 32. Citrus Ponds surface light penetration, measured as micro-einsteins/M2/sec by light meter (——— = Pond One, — — — = Pond Two, ······· = Pond Three).

showed an increasing trend, and were less variable after hyacinth disappearance. The graph depicting light penetration at one meter depths (Fig. 33) shows a much closer relationship between vegetation cover and light penetration than did surface light penetration. Light penetration was minimal at the one meter level when hyacinth mats were present, and when phytoplankton blooms were occurring. Light penetration was maximal during winter (cool water months), when vegetation cover and phytoplankton blooms were minimal. Figures 34-35 show light penetration profiles for several sampling dates during the study.

Light penetration in the surface of Pond One was negatively correlated with total chrysophytes, total phytoplankton diatoms, and percent total vegetation cover, and positively correlated with dissolved oxygen. No significant correlations were found in the surface of Ponds Two and Three.

Light penetration was negatively correlated with both water temperature and percent total vegetation cover, and positively correlated to dissolved oxygen in the pond depths.

Percent Total Vegetation Cover

Estimates were made throughout the study to determine what percentage of the pond surfaces were covered with floating vegetation (Fig. 36). The water hyacinth and pennywort populations decrease their percentage of surface coverage during winter in northern Florida due to frost damage and decreased growth rates.

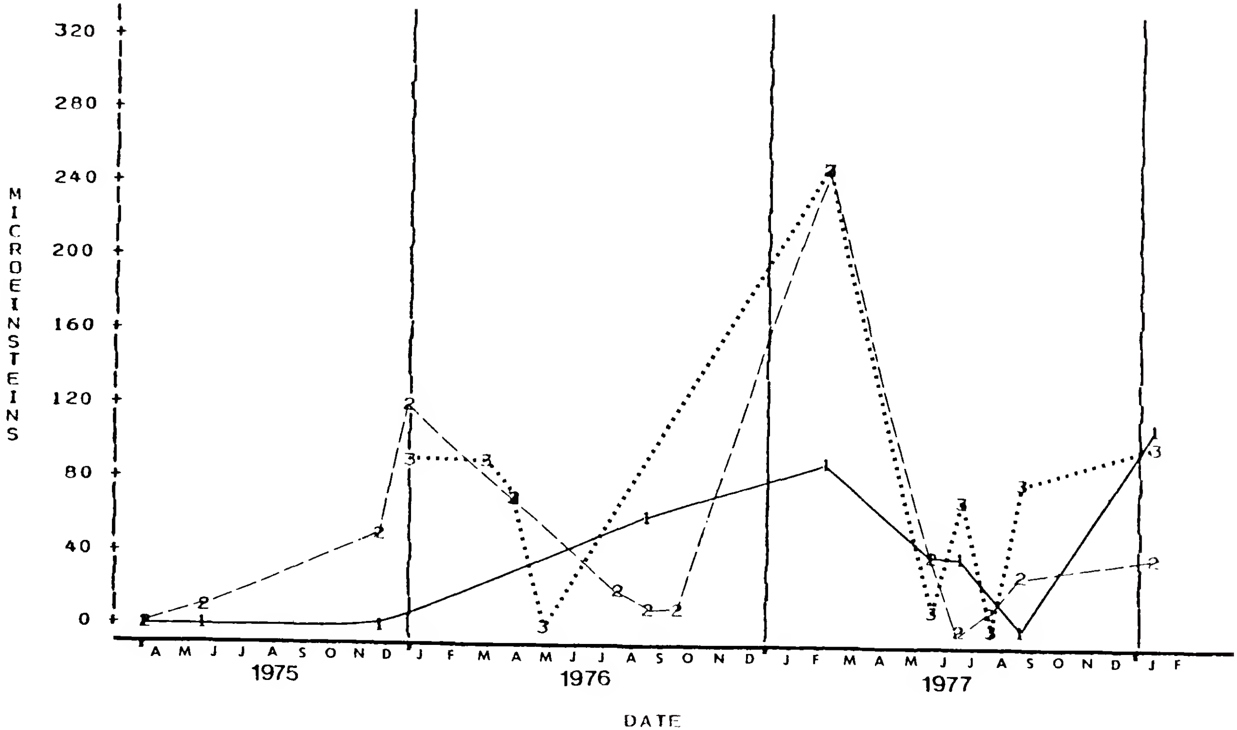


Figure 33. Citrus Ponds one meter depth light penetration, measured as microeinsteins/M^2/sec by light meter (——— = Pond One, – – – = Pond Two, ······· = Pond Three).

Figure 34. Pond One light penetration profiles, measured as microeinsteins/M^2/sec with depth. Light penetration measurements were taken above and below the pond surface.

a) June 4, 1975, profile beneath actively growing hyacinth populations (thick mat of hyacinths was found above the pond surface).

b) December 10, 1975, profile beneath actively growing water hyacinth populations (thin mat with large holes, due to frost kill-back).

c) August 26, 1976, profile beneath large floating mats of dead and decaying organic material ("sudds") four months after chemical treatment of water hyacinth populations.

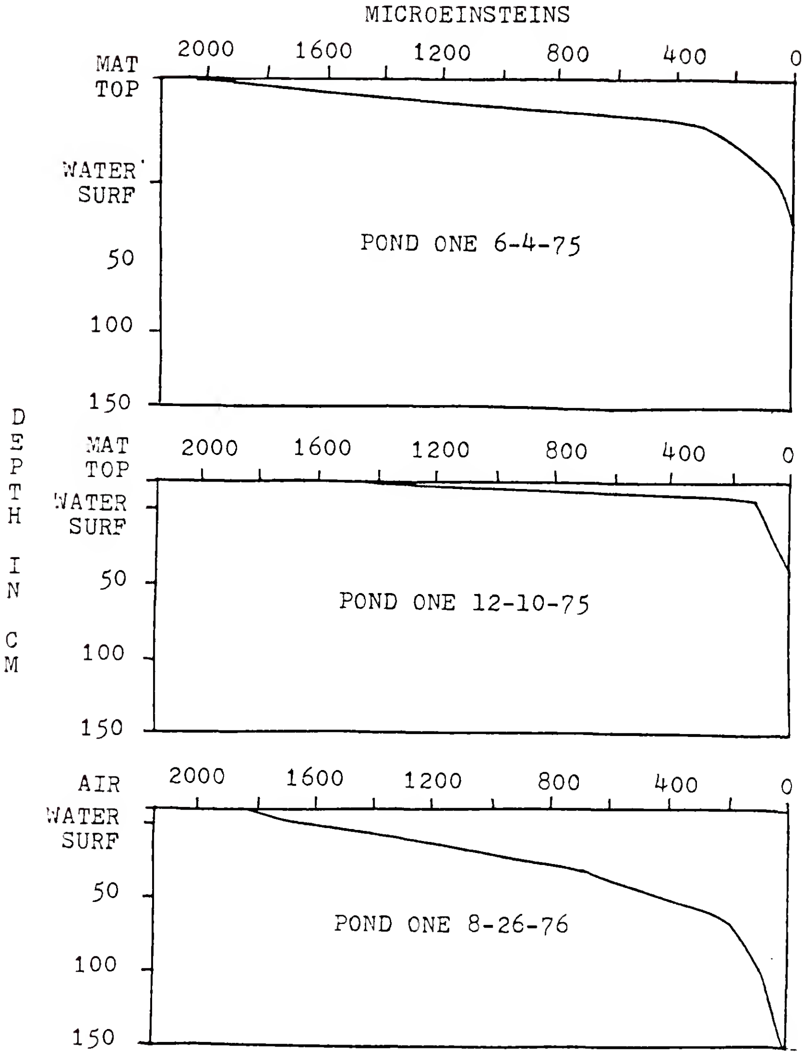
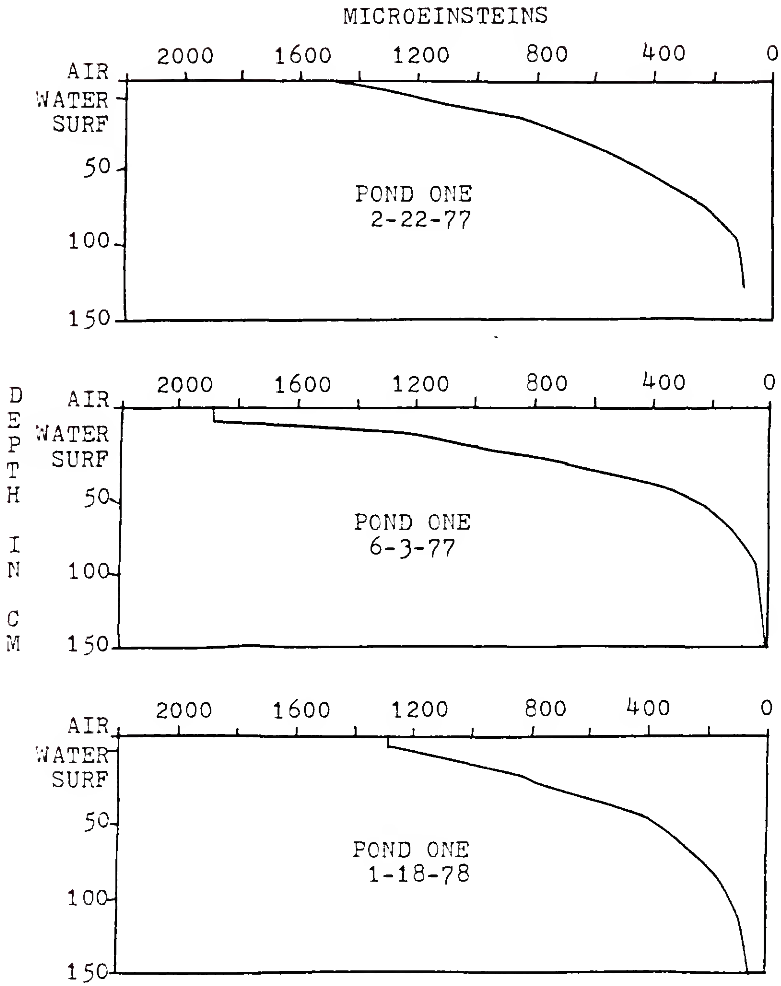

MICROEINSTEINS
2000 1600 1200 800 400 0
MAT TOP
WATER SURF
50
100
150
POND ONE 6-4-75
DEPTH IN CM
2000 1600 1200 800 400 0
MAT TOP
WATER SURF
50
100
150
POND ONE 12-10-75
2000 1600 1200 800 400 0
AIR
WATER SURF
50
100
150
POND ONE 8-26-76

Figure 35. Pond One light penetration profiles after establishment of open water conditions measured as microeinsteins/M^2/sec with depth.

a) February 22, 1977, profile four months after disappearance of sudds and establishment of open water conditions (ten months after chemical treatment).

b) June 3, 1977, profile eight months after established open water conditions.

c) January 18, 1978, profile fifteen months after established open water conditions (twenty-one months after chemical treatment).


MICROEINSTEINS
2000
1600
1200
800
400
0
AIR
WATER
SURF
50
100
150
POND ONE
2-22-77
DEPTH IN CM
POND ONE
6-3-77
POND ONE
1-18-78

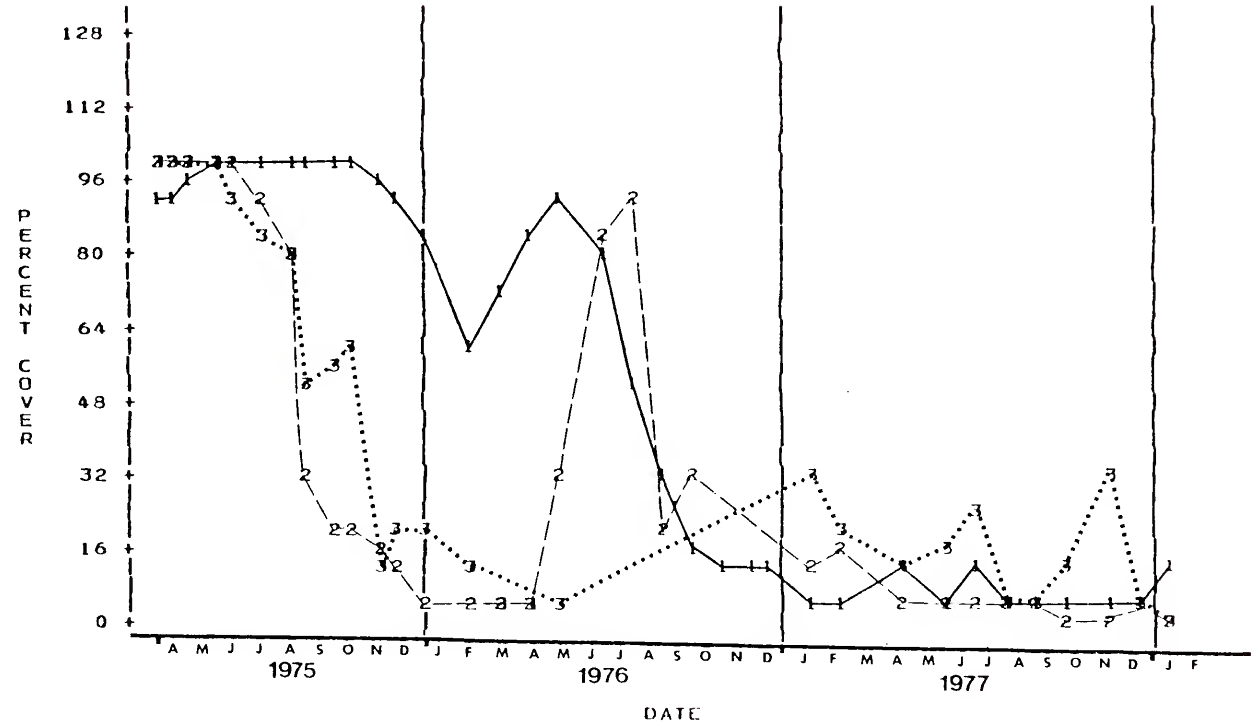


Figure 36. Citrus Ponds percent of total vegetation cover (water hyacinth, pennywort, and duckweed populations included) on the pond surfaces (——— = Pond One, — — — = Pond Two, ·······= Pond Three).

Duckweed only appeared in quantity in Pond Two during 1976 when it covered up to 89 percent of the pond surface. In general, most floating vegetation problems were well under control by 1977 except for occasional small recurring marginal fringes. The percentage of total vegetation cover in 1977 for Ponds One and Two varied between 1 and 15 percent, and 1 to 30 percent in Pond Three.

Phytoplankton

The phytoplankters to be discussed in the following sections are grouped according to their placement in the classification hierarchy. Total phytoplankton is discussed first, followed by discussions of the major algal groups (blue-green algae, chrysophytes, and green algae) and their dominant species found during the study.

Total Phytoplankton

Total surface phytoplankton ranged from 6.84×10^3 to 1.07×10^7 cells/liter in Pond One, 5.81×10^3 to 5.31×10^7 cells/liter in Pond Two, and from 3.48×10^2 to 7.95×10^6 cells/liter in Pond Three during the study (Fig. 37).

Total phytoplankton was found to be maximal during cool water periods and minimal during warm water periods under actively growing hyacinth mats. This seems to be due to increased light penetration during winter when the hyacinth coverage decreased,

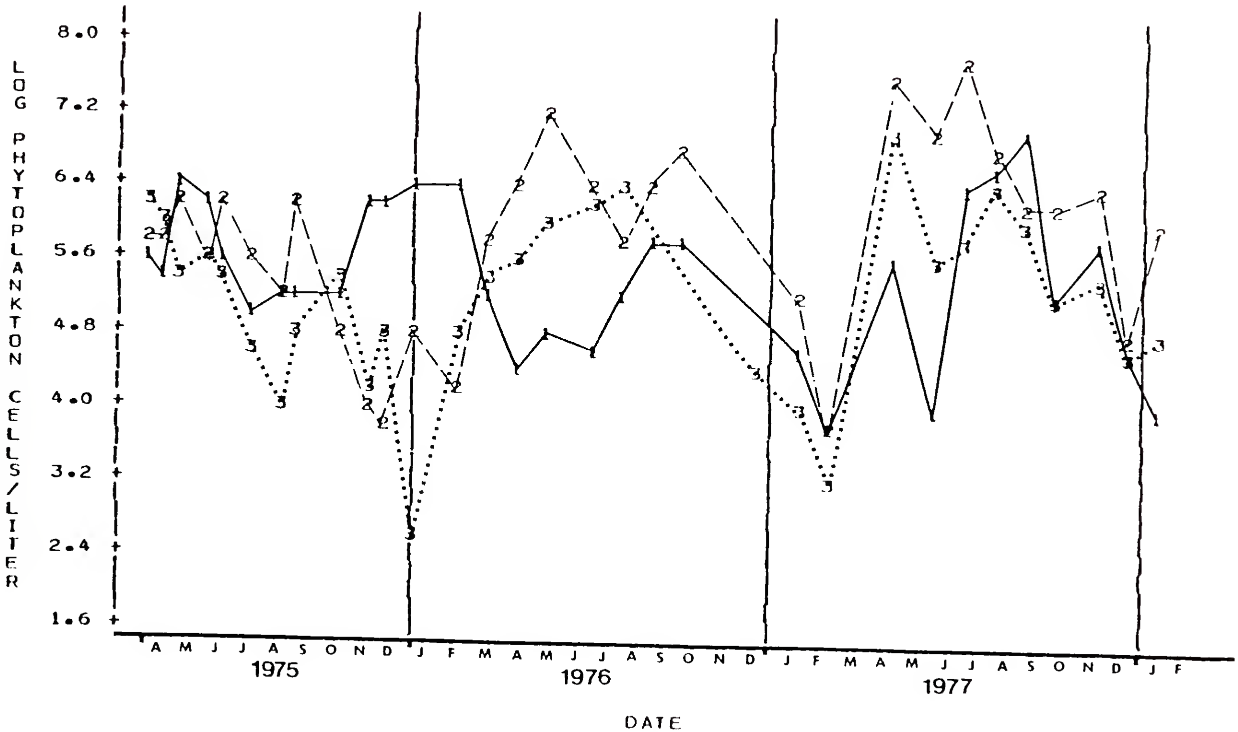


Figure 37. Citrus Ponds total surface phytoplankton, expressed as the number of cells/liter in log10
(——— = Pond One, – – – = Pond Two, ········ = Pond Three).

and decreased light penetration in summer when hyacinth mats are growing most actively.

Total phytoplankton decreased due to decreased light penetration and foul water conditions after the hyacinths were treated, and later increased after open water conditions were established. Total phytoplankton was minimal during cool water periods and maximal during warm water periods after open water conditions were established.

Total phytoplankton was positively correlated with water temperature and pH, and negatively correlated with Secchi disk disappearance in the surfaces of Pond Two and Three. Total phytoplankton was negatively correlated with magnesium in the surface of Pond One.

Stepwise multiple regressions were used to select the best possible models to explain the variations in the data. Stepwise multiple regressions selected soluble salts as the best model for Pond One, pH, bicarbonate, soluble salts, and specific conductivity for Pond Two, and bicarbonate and percent total vegetation cover for Pond Three.

Total Blue-Green Algae

Total surface blue-green algae reached a maximum of 1.06×10^7 cells/liter in Pond One, 5.31×10^7 cells/liter in Pond Two, and 2.61×10^6 cells/liter in Pond Three during the study (Fig. 38).

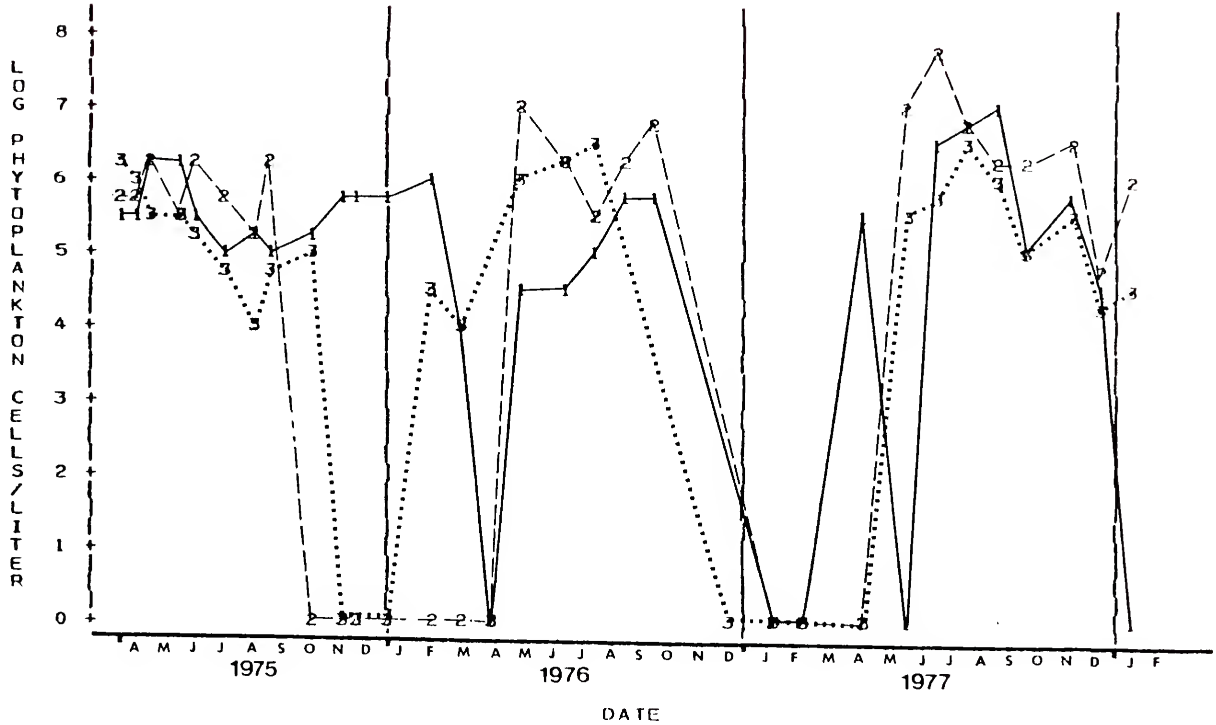


Figure 38. Citrus Ponds total surface blue-green algae, expressed as the number of cells/liter in log10
(——— = Pond One, – – – = Pond Two, ······· = Pond Three).

Total blue-green algae showed a distribution similar to that of total phytoplankton in all three ponds. This was not unexpected since on many sampling dates total phytoplankton was mostly composed of blue-green algae.

Blue-green algae were prevalent throughout the year beneath actively growing hyacinth populations, but decreased rapidly when hyacinth populations were dying (after herbicide application). Blue-green algae populations were minimal during cool water periods, and maximal during warm water periods after hyacinth disappearance (open water conditions).

Total blue-green algae were positively correlated with water temperature, and percent total vegetative cover, and negatively correlated with Secchi disk disappearance in the pond surfaces.

Stepwise multiple regressions were used to select the best possible models to explain the variations in the data in all ponds. Stepwise multiple regressions selected water temperature as the best model for Pond One, nitrate-nitrogen and Secchi disk disappearance for Pond Two, and bicarbonate and specific conductivity for Pond Three.

Anabaena Schmerer Elenkin

This filamentous blue-green alga reached a maximum of 1.03×10^5 cells/liter in Pond One, 5.00×10^6 cells/liter in Pond Two, and 6.55×10^5 cells/liter in Pond Three during the study (Fig. 39).

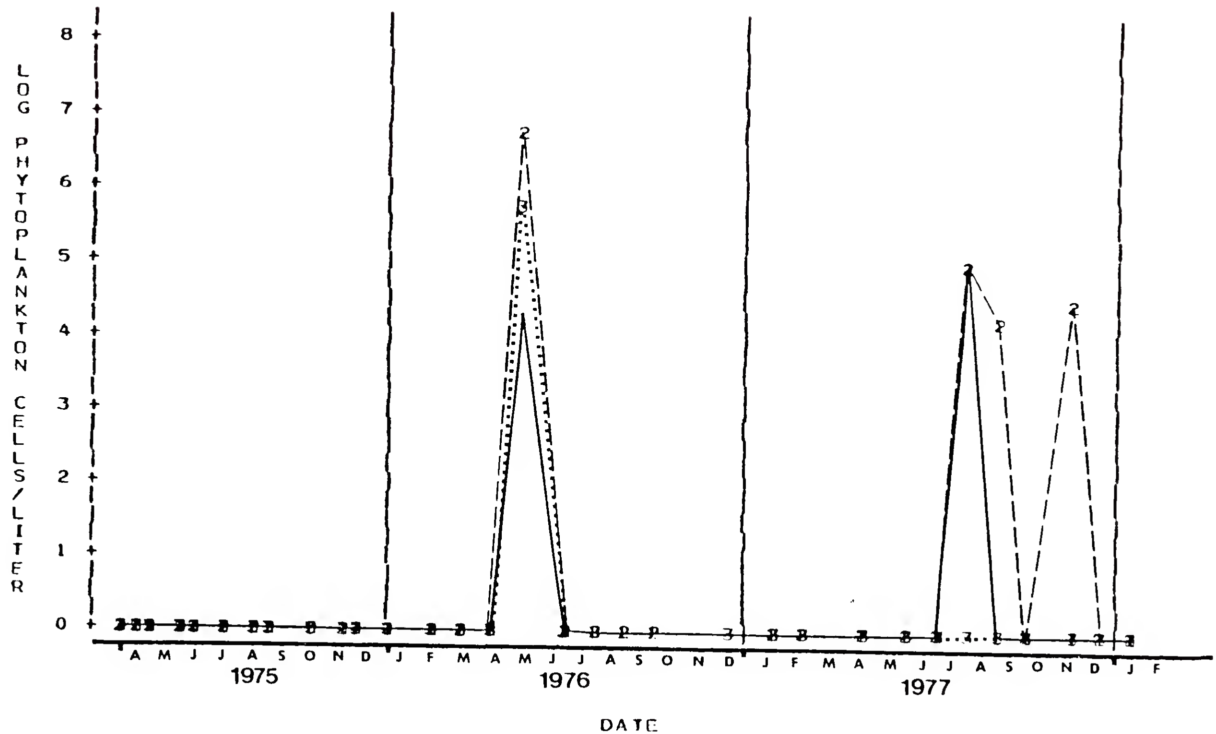


Figure 39. Citrus Ponds surface Anabaena Schmerer, expressed as the number of cells/liter in log10
(——— = Pond One, – – – = Pond Two, ········ = Pond Three).

A. Schmerer populations were maximal on one sampling date in the spring of 1976 in all three ponds. Other blooms occurred in Ponds One and Two during summer and fall 1977.

A. Schmerer appears to reach maximal populations during warm water periods under open water conditions.

No significant correlations were found in any of the three ponds, and stepwise multiple regressions did not provide significant models.

Anabaena spiroides Klebahn

Anabaena spiroides was not found during the study in Pond One. *A. spiroides* bloomed during the summers of 1976 and 1977 in Ponds Two and Three. It reached a maximum of 4.06×10^6 cells/liter in Pond Two, and 1.59×10^6 cells/liter in Pond Three during the study (Fig. 40).

A. spiroides, like *A. Schmerer*, appears to reach maximal populations during warm water periods under open water conditions.

No significant correlations were found in any of the three ponds, and stepwise multiple regressions did not provide significant models.

Oscillatoria limnetica Lemmermann

This filamentous blue-green alga reached a maximum of 1.85×10^6 cells/liter in Pond One, 1.78×10^6 cells/liter in Pond Two, and 1.89×10^6 cells/liter in Pond Three during the study (Fig. 41).

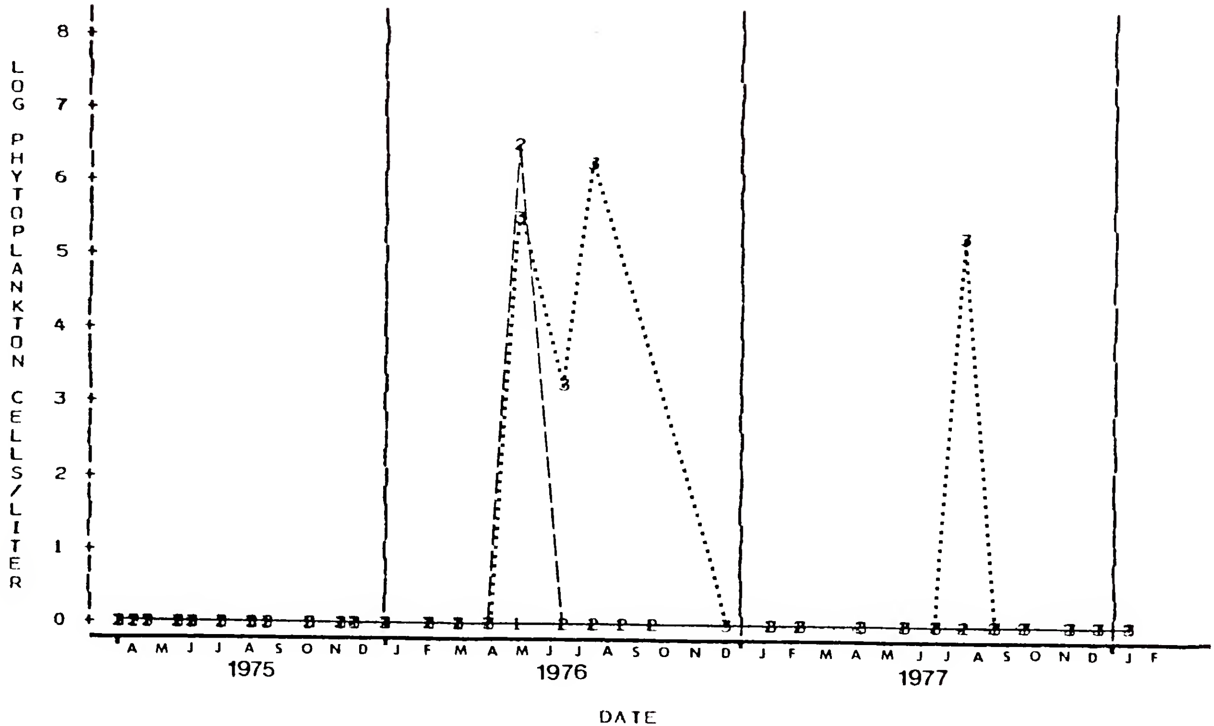


Figure 40. Citrus Ponds surface _Anabaena spiroides_, expressed as the number of cells/liter in log10 (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

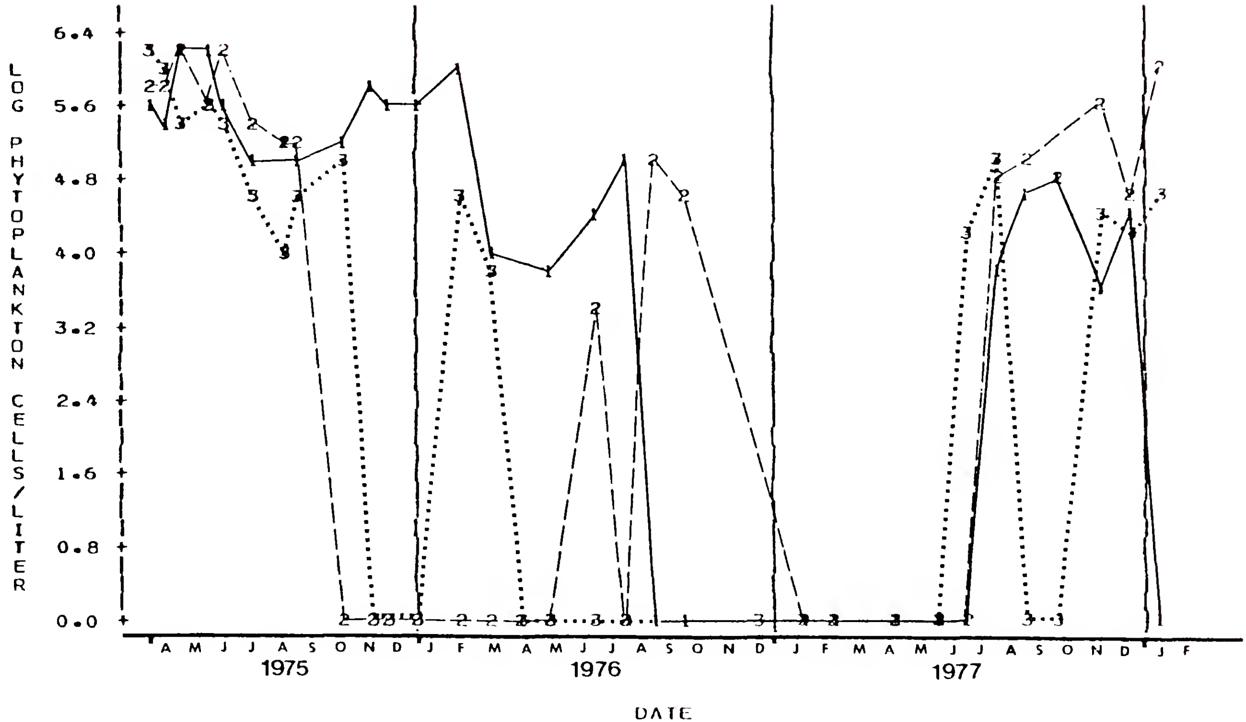


Figure 41. Citrus Ponds surface <u>Oscillatoria</u> <u>limnetica</u>, expressed as the number of cells/liter in log10
(——— = Pond One, — — — = Pond Two, ········ = Pond Three).

O. limnetica dominated the phytoplankton populations beneath actively growing populations of hyacinths in all three ponds, where it occurred in maximal populations during cool water periods. The *O. limnetica* populations decreased during hyacinth disappearance and did not return until open water conditions had been established. *O. limnetica* bloomed in warm or cool water conditions after hyacinth disappearance.

No significant correlations were found in any of the three ponds, and stepwise multiple regressions did not provide significant models for Pond One. However, soluble salts, potassium, light penetration, and nitrate-nitrogen were selected as the best model for Pond Two, while bicarbonate and specific conductivity were selected as the best model for Pond Three.

Oscillatoria subbrevis Schmidle

This filamentous blue-green alga reached a maximum of 1.06 X 10^7 cells/liter in Pond One, 5.31 X 10^7 cells/liter in Pond Two, and 2.17 X 10^6 cells/liter in Pond Three (Fig. 42).

O. subbrevis only occurred after hyacinth disappearance in all ponds. This alga reached maximal concentrations after water quality conditions had improved (1977) and warm water temperatures were prevalent.

No significant correlations were found in any of the three ponds. Stepwise multiple regressions selected water temperature as the best model for Pond One, nitrate-nitrogen and Secchi disk disappearance for Pond Two. No significant models were selected for Pond Three.

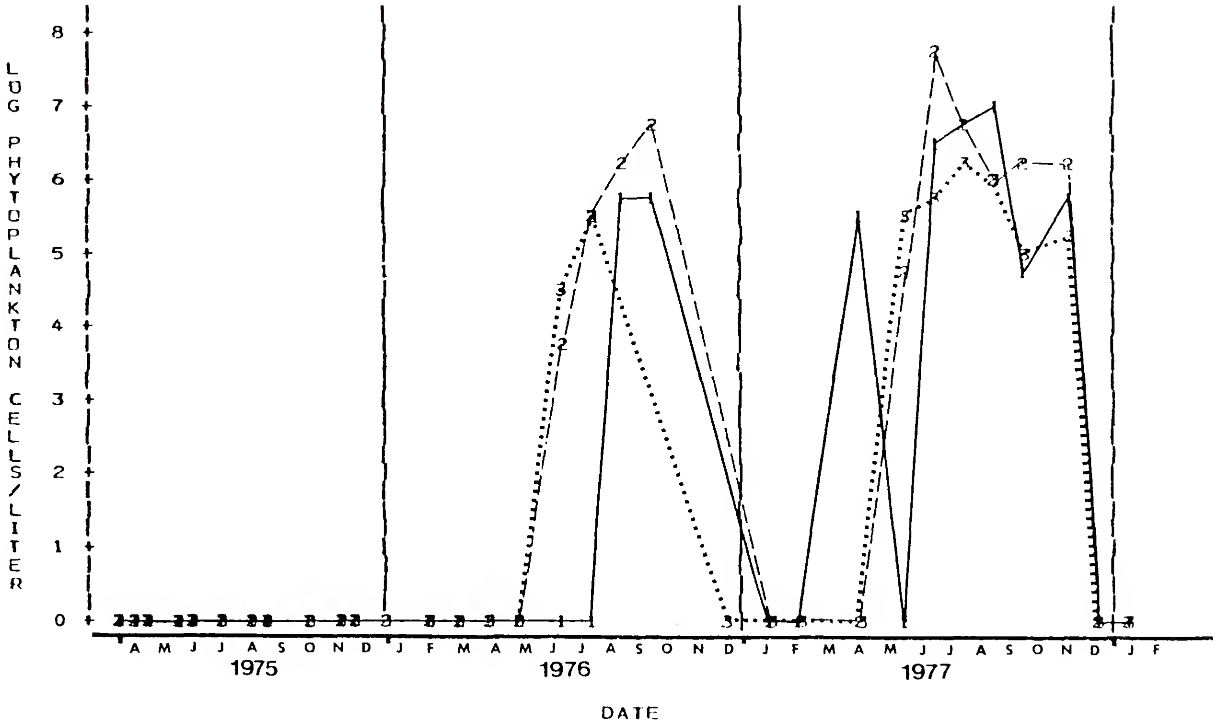


Figure 42. Citrus Ponds surface <u>Oscillatoria subbrevis</u>, expressed as the number of cells/liter in $\log_{10}$
(——— = Pond One, – – – = Pond Two, ········ = Pond Three).

Microcystis aeruginosa Kuetz

This colonial blue-green alga was not found during the study in Pond One. This species reached a maximum concentration of 3.24×10^6 cell/liter in Pond Two, and 1.72×10^6 cells/liter in Pond Three (Fig. 43).

M. aeruginosa occurred only during the summer of 1976 in Ponds Two and Three. This was immediately after hyacinth disappearance when water quality conditions had not improved, and during warm water conditions.

No significant correlations were found in any of the three ponds. Stepwise multiple regressions did not provide significant models for Ponds One and Three, but did select percent total vegetation cover and light penetration as the best model for Pond Two.

Total Chrysophytes

Total chrysophytes reached a maximum of 1.39×10^6 cells/liter in Pond One, 2.01×10^6 cells/liter in Pond Two, and 1.89×10^5 cells/liter in Pond Three during the study (Fig. 44).

Total chrysophytes were very prevalent beneath actively growing hyacinth populations (Pond One) occurring in highest concentration during cool water periods. Total chrysophytes decreased after hyacinth disappearance.

Total chrysophyte populations were quite variable in Ponds Two and Three during the study. These populations fluctuated

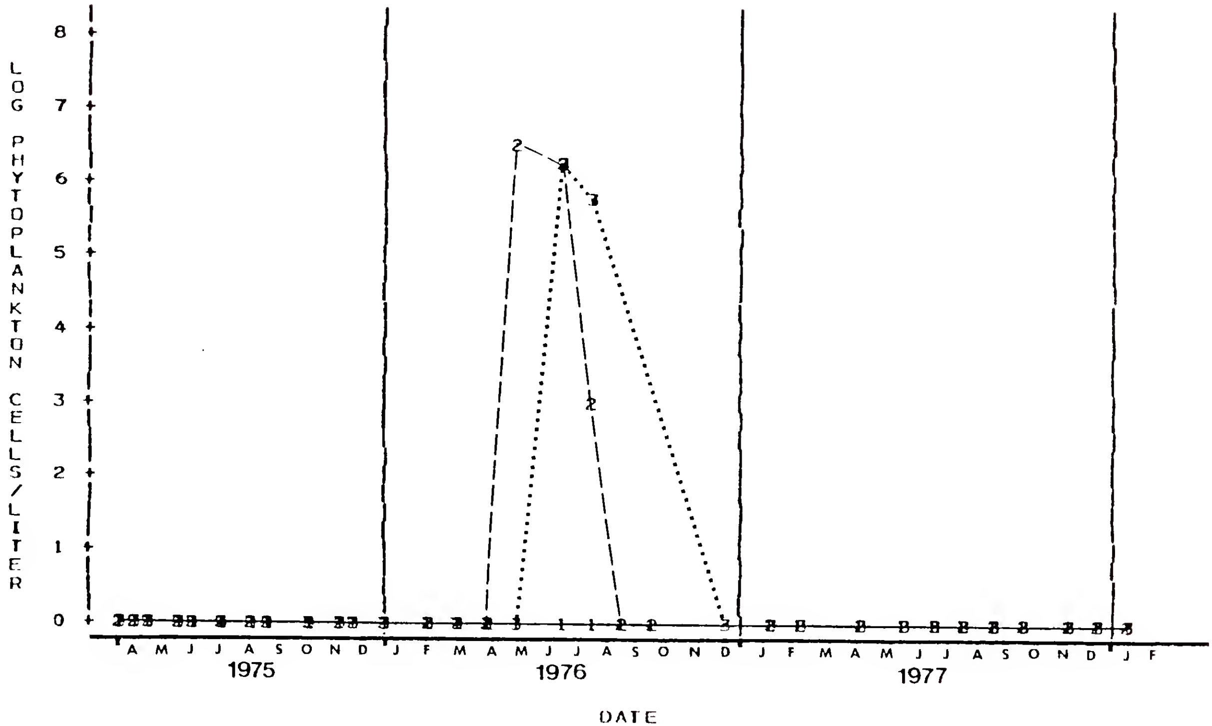


Figure 43. Citrus Ponds surface <u>Microcystis aeruginosa</u>, expressed as the number of cells/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

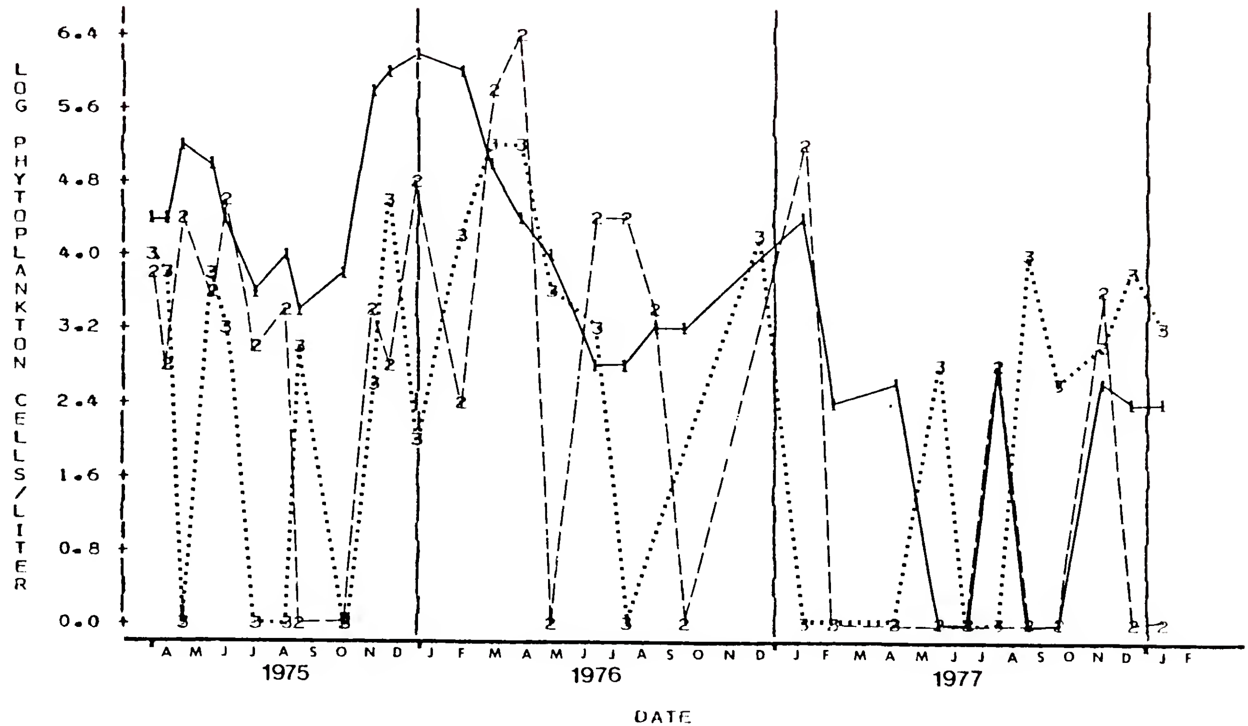


Figure 44. Citrus Ponds total surface chrysophytes, expressed as the number of cells/liter in log10 (———— = Pond One, – – – = Pond Two, ······· = Pond Three).

with varying light penetration, water temperature, and blue-green phytoplankton populations.

Total chrysophytes were negatively correlated with specific conductivity, light penetration, and water temperature in Pond One, with calcium, pH, and soluble salts in Pond Two, and with available phosphate-phosphorus in Pond Three.

Stepwise multiple regressions selected turbidity as the best possible model for Pond One, bicarbonate, available phosphate-phosphorus, calcium, and magnesium for Pond Two, and bicarbonate and water temperature in Pond Three.

Total Phytoplankton Diatoms

Total phytoplankton diatoms reached a maximum of 1.39 X 10^6 cells/liter in Pond One, 2.01 X 10^6 cells/liter in Pond Two, and 1.49 X 10^5 cells/liter in Pond Three during the study (Fig. 45).

Comparison of the total chrysophytes and total phytoplankton diatoms graphs show that the two are very similar. This is because the phytoplankton diatoms accounted for the vast majority of the total chrysophytes found during the study.

Total phytoplankton diatoms were negatively correlated to calcium, magnesium (Pond One), specific conductivity (Pond One), light penetration, soluble salts, pH, dissolved oxygen, and water temperature (Pond One) in ponds One and Two, and positively correlated to available phosphate-phosphorus, and percent total vegetation cover. Secchi disk disappearance was negatively correlated to total phytoplankton diatoms in Pond Three.

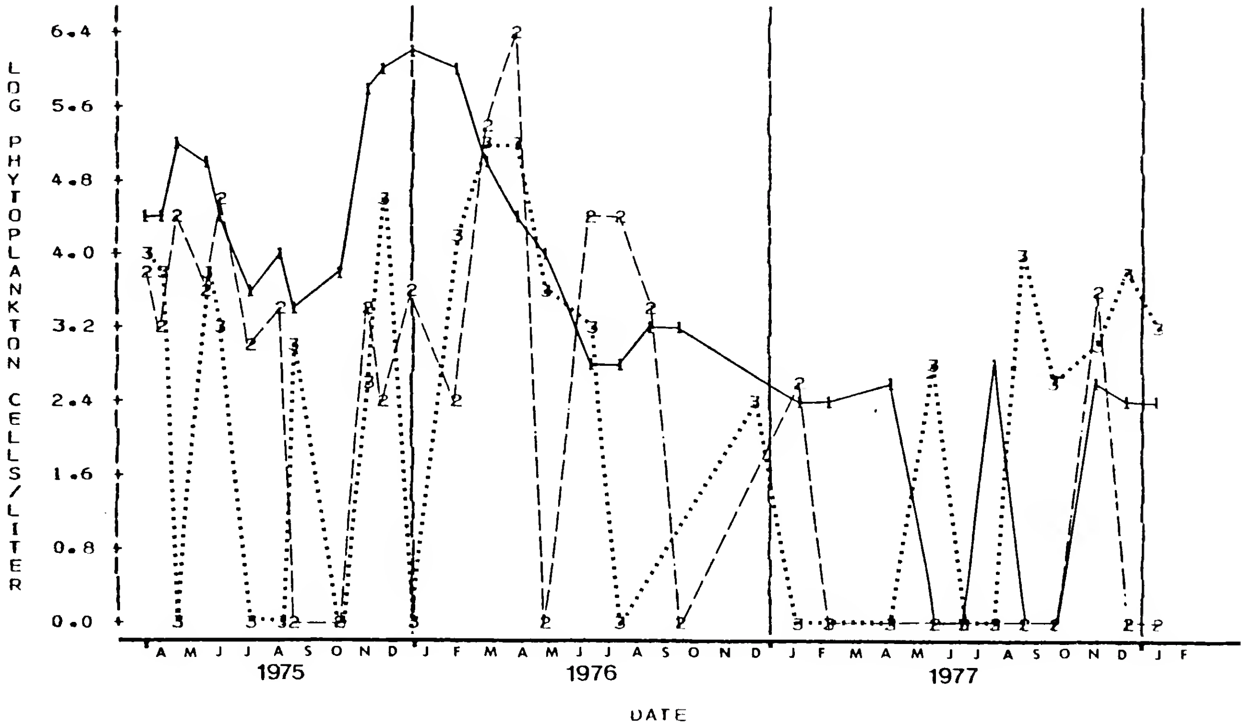


Figure 45. Citrus Ponds total surface phytoplanktonic diatoms, expressed as the number of cells/liter in $\log_{10}$
(——— = Pond One, — — — = Pond Two, ········ = Pond Three).

Stepwise multiple regressions selected turbidity as the best possible model for Pond One, bicarbonate, soluble salts, available phosphate-phosphorus, and calcium for Pond Two, and water temperature and percent total vegetation cover for Pond Three.

Fragilaria capucina var. *mesolepta* (Rabh.) Grunow

This filamentous diatom reached a maximum of 8.58 X 10^5 cells/liter in the phytoplankton of Pond One, 2.09 X 10^5 cells/liter in Pond Two, and was not found in Pond Three during the study (Fig. 46).

F. capucina var. *mesolepta* was mostly found during cool water conditions under actively growing hyacinths. *F. capucina* var. *mesolepta* was also found in Pond Two during cool water periods soon after hyacinth disappearance. Apparently *F. capucina* var. *mesolepta* grew best when water quality conditions were poor and did not occur as abundantly after water quality improved.

No significant correlations were found in any of the three ponds. Stepwise multiple regressions did not provide significant models for Ponds One and Three, but did select pH, available phosphate-phosphorus, water temperature, and nitrate-nitrogen as the best model for Pond Two.

Melosira granulata var. *angustissima* Müll.

This filamentous planktonic diatom species reached a maximum of 3.70 X 10^5 cells/liter in Pond One, 1.80 X 10^6 cells/liter

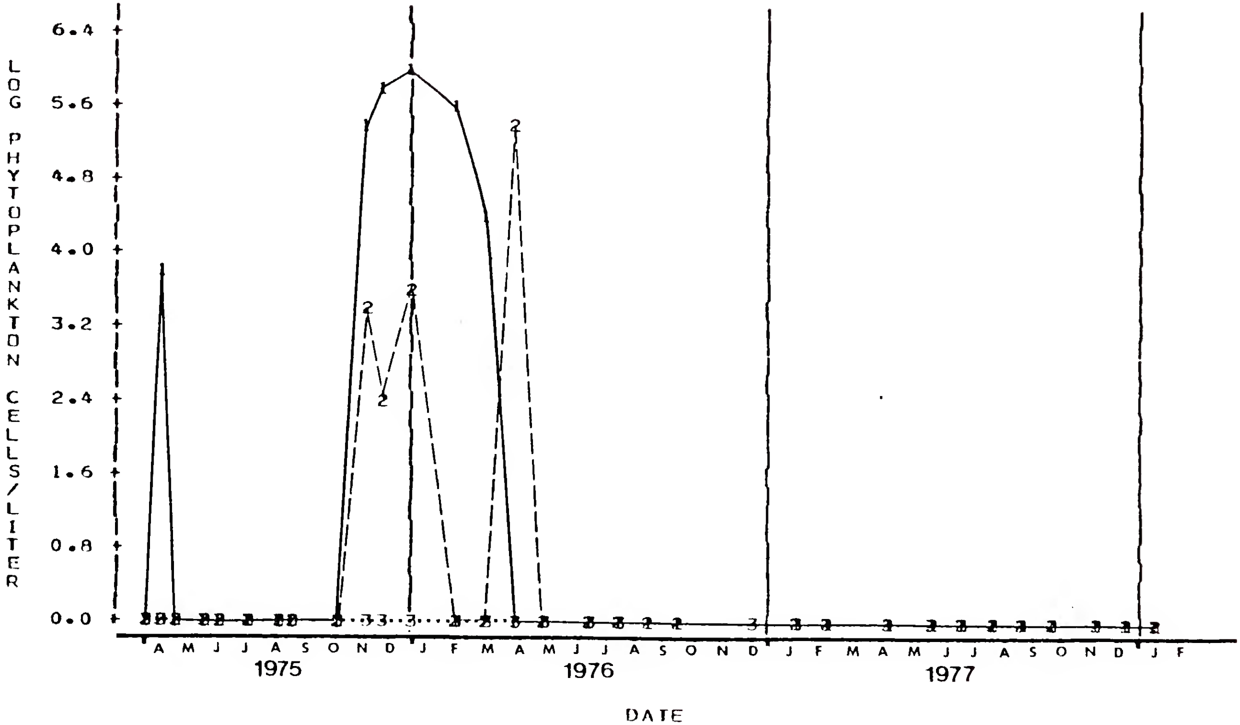


Figure 46. Citrus Ponds surface phytoplanktonic <u>Fragilaria capucina</u> var. <u>mesolepta</u>, expressed as the number of cells/liter in log10 (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

in Pond Two, and 1.40 X 10^5 cells/liter in Pond Three during the study (Fig. 47).

M. granulata var. *angustissima* was found during cool water conditions under actively growing hyacinths. *M. granulata* var. *angustissima* was also found in Ponds Two and Three soon after hyacinth disappearance (except for two smaller blooms in Pond Three in 1977).

The distribution of this diatom phytoplankter was similar to that of *Fragilaria capucina* var. *mesolepta*, since it also grew best when water quality conditions were poor, and did not occur as abundantly after water quality improved.

No significant correlations were found in any of the three ponds. Stepwise multiple regressions did not provide significant models for Pond One, but did select available phosphate-phosphorus, calcium, magnesium, and percent total vegetation cover for Pond Two, and water temperature and percent total vegetation cover for Pond Three.

Synura uvella Ehrenberg

Synura uvella reached a maximum of 2.13 X 10^4 cells/liter in Pond One, 3.62 X 10^5 cells/liter in Pond Two, and 5.42 X 10^4 cells/liter in Pond Three during the study (Fig. 48).

This colonial chrysophyte occurred during cool water months in all ponds after hyacinth disappearance, when water quality had not yet improved.

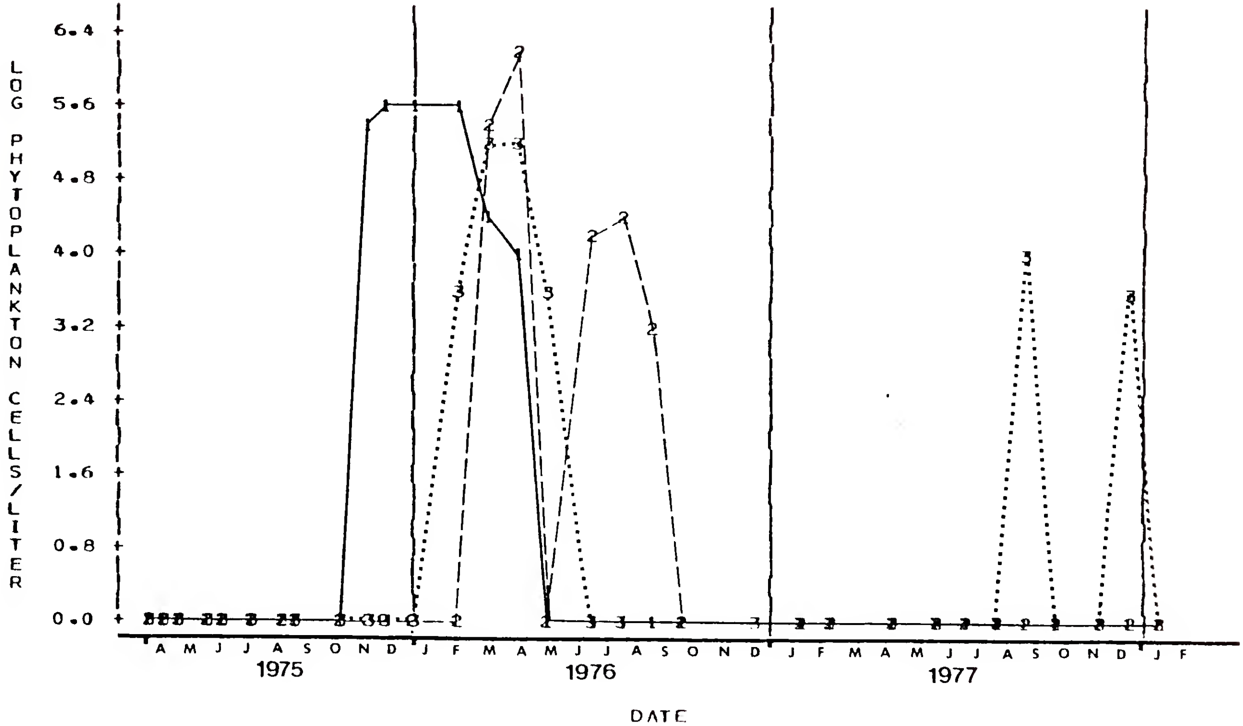


Figure 47. Citrus Ponds surface phytoplanktonic Melosira granulata var. mesolepta, expressed as the number of cells/liter in $\log_{10}$ (——— = Pond One, — — — = Pond Two, ······· = Pond Three).

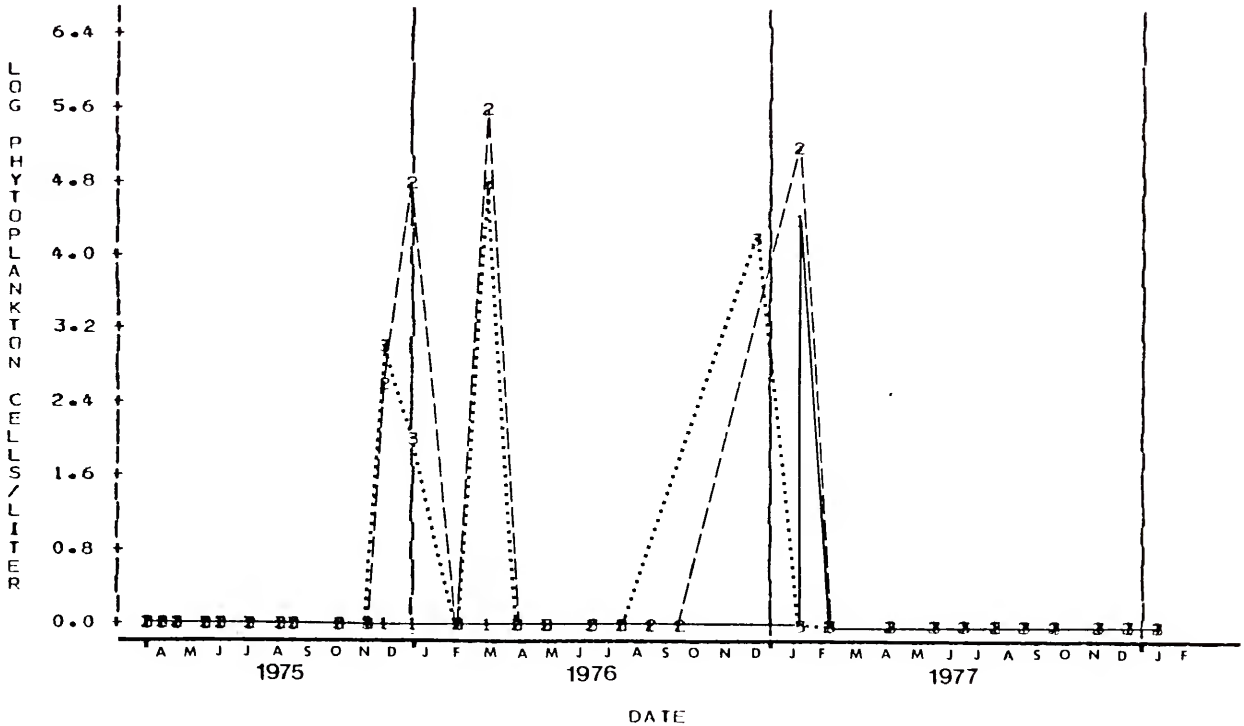


Figure 48. Citrus Ponds surface _Synura uvella_, expressed as the number of cells/liter in $\log_{10}$
(——— = Pond One, – – – = Pond Two, ······· = Pond Three).

No significant correlations were found in any of the three ponds. Stepwise multiple regressions did not provide significant models for Pond One, but did select calcium for Pond Two, and bicarbonate and potassium for Pond Three.

Total Green Algae

This group of algae reached a maximum of 6.72 X 10^5 cells/liter in Pond One, 3.60 X 10^5 cells/liter in Pond Two, and 7.95 X 10^6 cells/liter in Pond Three during the study (Fig. 49).

The distribution of total green algae under actively growing hyacinths was similar in all three ponds at the beginning (1975) and near the end of the study (1977).

The green algae grew best during cool water periods, and decreased in numbers during warm water periods under actively growing hyacinth populations. Green algae populations fluctuated greatly after hyacinth disappearance while water quality conditions were improving. The green algae populations stabilized after water quality had improved in all three ponds (1977).

This algal group was negatively correlated with turbidity, and positively correlated with potassium in Pond One. This algal group was negatively correlated with bicarbonate, carbon dioxide, turbidity, Sechhi disk disappearance (Pond Three), potassium (Pond Three), and available phosphate-phosphorus (Pond Three) in Ponds Two and Three. Total green algae was positively correlated with pH in Ponds Two and Three, and water temperature in Pond Two.

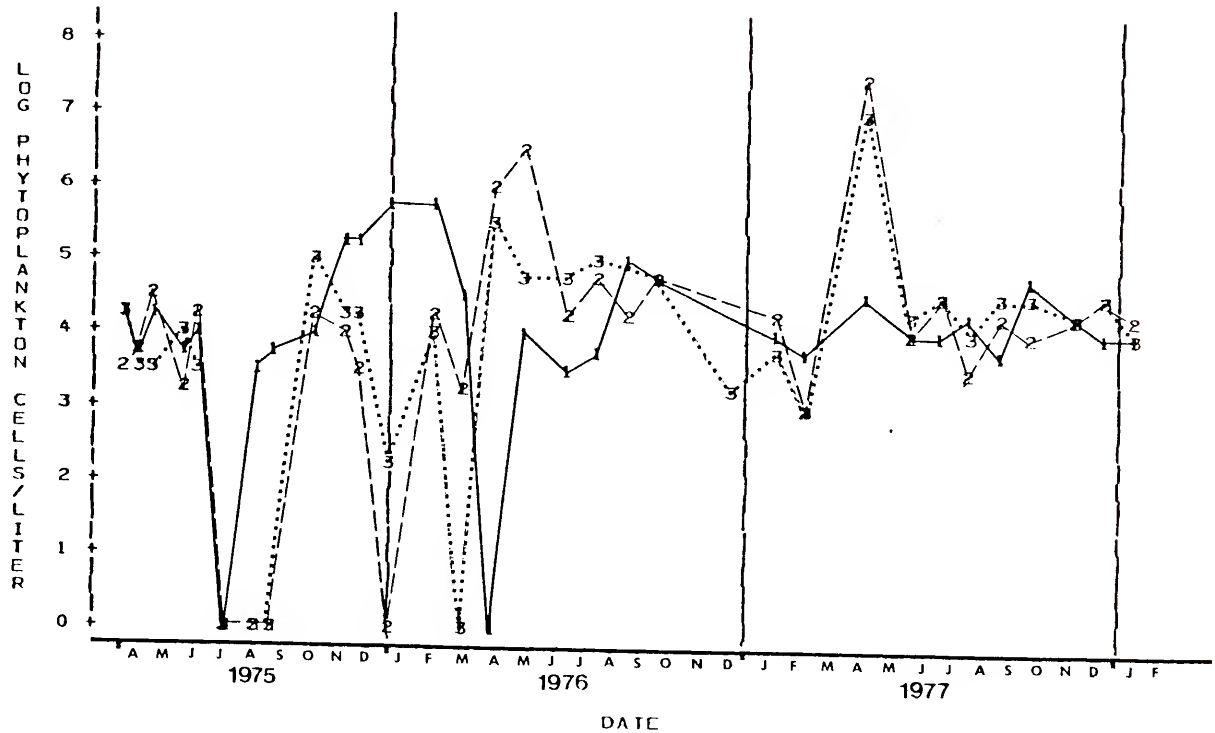


Figure 49. Citrus Ponds total surface green algae, expressed as the number of cells/liter in log10
(——— = Pond One, – – – = Pond Two, ······· = Pond Three).

Stepwise multiple regressions selected water temperature as the best possible model for Pond One, calcium for Pond Two, and bicarbonate and potassium for Pond Three.

Unidentified Green Unicells

These small unidentified green algae appear to be similar to *Chlamydomonas* spp., *Chlorococcum* spp., *Chlorella* spp., and *Colacium* spp. Various attempts to culture these algae (in order to aid in their identification) were unsuccessful. These algae reacted positively to the Lugol's iodine test, indicating that they were members of the Chlorophyta.

Unidentified green unicells reached a maximum of 1.62 X 10^5 cells/liter in Pond One, 5.80 X 10^4 cells/liter in Pond Two, and 5.22 X 10^4 cells/liter in Pond Three during the study (Fig. 50).

Graphic comparison of the distributions of total green algae and unidentified green unicells shows that the two distributions are very similar. In fact, unidentified green unicells composed the majority of the total green algae during most of the study. These algae grew best during cool water periods, and decreased in numbers during warm water periods under actively growing hyacinth populations. These algae populations fluctuated greatly after hyacinth disappearance while water quality conditions were improving. The unidentified green unicell populations stabilized after water quality had improved in all three ponds (1977).

No significant correlations were found in any of the three ponds.

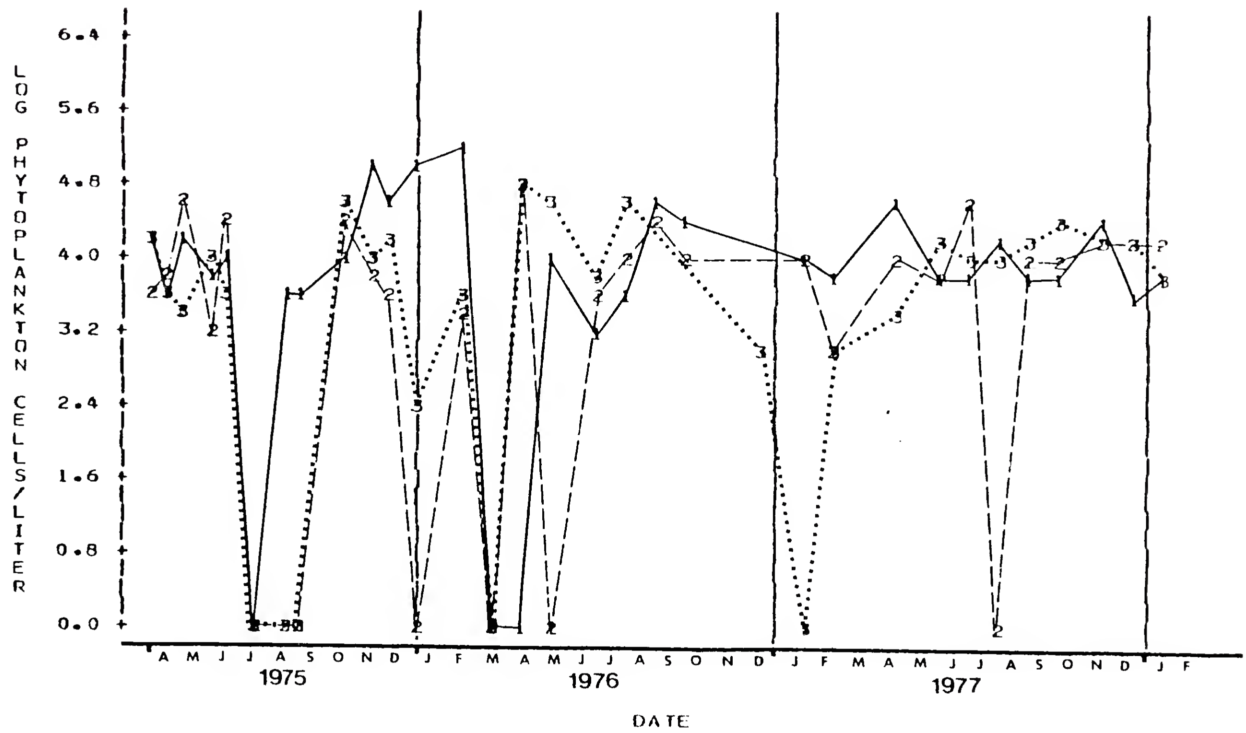


Figure 50. Citrus Ponds surface unidentified green unicells, expressed as the number of cells/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ... = Pond Three).

Stepwise multiple regressions selected pH as the best possible model for Pond One, pH, calcium, magnesium, and light penetration for Pond Two, and bicarbonate and potassium for Pond Three.

Eudorina spp.

This colonial green alga reached a maximum of 3.71 X 10^4 cells/liter in Pond One, 2.08 X 10^6 cells/liter in Pond Two, and 2.91 X 10^5 cells/liter in Pond Three during the study (Fig. 51).

Eudorina spp. occurred in Ponds Two and Three shortly after hyacinth disappearance (1975), and during the next year when water quality had not significantly improved. *Eudorina* spp. occurred during hyacinth disappearance in Pond One when water conditions were quite foul. *Eudorina* spp. was not found in any pond after water quality had improved.

No significant correlations were found in any of the three ponds. Stepwise multiple regressions selected turbidity as the best possible model for Pond One, available phosphate-phosphorus for Pond Two, and bicarbonate and available phosphate-phosphorus in Pond Three.

Ulothrix spp.

This filamentous green alga was only found in Pond One during the study, where it reached a maximum of 5.58 X 10^5

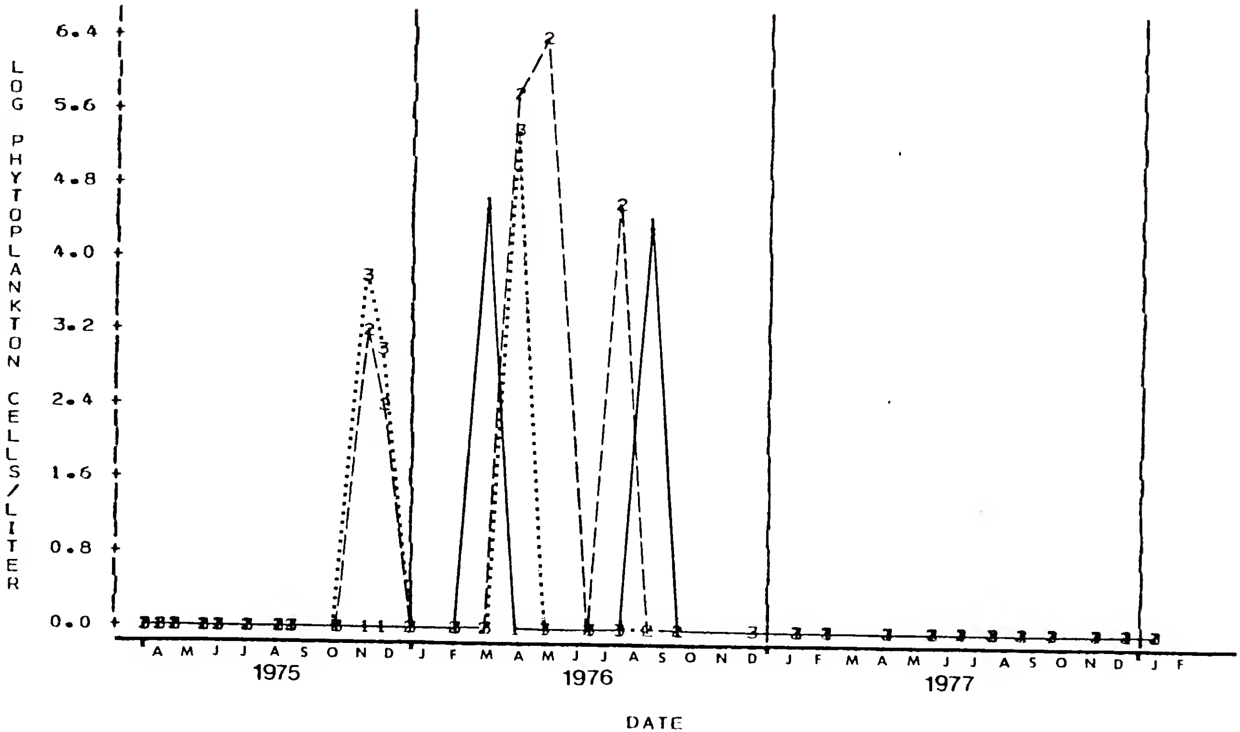


Figure 51. Citrus Ponds surface <u>Eudorina</u> spp., expressed as the number of cells/liter in log10 (——— = Pond One, – – – = Pond Two, ... = Pond Three).

cells/liter (Fig. 52). It was found only during cool water periods beneath actively growing populations of water hyacinths.

No significant correlations were found in any of the three ponds. Stepwise multiple regressions did not provide significant models.

Volvox spp.

This colonial green alga was found only in Ponds Two and Three during the study. It reached a maximum of 3.60×10^7 cells/liter in Pond Two, and 7.95×10^6 cells/liter in Pond Three (Fig. 53). Both maxima occurred during the spring of 1977. This was during the open water period on these ponds when water quality conditions had improved.

No significant correlations were found in any of the three ponds, and stepwise multiple regressions did not provide significant models.

Euglena spp.

This unicellular member of the Euglenophyta reached a maximum of 1.21×10^4 cells/liter in Pond One, 3.68×10^4 cells/liter in Pond Two, and 3.48×10^3 cells/liter in Pond Three during the study (Fig. 54).

Euglena spp. appeared in all the ponds after herbicide application while the hyacinth mats were dead and decaying, and when water quality conditions were foul. *Euglena* spp. persisted during the year following hyacinth disappearance in

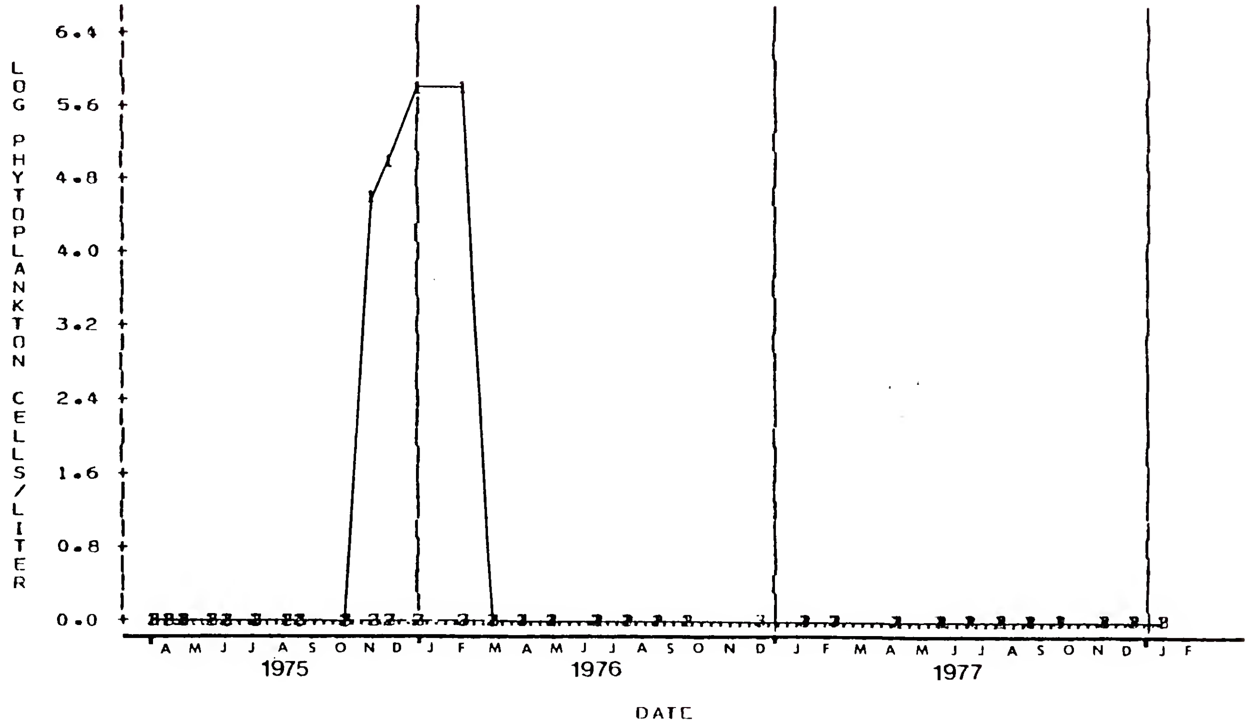


Figure 52. Citrus Ponds surface Ulothrix spp., expressed as the number of cells/liter in $\log_{10}$
(——— = Pond One, – – – = Pond Two, ... = Pond Three).

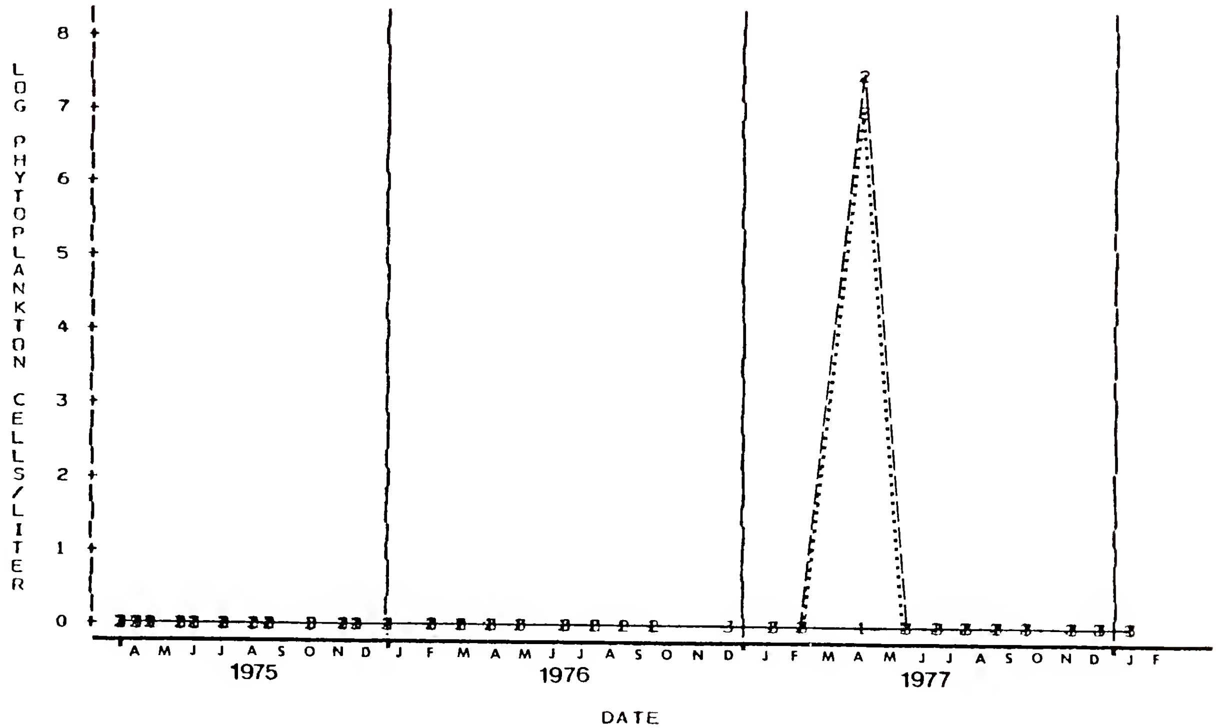


Figure 53. Citrus Ponds surface <u>Volvox</u> spp., expressed as the number of cells/liter in $\log_{10}$
(——— = Pond One, – – – = Pond Two, ······· = Pond Three).

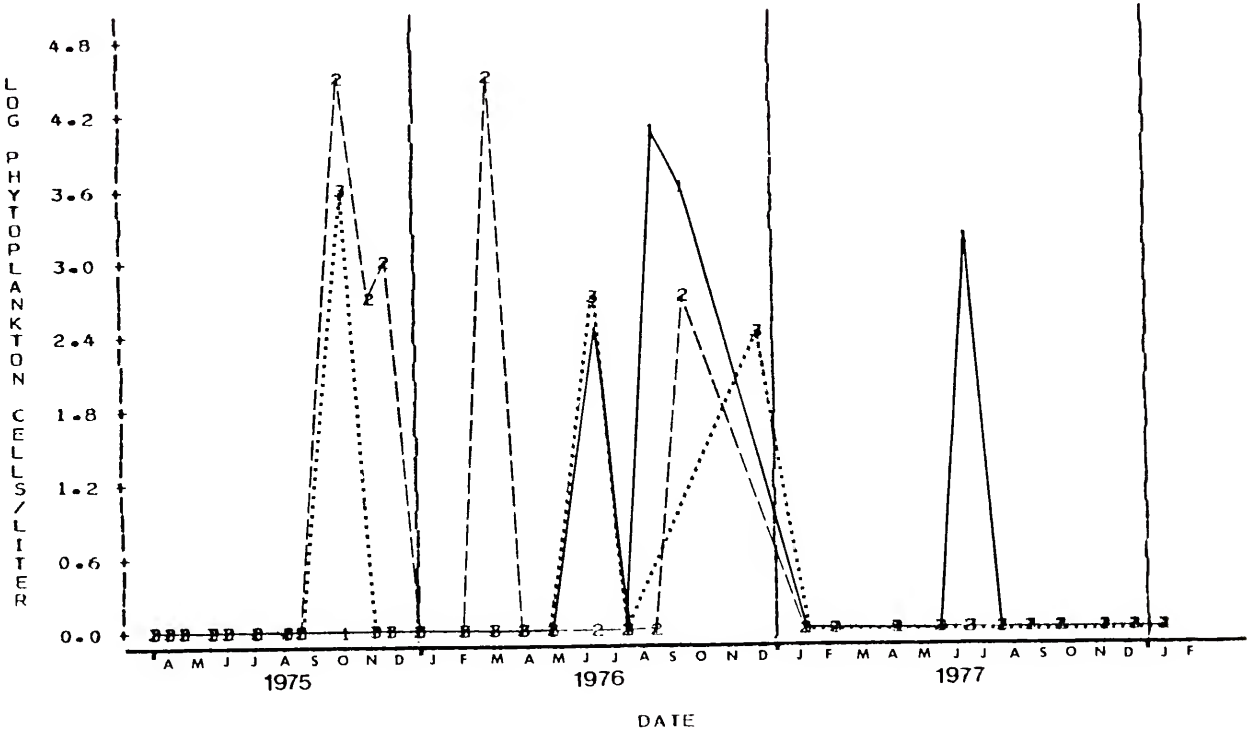


Figure 54. Citrus Ponds surface *Euglena* spp., expressed as the number of cells/liter in log10 (——— = Pond One, – – – = Pond Two, ······· = Pond Three).

all three ponds, showing several smaller blooms while water quality had not significantly improved. *Euglena* spp. was not found after water quality improved.

No significant correlations were found in any of the three ponds. Stepwise multiple regressions did not provide significant models for Ponds Two and Three, but did select water temperature for Pond One.

Zooplankton

The zooplankters to be discussed in the following sections are grouped according to size (macrozooplankters and microzooplankters) and their placement in the classification hierarchy. Total zooplankton is discussed first, followed by total macrozooplankton and the dominant macrozooplankters. This is followed by a discussion of the dominant microzooplankters found during the study.

Total Zooplankton

Total surface zooplankton reached a maximum of 1.82×10^4 zooplankters/liter and a minimum of 38.6 zooplankters/liter in Pond One, from 51.1 to 1.72×10^4 zooplankters/liter in Pond Two, and from 28.75 to 1.39×10^4 zooplankters/liter in Pond Three during the study (Fig. 55).

Total zooplankton reached many of its highest concentrations beneath actively growing hyacinth populations. Zooplankton was maximal during early spring, and minimal during summer beneath

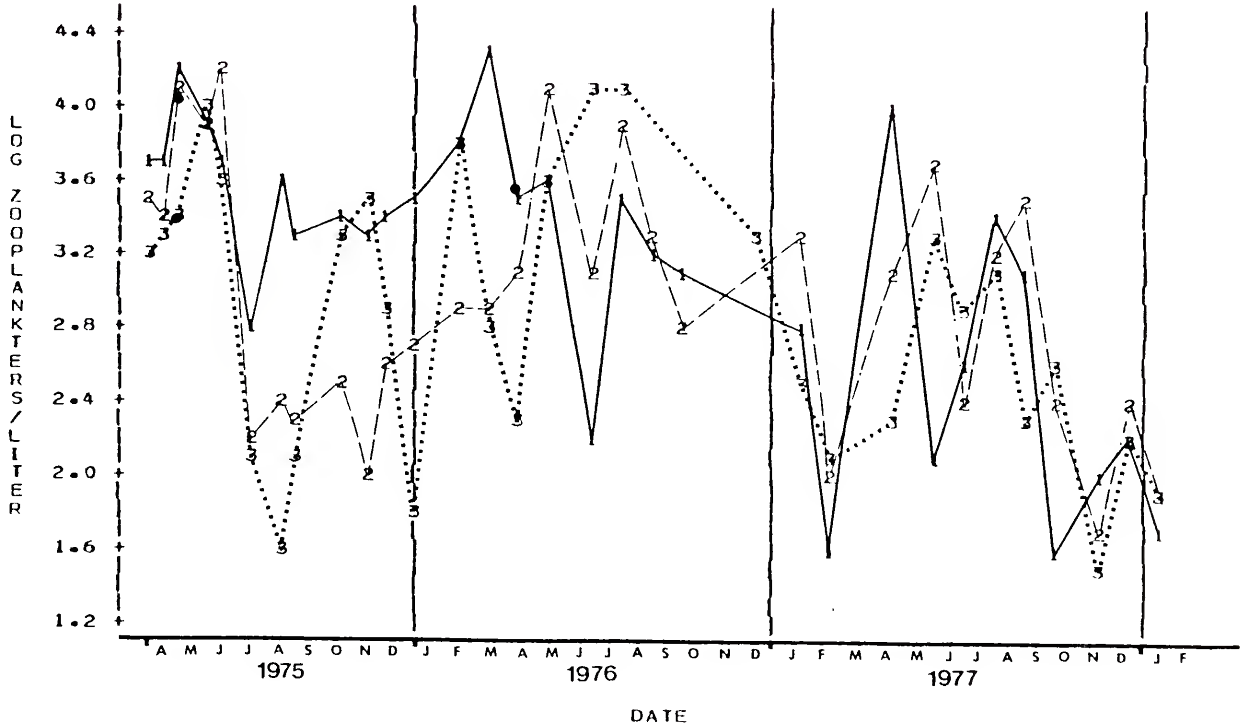


Figure 55. Citrus Ponds total surface zooplankton, expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ······· = Pond Three).

actively growing hyacinths. When open water conditions were established zooplankton populations were minimal during spring, and maximal during summer. Zooplankton populations fluctuated greatly during the study, reaching large population peaks, and then quickly dying off.

Total zooplankton was positively correlated to percent total vegetation cover, total phytoplankton, total desmids, total blue-green algae, *Oscillatoria limnetica*, total phytoplankton diatoms, *Fragilaria capucina* var. *mesolepta*, and *Melosira granulata* var. *angustissima*, and negatively correlated with dissolved oxygen in Pond One. Total zooplankton was found to be positively correlated to total phytoplankton and total green algae in Pond Two. Total zooplankton was positively correlated to total phytoplankton, total blue-green algae, *Anabaena spiroides*, total green algae, total desmids, unidentified green unicells, and water temperature in Pond Three.

Stepwise multiple regressions selected dissolved oxygen and total phytoplankton as the best possible model for Pond One, water temperature and percent total vegetation cover for Pond Two. Stepwise multiple regressions did not provide significant models for Pond Three.

Total Macrozooplankton

Total surface macrozooplankton reached a maximum of 504.0 zooplankters/liter in Pond One, 617.0 zooplankters/liter in Pond Two, and 821.0 zooplankters/liter in Pond Three during the study (Fig. 56).

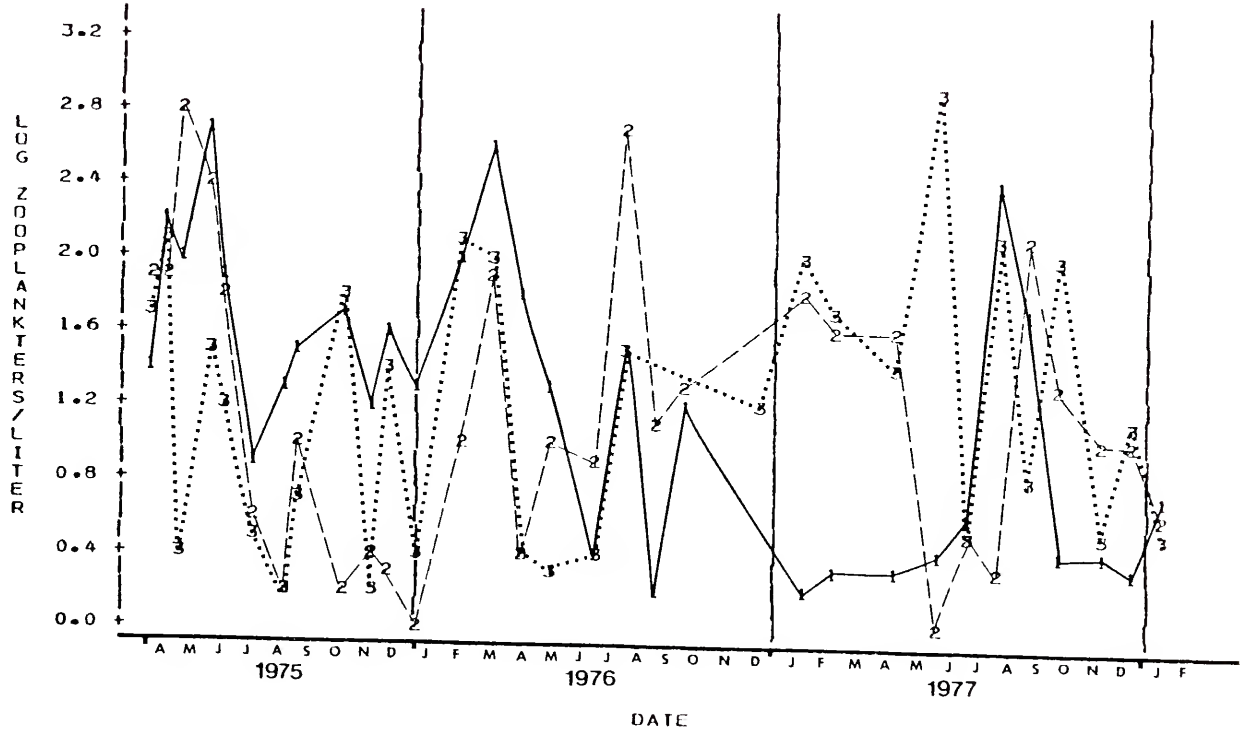


Figure 56. Citrus Ponds total surface macrozooplankton, expressed as the number of zooplankters/liter in log10 (——— = Pond One, — — — = Pond Two, ······· = Pond Three).

The distribution of macrozooplankton has many similarities with that of total zooplankton. Macrozooplankton was maximal during spring and minimal during summer beneath actively growing hyacinth populations. Macrozooplankton bloomed throughout the year after hyacinth disappearance.

Total macrozooplankton in Ponds One and Three was positively correlated to total phytoplankton, total blue-green algae, and total phytoplankton diatoms, and negatively correlated with total desmids, and total *Scenedesmus*. Total macrozooplankton was positively correlated with percent total vegetation cover, and negatively correlated with *Fragilaria capucina* var. *mesolepta*, and dissolved oxygen in Pond Two.

Stepwise multiple regressions did not provide significant models for Pond Three, but did select dissolved oxygen for Pond One, and percent total vegetation cover for Pond Two.

Macrozooplankters

Cyclops spp.

This copepod species reached a maximum of 308.0 zooplankters/liter in Pond One, 492.0 zooplankters/liter in Pond Two, and 799.0 zooplankters/liter in Pond Three during the study (Fig. 57).

The distribution of *Cyclops* spp. is similar to that of macrozooplankton since *Cyclops* spp. made up a large portion of the total macrozooplankton on most sampling dates.

Maximal *Cyclops* spp. populations were found during spring, and minimal populations during summer and winter beneath actively

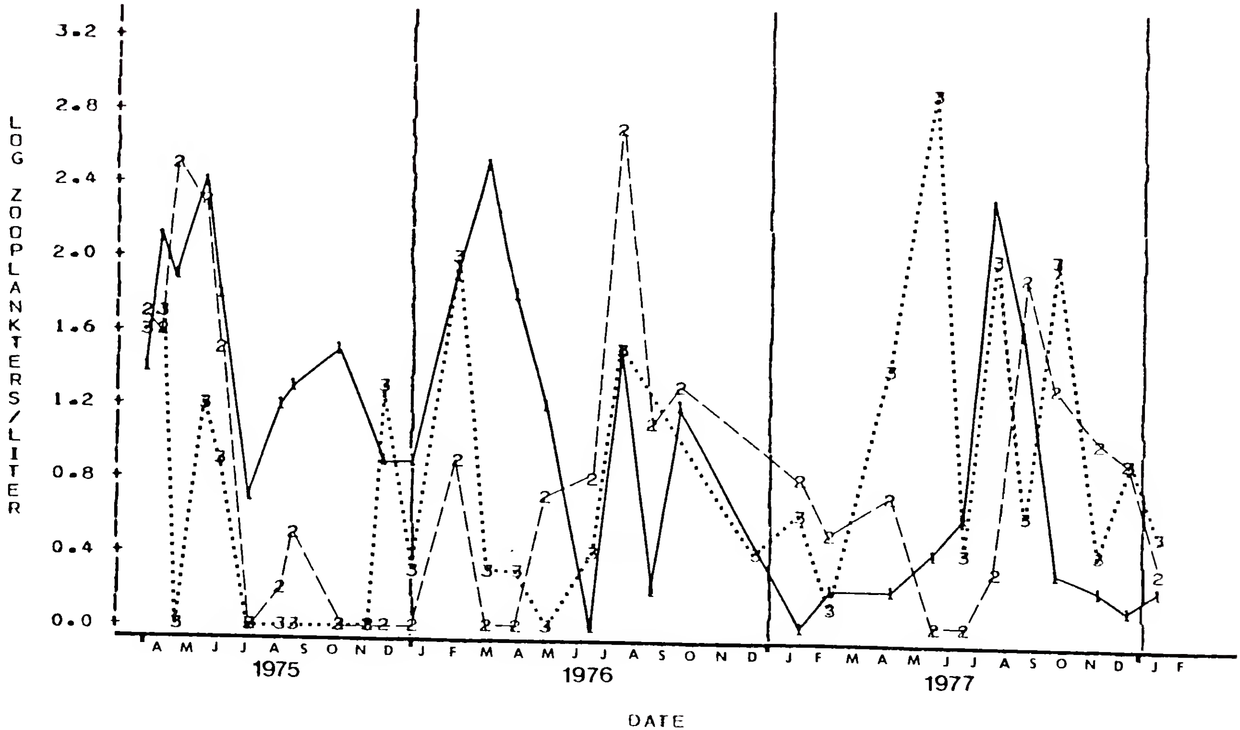


Figure 57. Citrus Ponds surface Cyclops spp., expressed as the number of zooplankters/liter in log10 (——— = Pond One, – – – = Pond Two, ······· = Pond Three).

growing hyacinth populations. *Cyclops* spp. were only found in small numbers while hyacinths were dying, and water quality conditions were poor. *Cyclops* spp. populations were maximal during warm water months after hyacinth disappearance.

Cyclops spp. was found to be positively correlated to total phytoplankton, total blue-green algae, total *Oscillatoria, Oscillatoria limmetica,* total phytoplankton diatoms, and percent total vegetation cover in Pond One. *Cyclops* spp. was negatively correlated to total desmids, total *Scenedesmus,* and dissolved oxygen.

Cyclops spp. was positively correlated to total blue-green algae, total *Oscillatoria, Oscillatoria limmetica,* unidentified green unicells, and percent total vegetation cover in Pond Two. *Cyclops* spp. was negatively correlated to *Fragilaria capucina* var. *mesolepta, Euglena* spp., and dissolved oxygen.

Cyclops was positively correlated to total phytoplankton, total green algae, unidentified green unicells, total *Oscillatoria,* and *Oscillatoria subbrevis* in Pond Three.

Stepwise multiple regressions selected dissolved oxygen as the best possible model for Pond One, percent total vegetation cover for Pond Two, and total phytoplankton for Pond Three.

Ceriodaphnia spp.

This cladoceran species reached a maximum of 70.8 zooplankters/liter in Pond One, 120.0 zooplankters/liter in Pond Two, and 11.5 zooplankters/liter in Pond Three during the study (Fig. 58).

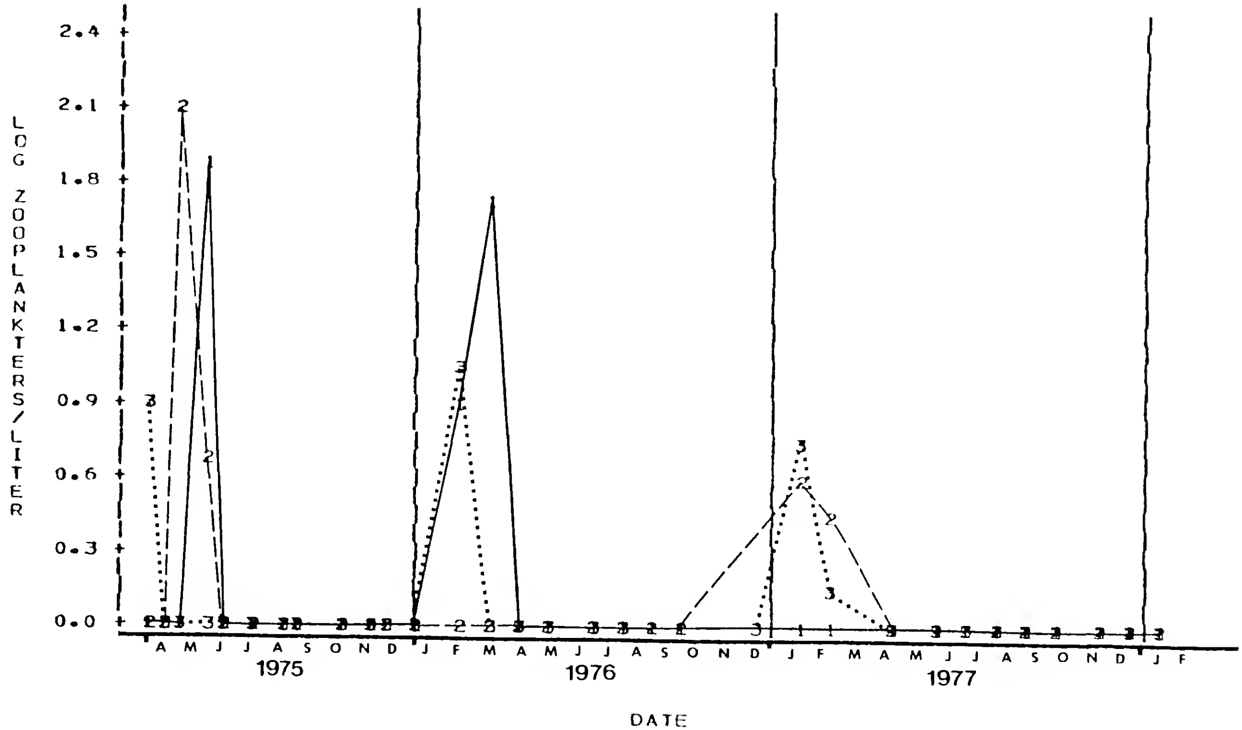


Figure 58. Citrus Ponds surface *Ceriodaphnia* spp., expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

Ceriodaphnia spp. occurred maximally during early spring beneath actively growing water hyacinth populations. This cladoceran species also occurred (but in lesser numbers) during early spring after open water conditions were established.

This species was positively correlated to *Eudorina* spp., and total phytoplankton diatoms in Pond One, and to percent total vegetation cover in Pond Two. Water temperature was negatively correlated to *Ceriodaphnia* spp. in Pond Three.

Stepwise multiple regressions did not provide a significant model for Pond One, but did select water temperature for Pond Two, and water temperature, percent total vegetation cover, and total phytoplankton for Pond Three.

Chydorus spp.

This cladoceran species reached a maximum of 127.0 zooplankters/liter in Pond One, 190.0 zooplankters/liter in Pond Two, and 60.3 zooplankters/liter in Pond Three during the study (Fig. 59).

Chydorus spp. occurred maximally during early spring (1975) beneath actively growing water hyacinth populations. Another small bloom of *Chydorus* spp. occurred during the spring of 1976 in Ponds Two and Three, after hyacinth disappearance and before water quality conditions had improved.

Chydorus spp. was not significantly correlated with any parameters in Pond One. This zooplankter was positively correlated in Pond Two with *Oscillatoria limnetica*, total phytoplankton

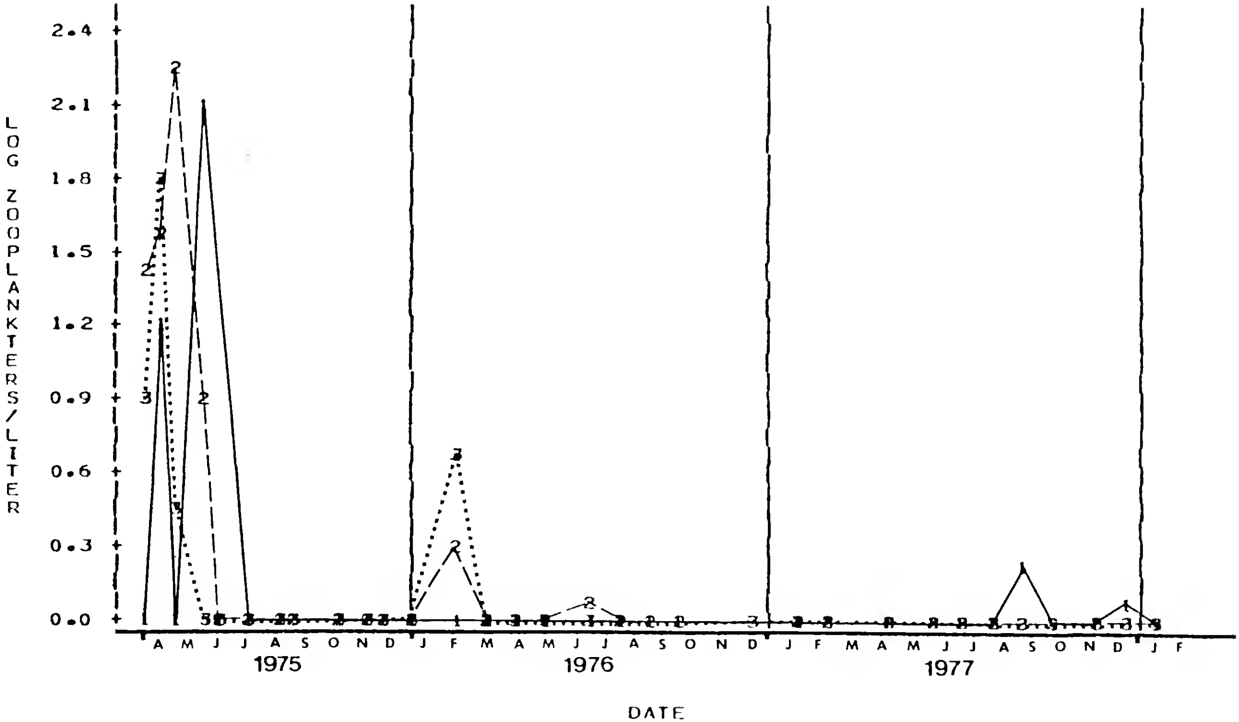


Figure 59. Citrus Ponds surface Chydorus spp., expressed as the number of zooplankters/liter in $\log_{10}$
(——— = Pond One, — — — = Pond Two, ········ = Pond Three).

diatoms, *Melosira granulata,* and percent total vegetation cover, and negatively correlated with dissolved oxygen. *Chydorus* spp. was positively correlated with *Oscillatoria limnetica,* and percent total vegetation cover, and negatively correlated with dissolved oxygen in Pond Three.

Stepwise multiple regressions selected pH, percent total vegetation cover, and total phytoplankton as the best possible model for Pond One, and percent total vegetation cover for Ponds Two and Three.

Total chironomid larvae

This group of closely related dipteran fly larvae reached a maximum of 35.9 zooplankters/liter in Pond One, 31.9 zooplankters/liter in Pond Two, and 56.9 zooplankters/liter in Pond Three during the study (Fig. 60).

Chironomid larvae were commonly associated with actively growing hyacinth populations and were even found one year after hyacinth disappearance while water quality conditions were still not significantly improved. Chironomid larvae were not commonly found after water quality had improved.

Total chironomid larvae were positively correlated to total phytoplankton, *Oscillatoria limnetica,* total phytoplankton diatoms, *Fragilaria capucina* var. *mesolepta, Melosira granulata* var. *angustissima, Ulothrix* spp., and percent total vegetation cover in Pond One, and negatively correlated to total desmids, total *Scenedesmus,* total euglenoids, and dissolved oxygen.

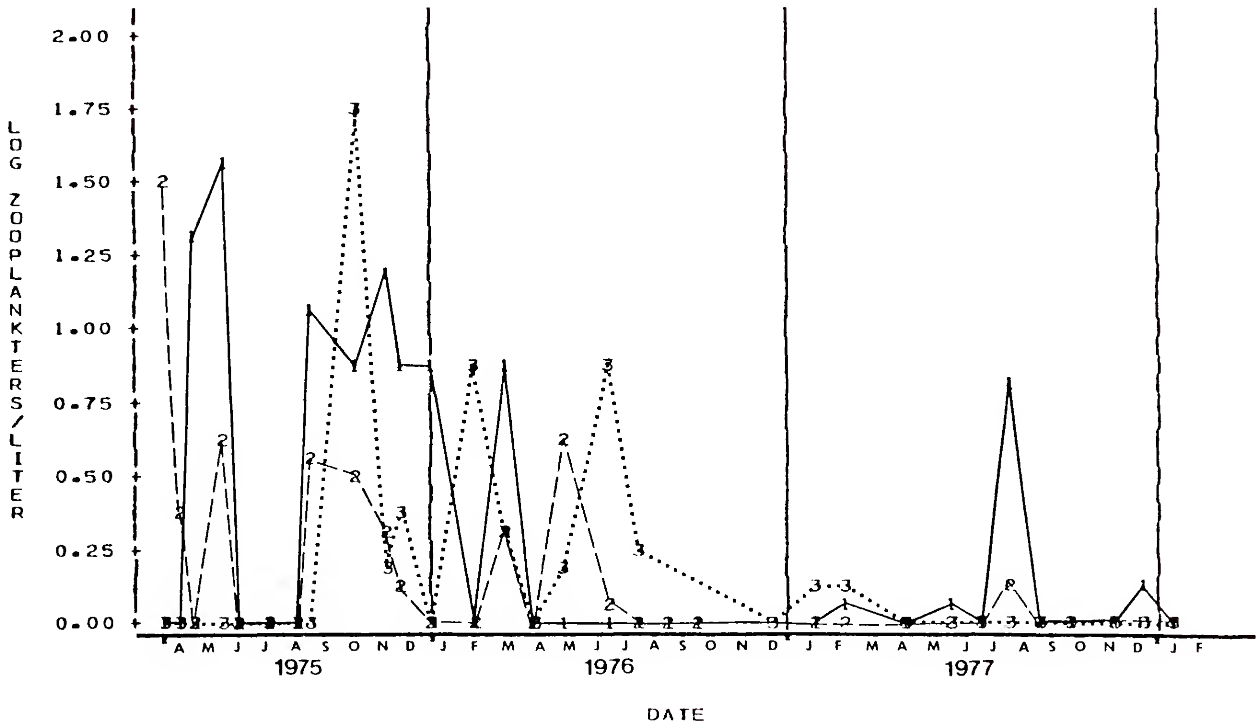


Figure 60. Citrus Ponds total surface chironomid larvae, expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

Total chironomid larvae was found to be positiviely correlated to *Melosira granulata*, and percent total vegetation cover, and negatively correlated to *Oscillatoria subbrevis*, and dissolved oxygen in Pond Two. These zooplankters were positively correlated with *Euglena* spp. and total *Scenedesmus*, and negatively correlated with total euglenoids in Pond Three.

Stepwise multiple regressions did not provide a significant model for Pond Three, but did select percent total vegetation cover for Ponds One and Two.

Microzooplankters

Nauplii larvae

Nauplii larvae reached a maximum of 3.57 X 10^3 zooplankters/liter in Pond One, 1.2 X 10^3 zooplankters/liter in Pond Two, and 456.0 zooplankters/liter in Pond Three during the study (Fig. 61).

These copepod larvae were very common members of the zooplankton community beneath actively growing populations of hyacinths. They were found in largest concentrations during spring and in smaller fluctuating concentrations during the rest of the year. Large fluctuations of populations occurred in all ponds after hyacinth disappearance.

Nauplii larvae in Pond One were positively correlated with total phytoplankton, and negatively correlated with dissolved oxygen. Nauplii larvae in Pond Two were positively correlated with total green algae, unidentified green unicells, and total

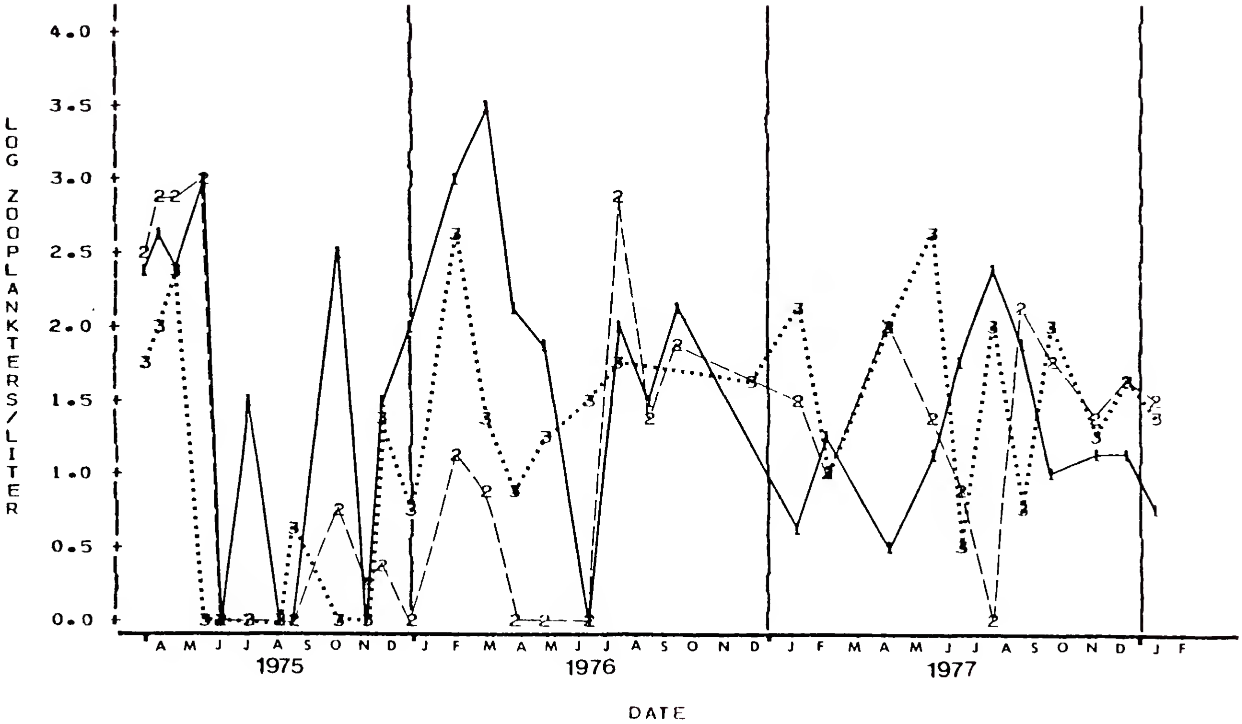


Figure 61. Citrus Ponds surface nauplii larvae, expressed as the number of zooplankters/liter in $\log_{10}$
(——— = Pond One, – – – = Pond Two, ······· = Pond Three).

Oscillatoria, and negatively correlated with *Fragilaria capucina* var. *mesolepta*, and dissolved oxygen.

Stepwise multiple regressions did not provide significant models for Ponds One and Two, but did select pH, dissolved oxygen, and total phytoplankton in Pond Three.

Total *Arcella* spp.

Several species of this rhizopod protozoan were found during the study. Total *Arcella* spp. reached a maximum of 6.53×10^3 zooplankters/liter in Pond One, 7.92×10^3 zooplankters/liter in Pond Two, and 5.12×10^3 zooplankters/liter in Pond Three (Fig. 62). This rhizopod protozoan was commonly found throughout the year beneath actively growing hyacinth populations. *Arcella* spp. did well while hyacinths were dying and decaying after hyacinth treatment.

Arcella spp. were commonly found in all three ponds as long as water hyacinths or foul water quality conditions existed; however they were not frequently found when water hyacinths disappeared and water quality improved. This rhizopod protozoan, as well as *Centropyxis aculeata*, and *Difflugia bacillifera*, apparently fed upon the hyacinth roots or other detritus originating from the water hyacinth populations. When detrital material, or other hyacinth-related food sources disappeared, rhizopod protozoan species were no longer found in abundance.

Total *Arcella* spp. was positively correlated to *Oscillatoria limmetica*, total plankton diatoms (Ponds One and Two), *Melosira*

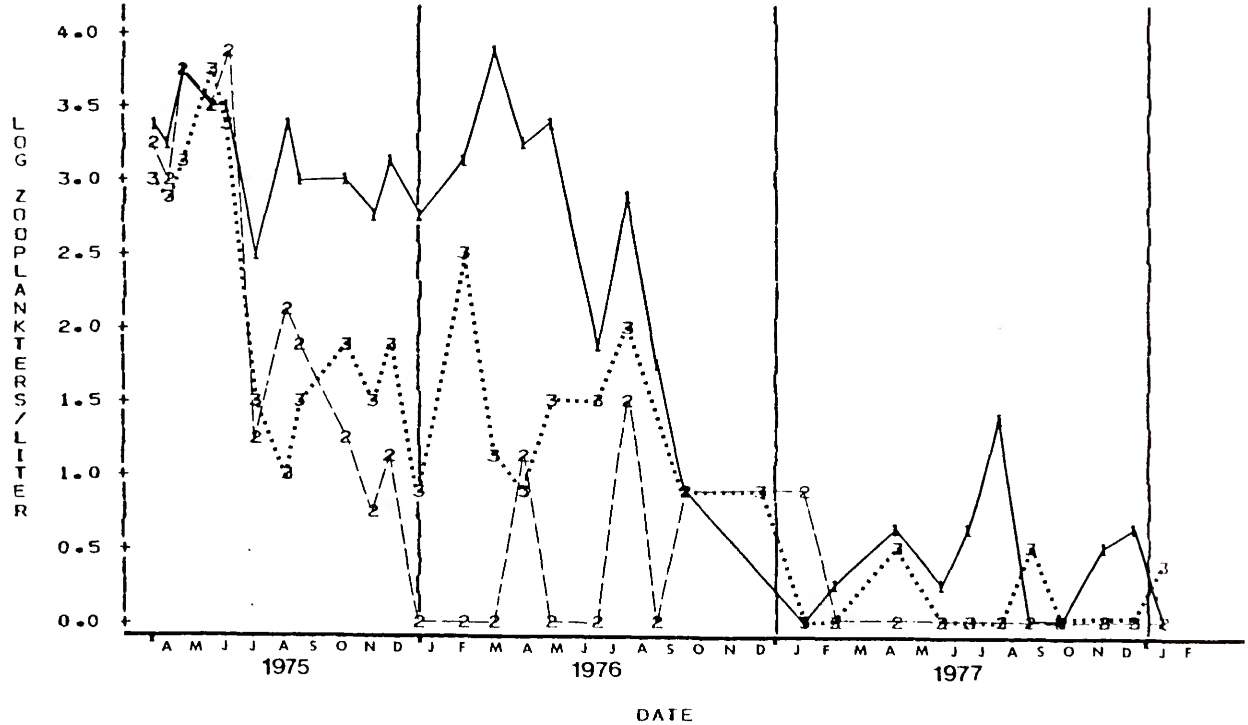


Figure 62. Citrus Ponds total surface <u>Arcella</u> spp., expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

granulata (Ponds One and Two), percent total vegetation cover, total blue-green algae (Pond One), and total chrysophytes (Pond Two) in all three ponds. Total *Arcella* spp. was negatively correlated to total euglenoids, *Oscillatoria subbrevis*, dissolved oxygen, *Colacium vesciculosum*, total *Tetraedron* (Ponds One and Three), total desmids (Ponds One and Two), and total *Scenedesmus* (Ponds One and Two) in all three ponds.

Stepwise multiple regressions selected dissolved oxygen and percent total vegetation cover as the best possible model for Pond One, pH and percent total vegetation cover for Pond Two, and percent total vegetation cover for Pond Three.

Centropyxis aculeata Stein

This rhizopod protozoan species reached a maximum of 2.59 X 10^3 zooplankters/liter in Pond One, 3.47 X 10^3 zooplankters/liter in Pond Two, and 1.65 X 10^3 zooplankters/liter in Pond Three during the study (Fig. 63).

Centropyxis aculeata showed a distribution similar to that of total *Arcella* spp. *C. aculeata* was commonly found beneath actively growing water hyacinth populations, after the plants were chemically treated, and until water quality conditions improved. *Centropyxis aculeata* apparently fed upon the roots or other detritus originating from water hyacinth populations.

Centropyxis aculeata was positively correlated to *Oscillatoria limnetica*, total plankton diatoms, and percent total vegetation cover in all three ponds. *C. aculeata* was

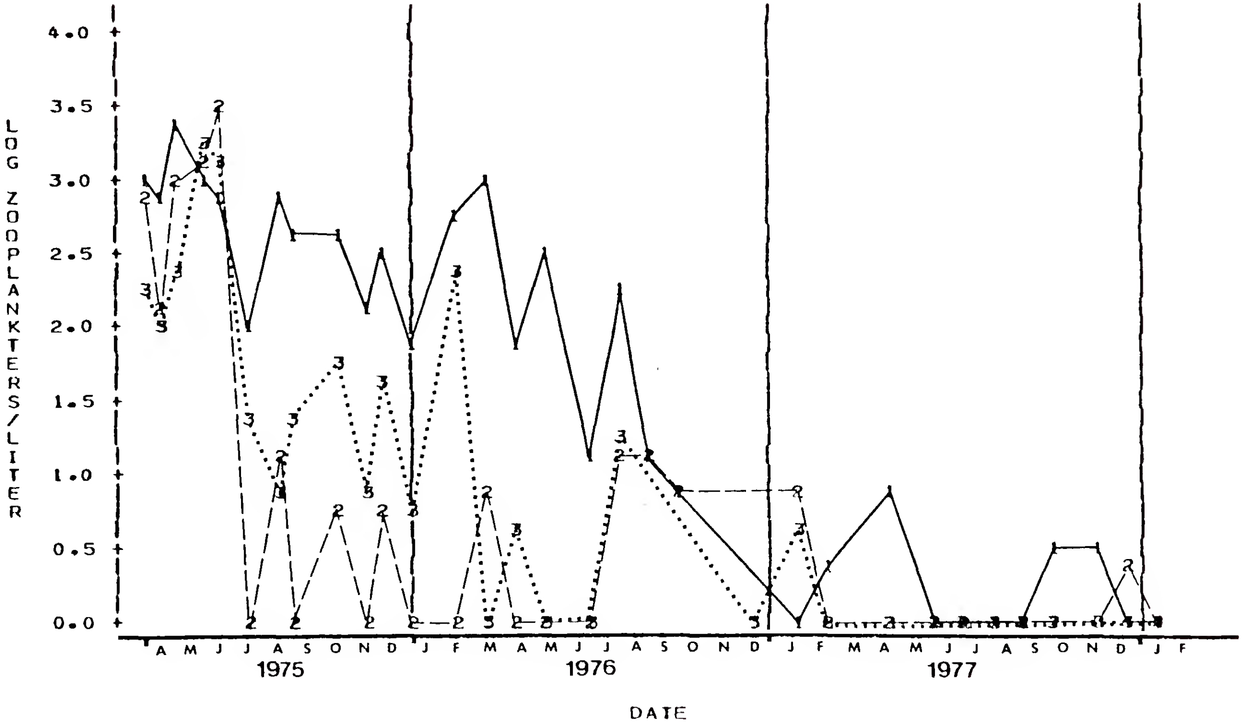


Figure 63. Citrus Ponds Surface <u>Centropyxis</u> <u>aculeata</u>, expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

also positively correlated to *Fragilaria capucina* var. *mesolepta*, *Melosira granulata* var. *angustissima* and total blue-green algae in Pond One, and to *Melosira granulata* and total chrysophytes in Pond Two.

This zooplankter was negatively correlated to *Colacium vesciculosum*, total euglenoids, and dissolved oxygen in all three ponds. *C. aculeata* was also negatively correlated to total *Scenedesmus*, *Oscillatoria subbrevis*, total *Tetraedron*, and *Tetraedron minimum* in Pond One and Three, and to total desmids in Pond One.

Stepwise multiple regressions selected percent total vegetation cover as the best possible model for all three ponds.

Difflugia bacillifera Penard.

This rhizopod protozoan species reached a maximum of 2.83×10^3 zooplankters/liter in Pond One, 3.14×10^3 zooplankters/liter in Pond Two, and 1.49×10^3 zooplankters/liter in Pond Three during the study (Fig. 64).

Difflugia bacillifera, with a distribution similar to that of total *Arcella* spp. and *Centropyxis aculeata*, was commonly found beneath hyacinth populations. They were still frequently found after the hyacinth populations had been removed, but only until water quality conditions improved.

Difflugia bacillifera was positively correlated to *Oscillatoria limnetica*, and percent total vegetation cover in all three ponds, to total *Oscillatoria* in Ponds Two and Three,

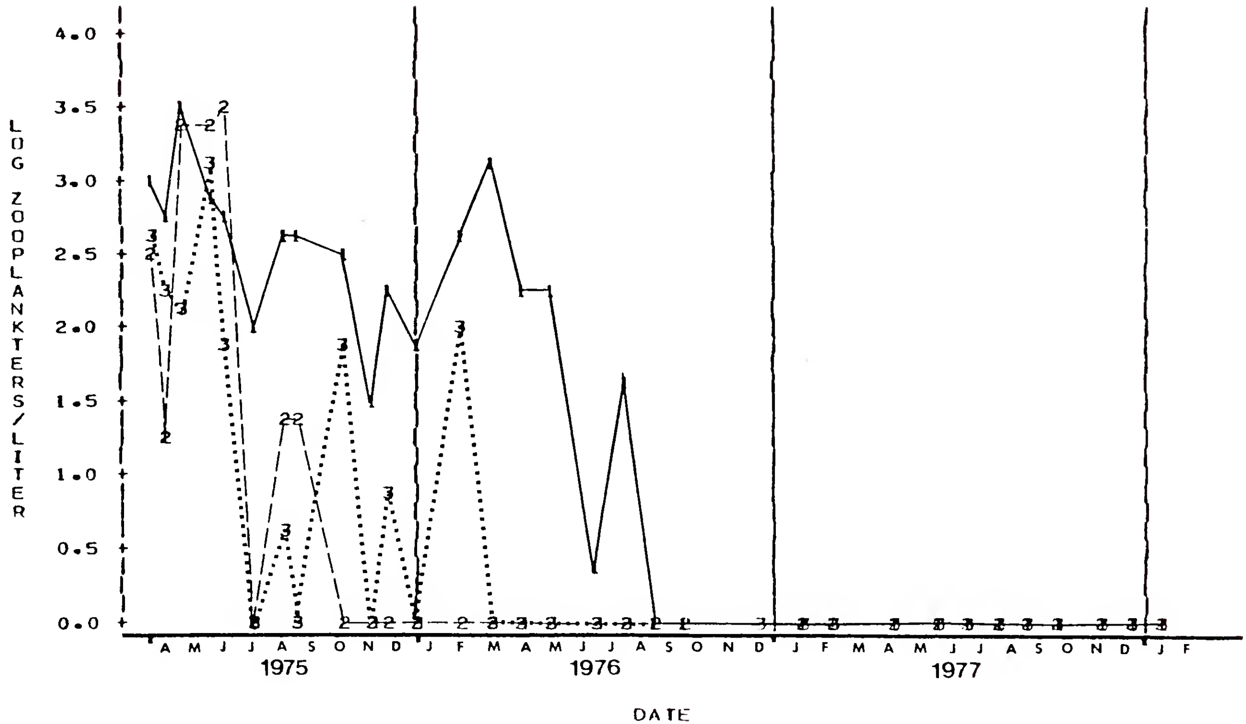


Figure 64. Citrus Ponds surface *Difflugia bacillifera*, expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, — — — = Pond Two, ······· = Pond Three).

and to total phytoplankton diatoms in Ponds One and Two. *D. bacillifera* was also positively correlated to *Fragilaria capucina* var. *mesolepta* and *Melosira granulata* var. *angustissima* in Pond One, to *Melosira granulata* in Pond Two, and to total blue-green algae in Pond Three.

This zooplankter was negatively correlated to *Oscillatoria subbrevis,* total euglenoids, and dissolved oxygen in all three ponds. *D. bacillifera* was also negatively correlated to *Tetraedron minimum,* and total *Tetraedron* in Ponds One and Three, and to total desmids, *Scenedesmus quadricaudata,* total *Scenedesmus* spp., *Golenkinia* spp., *Colacium vesciculosum, Ankistrodesmus* spp., and *Euglena* spp. in Pond One.

Stepwise multiple regressions selected percent total vegetation cover as the best possible model for all three ponds.

Total rotifers

Total rotifers reached a maximum of 2.77 X 10^3 zooplankters/liter in Pond One, 1.16 X 10^4 zooplankters/liter in Pond Two, and 1.37 X 10^4 zooplankters/liter in Pond Three during the study (Fig. 65). Total rotifers composed the bulk of the total zooplankton populations on most sampling dates. Comparison of the two graphs (Figs. 55 and 65) will show they are similar.

Total rotifers were found throughout the year, and reached several large concentrations beneath actively growing hyacinth populations. Total rotifers were maximal during early spring, and minimal during summer beneath such hyacinths. Total rotifers fluctuated greatly during the study, reaching large population

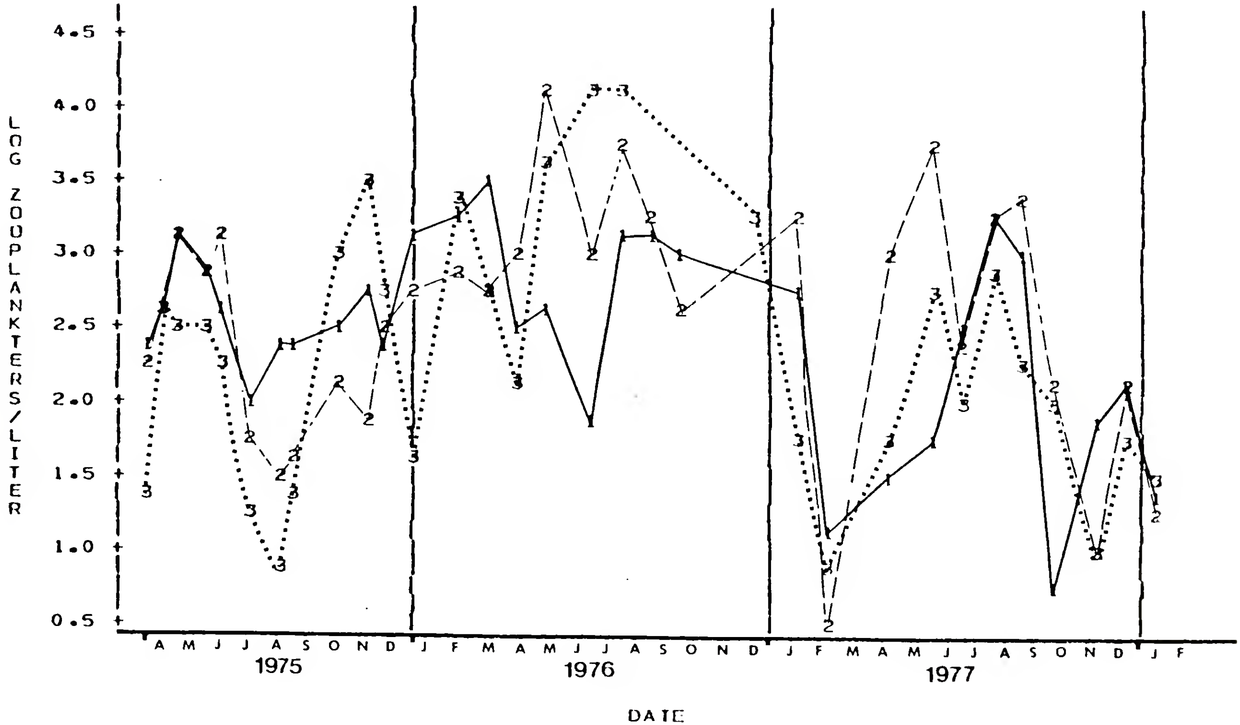


Figure 65. Citrus Ponds total surface rotifers, expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

peaks, and then quickly dying off. When open water conditions were established (after hyacinth disappearance), rotifer populations were minimal during cool water periods and maximal during summer.

Total rotifers were negatively correlated to *Colacium vesciculosum* and total euglenoids in Ponds One and Two, and to *Scenedesmus bijuga* and dissolved oxygen in Pond One.

Total rofiters were positively correlated to total phytoplankton in all three ponds, and also to *Eudorina* spp., and *Melosira granulata* var. *angustissima* in Ponds One and Two, and to total green algae, *Microcystis aeruginosa, Anabaena spiroides,* and water temperature in Ponds Two and Three. Total rotifers were also positively correlated to *Fragilaria capucina* var. *mesolepta,* total *Oscillatoria,* percent total vegetation cover, total phytoplankton diatoms, and total blue-green algae in Pond One, and to total desmids, unidentified green unicells, total *Anabaena,* total *Scenedesmus, Euglena* spp., *Anabaena spiroides, Golenkinia* spp., *Scenedesmus bijuga,* and *Ankistrodesmus* spp. in Pond Three.

Stepwise multiple regressions selected total phytoplankton as the best possible model for Pond One, and water temperature as the best model for Ponds Two and Three.

Brachionus havannaensis Pallas

This rotifer species was one of the most commonly occurring zooplankters during the study. It reached a maximum of 1.18 X

10^3 zooplankters/liter in Pond One, 4.34 X 10^3 zooplankters/liter in Pond Two, and 4.16 X 10^3 zooplankters/liter in Pond Three (Fig. 66).

Brachionus havannaensis was found during warm water months, only after hyacinth treatment. *B. havannaensis* thrived under open water conditions as water quality improved.

Brachionus havannaensis was negatively correlated to total plankton diatoms in Pond One and Two, and to *Oscillatoria limnetica* and percent total vegetation cover in Ponds One and Three.

This rotifer was positively correlated to *Oscillatoria subbrevis,* water temperature, and total phytoplankton in all three ponds, and also to *Golenkinia* spp. in Ponds One and Three, and to total *Anabaena,* total blue-green algae, and *Microcystis aeruginosa* in Ponds Two and Three. *B. havannaensis* was also positively correlated to *Euglena* spp., *Dictyosphaerium* spp., and total euglenoids in Pond One, to *Anabaena Schermer,* and total green algae in Pond Two, and to dissolved oxygen, *Anabaena spiroides,* total desmids, total *Scenedesmus, Scenedesmus quadricaudata, Scenedesmus bijuga,* total *Tetraedron,* and *Tetraedron minimum* in Pond Three.

Stepwise multiple regressions selected water temperature, percent total vegetation cover, and total phytoplankton as the best possible model for Pond One, water temperature for Pond Two, and water temperature and dissolved oxygen in Pond Three.

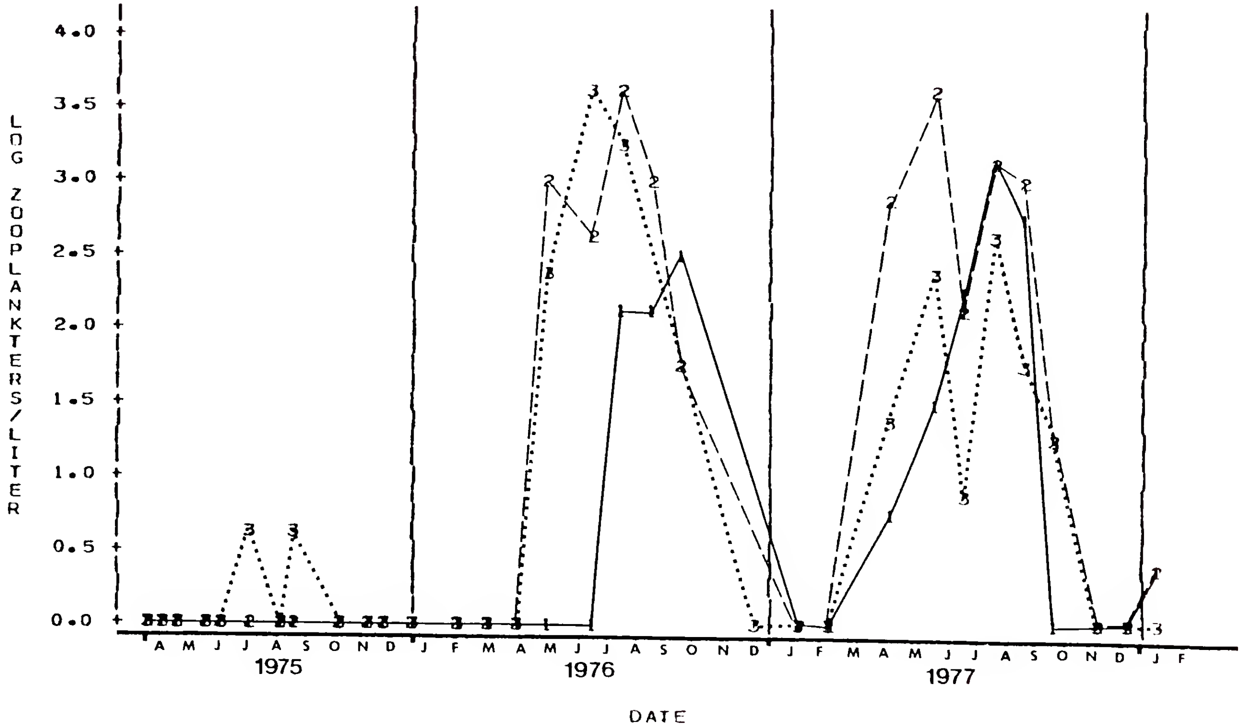


Figure 66. Citrus Ponds surface Brachionus havannaensis, expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ... = Pond Three).

<u>*Brachionus plicatilus* Pallas</u>

This rotifer species was another zooplankter commonly found during the study. It reached a maximum of 126.0 zooplankters/liter in Pond One, 152.0 zooplankters/liter in Pond Two, and 1.06×10^3 zooplankters/liter in Pond Three during the study (Fig. 67).

Brachionus plicatilus was found during warm water months, but only after water hyacinth treatment. *B. plicatilus* (like *B. havannaensis*) thrived under open water conditions, as water quality improved.

This zooplankter was negatively correlated to percent total vegetation cover and *Oscillatoria limnetica* in Ponds One and Three, and to total phytoplankton diatoms in Pond Two.

Brachionus plicatilus was positively correlated to total phytoplankton, water temperature, *Oscillatoria subbrevis,* and *Golenkinia* spp. in all three ponds, and also to *Anabaena Schermer* in Ponds One and Two, and to total green algae, *Scenedesmus bijuga,* total blue-green algae, total *Anabaena,* and *Microcystis aeruginosa* in Ponds Two and Three. *B. plicatilus* was also positively correlated to *Dictyosphaerium* spp., total euglenoids, and *Euglena* spp. in Pond One, to total *Oscillatoria* in Pond Two, and to *Anabaena spiroides,* dissolved oxygen, total desmids, unidentified green unicells, total *Scenedesmus, Scenedesmus quadricaudata,* total *Tetraedron,* and *Tetraedron minimum* in Pond Three.

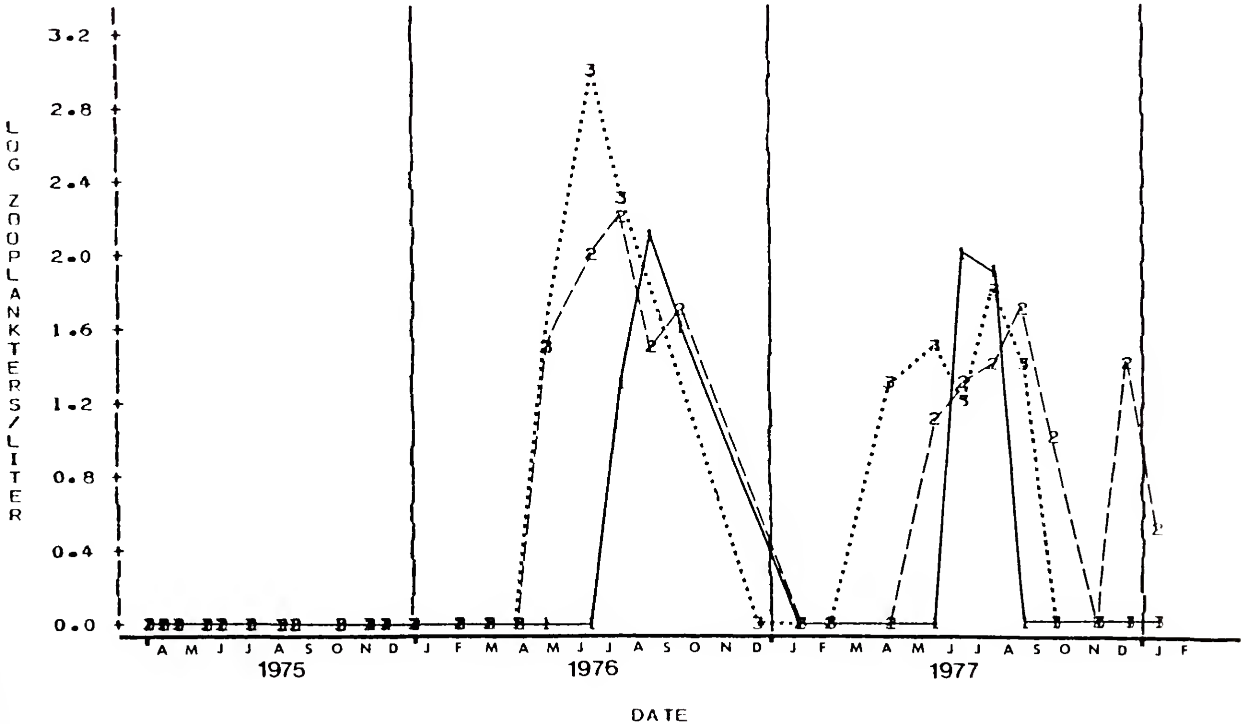


Figure 67. Citrus Ponds surface Brachionus plicatilus, expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, — — — = Pond Two, ······· = Pond Three).

Stepwise multiple regressions selected water temperature as the best possible model for Pond One, water temperature, pH, percent total vegetation cover, and total phytoplankton for Pond Two, and water temperature and dissolved oxygen for Pond Three.

Polyarthra spp.

This rotifer species reached a maximum of 109.0 zooplankters/liter in Pond One, 3.89 X 10^3 zooplankters/liter in Pond Two, and 1.25 X 10^3 zooplankters/liter in Pond Three during the study (Fig. 68).

Polyarthra spp. were not commonly found beneath actively growing hyacinth populations, but were more common after hyacinth treatment. *Polyarthra* spp. thrived among dead and decaying hyacinths, and during other poor water quality conditions. *Polyarthra* spp. were found only in small fluctuating populations after open water and improved water quality conditions were established.

Polyarthra spp. were negatively correlated to *Oscillatoria limnetica* in all three ponds, and also to percent total vegetation cover in Ponds One and Three, and to total *Oscillatoria* in Ponds Two and Three.

This zooplankter was positively correlated to *Eudorina* spp. and *Anabaena spiroides* in Ponds Two and Three, to *Scenedesmus quadricaudata* in Ponds One and Three, and to *Oscillatoria subbrevis*, *Euglena* spp., water temperature, total desmids, total *Scenedesmus*, *Dictyosphaerium* spp., and *Golenkinia*

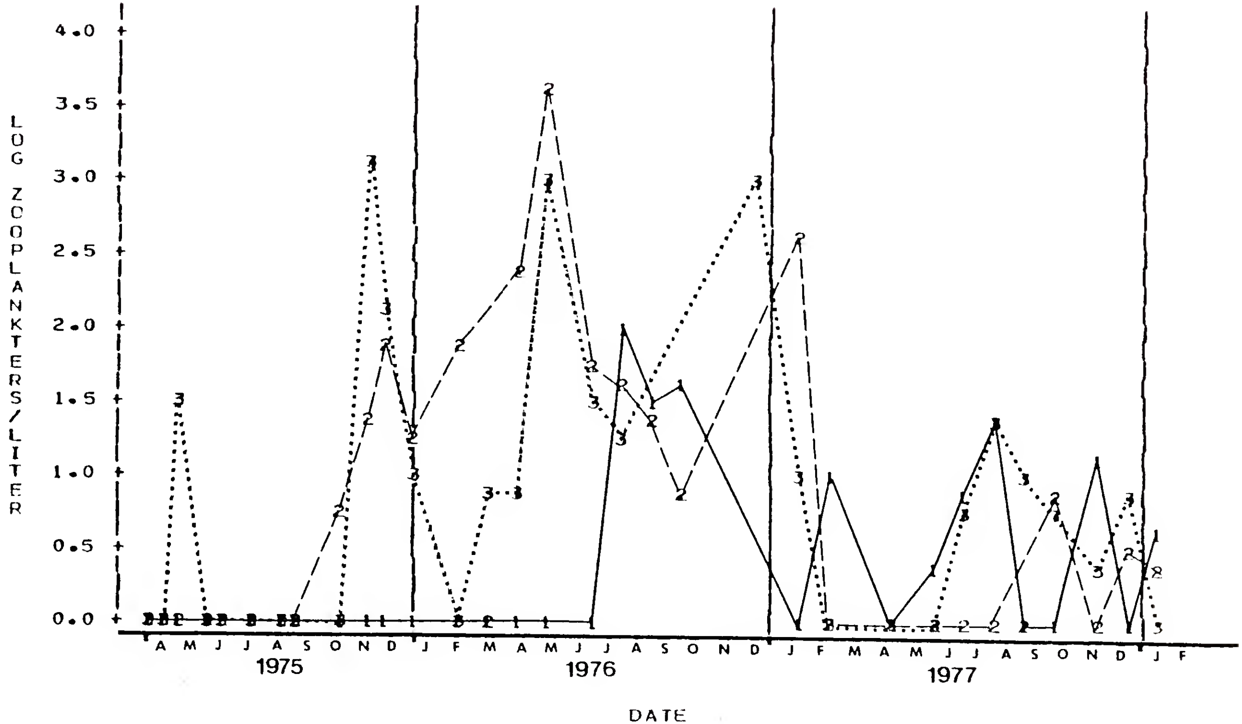


Figure 68. Citrus Ponds surface <u>Polyarthra</u> spp., expressed as the number of zooplankters/liter in $\log_{10}$ (——— = Pond One, – – – = Pond Two, ······· = Pond Three).

spp. in Pond One. *Polyarthra* spp. were also positively correlated to *Microcystis aeruginosa, Fragilaria capucina* var. *mesolepta, Melosira granulata* var. *angustissima*, and total *Anabaena*, and *Anabaena Schermer* in Pond Three.

Stepwise multiple regressions did not provide a significant model for Pond Two, but did select percent total vegetation cover as the best possible model for Ponds One and Three.

Periphyton Diatoms

Periphyton Diatom Densities

The density of periphyton diatoms was determined from samples collected in the pond surfaces and specific depths throughout the study. The periphyton diatom densitites in the surface of Pond One ranged from 1.88 X 10^3 to 2.58 X 10^6 diatom valves/cm^2, while the one meter depth densitites varied from 946.0 to 4.71 X 10^6 valves/cm^2 (Fig. 69). Densities ranged from 754.0 to 1.52 X 10^6 valves/cm^2 in the surface of Pond Two, from 87.0 to 3.10 X 10^6 valves/cm^2 at one meter depth, and from 87.0 to 2.88 X 10^6 valves/cm^2 at two meter depths (Fig. 70). Diatom densities in Pond Three ranged from 5.70 X 10^3 to 3.49 X 10^6 valves/cm^2 in the pond surface, and from 87.0 to 2.51 X 10^6 valves/cm^2 at a one meter depth during the study (Fig 71).

Periphyton diatom densities in the surface of Pond One were fairly large, but fluctuated widely under actively growing populations of water hyacinths. Densities were minimal shortly after hyacinth treatment when dead and decaying plant material

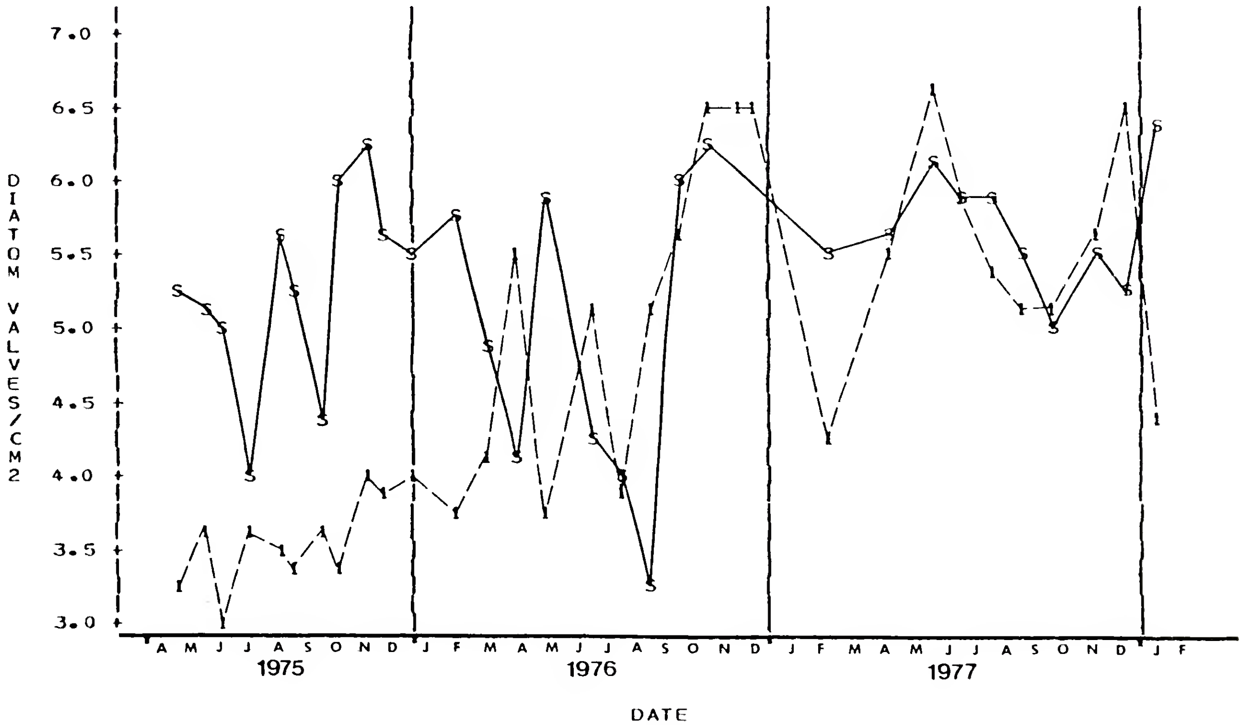


Figure 69. Pond One periphyton diatom densities, expressed as the number of diatom valves/cm2 in log10 (——— = pond surface, — — — = one meter depth).

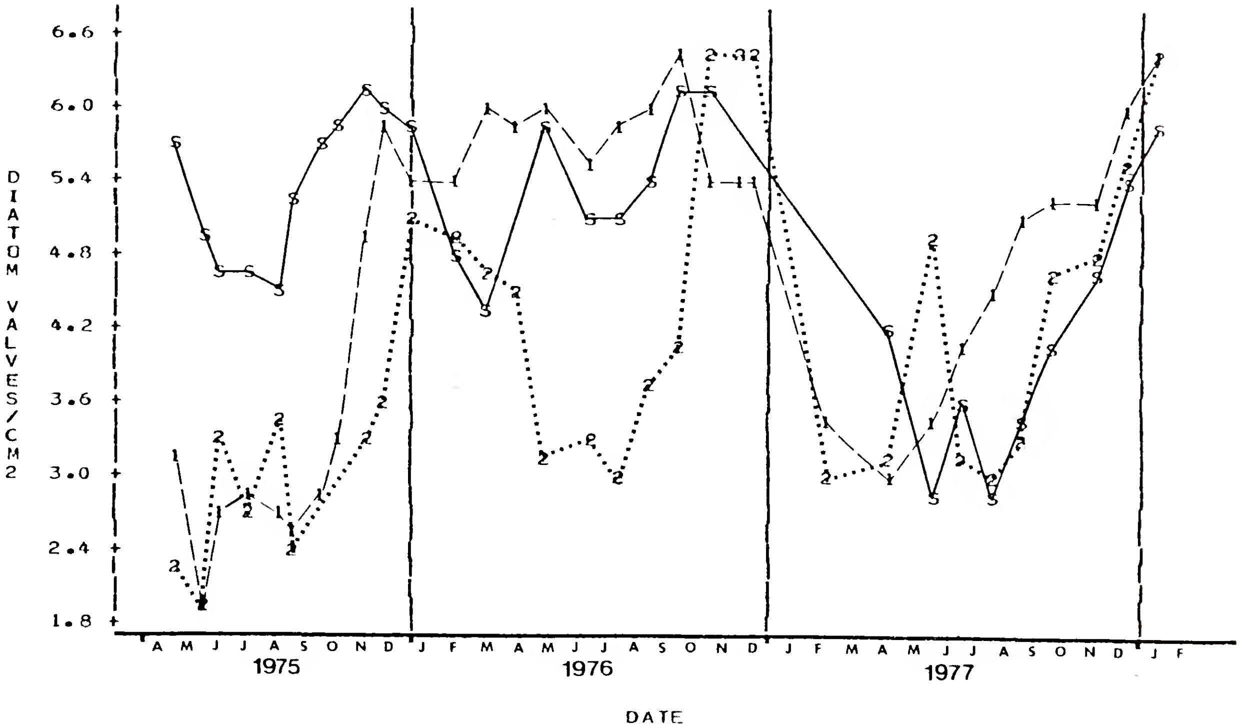


Figure 70. Pond Two periphyton diatom densities, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, — — — = one meter depth, ········ = two meter depth).

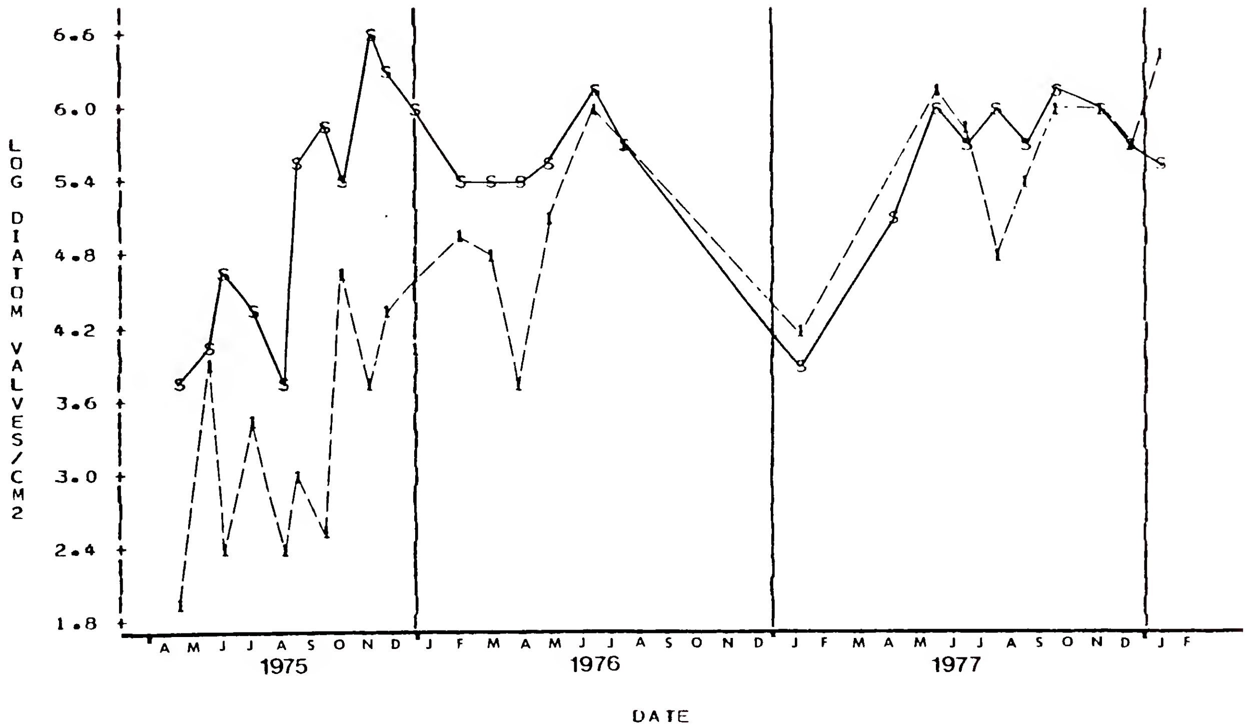


Figure 71. Pond Three periphyton diatom densities, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

was present. Surface diatom densities remained high and fluctuated less after hyacinth disappearance and the return of open water conditions (with improved water quality). The one meter depth diatom densities were minimal below actively growing hyacinths, but increased dramatically as hyacinths were removed and water quality improved. Surface periphyton diatom densities averaged 73 times larger than the one meter densities for the same sampling date in Pond One under actively growing hyacinths. One meter diatom densities surpassed surface densities on several dates after hyacinth disappearance.

Diatom densities in the surface of Pond Two decreased during hyacinth treatment, but increased steadily as the hyacinths disappeared and open water conditions were achieved. Diatom densities remained fairly high, but fluctuating, the year after hyacinth disappearance (1976), while water quality conditions had not significantly improved. The density of periphyton diatoms in the pond surface was much lower after water quality improved (1977), reaching higher concentrations during cool water months.

The one and two meter depth diatom densities were minimal below actively growing hyacinths but increased greatly as hyacinths disappeared and water quality improved. The average surface periphyton diatom density was 180 times greater than the average one meter density, and 130 times greater than the average two meter diatom density under actively growing water hyacinths in Pond Two. Diatoms were often denser at the one or two meter depths than in the pond surface after hyacinth disappearance.

A large decrease was noted in the two meter depth diatom density in Pond Two during the summer of 1976. This decrease in diatoms coincided with a decrease in light penetration (Fig. 33) and Secchi disk disappearance (Fig. 31) and by large phytoplankton blooms.

Diatom densities in the surface of Pond Three increased as hyacinths disappeared. Surface diatom densities usually remained at high levels after hyacinth disappearance, normally surpassing the densities found under actively growing hyacinths.

The one meter depth diatom densities were much less than the surface densities under actively growing hyacinth populations. The surface diatom densities average 90 times greater than the one meter periphyton diatom densities. As in the other ponds, one meter diatom densities increased greatly as hyacinths disappeared and as water quality improved. Diatoms were often denser at the one meter depth, than in the pond surface after hyacinth disappearance.

Periphyton diatom density was found to be positively correlated to *Navicula minima*, *Cyclotella Meneghiniana*, and *Nitzschia palea* in all the pond surfaces and depths, and to *Stephanodiscus astrea* var. *minutula* and *Nitzschia amphibia* in the pond depths. Diatom density in the pond depths was negatively correlated to percent total vegetation cover, diatom species diversity, diatom species evenness, and the number of diatom species.

Chemical and physical parameters found to be positively correlated to periphyton diatom densities in the pond surfaces included calcium, potassium, specific conductivity, and soluble salts in Pond One, and calcium in Pond Two. Chemical and physical parameters found to be negatively correlated in the pond surfaces included bicarbonate in Pond One, specific conductivity, soluble salts, pH, and water temperature in Pond Two, and to bicarbonate, available phosphate-phosphorus, carbon dioxide, turbidity, and percent total vegetation cover in Pond Three.

Surface periphyton diatom densities were found to be positively correlated to unidentified green unicells and total green algae in Ponds One and Three, and negatively correlated to total phytoplankton and total *Oscillatoria* in Pond Two during the study.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at a one meter depth. Available phosphate-phosphorus was the best surface model in Pond Two. Bicarbonate, potassium, Secchi disk disappearance, and percent total vegetation cover was the best model at the one meter depth. Bicarbonate, potassium, and water temperature was the best model at the two meter depth of Pond Two. Calcium and specific conductivity was the best surface model, while bicarbonate and potassium was the best one meter depth model in Pond Three.

Periphyton Diatom Species Diversity

Species diversity was measured by using the Shannon-Weaver index. The larger the index, the greater the species diversity of that sample. The surface of Pond One reached a maximum species diversity of 3.6032, while the surface of Pond Two reached 3.2459, and the surface of Pond Three reached 3.3368 during the study (Fig. 72). At a one meter depth, the periphyton diatom species diversity indices reached a maximum of 3.7354 in Pond One, 3.9480 in Pond Two, and 4.2601 in Pond Three (Fig. 73).

Periphyton diatom species diversity indices showed that the surface diatom communities (average was 2.4375) were less diverse than those in the pond depths (average was 3.0088) under actively growing water hyacinth populations. The average surface diversities were low (ranging from 0.8607 to 1.5463), while the average diversities in the pond depths were much higher (ranging from 2.7253 to 3.5380) during hyacinth treatment and disappearance. With the establishment of open water conditions after hyacinth disappearance, the average surface diversities (ranging from 1.8748 to 2.5265) were similar to the average diversities at greater depths (ranging from 2.1297 to 2.3707).

Periphyton diatom species diversities in the surface of Pond One were normally higher beneath actively growing hyacinth populations than under open water conditions after hyacinth disappearance.

Species diversities decreased dramatically in the surfaces of all ponds after chemical treatment of the hyacinth populations and remained low while the dying plants were present. Species diversities attained fairly high but fluctuating levels in the surface of Ponds Two and Three after hyacinth disappearance. These levels were comparable with the species diversities found before hyacinth treatment.

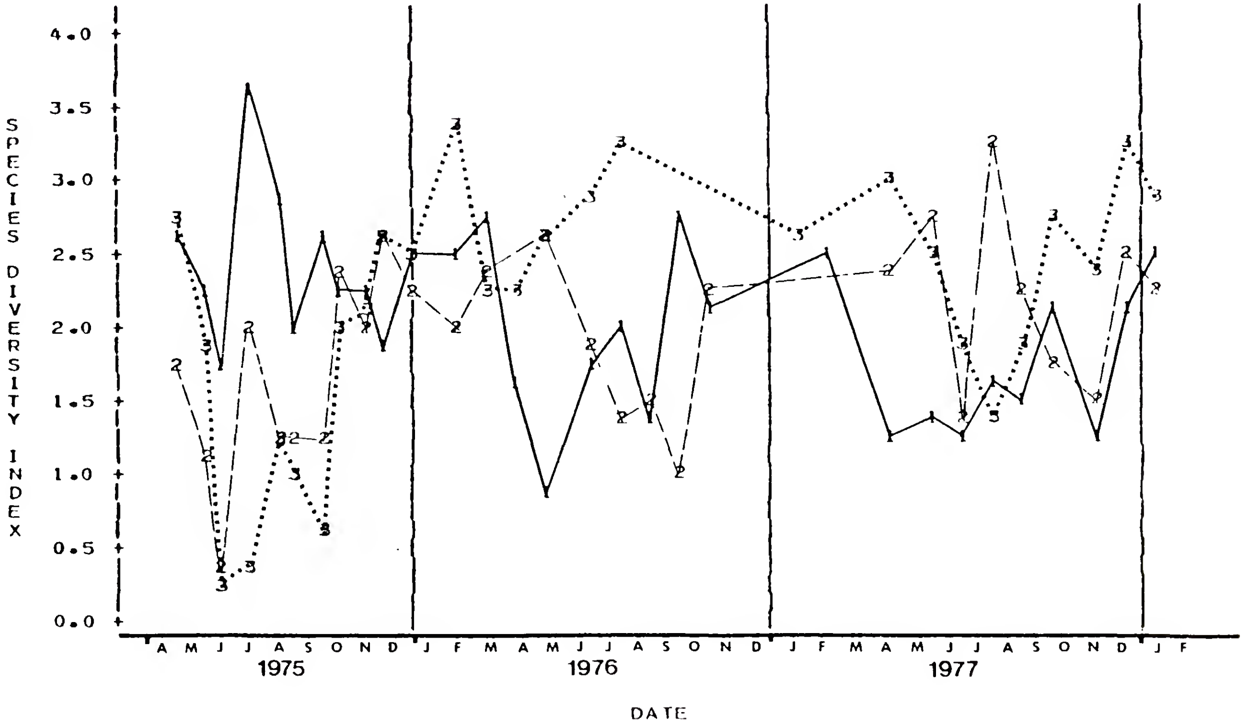


Figure 72. Citrus Ponds surface periphyton diatom species diversity, expressed in terms of the Shannon-Weaver species diversity index
(——— = Pond One, — — — = Pond Two, ······· = Pond Three).

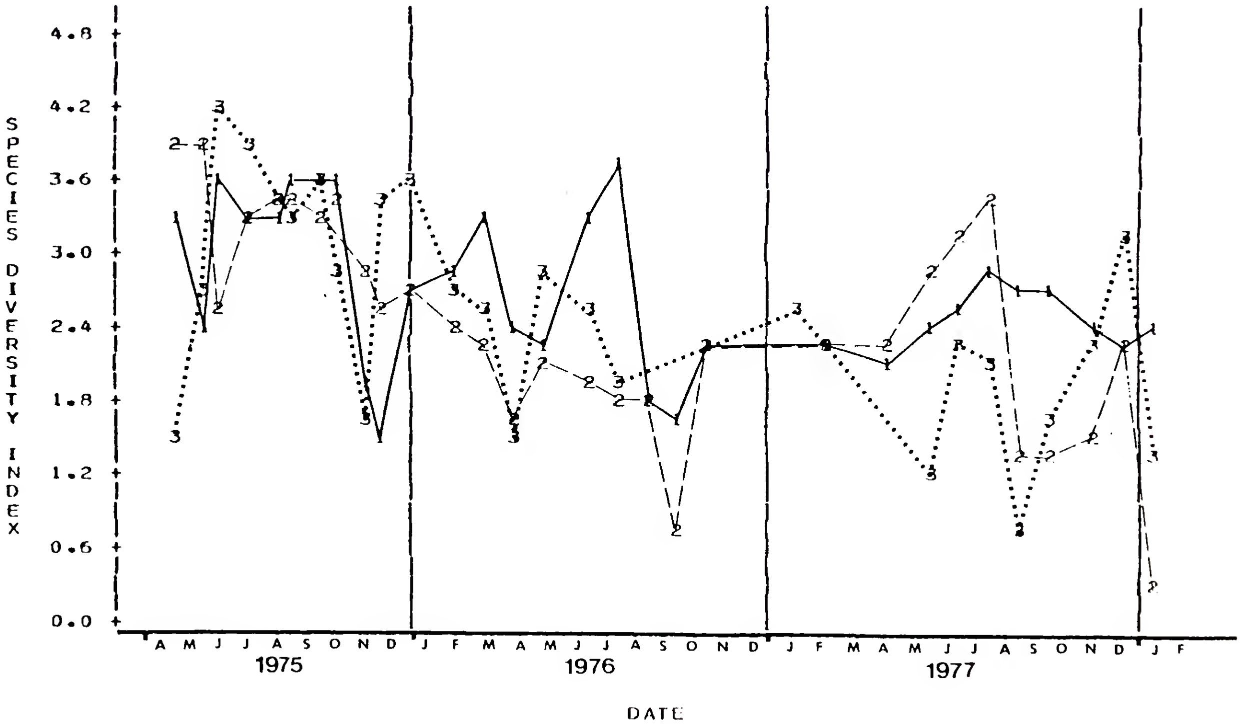


Figure 73. Citrus Ponds one meter depth periphyton diatom species diversity, expressed in terms of the Shannon-Weaver species diversity index (——— = Pond One, — — — = Pond Two, ······· = Pond Three).

One meter periphyton diatom species diversities were similar in all three ponds. Species diversity was at its highest levels after hyacinth treatment and decreased slightly the next year as open water conditions returned. Several larger species diversity peaks occurred during 1977 as water quality improved, perhaps in response to large phytoplankton blooms.

Surface periphyton diatom species diversity was negatively correlated to percent total vegetation cover, *Oscillatoria limnetica*, available phosphate-phosphorus, bicarbonate, and carbon dioxide in Ponds Two and Three, and magnesium in Ponds One and Three. Dissolved oxygen was positively correlated to surface diatom species diversity in Ponds Two and Three. Other parameters commonly found negatively correlated to surface diatom species diversity were potassium, water temperature, total *Oscillatoria*, calcium, soluble salts, and *Oscillatoria subbrevis*. Total green algae, unicellular green algae, and pH, were parameters commonly found positively correlated to surface diatom species diversity.

Diatom species diversities in the pond depths were positively correlated to carbon dioxide, total phosphate-phosphorus, available phosphate-phosphorus, and percent total vegetation cover, and negatively correlated to soluble salts, periphyton diatom density, and *Oscillatoria subbrevis*. Other parameters commonly found negatively correlated to diatom species diversity in the pond depths were pH, total phytoplankton, total green algae, and specific conductivity. Water temperature, total *Oscillatoria*, *Oscillatoria limnetica*, total blue-green algae, turbidity, and bicarbonate were often positively correlated.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Bicarbonate, soluble salts, and magnesium was the best surface model in Pond Two, while total phytoplankton was the best model at the one meter depth, and soluble salts, potassium, and nitrate-nitrogen was the best model at the two meter depth in Pond Two. Bicarbonate and water temperature was the best surface model, while bicarbonate and soluble salts was the best one meter depth model in Pond Three.

Periphyton Diatom Species Evenness

Species evenness was measured by using a species evenness index which ranged from 0.0 to 1.0. An index of 1.0 would represent a community in which an equal number of individuals from each species is found. A low species evenness index would represent a community in which many individuals were found of one or several species, while fewer members of other species were found.

A maximum surface periphyton diatom species evenness index of 0.8209 was reached in Pond One, 0.8115 in Pond Two, and 0.8764 in the surface of Pond Three during the study (Fig. 74). A maximum one meter depth periphyton diatom species evenness index of 0.09050 was reached in Pond One, 0.8988 in Pond Two, and 0.8960 at a one meter depth in Pond Three during the study (Fig. 75).

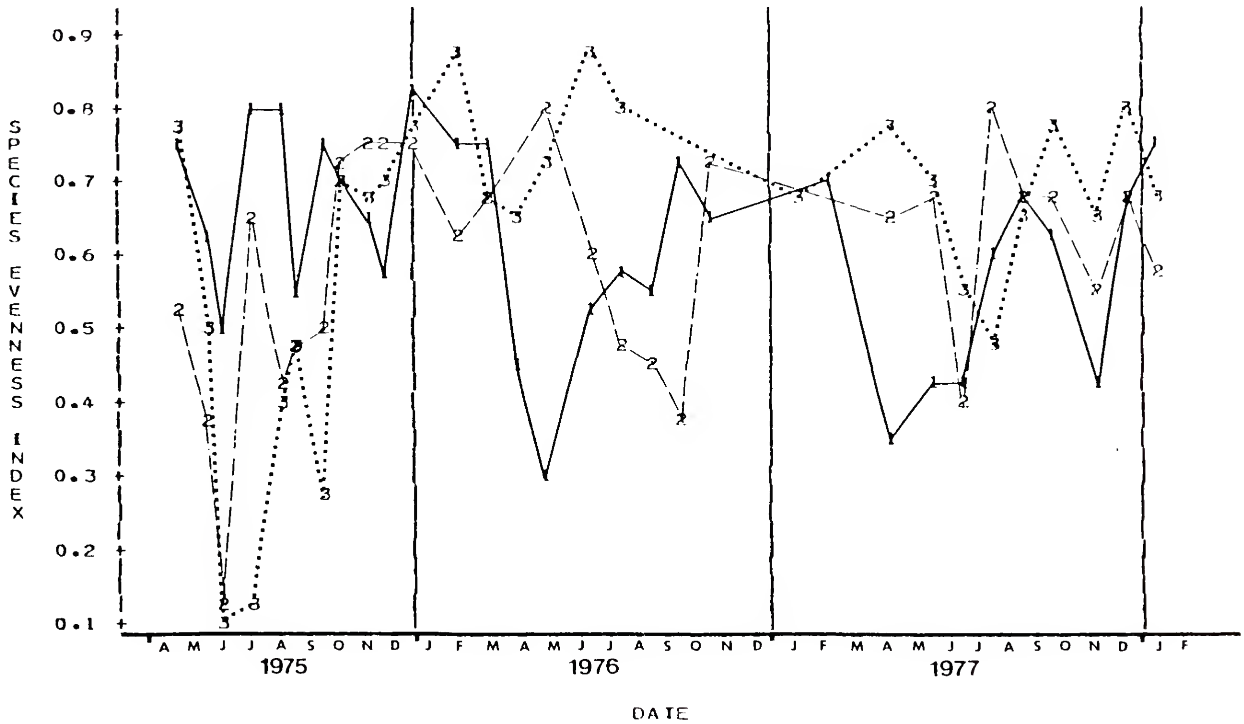


Figure 74. Citrus Ponds surface periphyton diatom species evenness, expressed in terms of the species evenness index (——— = Pond One, — — — = Pond Two, ········ = Pond Three).

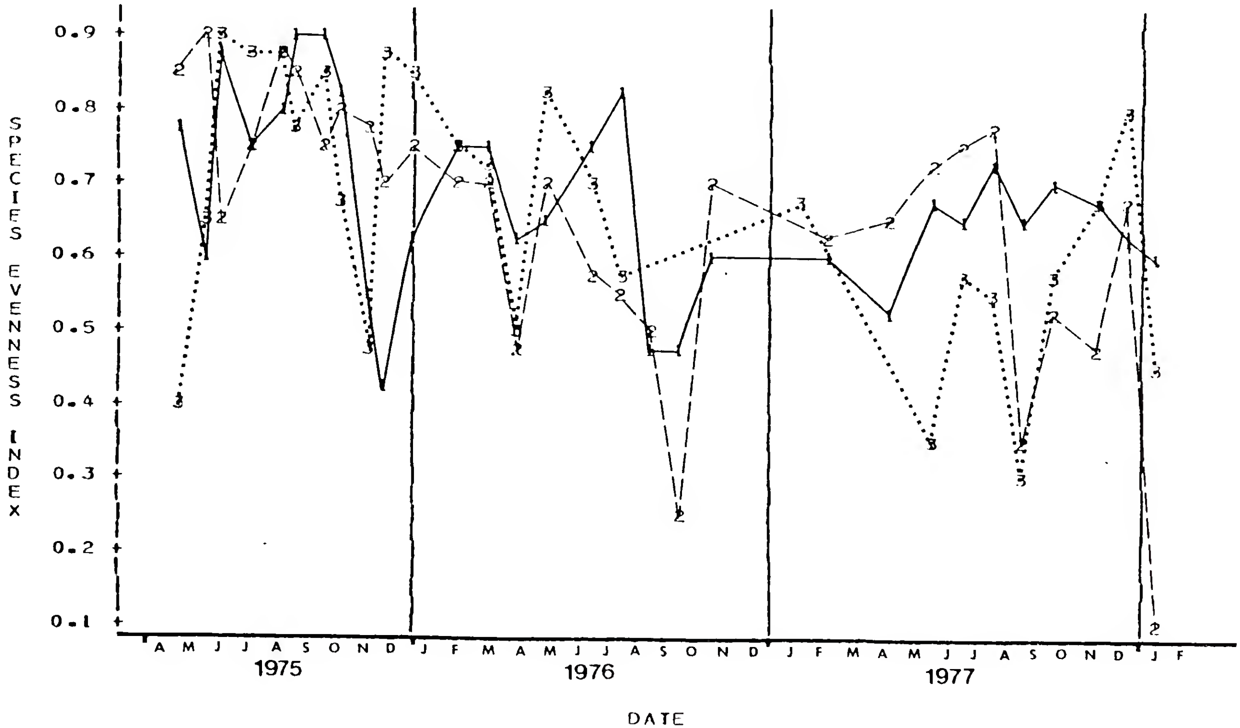


Figure 75. Citrus Ponds one meter depth periphyton diatom species evenness, expressed in terms of the species evenness index
(——— = Pond One, — — = Pond Two, ········ = Pond Three).

Surface species evenness fluctuated greatly in all three ponds during the study. Species evenness was normally quite high before and after hyacinth disappearance. Species evenness was minimal in all ponds after herbicide application when dead and decaying plants persisted. The surface species evenness returned to its usual high level after the floating organic matter disappeared.

One meter periphyton diatom species evenness was found to fluctuate greatly in all three ponds during the study, but the general trend was for a decrease in species evenness with time. Species evenness increased during hyacinth treatment.

In summary, surface species evenness fluctuated greatly during the study and reached its lowest levels during chemical treatment. One meter periphyton diatom species evenness reached its maximum during chemical treatment, and in general, decreased after hyacinth disapperance.

Periphyton diatom species evenness was found to be correlated to the same parameters as was periphyton diatom diversity in the pond surfaces and depths.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Turbidity, Secchi disk disappearance, and total phytoplankton was the best surface model, while total phytoplankton was the best model at the one meter depth, and bicarbonate, soluble salts, and nitrate-nitrogen was the best model at the two meter depth in

Pond Two. Water temperature and percent total vegetation cover was the best surface model, while soluble salts and Secchi disk disappearance was the best one meter depth model in Pond Three.

Number of Diatom Species

The number of diatom species found per 200 valve count in the surface of Pond One fluctuated from 5 to 22 species, and from 6 to 17 species in the surface of Pond Two, and from 4 to 18 species in the surface of Pond Three during the study (Fig. 76). The number of species found at one meter depths varied from 10 to 23 species in Pond One, from 5 to 24 species in Pond Two, and from 6 to 27 in Pond Three during the study (Fig. 77).

The number of diatom species in the pond surfaces fluctuated during the study, but remained fairly constant (most often between 9 and 14 species per 200 valve count). The number of species in the surface of Ponds Two and Three decreased greatly during hyacinth treatment and increased as hyacinth disappearance occurred.

The number of diatom species at one meter depths fluctuated greatly during the study but generally decreased after hyacinth disappearance. For example, values in Pond One normally fluctuated between 15 and 20 species per 200 valves before hyacinth disappearance, and between 11 and 16 species after hyacinth disappearance.

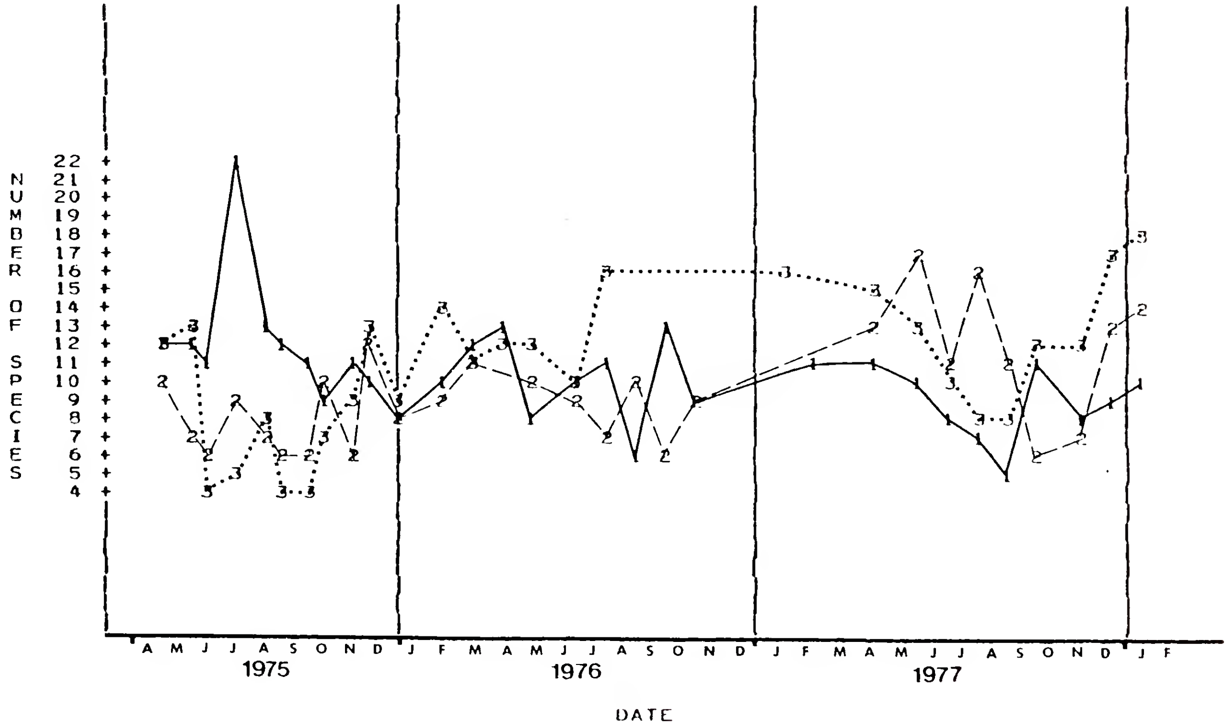


Figure 76. Citrus Ponds surface number of diatom species, expressed as the number of diatom species found per 200 valve count (——— = Pond One, – – – = Pond Two, ········ = Pond Three).

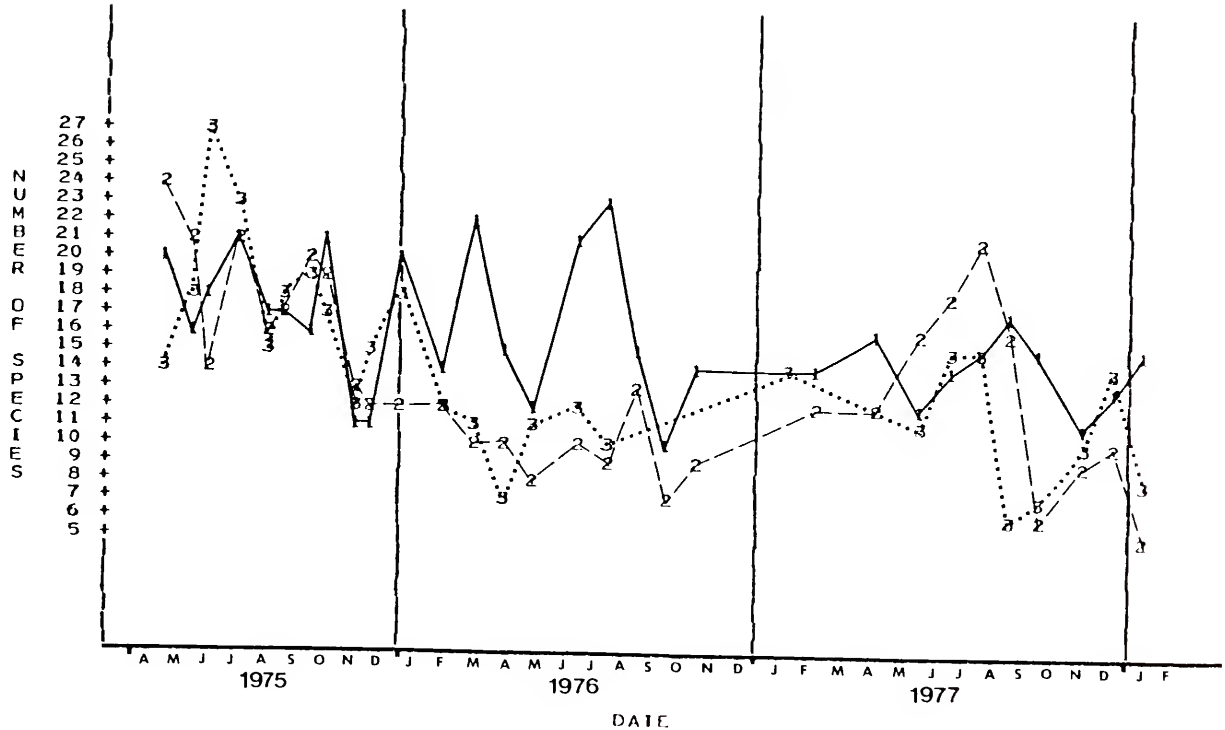


Figure 77. Citrus Ponds one meter depth number of diatom species expressed as the number of diatom species found per 200 valve count
(——— = Pond One, — — — = Pond Two, ······· = Pond Three).

The number of periphyton diatom species found in the pond surfaces and depths was correlated to the same parameters as was periphyton diatom diversity and periphyton diatom species evenness in the pond surfaces and depths.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Turbidity, available phosphate-phosphorus, and total phytoplankton was the best surface model, while calcium and magnesium was the best model at the one meter depth, and available phosphate-phosphorus, specific conductivity, and percent total vegetation cover was the best model at the two meter depth in Pond Two. Light penetration and available phosphate-phosphorus was the best surface model, while bicarbonate and Secchi disk disappearance was the best one meter depth model in Pond Three.

Achnanthes exigua var. *heterovalvata* Krasske

This periphyton diatom species was abundant in all three ponds during the study. This diatom reached a maximum of 1.59 X 10^5 valves/cm^2 in the surface of Pond One, and 2.83 X 10^5 valves/cm^2 at a one meter depth (Fig 78). *A. exigua* var. *heterovalvata* reached a surface maximum of 3.08 X 10^4 valves/ cm^2, a one meter maximum of 2.75 X 10^5 valves/cm^2, and a two meter maximum of 7.20 X 10^4 valves/cm^2 in Pond Two (Fig. 79). This species reached a surface maximum of 4.54 X 10^5 valves/cm^2, and a one meter maximum of 6.30 X 10^4 valves/cm^2 in Pond Three (Fig. 80).

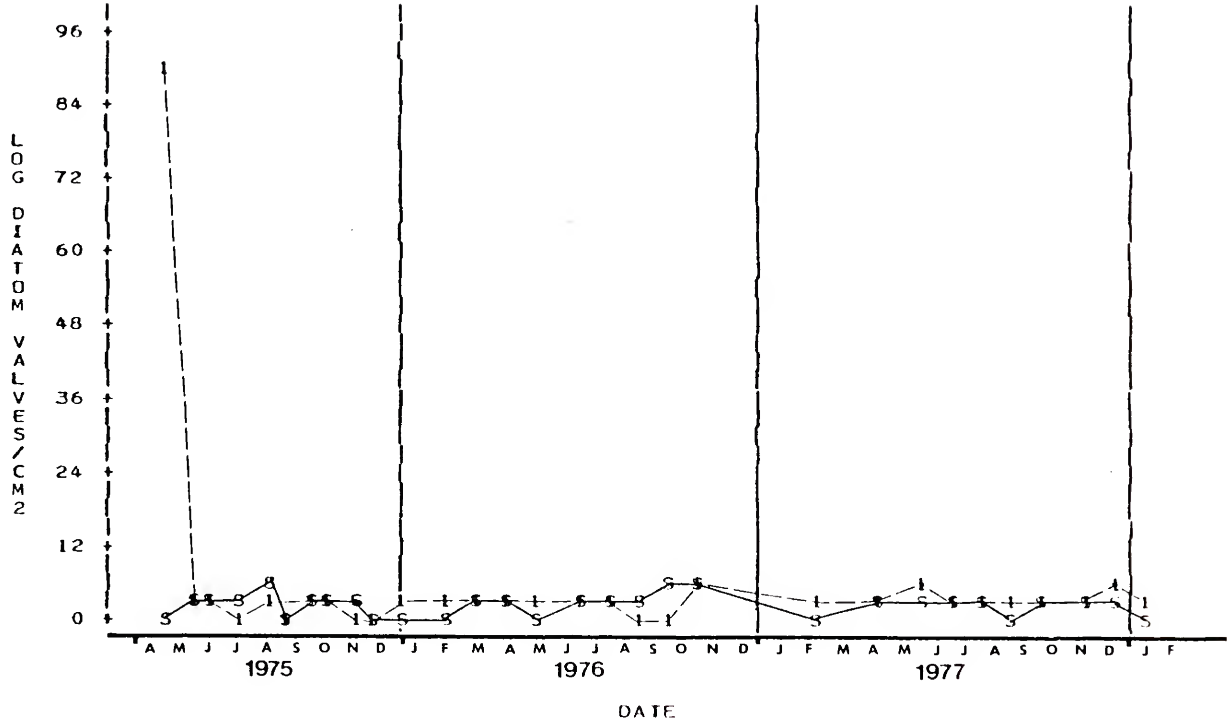


Figure 78. Pond One _Achnanthes exigua_ var. _heterovalvata_, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

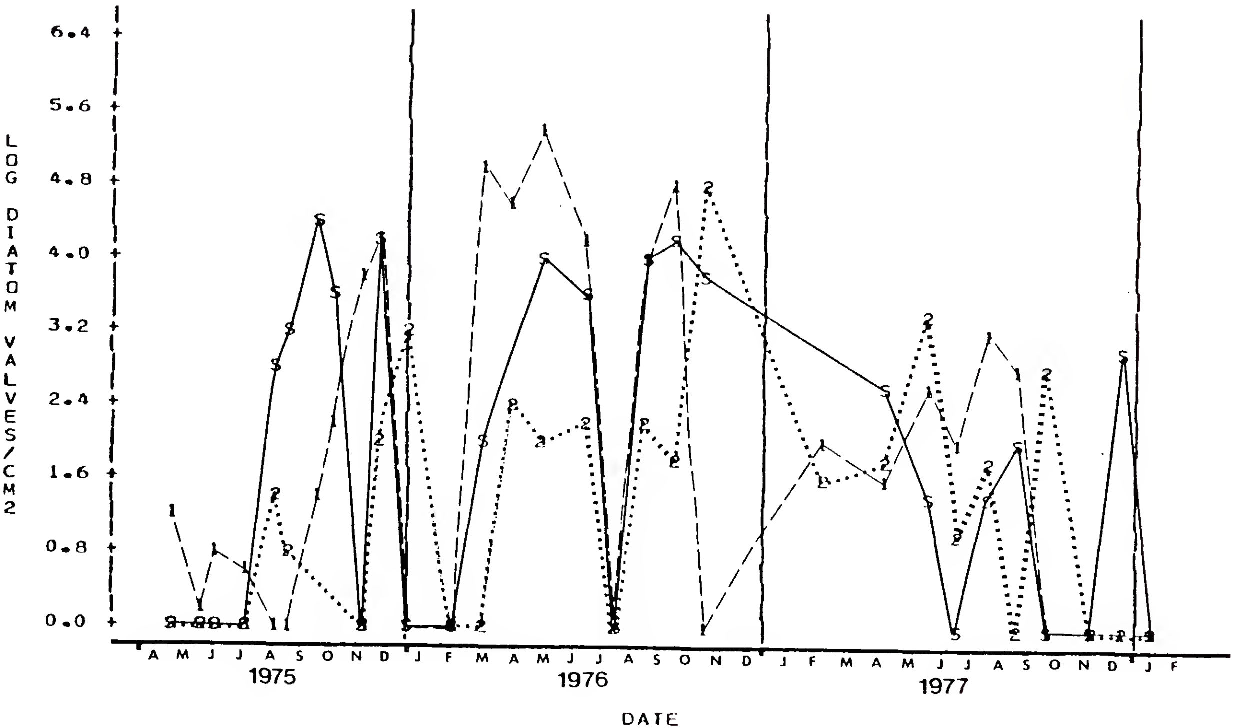


Figure 79. Pond Two Achnanthes exigua var. heterovalvata, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, — — — = one meter depth, ... = two meter depth)

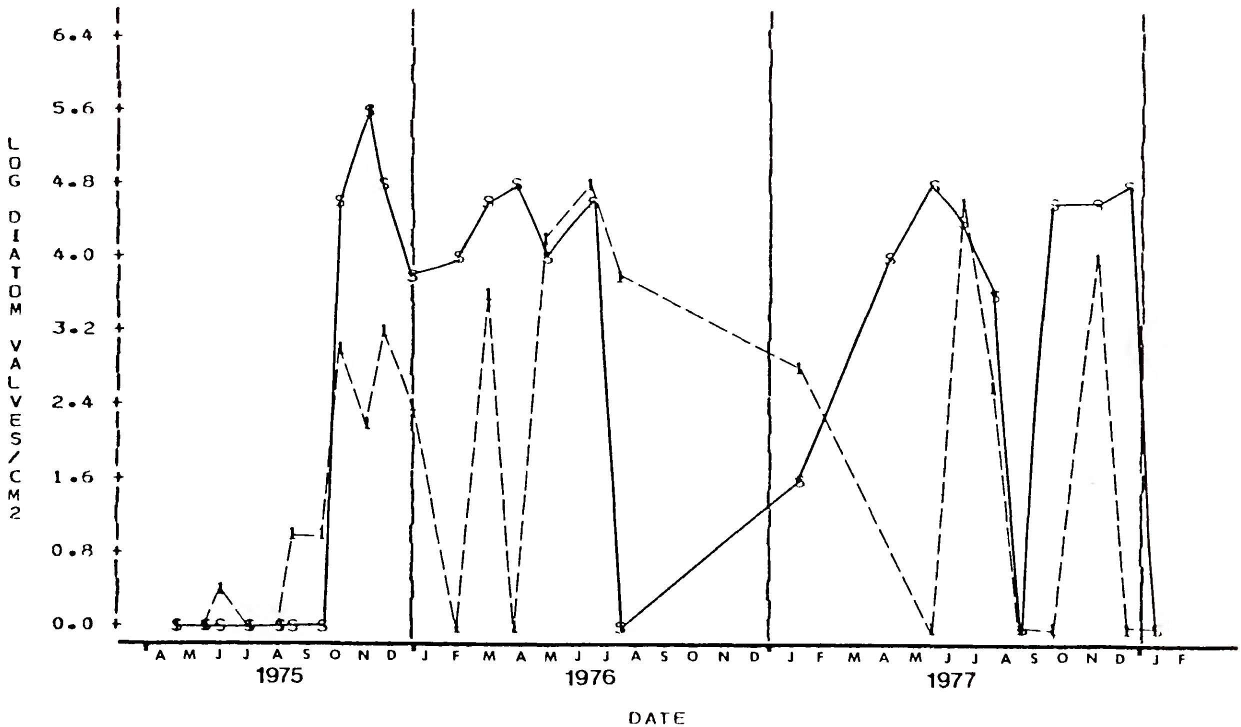


Figure 80. Pond Three <u>Achnanthes exigua</u> var. <u>heterovalvata</u>, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

The distributions of *Achnanthes exigua* var. *heterovalvata* were similar in Ponds Two and Three. Low numbers of this species were found in both pond surfaces under actively growing hyacinth populations. Large fluctuating populations occurred during hyacinth treatment and after hyacinth disappearance. Large fluctuating surface populations occurred throughout the study period. The distributions of *A. exigua* var. *heterovalvata* in the depths of Ponds Two and Three were similar to those of the surface; however, fewer diatoms of this species occurred in the depths than in the surface samples during the several months before the hyacinth cover disappeared and before water quality improved.

This periphyton diatom species was found to be positively correlated to water temperature and bicarbonate in the surface of Pond One. This diatom was positively correlated to pH and specific conductivity in the pond depths and negatively correlated to carbon dioxide and soluble salts. There were no significant correlations in the surface of Pond Two. This species was positively correlated to water temperature, total green algae, *Anabaena spiroides*, and *Microcystis aeruginosa*, and negatively correlated to carbon dioxide, *Oscillatoria limnetica*, and total *Oscillatoria* at a one meter depth in Pond Two. This diatom was positively correlated to *Oscillatoria limnetica* at a two meter depth. *A. exigua* var. *heterovalvata* was positively correlated to total green algae, and negatively correlated to percent total vegetation cover, bicarbonate, turbidity, available phosphate-phosphorus, carbon dioxide, *Oscillatoria limnetica*, and total *Oscillatoria* in the surface of Pond Three. This diatom was positively correlated with *Anabaena spiroides*, total *Anabaena*, and *Microcystis aeruginosa* at a one meter depth.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. The best surface and one meter depth model in Pond Two was pH, while bicarbonate, magnesium, and total phytoplankton was the best two meter depth model. Magnesium and total phytoplankton was the best surface model, while bicarbonate and potassium was the best one meter depth model in Pond Three.

Achnanthes hungarica Grunow

This periphyton diatom species reached a surface maximum of 6.20 X 10^4 valves/cm^2, and a one meter maximum of 6.26 X 10^4 valves/cm^2 in Pond One (Fig. 81). *A. hungarica* reached a surface maximum of 1.54 X 10^4 valves/cm^2, a one meter maximum of 1.08 X 10^5 valves/cm^2, and a two meter maximum of 2.08 X 10^3 valves/cm^2 in Pond Two (Fig. 82). *A. hungarica* reached a surface maximum of 1.15 X 10^5 valves/cm^2, and a one meter maximum of 4.34 X 10^4 valves/cm^2 in Pond Three (Fig. 83).

Large fluctuating populations of *A. hungarica* occurred in all three ponds. The surface populations of this species were minimal during and after hyacinth treatment in Ponds Two and Three, but increased dramatically after hyacinth disappearance.

This diatom was positively correlated to Secchi disk disappearance and negatively correlated to light penetration,

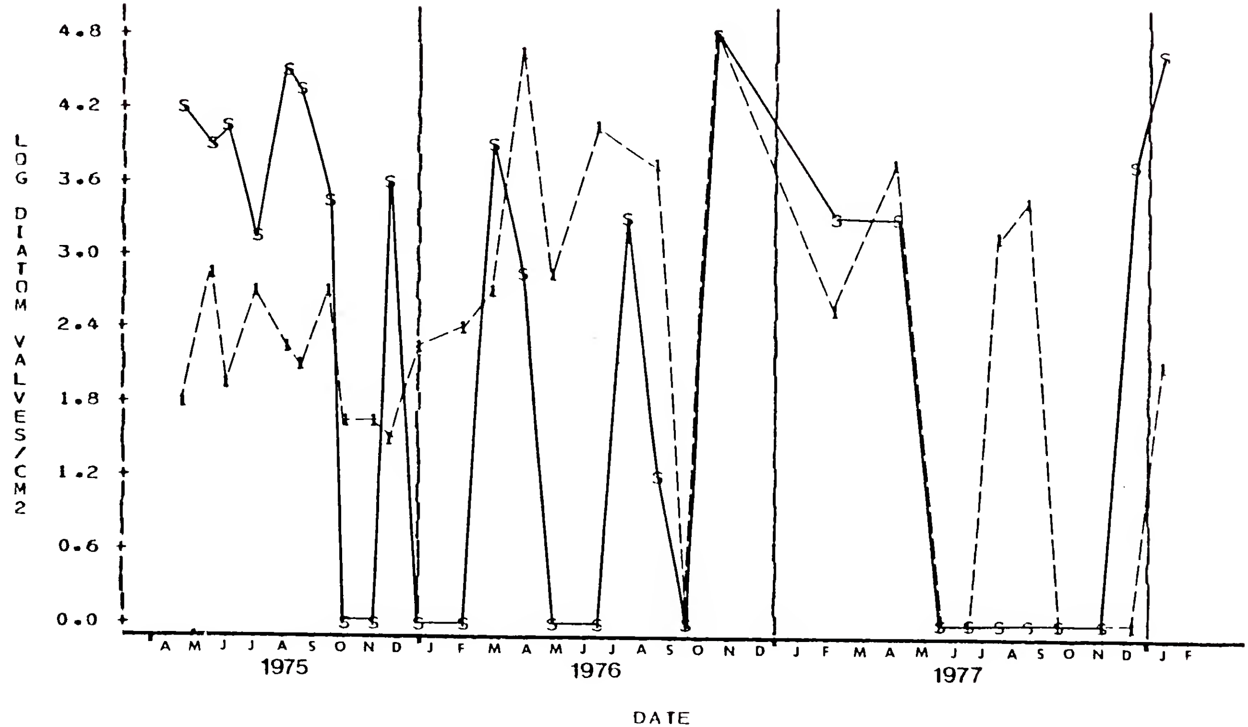


Figure 81. Pond One <u>Achnanthes hungarica</u>, expressed as the number of <u>diatom valves/cm^2 in log$_{10}$</u> (——— = pond surface, – – – = one meter depth).

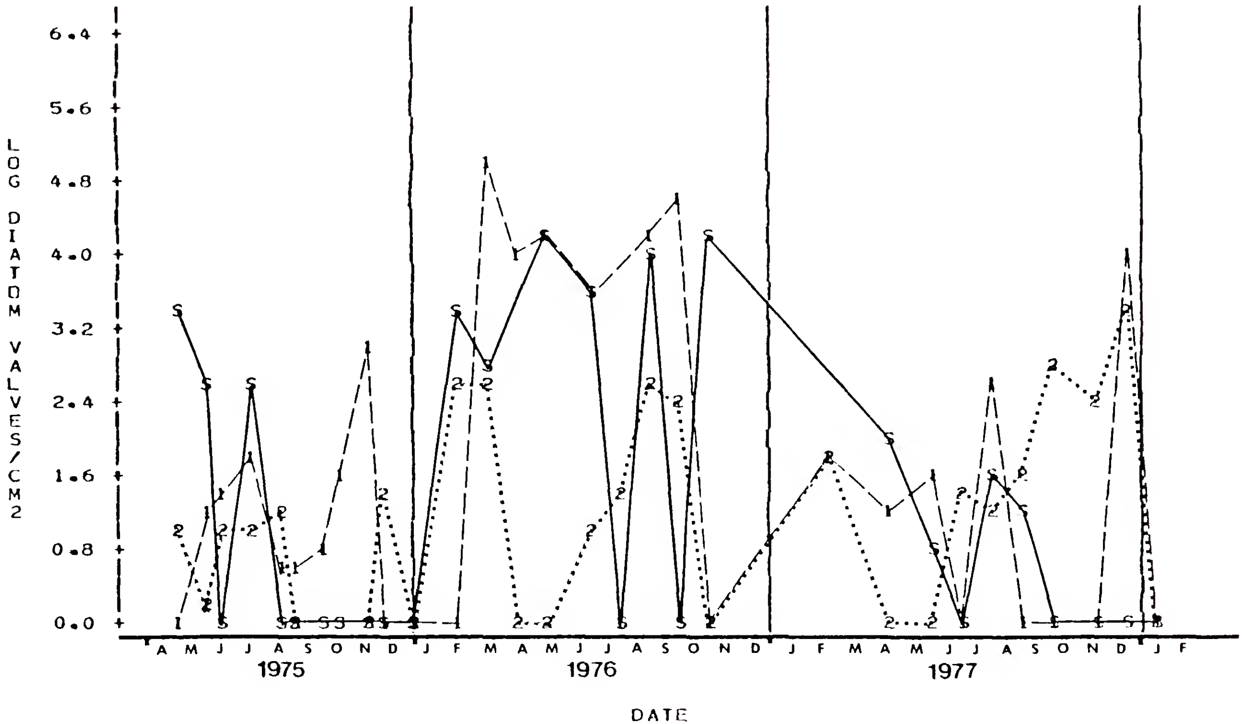


Figure 82. Pond Two <u>Achnanthes hungarica</u>, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, — — — = one meter depth, ·········= two meter depth).

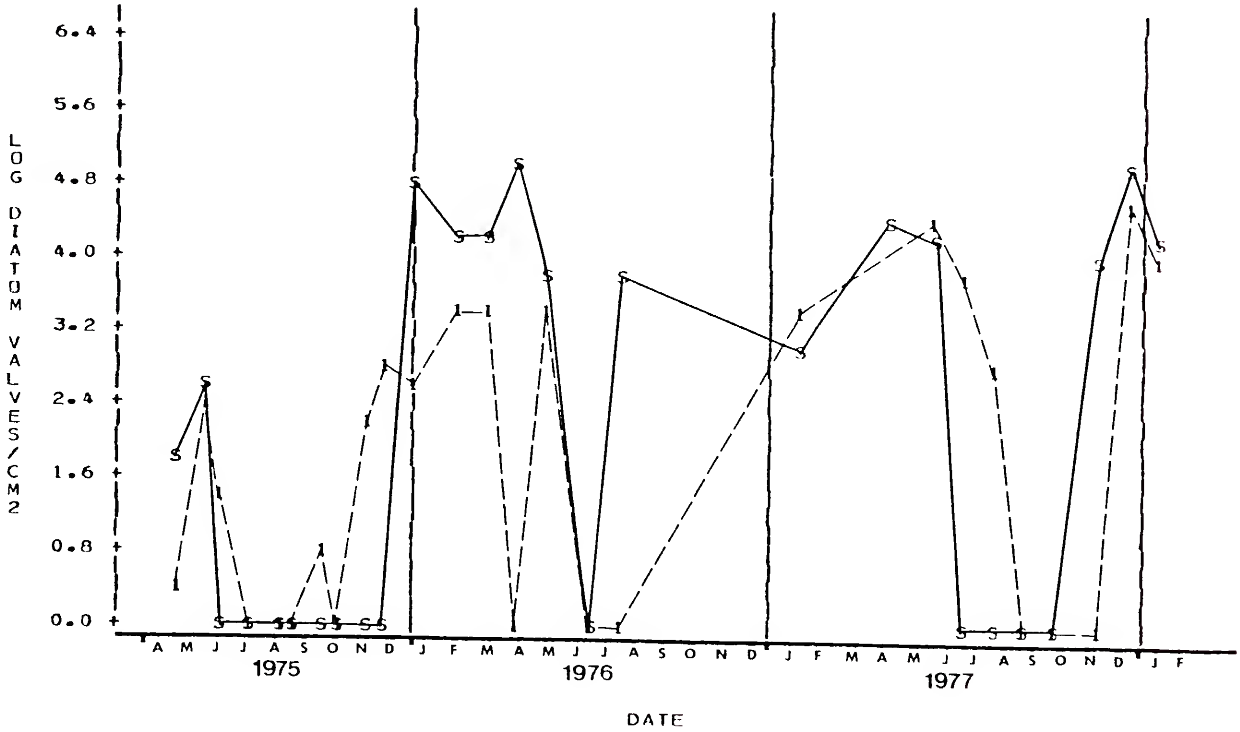


Figure 83. Pond Three Achnanthes hungarica, expressed as the number of diatom valves/cm^2 in log 10 (——— = pond surface, – – – = one meter depth).

soluble salts, calcium, *Oscillatoria subbrevis*, and total *Anabaena* in the surface of Pond One. *A. hungarica* was negatively correlated with specific conductivity, and total green algae at a one meter depth. This diatom was positively correlated with water temperature, *Anabaena spiroides*, and *Microcystis aeruginosa* in the surface of Pond Two. No significant correlations were found at the one meter depth in Pond Two, but this diatom was positively correlated to *Oscillatoria subbrevis* at the two meter depth. This diatom was positively correlated to dissolved oxygen and pH in the pond surface, and to soluble salts at a one meter depth in Pond Three. Negative correlations in Pond Three included percent total vegetation cover, water temperature, bicarbonate, and carbon dioxide in the pond surface, and percent total vegetation cover, bicarbonate, carbon dioxide, turbidity, total phosphate-phosphorus, and available phosphate-phosphorus at the one meter depth.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Turbidity was the best surface model in Pond Two. The best one meter depth model was pH while bicarbonate, turbidity, and percent total vegetation cover was the best model at a two meter depth in Pond Two. Bicarbonate and potassium was the best model in both the pond surface and depth in Pond Three.

Cyclotella Meneghiniana Kütz.

This periphyton diatom species reached a surface maximum of 8.38×10^4 valves/cm^2, and a one meter maximum of 2.67×10^5 valves/cm^2 in Pond One (Fig. 84). *C. Meneghiniana* reached a surface maximum of 8.82×10^4 valves/cm^2, a one meter maximum 2.02×10^5 valves/cm^2, and a two meter maximum of 7.20×10^4 valves/cm^2 in Pond Two (Fig. 85). This species reached a surface maximum of 2.20×10^5 valves/cm^2, and a one meter maximum of 8.53×10^5 valves/cm^2 in Pond Three (Fig. 86).

C. Meneghiniana populations fluctuated greatly before hyacinth treatment in Pond One and stabilized at dense populations after hyacinth disappearance. *C. Meneghiniana* was found to be in higher concentrations in the depths of Ponds Two and Three than in the pond surfaces during hyacinth treatment. *C. Meneghiniana* eventually reached high concentrations in the surface and depths of Pond Three after hyacinth disappearance. The populations of this diatom varied greatly in Pond Two.

This diatom was negatively correlated to percent total vegetation cover, and carbon dioxide in all the pond surfaces and depths. *C. Meneghiniana* was also negatively correlated to total phosphate-phosphorus, available phosphate-phosphorus, turbidity, *Oscillatoria limnetica,* and total *Oscillatoria,* and positively correlated to soluble salts, pH, and *Oscillatoria subbrevis,* at most stations. *C. Meneghiniana* also showed significant positive correlations at several stations with calcium, magnesium, specific conductivity, and total green algae.

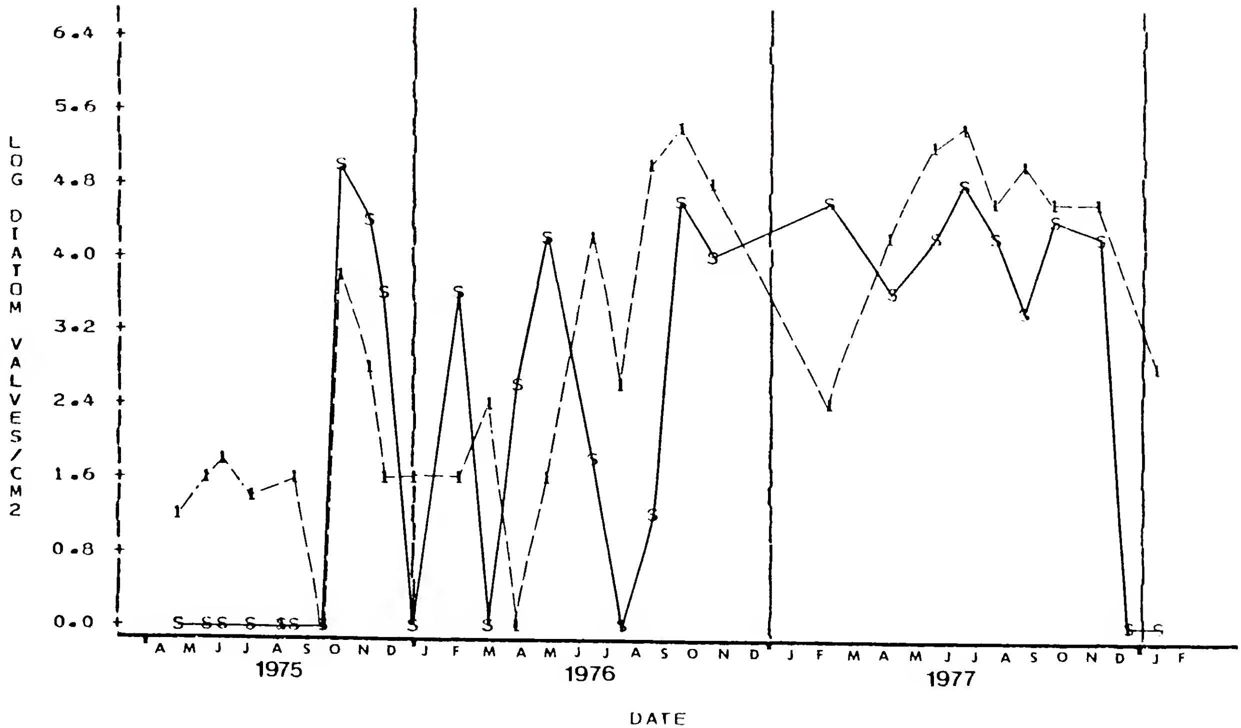


Figure 84. Pond One Cyclotella Meneghiniana, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

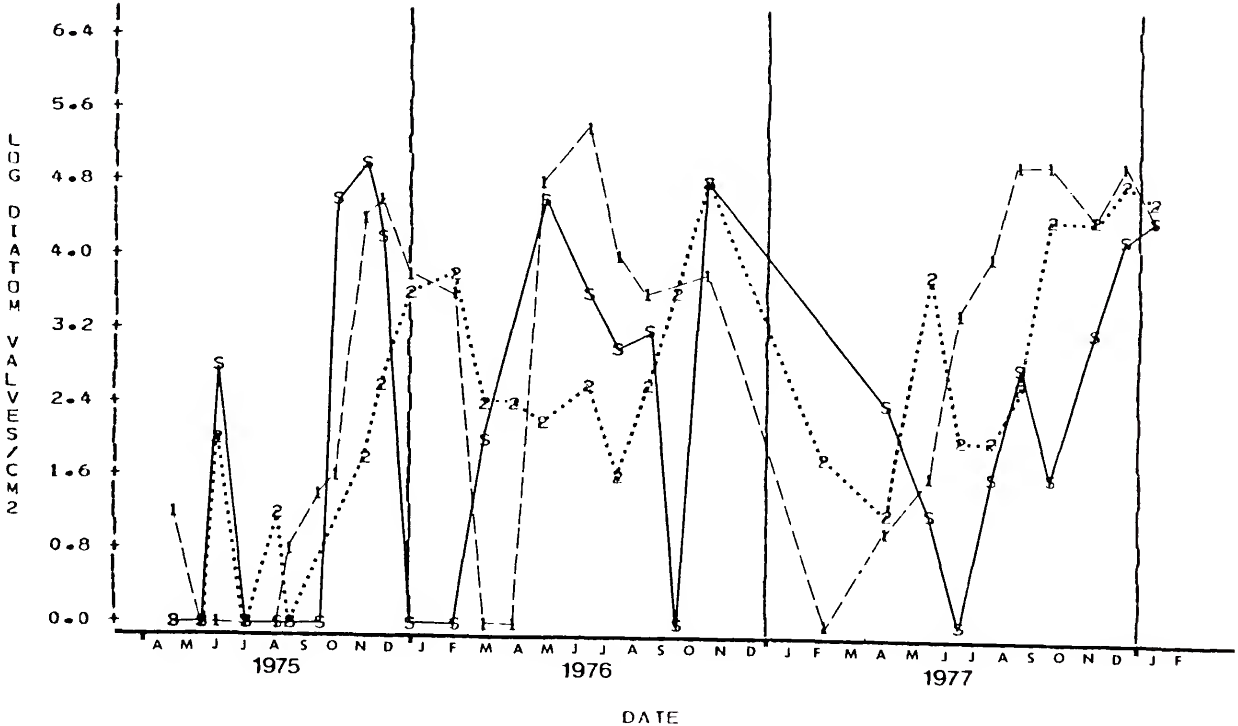


Figure 85. Pond Two Cyclotella Meneghiniana, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, — — — = one meter depth, ... = two meter depth).

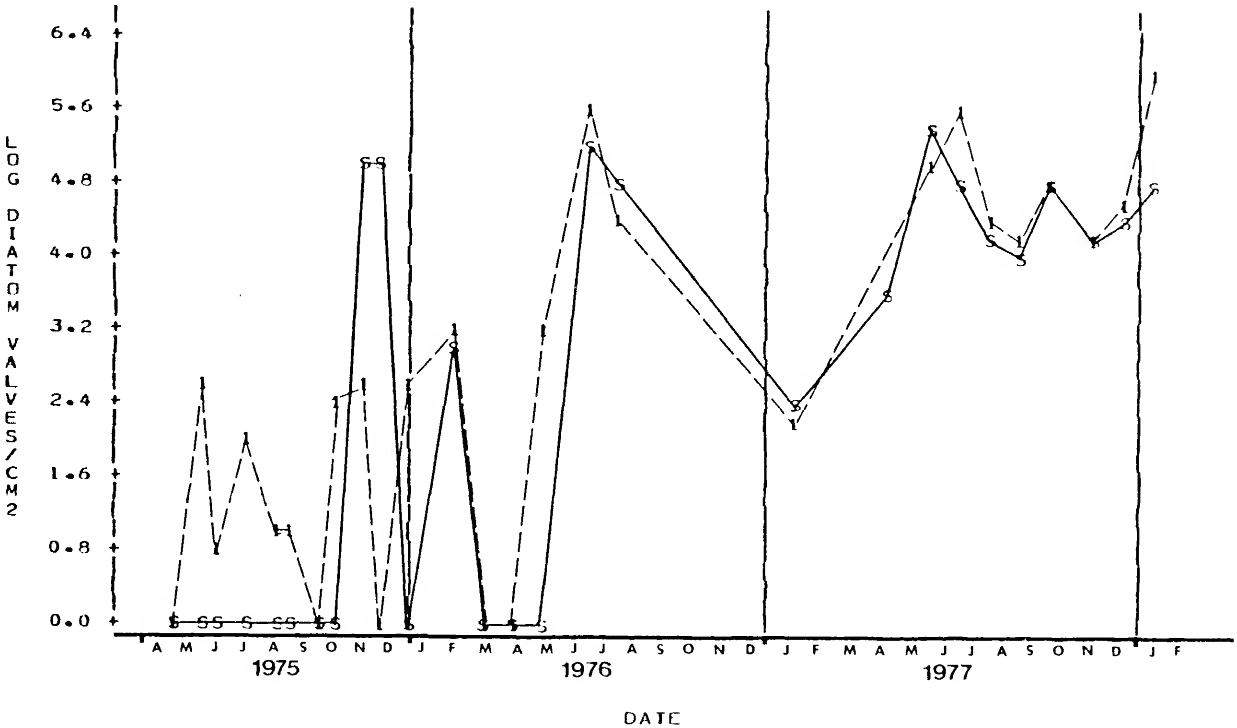


Figure 86. Pond Three Cyclotella Meneghiniana, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

Stepwise mulitple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Bicarbonate, available phosphate-phosphorus, and light penetration was the best surface model in Pond Two while turbidity and pH was the best one meter model, and bicarbonate, potassium, and specific conductivity was the best model at the two meter depth. Water temperature and total phytoplankton was the best model at the one meter depth in Pond Three. No significant models were found for the surface of Pond Three.

Eunotia curvata (Kütz.) Largerst.

This periphyton diatom species reached a surface maximum of 2.38 X 10^5 valves/cm^2, and one meter maximum of 7.06 X 10^4 valves/cm^2 in Pond One (Fig. 87). *E. curvata* reached a surface maximum of 1.66 X 10^5 valves/cm^2, a one meter maximum of 1.16 X 10^5 valves/cm^2, and a two meter maximum of 5.86 X 10^3 valves/cm^2 in Pond Two (Fig. 88). *E. curvata* attained a surface maximum of 4.36 X 10^4 valves/cm^2 and a one meter maximum of 3.47 X 10^4 valves/cm^2 in Pond Three (Fig. 89).

E. curvata attained large surface populations under actively growing hyacinths in all ponds, and also after hyacinth treatment when water quality conditions were foul. Surface populations of this diatom did not occur after hyacinth disappearance or after water quality improved. Populations of *E. curvata* occasionally occurred in the pond depths, after hyacinth disappearance.

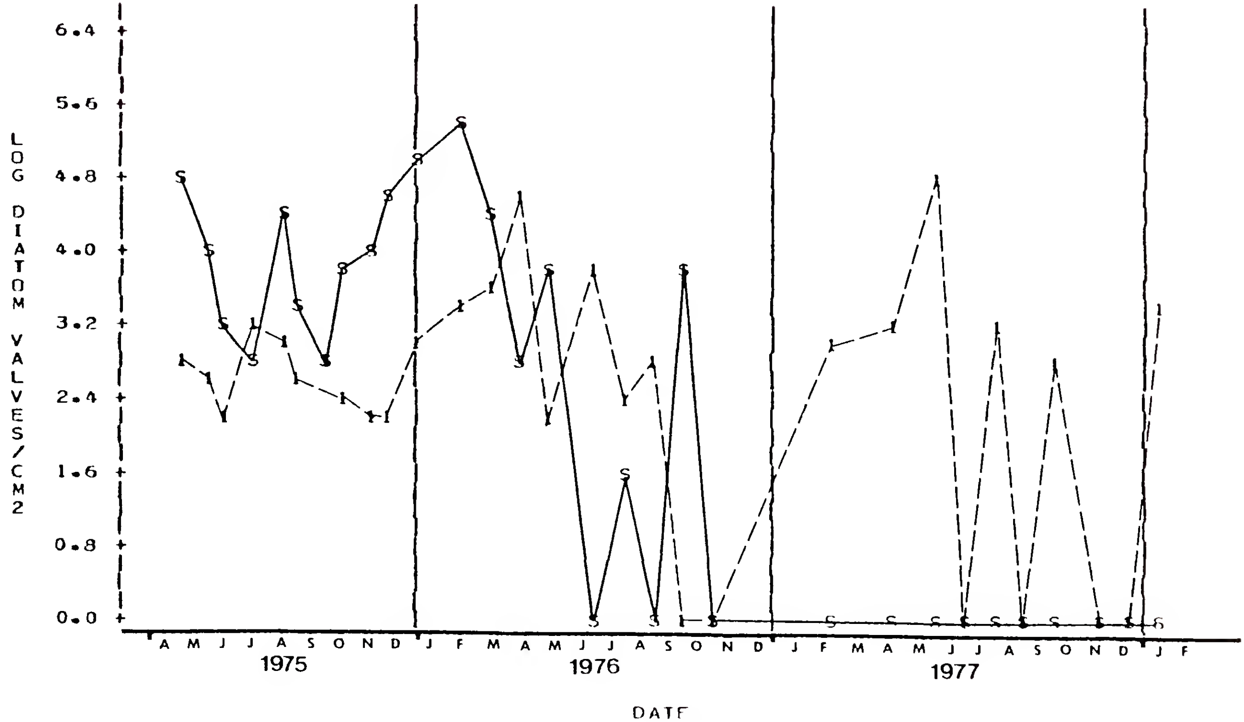


Figure 87. Pond One <u>Eunotia curvata</u>, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

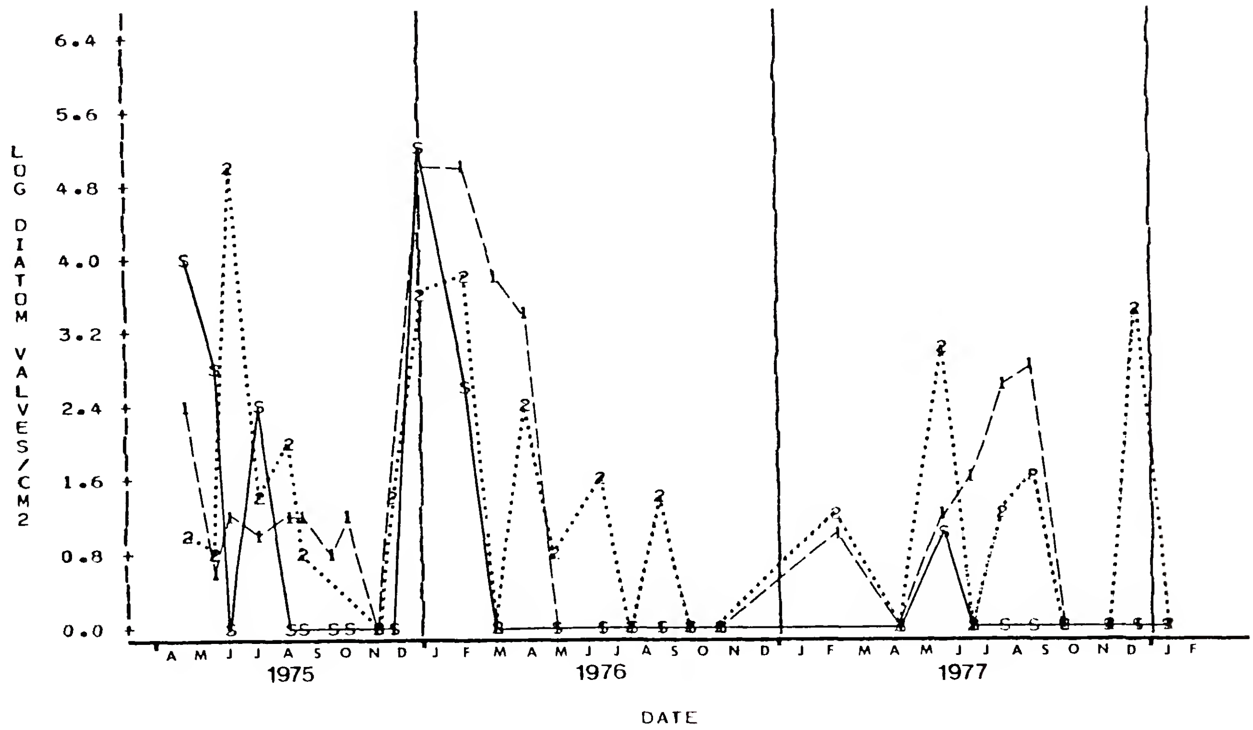


Figure 88. Pond Two Eunotia curvata, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, — — — = one meter depth, ········ = two meter depth).

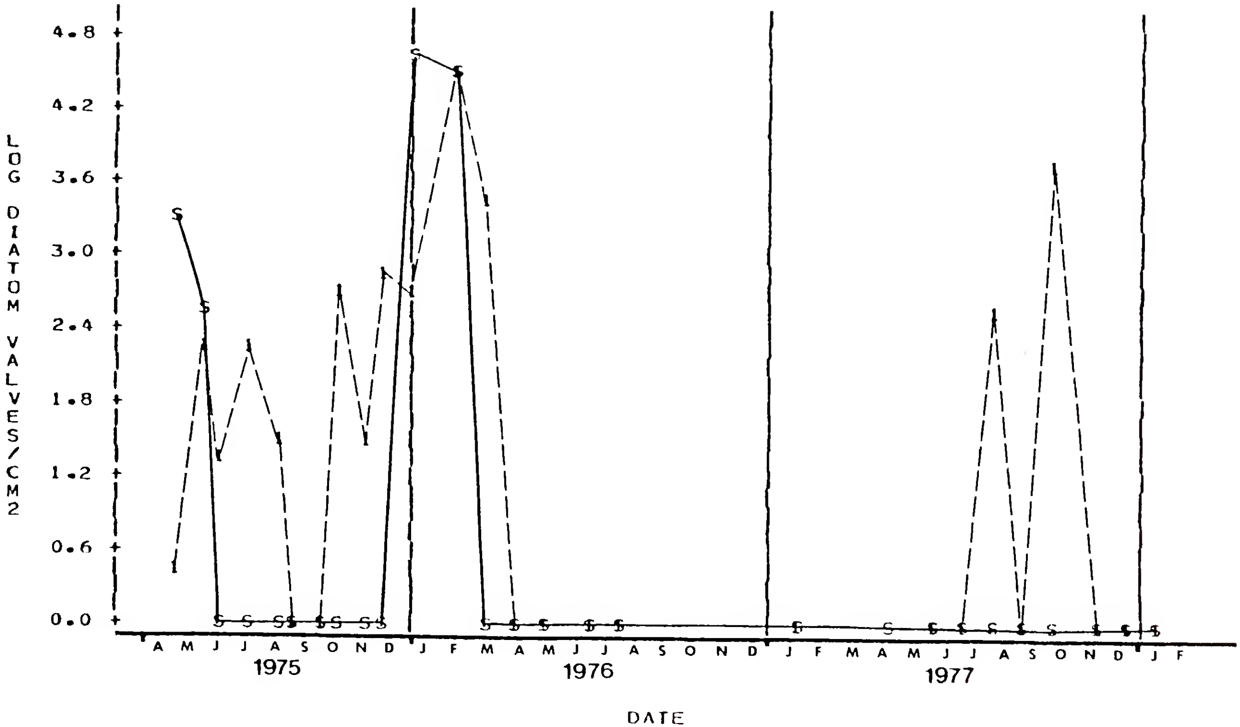


Figure 89. Pond Three <u>Eunotia curvata</u>, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

This periphyton diatom was found to be negatively correlated to calcium and magnesium in all the pond surfaces and depths. *E. curvata* was positively correlated to percent total vegetation cover, and negatively correlated to *Oscillatoria subbrevis* in the surfaces of Ponds One and Two, and in Pond One at the one meter depth.

This diatom was also positively correlated to carbon dioxide, available phosphate-phosphorus, and *Oscillatoria limnetica* in the surface of Pond One, and also negatively correlated to dissolved oxygen, light penetration, pH, bicarbonate, soluble salts, and specific conductivity. This diatom was also negatively correlated with total phytoplankton, total blue-green algae and total *Oscillatoria* at a one meter depth in Pond One. *E. curvata* was positively correlated to soluble salts and total green algae in the surface of Pond Two. Total blue-greens was negatively correlated to *E. curvata* at the one meter depth in Pond Two, while potassium, total phosphate-phosphorus, and available phosphate-phosphorus were positively correlated at the two meter depth. Soluble salts and total phytoplankton were negatively correlated to *E. curvata* in the pond surface, while pH was negatively correlated at the one meter depth in Pond Three. *E. curvata* was positively correlated to Secchi disk disappearance in the surface of Pond Three.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Nitrate-nitrogen was the best surface model in Pond Two. Specific conductivity, total vegetation cover, light penetration, and nitrate-nitrogen was the best one meter model in Pond Two, while water temperature was the best model at the two meter depth. Bicarbonate and water temperature was the best surface model in Pond Three, while bicarbonate and potassium was the best one meter depth model.

Eunotia pectinalis (Kütz.) Rabenhorst

This periphyton diatom species reached a surface maximum of 4.13×10^5 valves/cm^2, and a one meter maximum of 1.56×10^5 valves/cm^2 in Pond One (Fig. 90). *E. pectinalis* reached a surface maximum of 1.17×10^4 valves/cm^2, a one meter maximum of 4.22×10^5 valves/cm^2, and a two meter maximum of 1.20×10^4 valves/cm^2 in Pond Two (Fig. 91). This species reached a surface maximum of 1.01×10^5 valves/cm^2 and a one meter maximum of 2.30×10^4 valves/cm^2 in Pond Three (Fig. 92).

E. pectinalis was commonly found beneath actively growing hyacinths. No surface populations of this species occurred during hyacinth treatment in any of the three ponds, but large population peaks did occur soon after the hyacinth mats began to disappear. *E. pectinalis* was also commonly found after hyacinth disappearance, reaching large fluctuating populations in the pond surfaces and depths.

This periphyton diatom species was positively correlated to percent total vegetation cover, and negatively correlated to pH and soluble salts. *E. pectinalis* was positively correlated

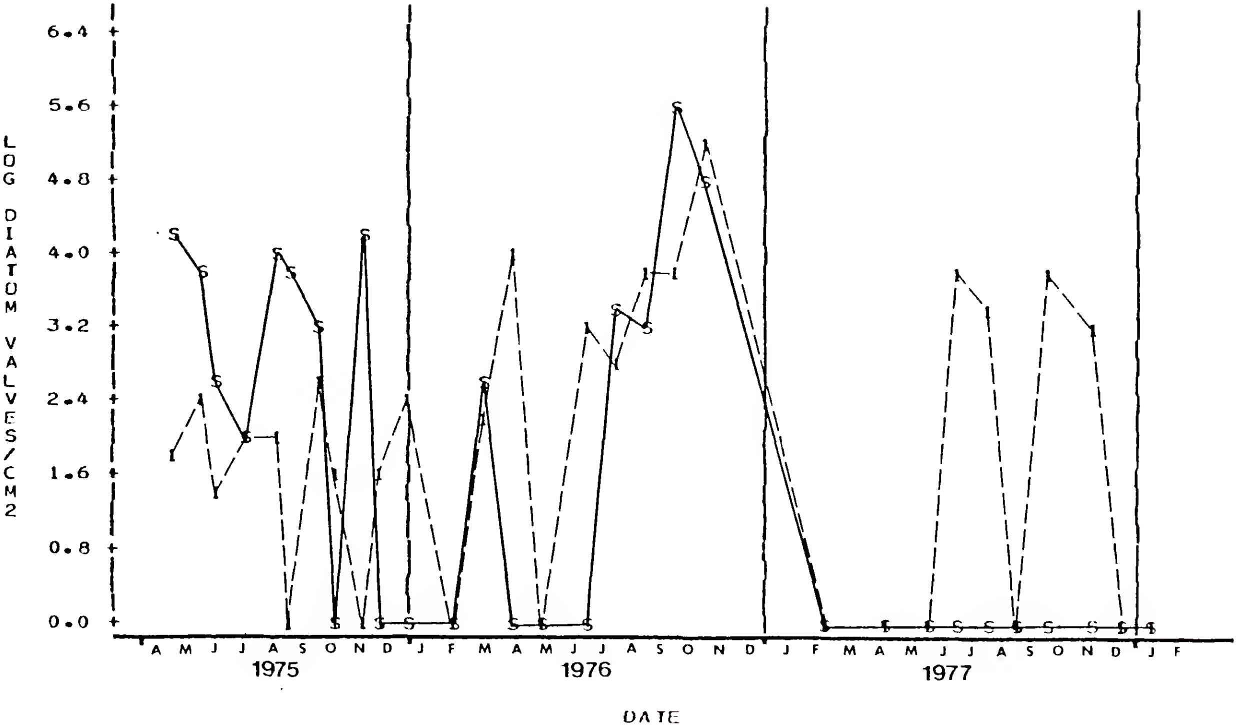


Figure 90. Pond One <u>Eunotia pectinalis</u>, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth)

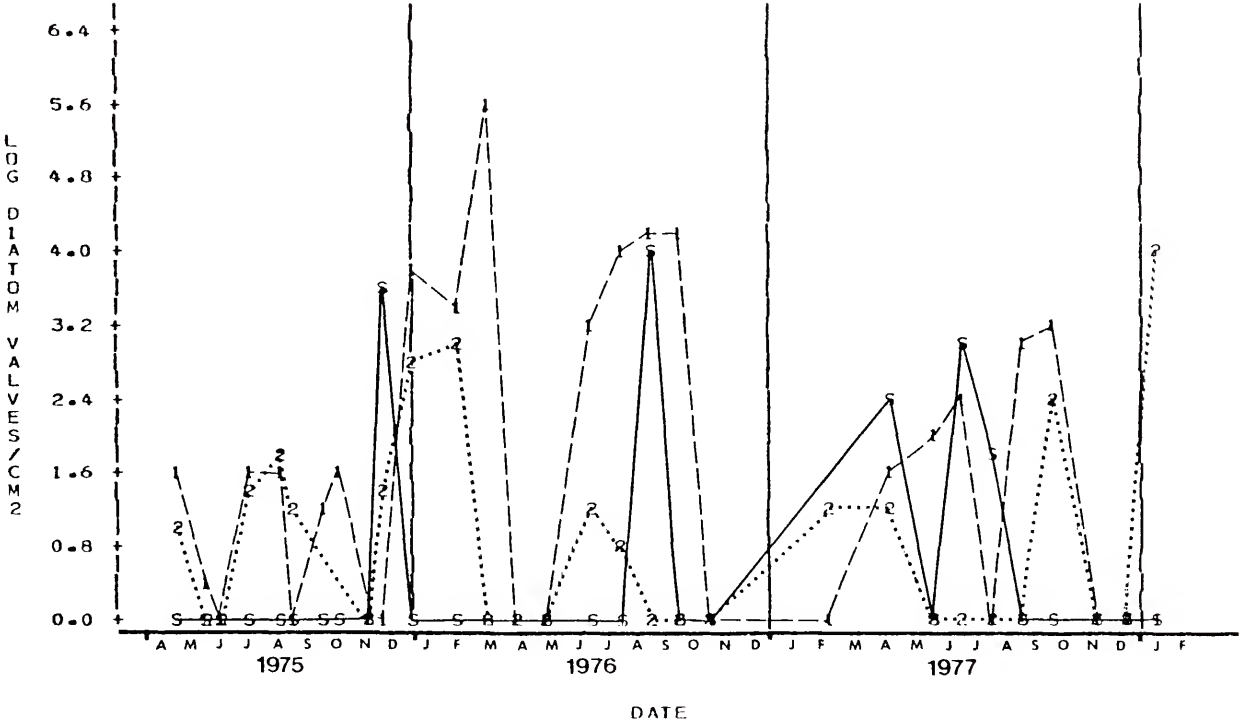


Figure 91. Pond Two *Eunotia pectinalis*, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth, ········ = two meter depth).

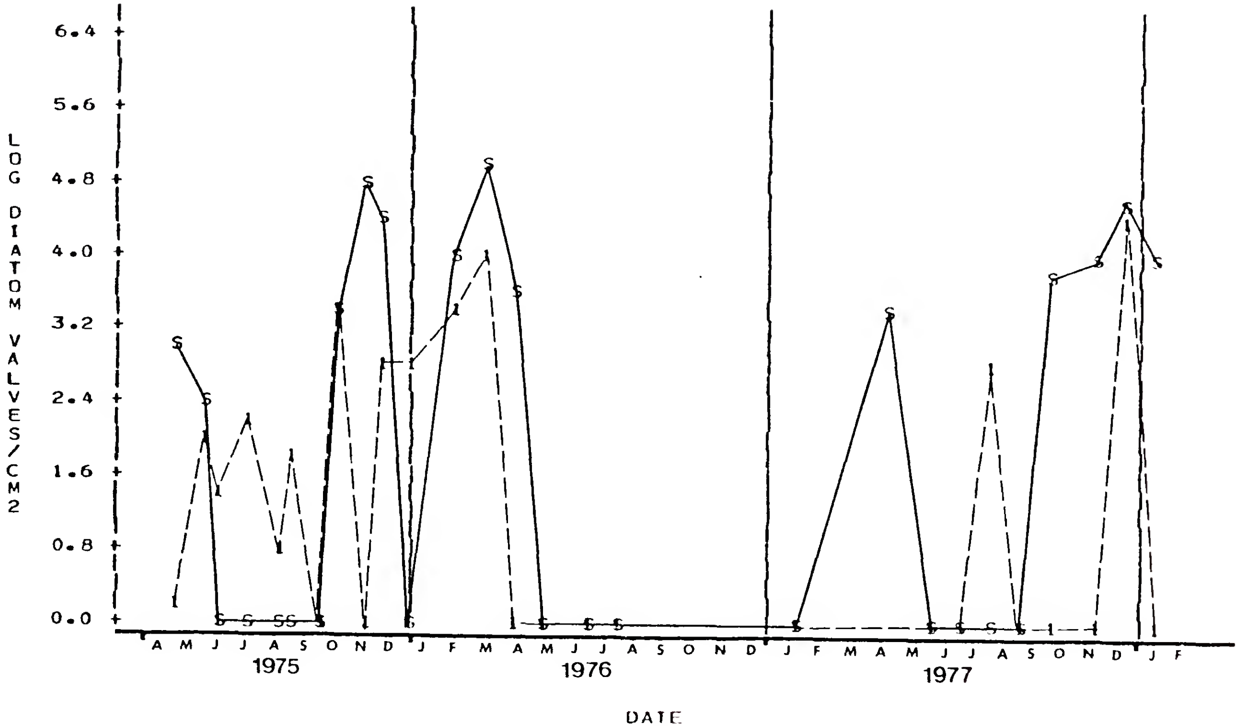


Figure 92. Pond Three Eunotia pectinalis, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

to *Oscillatoria subbrevis* and negatively correlated to potassium at a one meter depth in Pond One. No significant correlations were found in the surface of Pond Two, but at a one meter depth positive correlations were found with water temperature and *Oscillatoria subbrevis*. This diatom was negatively correlated with water temperature and positively correlated with dissolved oxygen at a two meter depth in Pond Two. *E. pectinalis* was negatively correlated with water temperature, *Oscillatoria subbrevis*, *Anabaena spiroides*, and total *Anabaena* in the surface of Pond Three. A positive correlation was found with *Oscillatoria limnetica* and negative correlations with pH, magnesium, and *Oscillatoria subbrevis* at a one meter depth in Pond Three.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Turbidity was the best surface model in Pond Two. Bicarbonate, soluble salts, total vegetation cover, and nitrate-nitrogen was the best one meter depth model in Pond Two, while calcium, magnesium, and percent total vegetation cover was the best two meter depth model in Pond Two. Specific conductivity and nitrate-nitrogen was the best surface model, while bicarbonate and potassium was the best one meter depth model in Pond Three.

Gomphonema affine var. *insigne* Kütz.

This periphyton diatom species reached a surface maximum of 6.89 X 10^4 valves/cm^2 and a one meter maximum of 2.03 X 10^5

valves/cm^2 in Pond One (Fig. 93). *G. affine* var. *insigne* reached a surface maximum of 2.28 X 10^5 valves/cm^2, a one meter maximum of 7.92 X 10^4 valves/cm^2, and a two meter maximum of 8.64 X 10^4 valves/cm^2 in Pond Two (Fig. 94). It reached a surface maximum of 1.48 X 10^5 valves/cm^2 and one meter maximum of 3.08 valves/cm^2 during the study in Pond Three (Fig. 95).

G. affine var. *insigne* was commonly found in the pond surfaces below actively growing hyacinth populations where it experienced large fluctuating populations before and after hyacinth treatment. This diatom species was not found during hyacinth treatment in Ponds Two and Three, but was common in the pond surfaces and depths after hyacinth disappearance.

This periphyton diatom species was found to be negatively correlated to percent total vegetation cover, total phosphate-phosphorus, and available phosphate-phosphorus in all the pond surfaces and depths except for the surface of Pond One. This diatom was positively correlated with light penetration in the pond surface and negatively correlated with potassium, total phytoplankton, and *Oscillatoria limnetica* at a one meter depth in Pond One.

G. affine var. *insigne* was positively correlated to pH, soluble salts, *Microcystis aeruginosa,* and total green algae, and negatively correlated with bicarbonate, carbon dioxide, and specific conductivity in the surface of Pond Two. A positive correlation with *Oscillatoria subbrevis* occurred at the one meter depth and a negative correlation with carbon dioxide was

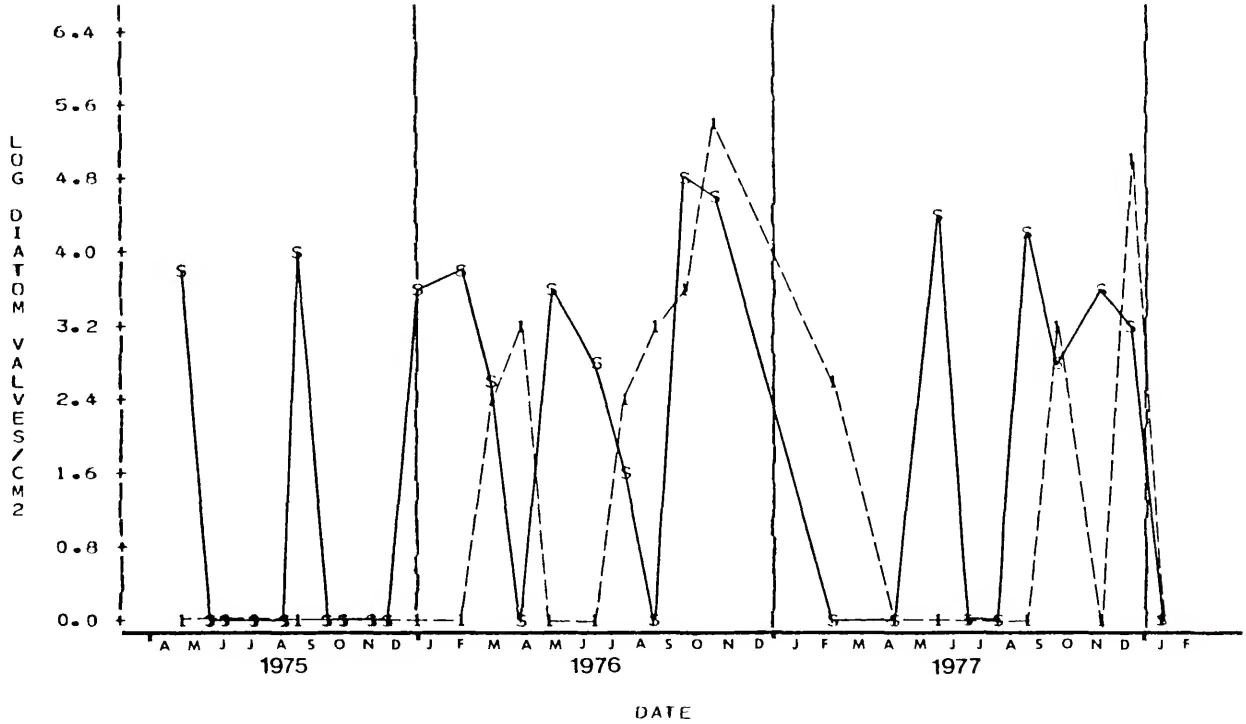


Figure 93. Pond One Gomphonema affine var. insigne, expressed as the number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

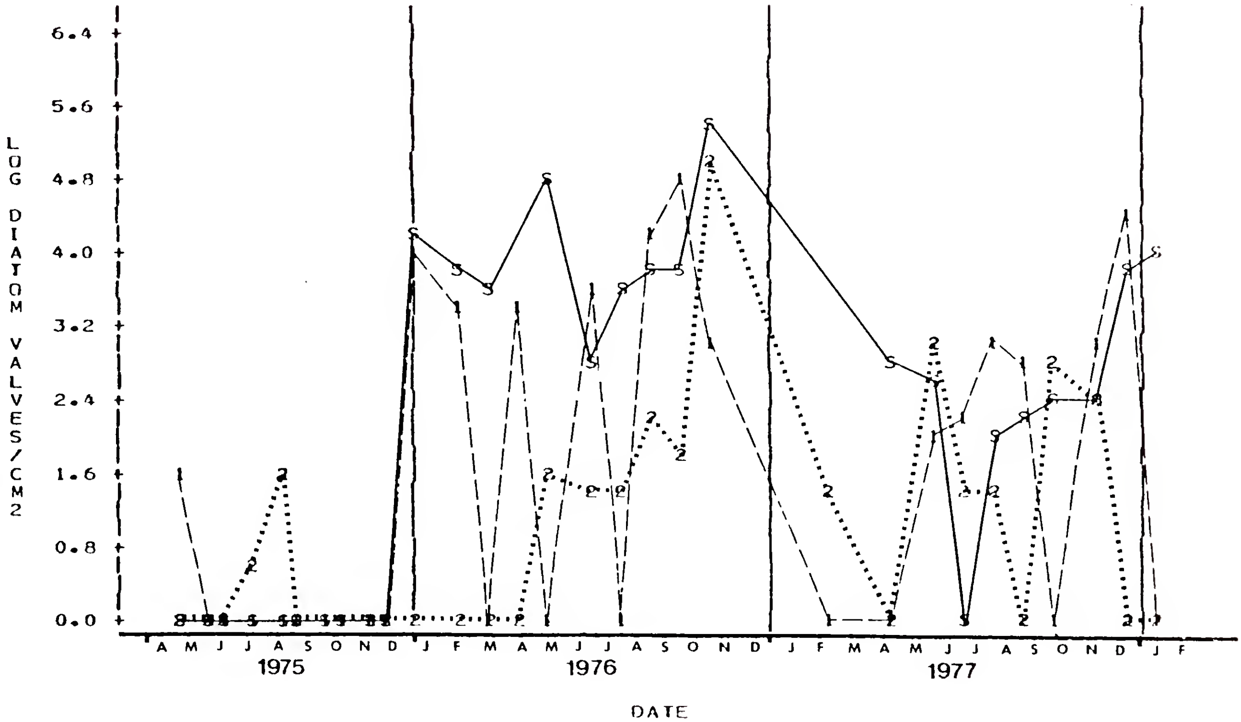


Figure 94. Pond Two Gomphonema affine var. insigne, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth, ········ = two meter depth).

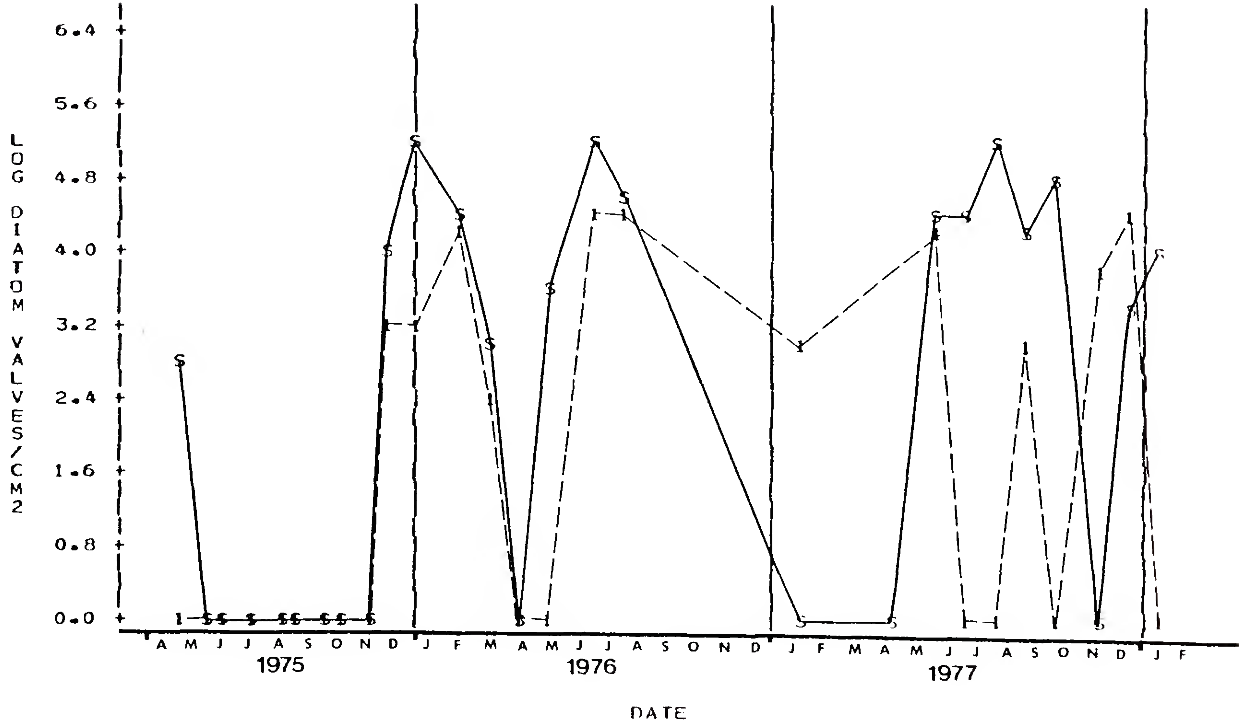


Figure 95. Pond Three *Gomphonema affine* var. *insigne*, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

found at a two meter depth. Positive correlations were found with pH, soluble salts, nitrate-nitrogen, calcium, total phytoplankton, total blue-green algae, *Oscillatoria subbrevis*, and total *Oscillatoria*.

G. affine var. *insigne* was negatively correlated to carbon dioxide, and magnesium in the surface and one meter depth of Pond Three. Other positive correlations in the pond surface included pH, *Oscillatoria subbrevis*, *Anabaena spiroides*, and total *Anabaena*, while turbidity and potassium were negatively correlated. *Oscillatoria limnetica* was negatively correlated and *Microcystis aeruginosa* was positively correlated at the one meter depth.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Soluble salts was the best surface model in Pond Two. The best one meter depth model was percent total vegetation cover, while potassium, nitrate-nitrogen, and Secchi disk disappearance was the best two meter depth model in Pond Two. Bicarbonate and turbidity was the best surface model, while pH and light penetration was the best one meter depth model in Pond Three.

Gomphonema gracile Ehr.

This periphyton diatom species reached a surface maximum of 2.62×10^4 valves/cm^2, and one meter maximum of 3.13×10^4 valves/cm^2 in Pond One (Fig. 96). *G. gracile* reached a surface maximum of 1.55×10^5 valves/cm^2, a one meter maximum of 8.25

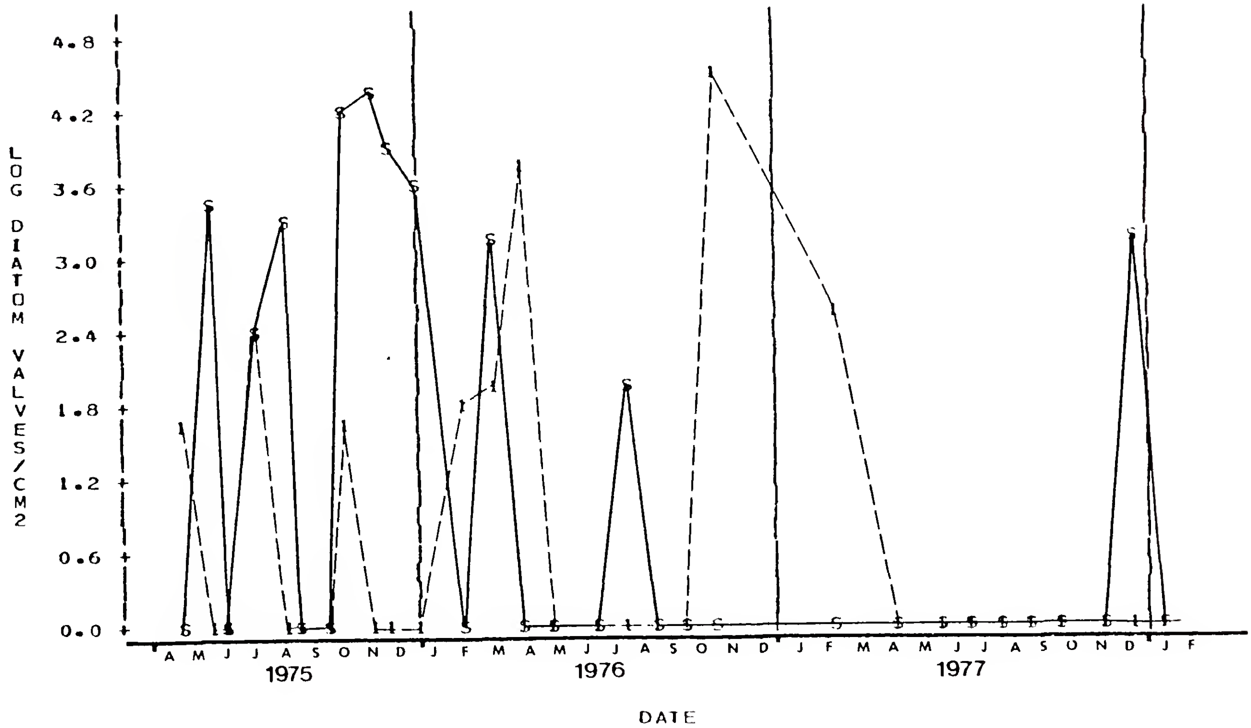


Figure 96. Pond One Gomphonema gracile, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, – – – = one meter depth).

$\times 10^4$ valves/cm^2, and a two meter maximum of 123.0 valves/cm^2 in Pond Two (Fig. 97). This species reached a surface maximum of 1.80×10^5 valves/cm^2 and a one meter maximum of 1.74×10^4 valves/cm^2 during the study in Pond Three (Fig. 98).

This periphyton diatom species was commonly found in the pond surfaces before and during hyacinth treatment, but was found less frequently and in lower concentrations after hyacinths disappeared and water quality improved. *G. gracile* was commonly found in the pond depths before and after water hyacinth disappearance.

Gomphonema gracile was positively correlated to percent total vegetation cover and negatively correlated to water temperature, light penetration, pH, bicarbonate, and soluble salts in the surface of Pond One. Negative correlations were found with potassium, total blue-green algae, total *Oscillatoria, Oscillatoria subbrevis,* and total green algae at a one meter depth in Pond One.

Pond Two surface populations of *G. gracile* were negatively correlated with water temperature, soluble salts, calcium, magnesium, specific conductivity, total phytoplankton, total blue-green algae, *Oscillatoria limnetica, Oscillatoria subbrevis,* and total *Oscillatoria,* and a positive correlation was found with *Anabaena spiroides* at a one meter depth in Pond Two. Positive correlations were found with carbon dioxide, potassium, total phosphate-phosphorus, and available phosphate-phosphorus, and a negative correlation with pH at a two meter depth in Pond Two.

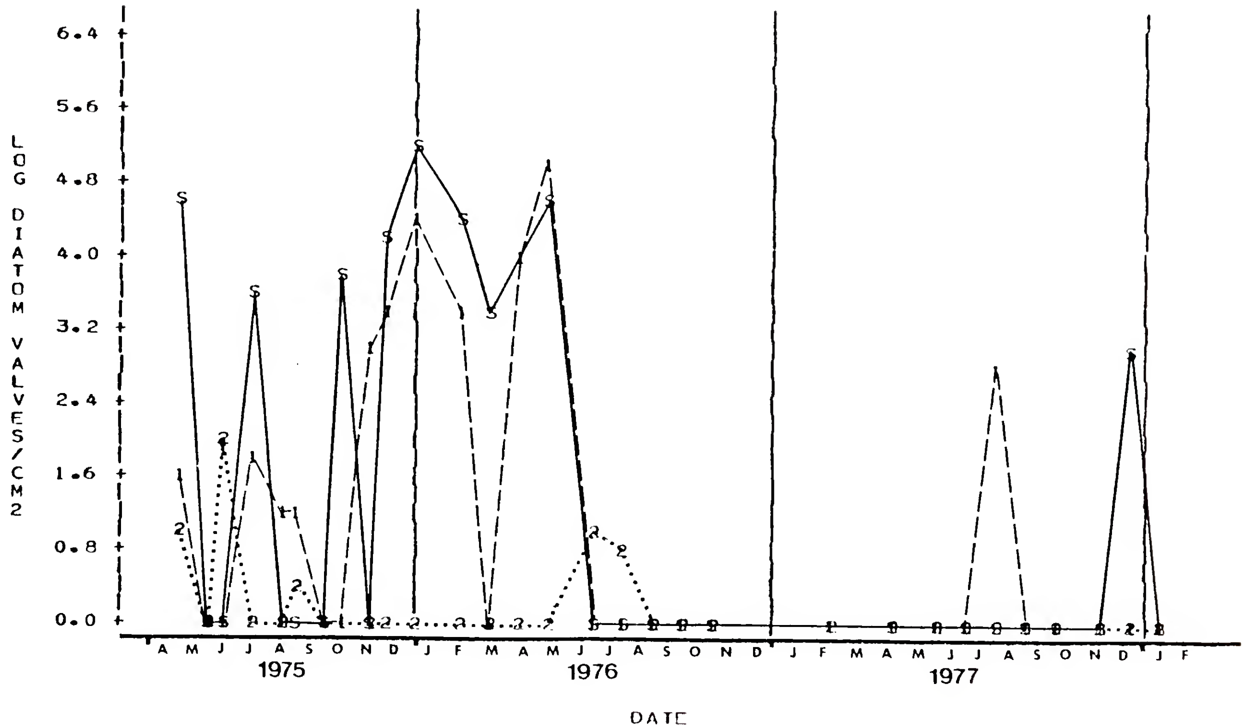


Figure 97. Pond Two *Gomphonema gracile*, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, — — — = one meter depth, ········· = two meter depth).

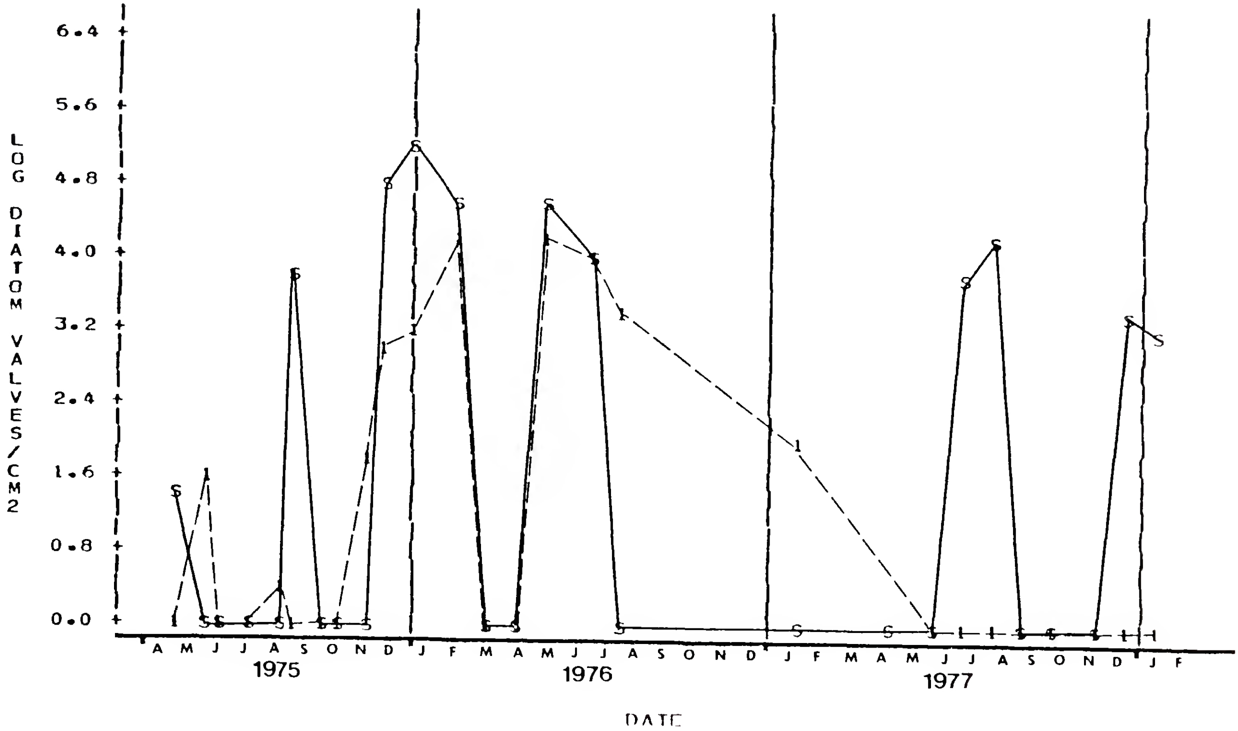


Figure 98. Pond Three Gomphonema gracile, expressed as number of diatom valves/cm^2 in log10 (——— = pond surface, – – – = one meter depth).

Negative correlations were found with calcium, magnesium, and light penetration in the surface of Pond Three. Negative correlations were found with calcium, magnesium, specific conductivity, *Oscillatoria limnetica*, and total *Oscillatoria* at a one meter depth in Pond Three, while positive correlations were found with *Anabaena spiroides*, *Anabaena schermer*, total *Anabaena*, and *Microcystis aeruginosa*.

Stepwise multiple regressions did not provide significant models for the surface or depths of Pond One. Nitrate-nitrogen was the best surface model in Pond Two. Specific conductivity, percent total vegetation cover, light penetration, and nitrate-nitrogen was the best one meter depth model, while pH, turbidity, and percent total vegetation cover was the best two meter depth model in Pond Two. Bicarbonate and water temperature was the best surface model in Pond Three, while water temperature and total phytoplankton was the best one meter depth model.

Gomphonema parvulum Kütz.

This periphyton diatom species reached a surface maximum of 4.39×10^5 valves/cm^2 and a one meter maximum of 9.39×10^5 valves/cm^2 in Pond One (Fig. 99). *G. parvulum* reached a surface maximum of 3.80×10^5, a one meter maximum of 4.95×10^4 valves/cm^2, and a two meter maximum of 1.06×10^3 valves/cm^2 in Pond Two (Fig. 100). Pond Three reached a surface maximum of 4.03×10^5 valves/cm^2 and a one meter maximum of 2.64×10^4 valves/cm^2 during the study (Fig. 101).

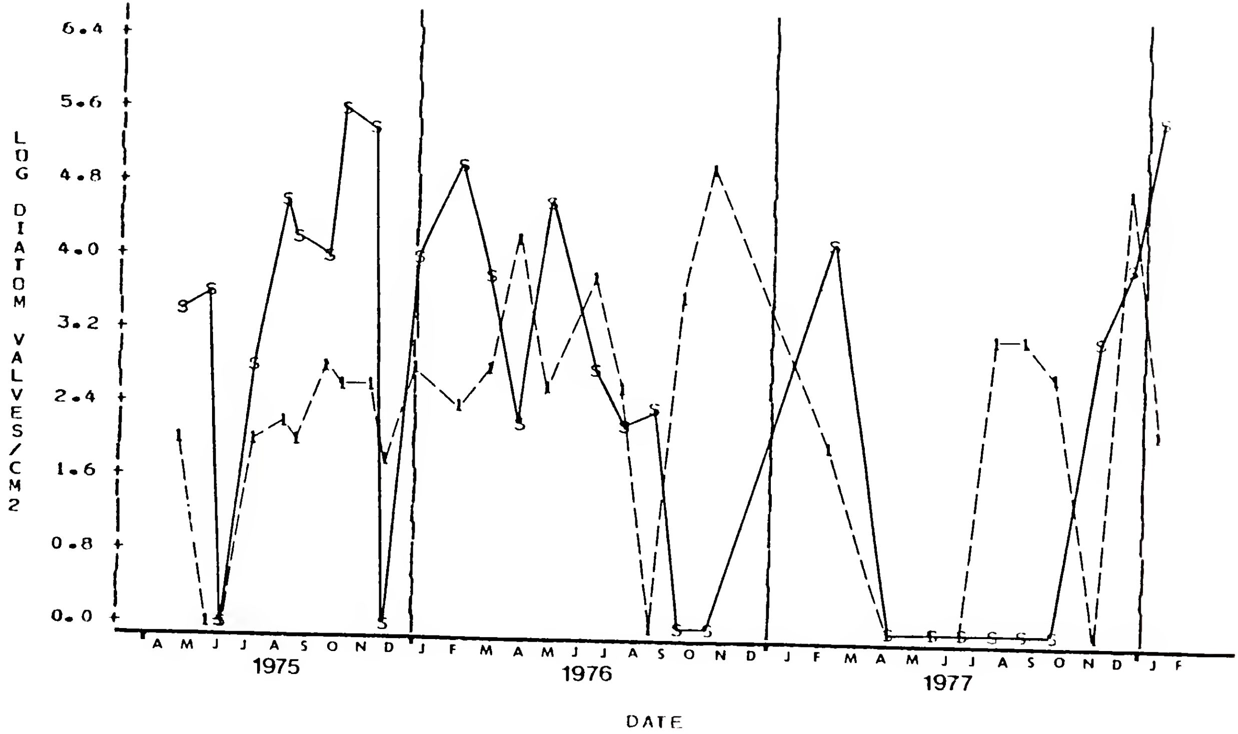


Figure 99. Pond One Gomphonema parvulum, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, – – – = one meter depth).

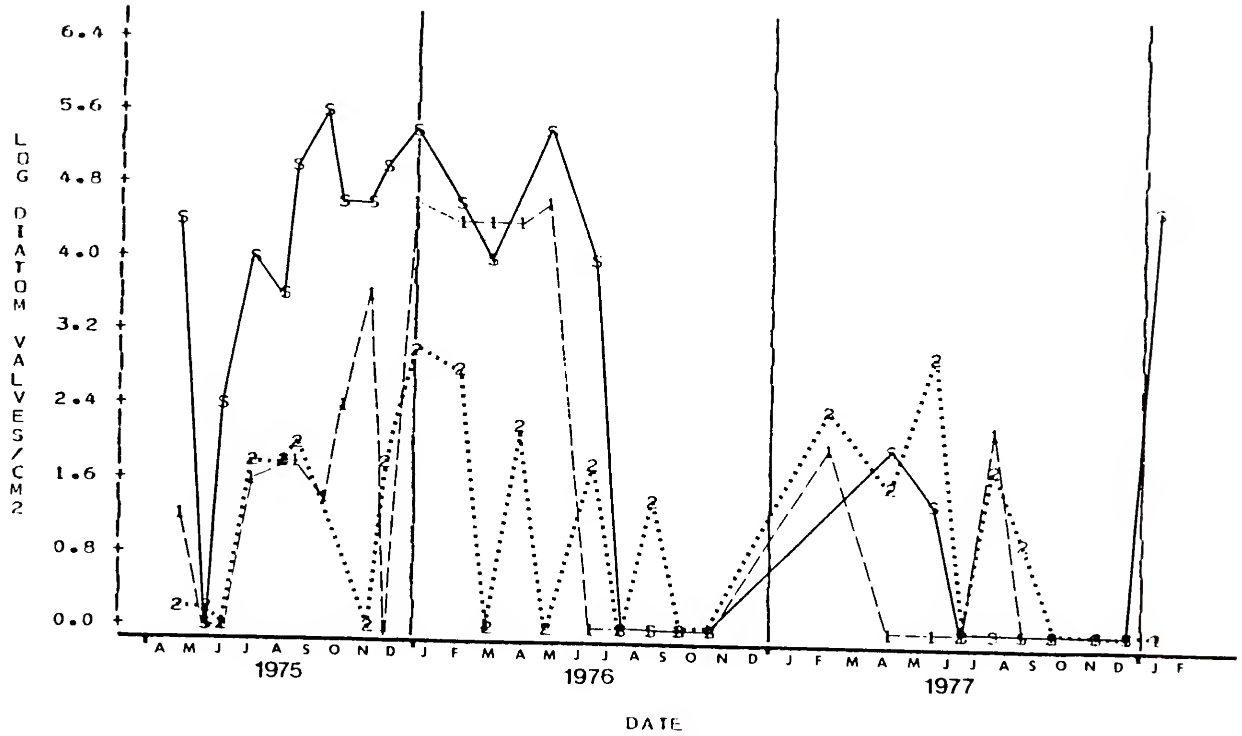


Figure 100. Pond Two Gomphonema parvulum, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, – – – = one meter depth, ········ = two meter depth).

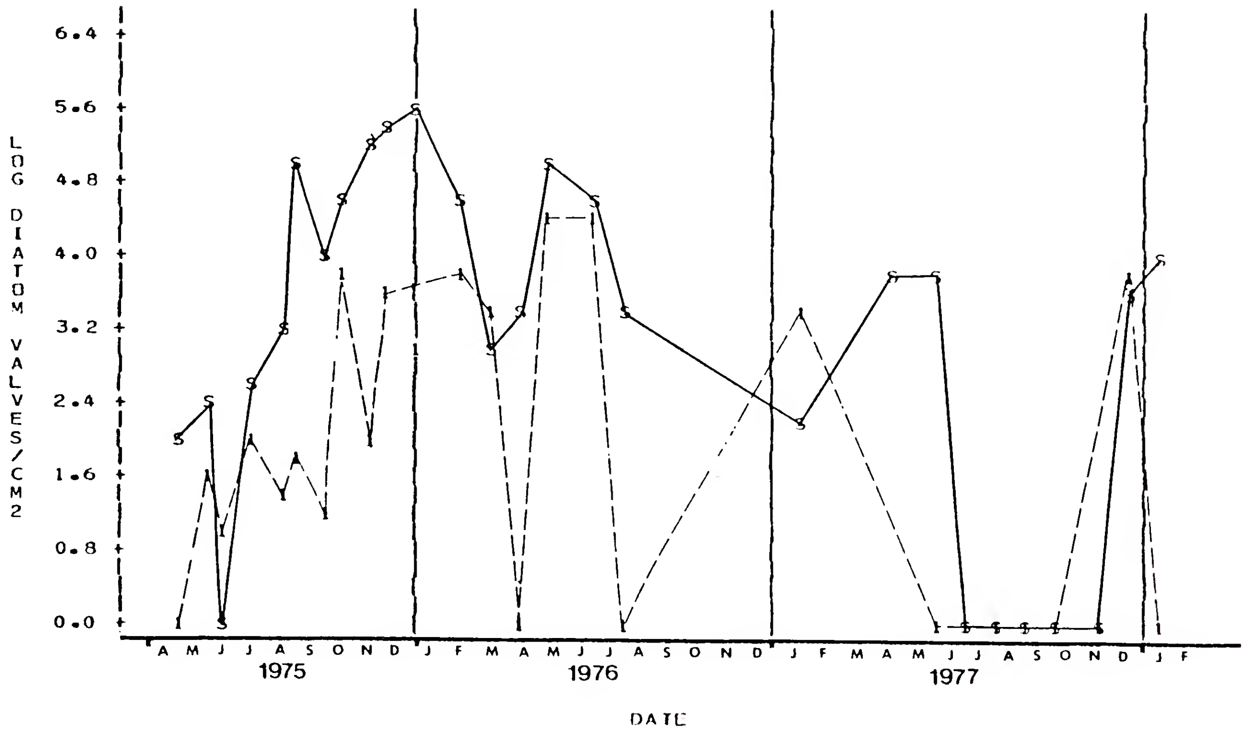


Figure 101. Pond Three Gomphonema parvulum, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

This diatom species was abundant in the pond surfaces and depths before, during, and after hyacinth treatment. It was commonly found in all ponds during foul water quality conditions. However, as water quality improved, populations of *G. parvulum* became less frequent, of smaller magnitude (except during cool water periods), and were entirely absent during very warm water periods. *G. parvulum* grew best during cool periods in the pond surfaces and during other parts of the year in the pond depths after water quality improved.

This diatom species was positively correlated to percent total vegetation cover, and negatively correlated with water temperature, pH, and soluble salts in the surface of Pond One. No significant correlations were found at a one meter depth in Pond One.

Negative correlations occurred with water temperature, calcium, pH, soluble salts, total phytoplankton, total blue-green algae, *Oscillatoria subbrevis*, and total *Oscillatoria*, and a postiive correlation with Secchi disk disappearance in the surface of Pond Two. Negative correlations were found with total blue-green algae, *Oscillatoria limnetica*, *Oscillatoria subbrevis*, and total *Oscillatoria*, and positive correlations with light penetration and *Anabaena spiroides* at a one meter dpeth in Pond Two. Secchi disk disappearance was positively correlated while total blue-green algae and total green algae were negatively correlated at a two meter depth in Pond Two.

G. parvulum was negatively correlated to calcium, magnesium, specific conductivity, total phytoplankton, total blue-green algae, *Oscillatoria subbrevis*, and total *Oscillatoria* in the surface of Pond Three. *G. parvulum* was negatively correlated with soluble salts, magnesium, specific conductivity, *Oscillatoria subbrevis*, and total *Oscillatoria* at a one meter depth in Pond Three.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. No significant models were found in the surface of Pond Two. Potassium, percent total vegetation cover, light penetration, and nitrate-nitrogen was the best one meter depth model, while water temperature was the best two meter depth model in Pond Two. Calcium and water temperature was the best surface model in Pond Three, while available phosphate-phosphorus and light penetration was the best one meter depth model.

Melosira granulata var. *angustissima* Müll.

This periphyton diatom species reached a surface maximum of 5.86 X 10^5 valves/cm^2 and a one meter maximum of 1.46 X 10^4 valves/cm^2 in Pond One (Fig. 102). *M. granulata* var. *angustissima* reached a surface maximum of 1.65 X 10^4 valves/cm^2, a one meter maximum of 5.20 X 10^5 valves/cm^2, and a two meter maximum of 4.32 X 10^4 valves/cm^2 in Pond Two (Fig. 103). This species reached a surface maximum of 3.40 X 10^5 valves/cm^2, and a one meter maximum of 1.23 X 10^6 valves/cm^2 during the study in Pond Three (Fig. 104).

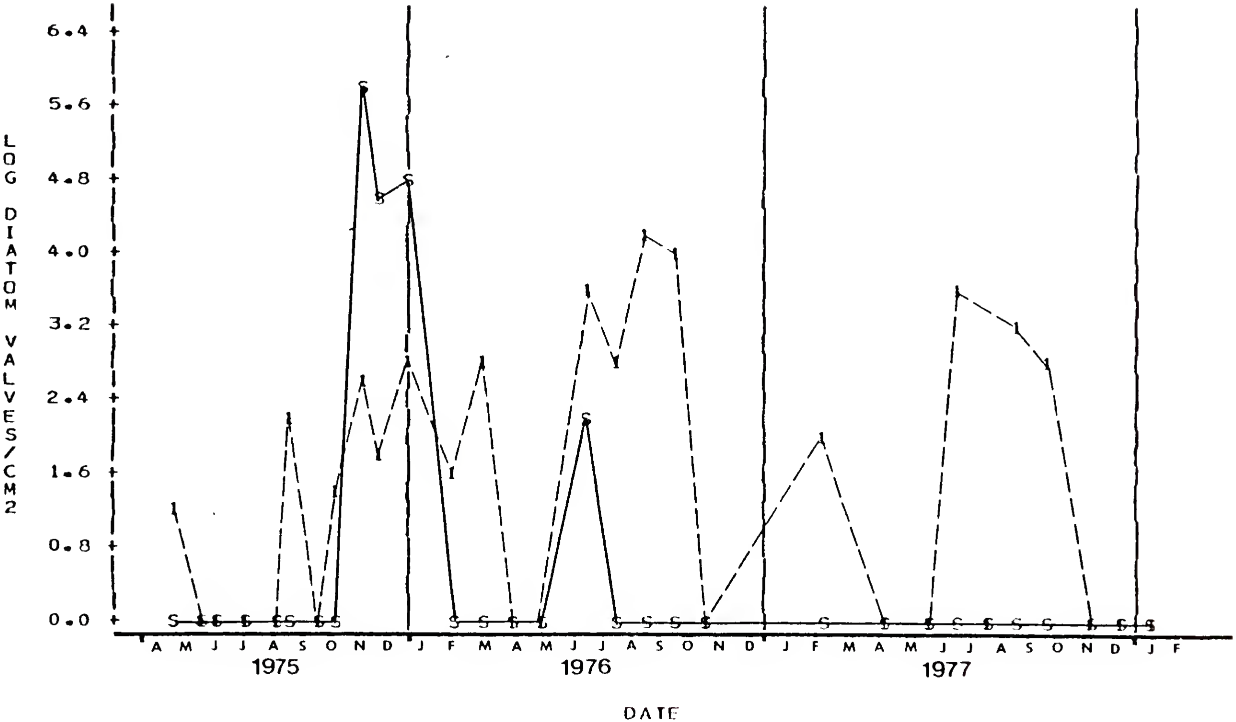


Figure 102. Pond One Melosira granulata var. angustissima, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

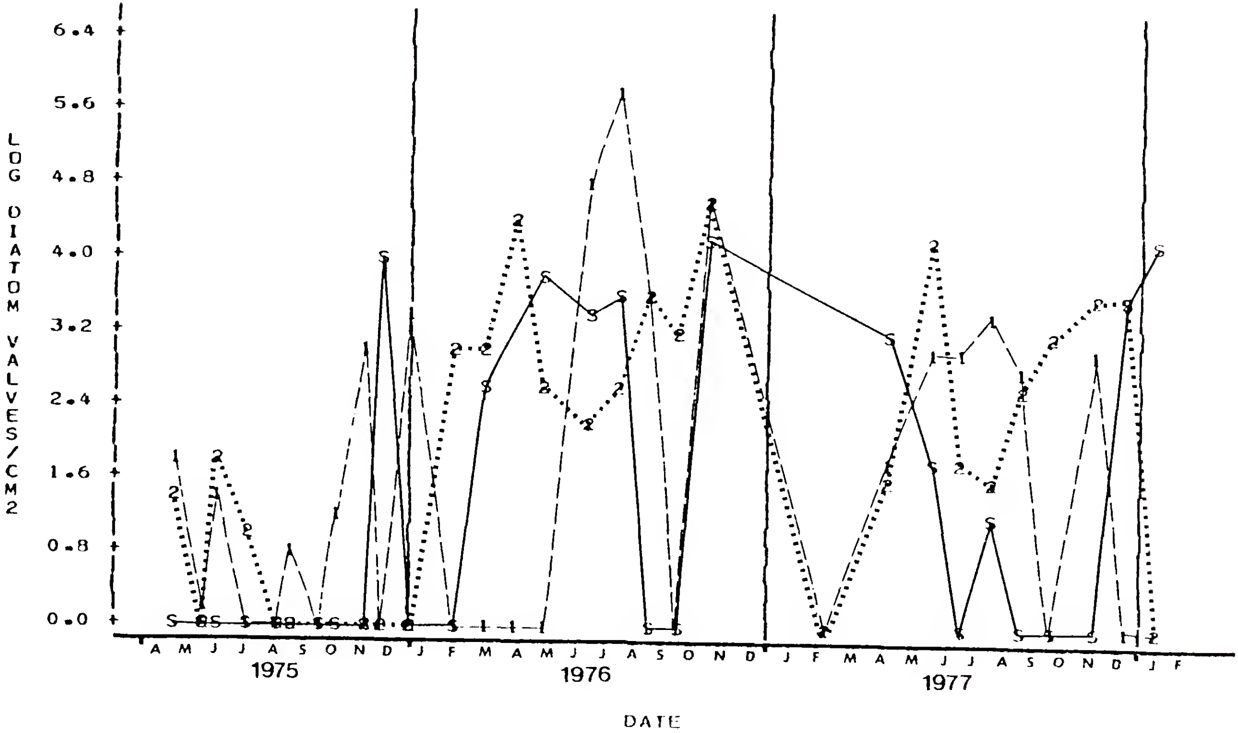


Figure 103. Pond Two Melosira granulata var. angustissima, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, — — — = one meter depth, ········· = two meter depth).

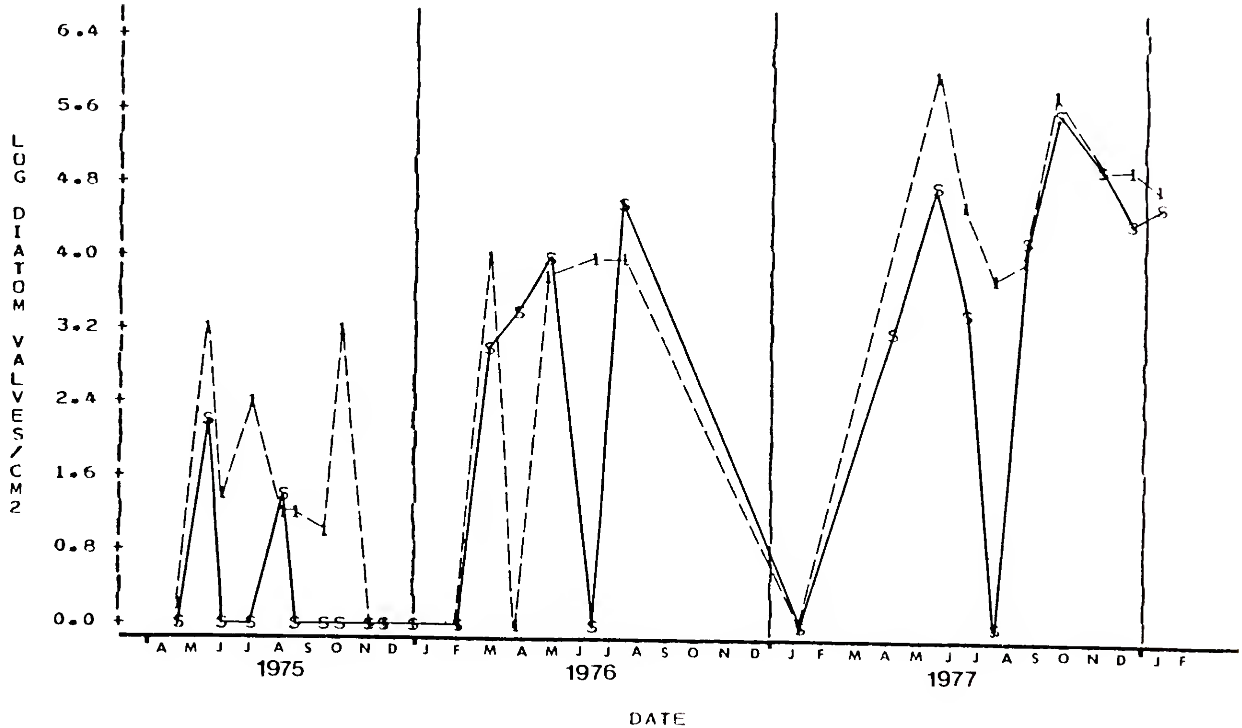


Figure 104. Pond Three <u>Melosira</u> <u>granulata</u> var. <u>angustissima</u>, expressed as number of diatom valves/cm^2 in log10 (——— = pond surface, – – – = one meter depth).

This species was frequently found in the pond depths and occasionally in the pond surfaces below actively growing hyacinth populations. It was not found during hyacinth treatment, but occurred frequently and abundantly in the pond surfaces and depths after hyacinth disappearance.

This planktonic and periphyton diatom species was positively correlated to percent total vegetation cover, and negatively correlated to water temperature, light penetration, and pH in the surface of Pond One. *Oscillatoria subbrevis* and total green algae were positively correlated at a one meter depth in Pond One.

Melosira granulata var. *angustissima* was positively correlated with light penetration, dissolved oxygen, pH, soluble salts, total phytoplankton, *Oscillatoria subbrevis*, and total green algae in the surface of Pond Three. This species was negatively correlated with percent total vegetation cover, carbon dioxide, and available phosphate-phosphorus in the surface of Pond Three. Water temperature, soluble salts, calcium, magnesium, total phytoplankton, total blue-green algae, *Oscillatoria subbrevis*, and total *Oscillatoria* were positively correlated to this diatom at a one meter depth in Pond Three, while carbon dioxide, available phosphate-phosphorus, and Secchi disk disappearance were negatively correlated.

Stepwise multiple regressions did not provide significant models for the surface or depths of Pond One. The best Pond Two surface model included pH, magnesium, and percent total vegetation cover. Turbidity, pH, potassium and water temperature was the best one meter depth model, while light penetration was the best two meter depth model in Pond Two. Total phytoplankton and magnesium was the best surface model in Pond Three, while bicarbonate and specific conductivity was the best one meter depth model.

Navicula confervacea Kütz.

This periphyton diatom species reached a surface maximum of 6.04 X 10^5 valves/cm^2 and a one meter maximum of 2.12 X 10^5 valves/cm^2 in Pond One (Fig. 105). *N. confervae* reached a surface maximum of 7.06 X 10^5 valves/cm^2, a one meter maximum of 2.18 X 10^5 valves/cm^2, and a two meter maximum of 7.68 X 10^4 valves/cm^2 in Pond Two (Fig. 106). This species reached a surface maximum of 6.98 X 10^5 valves/cm^2 and a one meter maximum of 3.83 X 10^4 valves/cm^2 during the study in Pond Three (Fig. 107).

N. confervae was abundantly and commonly found in the surfaces and depths of all ponds throughout the study. This diatom occurred beneath actively growing hyacinths and after hyacinth disappearance. Populations of this species were not found in the pond surfaces during hyacinth treatment.

No significant correlations were found for this diatom in the surface of Pond One. *N. confervae* was positively correlated with soluble salts, specific conductivity, *Oscillatoria subbrevis*, and total green algae at a one meter depth in Pond One, and negatively correlated with percent total vegetation cover. *N. confervae* was negatively correlated with total phytoplankton

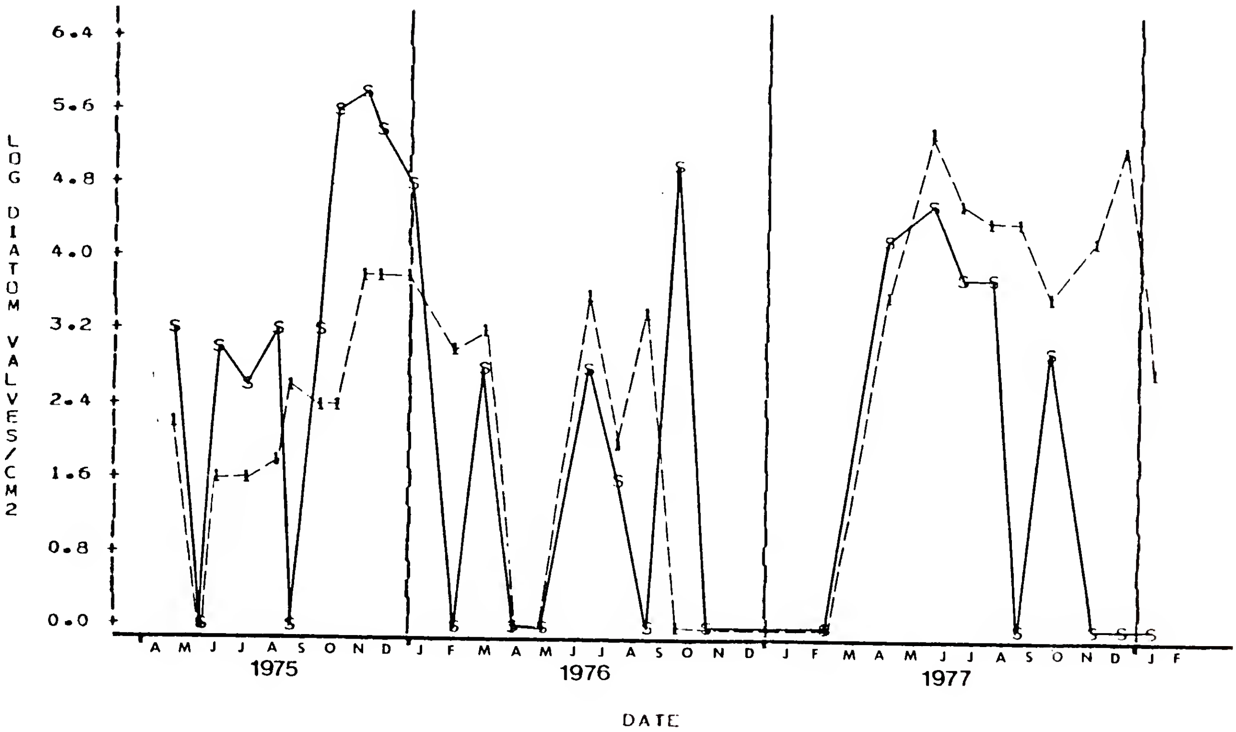


Figure 105. Pond One Navicula confervae, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

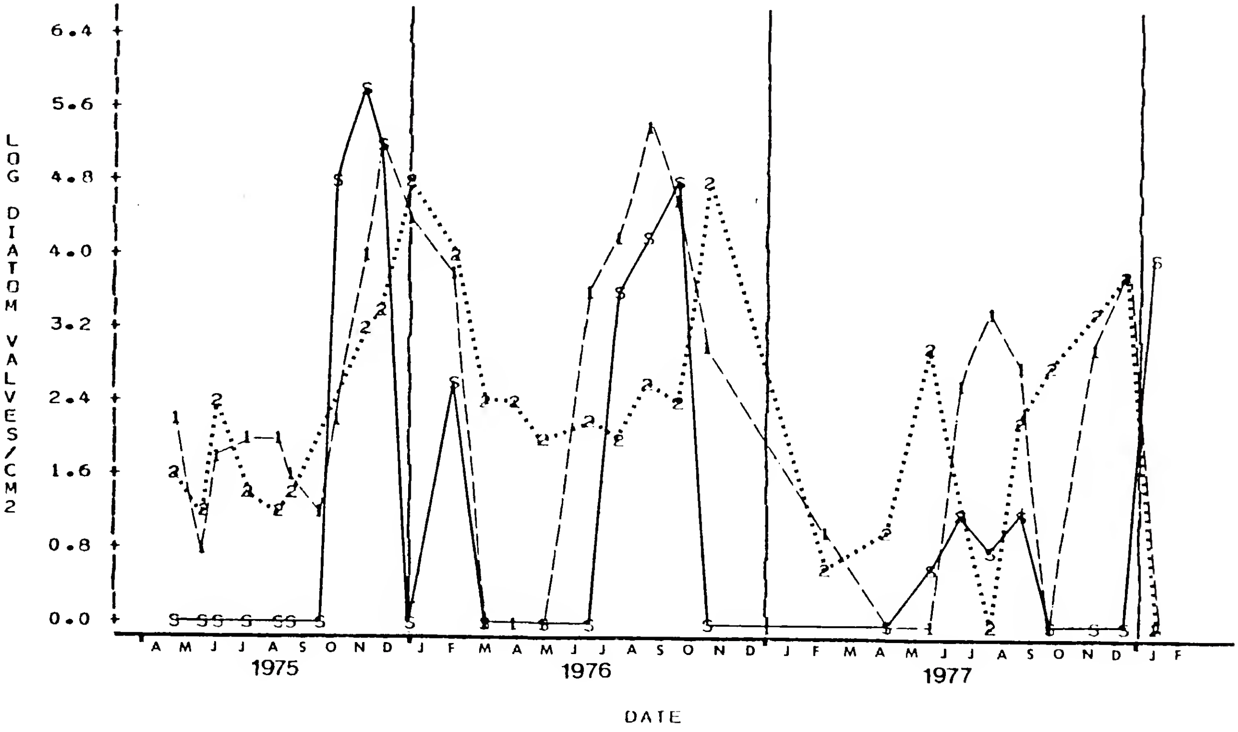


Figure 106. Pond Two *Navicula confervae*, expressed as number of diatom valves/cm^2 in $\log_{10}$
(——— = pond surface, — — — = one meter depth,
······· = two meter depth).

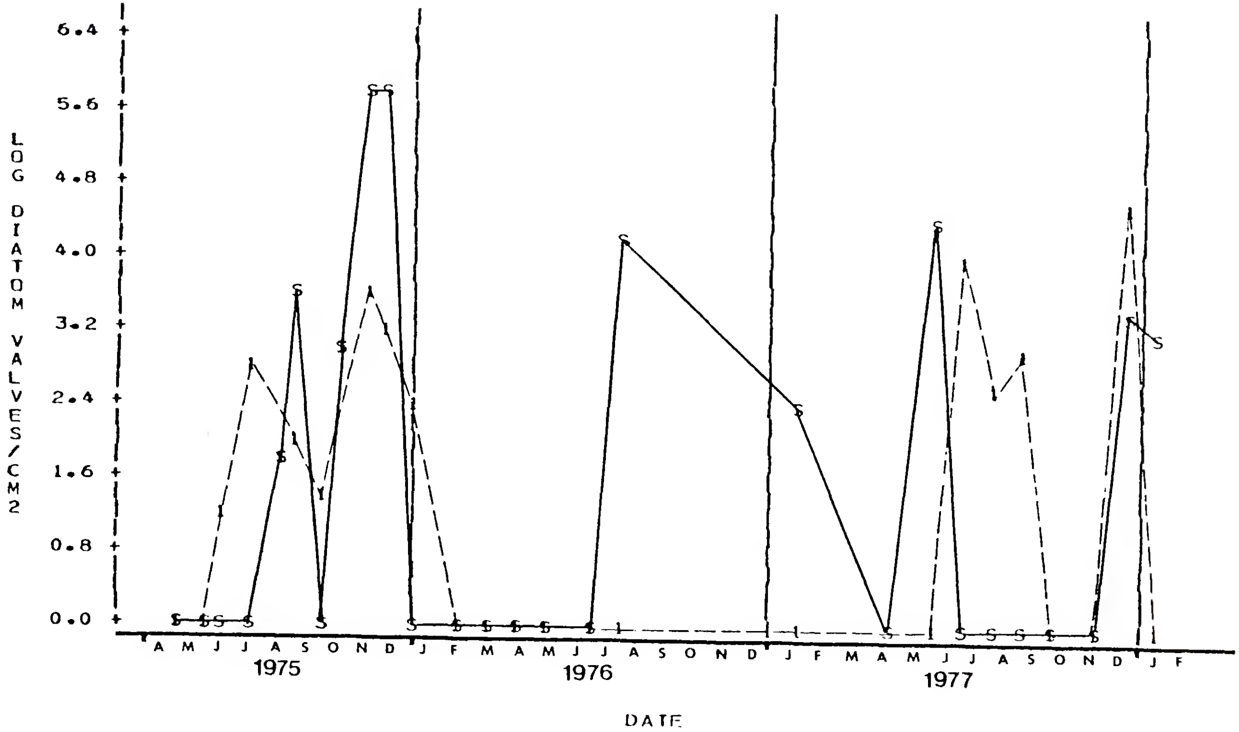


Figure 107. Pond Three <u>Navicula confervae</u>, expressed as number of diatom valves/cm2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

in the surface of Pond Two. Calcium, magnesium, and total phytoplankton were negatively correlated with this diatom at a one meter depth in Pond Two. This diatom was negatively correlated with calcium, magnesium, total phytoplankton, and total blue-green algae at a two meter depth, while nitrate-nitrogen was positively correlated. Water temperature was negatively correlated to *N. confervae* in the surface of Pond Three, while pH was negatively correlated at the one meter depth.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. Turbidity, magnesium, and Secchi disk disappearance was the best Pond Two surface model. Nitrate-nitrogen was the best one meter model in Pond Two, while potassium, percent total vegetation cover, and light penetration was the best two meter depth model. No significant models were found in the surface of Pond Three, while water temperature and total phytoplankton was the best one meter depth model.

Navicula minima Grun.

This periphyton diatom species reached a surface maximum of 1.08 X 10^6 valves/cm^2 and a one meter maximum of 2.38 X 10^6 valves/cm^2 in Pond One (Fig. 108). *N. minima* reached a surface maximum of 1.09 X 10^6 valves/cm^2, a one meter maximum of 2.39 X 10^6 valves/cm^2, and a two meter maximum of 1.61 X 10^6 valves/cm^2 in Pond Two (Fig. 109). This diatom reached a surface

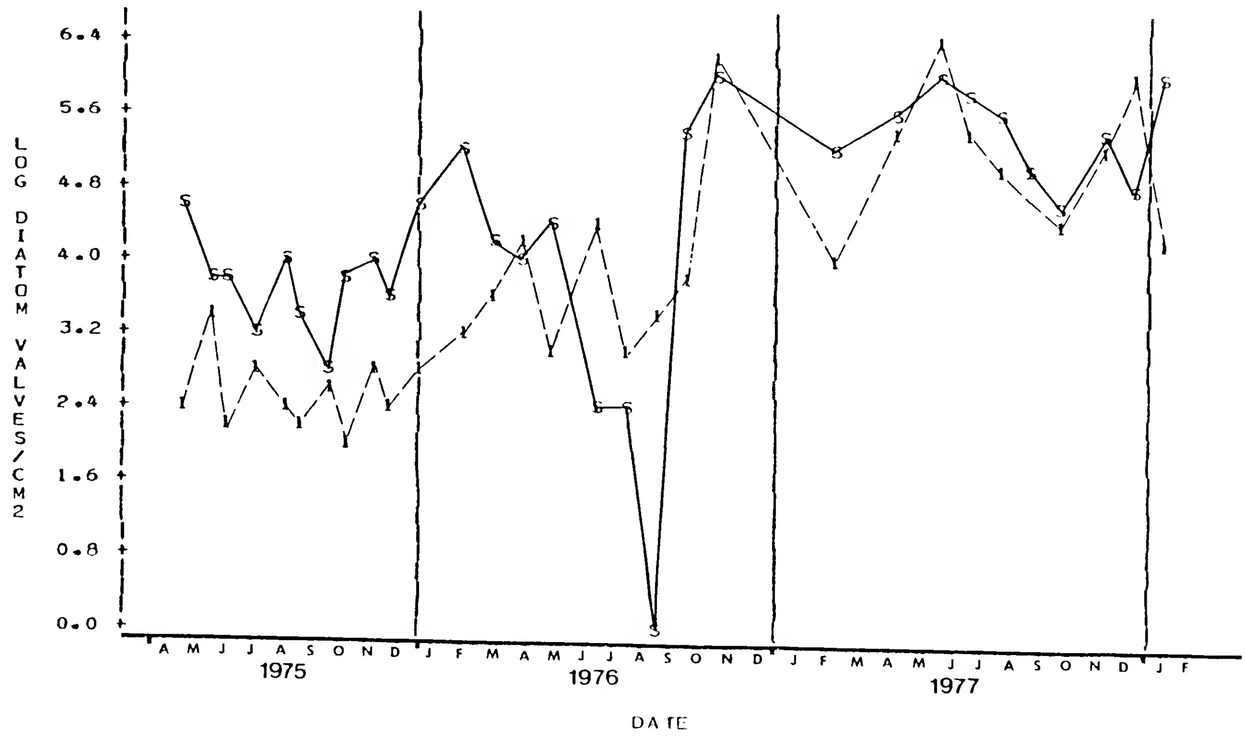


Figure 108. Pond One *Navicula minima*, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, — — — = one meter depth).

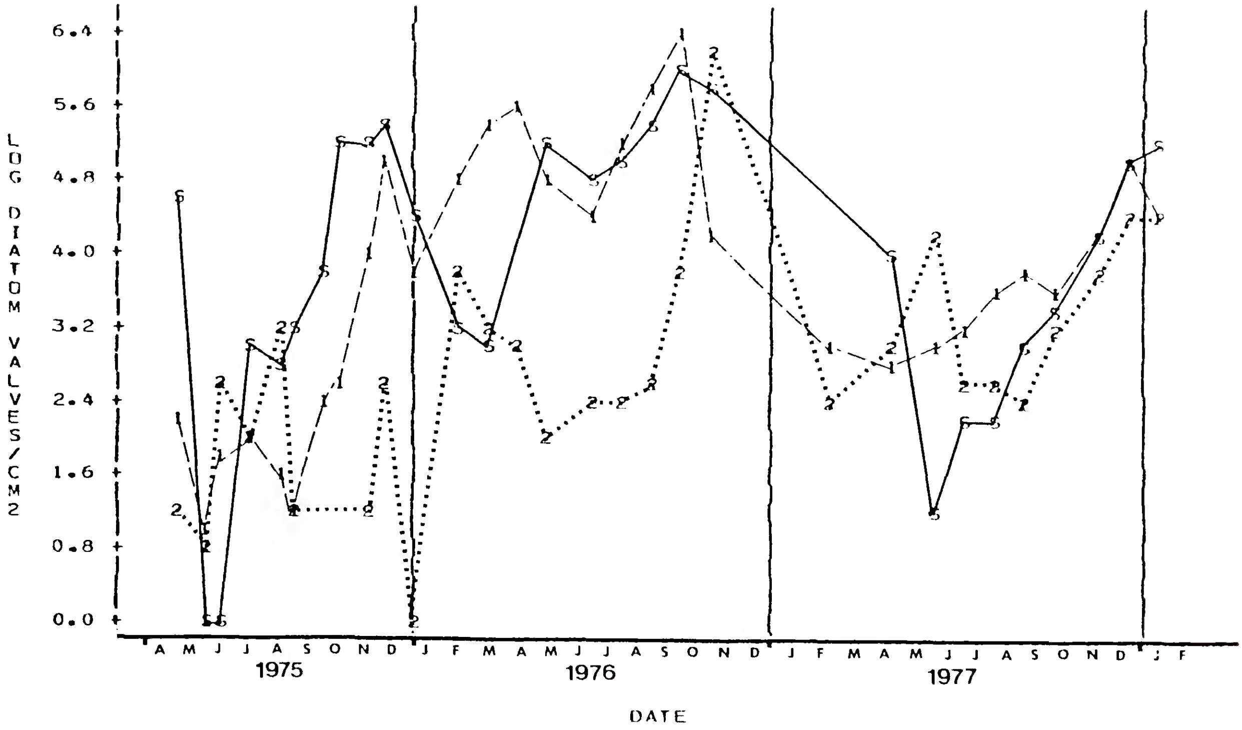


Figure 109. Pond Two Navicula minima, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, — — — = one meter depth, ········ = two meter depth).

maximum of 1.81×10^6 valves/cm^2 and a one meter maximum of 1.94×10^5 valves/cm^2 during the study in Pond Three (Fig. 110).

N. minima was very common and abundant in the pond surfaces and depths below actively growing hyacinth populations. *N. minima* populations declined dramatically during hyacinth treatment but increased to higher and more stable levels after hyacinth disappearance.

This species was negatively correlated with percent total vegetation cover and carbon dioxide in the surface and depths of all ponds.

This diatom was also positively correlated with dissolved oxygen, pH, soluble salts, calcium, and specific conductivity in the surface of Pond One. *N. minima* was also negatively correlated with available phosphate-phosphorus and *Oscillatoria limnetica*, and positively correlated with pH, soluble salts, calcium, specific conductivity, and *Oscillatoria subbrevis* at a one meter depth in Pond One.

N. minima was also negatively correlated with water temperature, potassium, total phosphate-phosphorus, available phosphate-phosphorus, specific conductivity, and total *Oscillatoria* in the surface of Pond Two. This diatom species was positively correlated with total green algae and negatively correlated with bicarbonate, total phosphate-phosphorus, and available phosphate-phosphorus at a one meter depth. This diatom was positively correlated with calcium, pH, soluble salts, nitrate-nitrogen, and total green algae at a two meter depth.

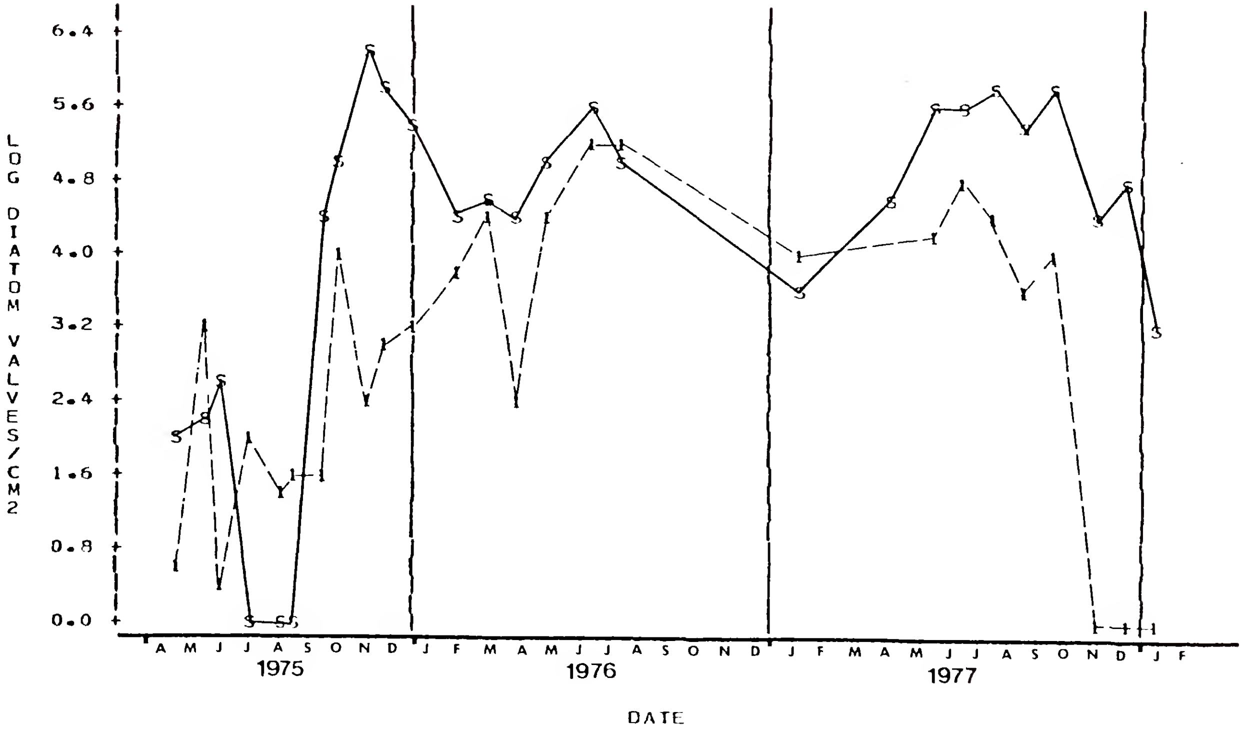


Figure 110. Pond Three Navicula minima, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

N. minima was also negatively correlated with total phosphate-phosphorus, available phosphate-phosphorus, and *Oscillatoria limnetica* in the surface of Pond Three, while positive correlations were found with *Oscillatoria subbrevis* and total green algae. *Oscillatoria limnetica* was negatively correlated with *N. minima*, while water temperature, total phytoplankton, *Oscillatoria subbrevis*, and *Anabaena spiroides* were positively correlated at a one meter depth in Pond Three.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. The best Pond Two surface model included pH, magnesium, and percent total vegetation cover. Secchi disk disappearance and total phytoplankton was the best one meter depth model, while soluble salts, calcium, and specific conductivity was the best two meter depth model in Pond Two. Bicarbonate and light penetration was the best Pond Three surface model, while bicarbonate and potassium was the best one meter depth model.

Nitzschia amphibia Grun.

This periphyton diatom species reached a surface maximum of 2.39×10^5 valves/cm^2 and a one meter maximum of 1.42×10^6 valves/cm^2 in Pond One (Fig. 111). *N. amphibia* reached a surface maximum of 1.32×10^5 valves/cm^2, a one meter maximum of 9.15×10^4 valves/cm^2, and a two meter maximum of 1.44×10^4 valves/cm^2 in Pond Two (Fig. 112). This species reached a surface maximum

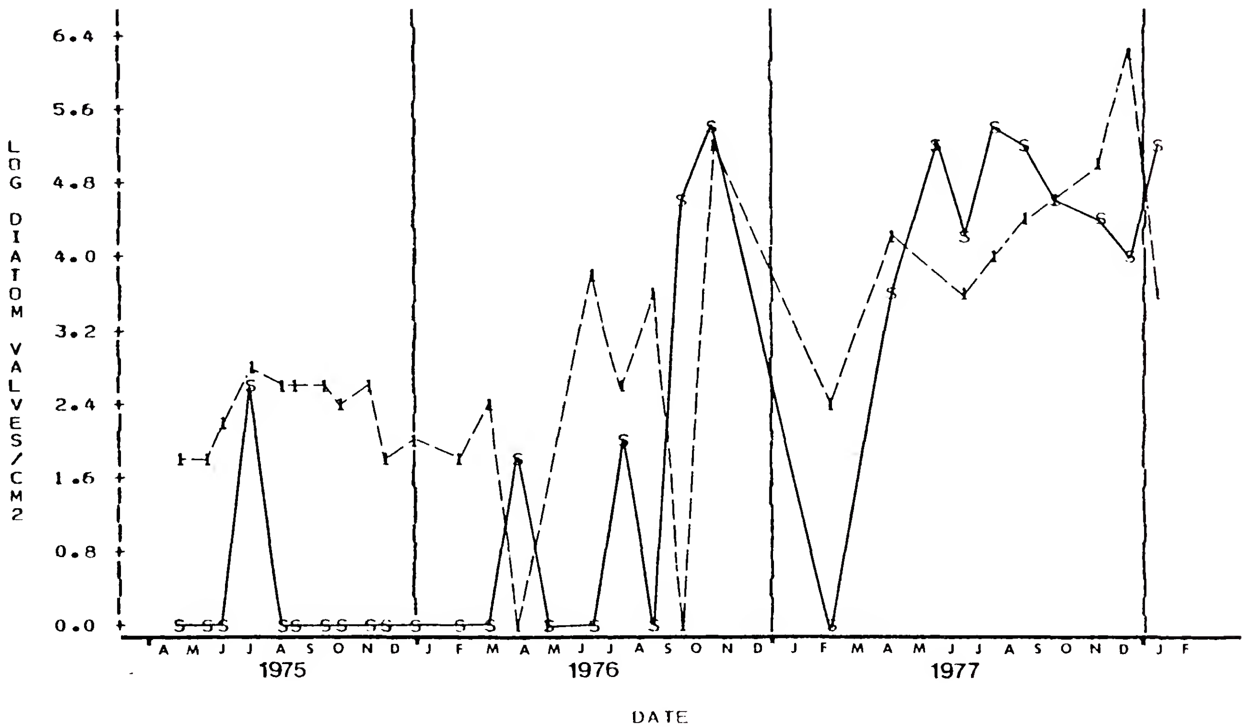


Figure 111. Pond One Nitzschia amphibia, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, – – – = one meter depth).

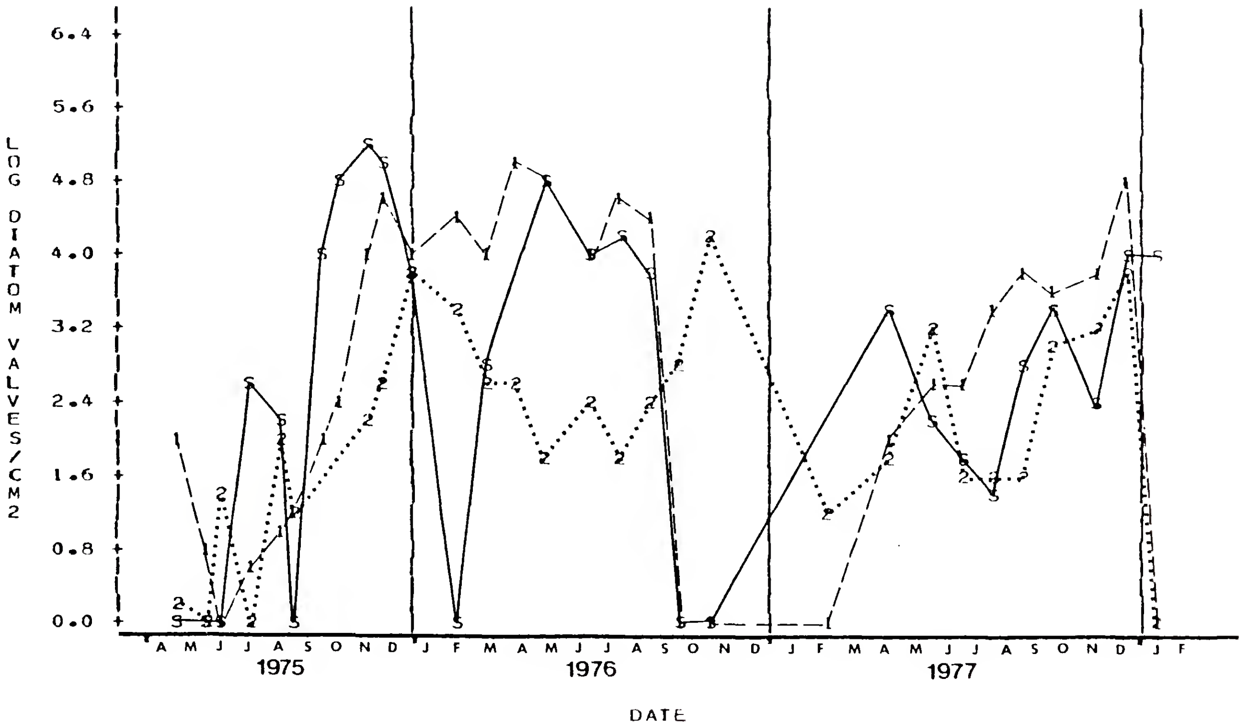


Figure 112. Pond Two Nitzschia amphibia, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth, ········ = two meter depth).

of 1.86 X 10^5 valves/cm^2 and a one meter maximum of 3.02 X 10^5 valves/cm^2 during the study in Pond Three (Fig. 113).

N. amphibia was occasionally found in low numbers in the pond surfaces below actively growing hyacinths, but was more common in the pond depths. This diatom species was common and abundant in all the pond surfaces and depths both during and after hyacinth disappearance.

This periphyton diatom was found to be negatively correlated to percent total vegetation cover and carbon dioxide in the surface and depths of all ponds.

N. amphibia was also negatively correlated with total phosphate-phosphorus and available phosphate-phosphorus in the surface of Pond One and was positively correlated to pH, soluble salts, calcium, specific conductivity, and *Oscillatoria subbrevis*. This diatom was positively correlated with pH, soluble salts, calcium, and specific conductivity at a one meter depth.

Nitzschia amphibia was also negatively correlated to water temperature, light penetration, bicarbonate, total blue-green algae, and total *Oscillatoria* in the surface of Pond Two, and positively correlated to *Microcystis aeruginosa*. *N. amphibia* was positively correlated to *Microcystis aeruginosa* and negatively correlated to total *Oscillatoria* at a one meter depth. This diatom was positively correlated to soluble salts and nitrate-nitrogen and negatively correlated to available phosphate-phosphorus at a two meter depth.

Nitzschia amphibia was also negatively correlated to water temperature, light penetration, bicarbonate, total blue-green

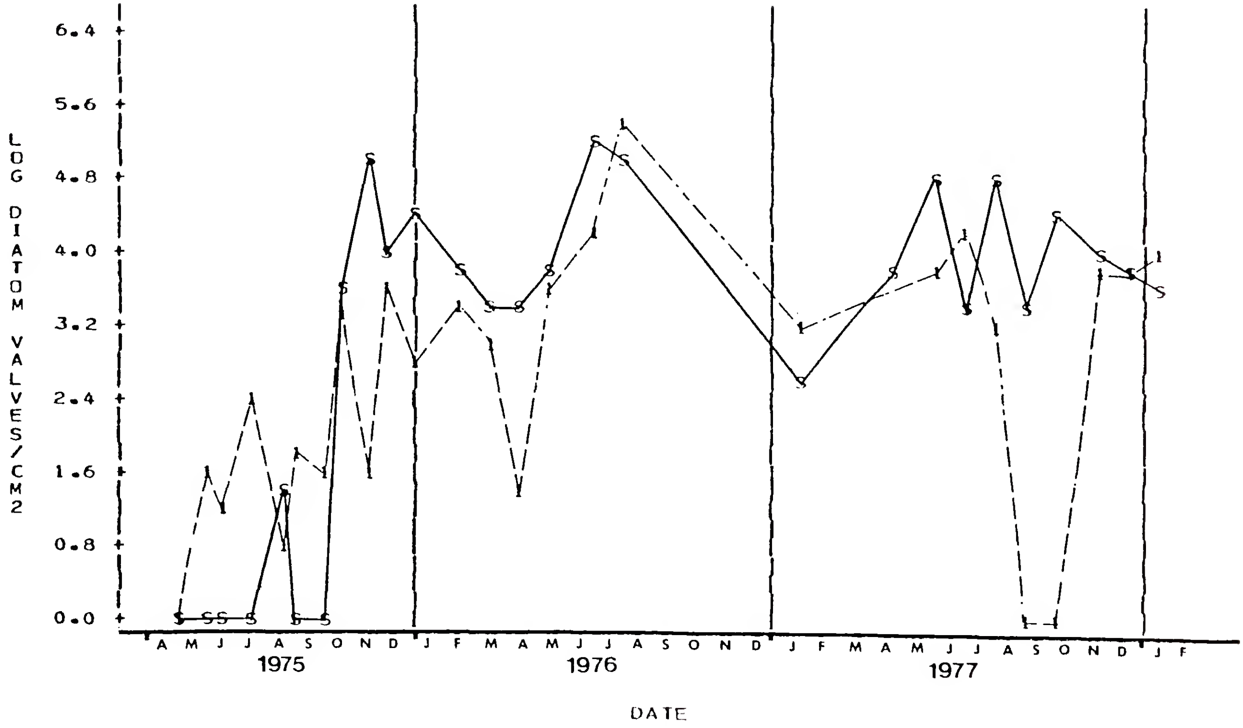


Figure 113. Pond Three Nitzschia amphibia, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

algae, and total *Oscillatoria* in the surface of Pond Two, and positively correlated to *Microcystis aeruginosa*. *N. amphibia* was positively correlated to *Microcystis aeruginosa* and negatively correlated to total *Oscillatoria* at a one meter depth. This diatom was positively correlated to soluble salts and nitrate-nitrogen and negatively correlated to available phosphate-phosphorus at a two meter depth.

N. amphibia was positively correlated to dissolved oxygen, pH, total *Anabaena, Oscillatoria subbrevis, Anabaena spiroides, Microcystis aeruginosa* and total green algae in the surface of Pond Three, and negatively correlated to bicarbonate, nitrate-nitrogen and available phosphate-phosphorous.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. No significant models were found in the surface of Pond Two. Available phosphate-phosphorus was the best one meter depth model in Pond Two while bicarbonate, specific conductivity, and percent total vegetation cover was the best two meter depth model. Water temperature and magnesium was the best surface model in Pond Three, while potassium and available phosphate-phosphorus, was the best one meter depth model.

Nitzschia palea (Kütz.) W. Smith

This periphyton diatom species reached a surface maximum of 6.74×10^5 valves/cm^2 and a one meter maximum of 2.12×10^5

valves/cm^2 in Pond One (Fig. 114). *N. palea* reached a surface maximum of 3.12 X 10^5 valves/cm^2, a one meter maximum of 2.70 X 10^5 valves/cm^2, and a two meter maximum of 5.47 X 10^5 valves/cm^2 in Pond Two (Fig. 115). This species reached a surface maximum of 6.37 X 10^5 valves/cm^2 and a one meter maximum of 5.32 X 10^5 valves/cm^2 during the study in Pond Three (Fig. 116).

N. palea was common and abundant in the pond surfaces and depths below actively growing hyacinth populations. This species was also successful during and after hyacinth disappearance in both the pond surfaces and depths.

This periphyton species was positively correlated to calcium and magnesium in the surface of Pond One. This diatom was positively correlated to water temperature, pH, bicarbonate, soluble salts, calcium, magnesium, specific conductivity, and *Oscillatoria subbrevis* at a one meter depth in Pond One, and negatively correlated to percent total vegetation cover, carbon dioxide, and *Oscillatoria limnetica*.

N. palea was positively correlated to *Oscillatoria limnetica* in the surface of Pond Two, and negatively correlated to water temperature, pH, soluble salts, total phytoplankton, *Oscillatoria subbrevis*, and *Anabaena spiroides*. No significant correlations were found at a one meter depth in Pond Two. *N. palea* was negatively correlated to percent total vegetation cover and total blue-green algae, and positively correlated to nitrate-nitrogen at a two meter depth in Pond Two.

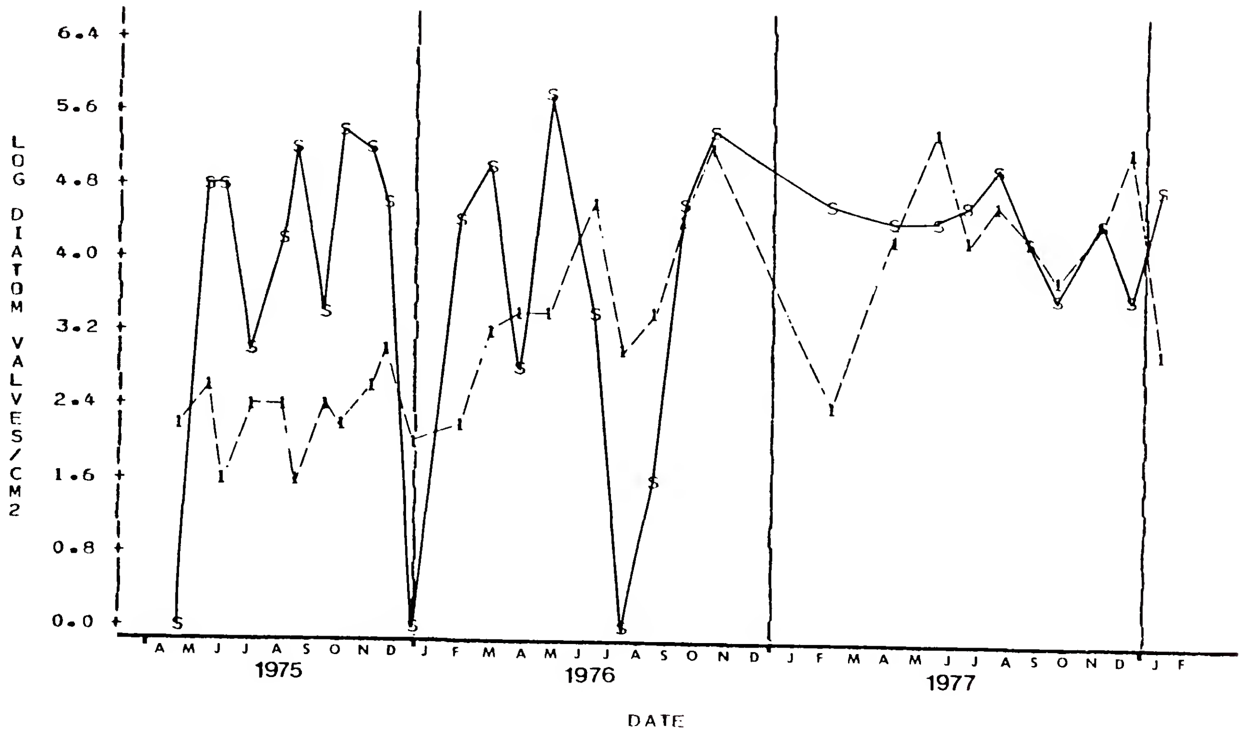


Figure 114. Pond One Nitzschia palea, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth).

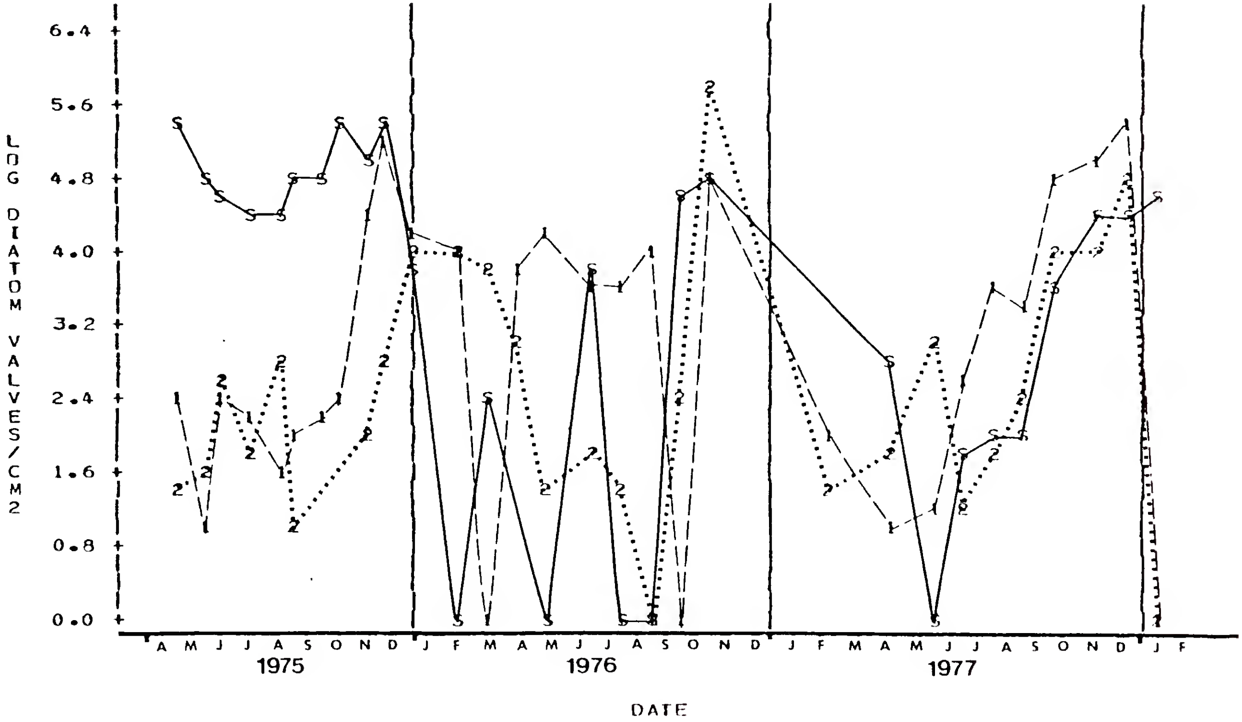


Figure 115. Pond Two Nitzschia palea, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth, ········ = two meter depth).

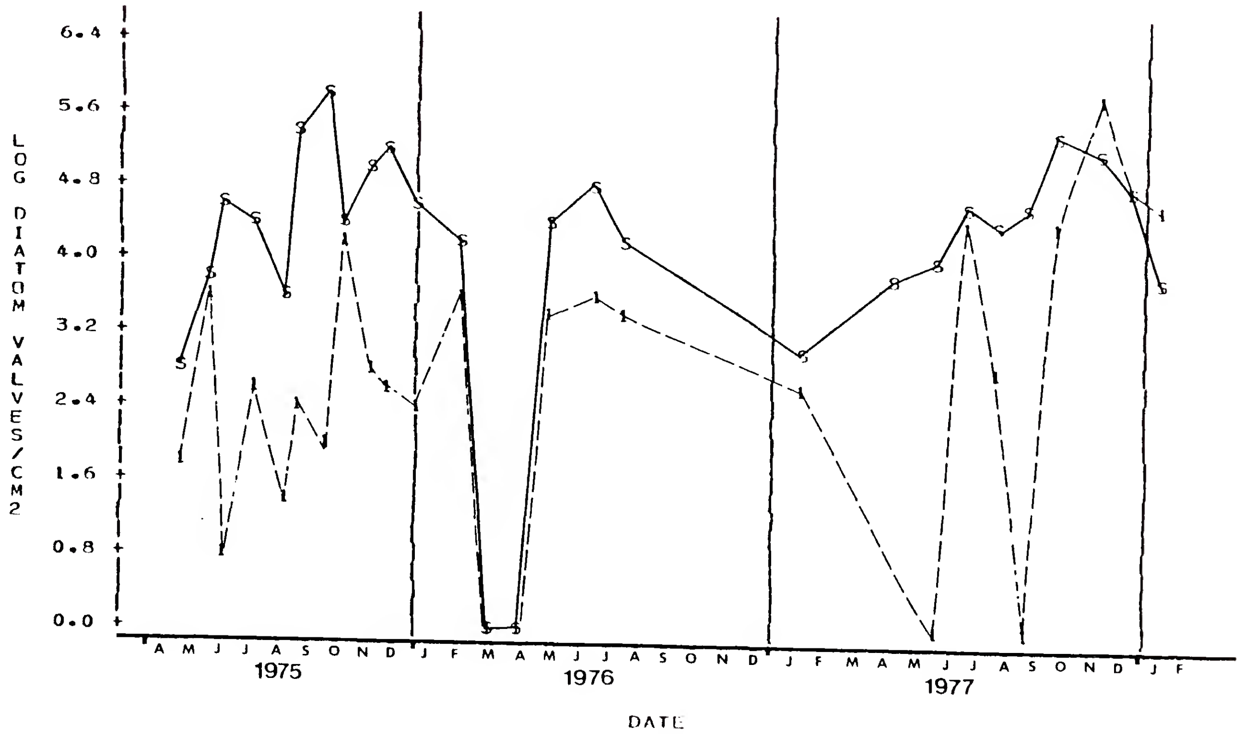


Figure 116. Pond Three *Nitzschia palea*, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, – – – = one meter depth).

No significant correlations were found in the surface of Pond Three, while carbon dioxide was negatively correlated to *N. palea* at the one meter depth.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One, but no significant models were found at the one meter depth. The best Pond Two surface model included pH, available phosphate-phosphorus, and light penetration while pH, bicarbonate, and total phytoplankton was the best two meter depth model. No significant models were found for Pond Two at the one meter depth. Bicarbonate and water temperature was the best surface model in Pond Three while water temperature and total phytoplankton was the best one meter depth model.

Stephanodiscus astrea var. *minutula* (Kütz.) Grun.

This periphyton diatom species reached a surface maximum of 2.91 X 10^4 valves/cm^2 and a one meter maximum of 5.65 X 10^5 valves/cm^2 in Pond One (Fig. 117). *S. astrea* var. *minutula* reached a surface maximum of 4.79 X 10^5 valves/cm^2, a one meter maximum of 3.01 X 10^6 valves/cm^2, and a two meter maximum of 2.29 X 10^6 valves/cm^2 in Pond Two (Fig. 118). This species reached a surface maximum of 4.74 X 10^5 valves/cm^2 and a one meter maximum of 1.51 X 10^6 valves/cm^2 in Pond Three during the study (Fig. 119).

This species was not commonly found under actively growing hyacinth populations in either the pond surfaces or depths. However, it was quite common and abundant after hyacinth disappearance.

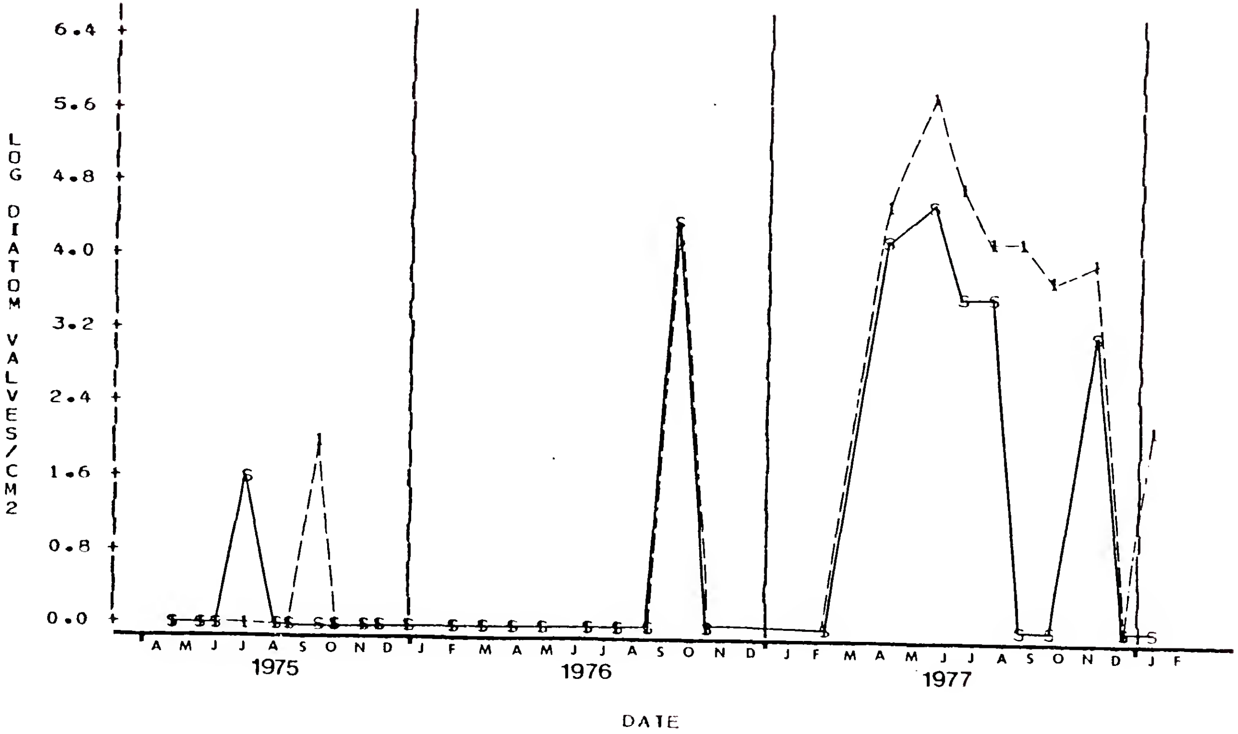


Figure 117. Pond One Stephanodiscus astrea var. minutula, expressed as number of diatom valves/cm2 in log10 (——— = pond surface, – – – = one meter depth).

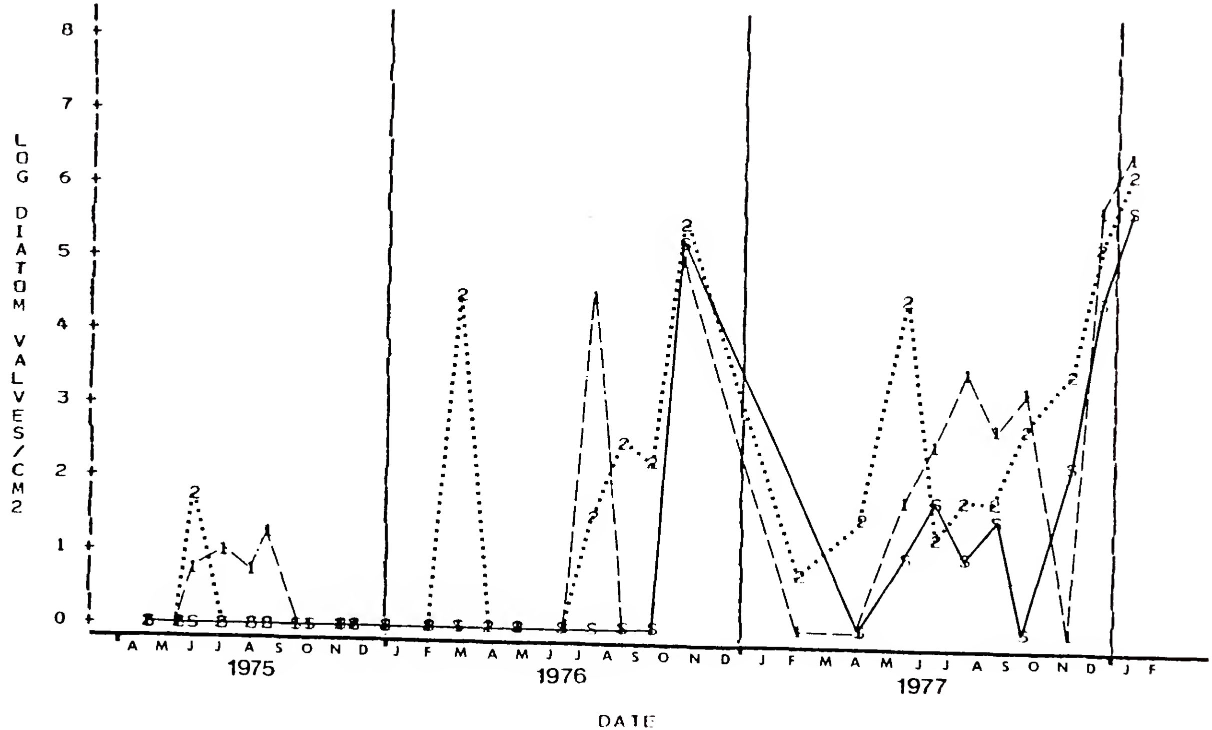


Figure 118. Pond Two <u>Stephanodiscus astrea</u> var. <u>minutula</u>, expressed as number of diatom valves/cm2 in log10. (———— = pond surface, — — — = one meter depth, ········· = two meter depth).

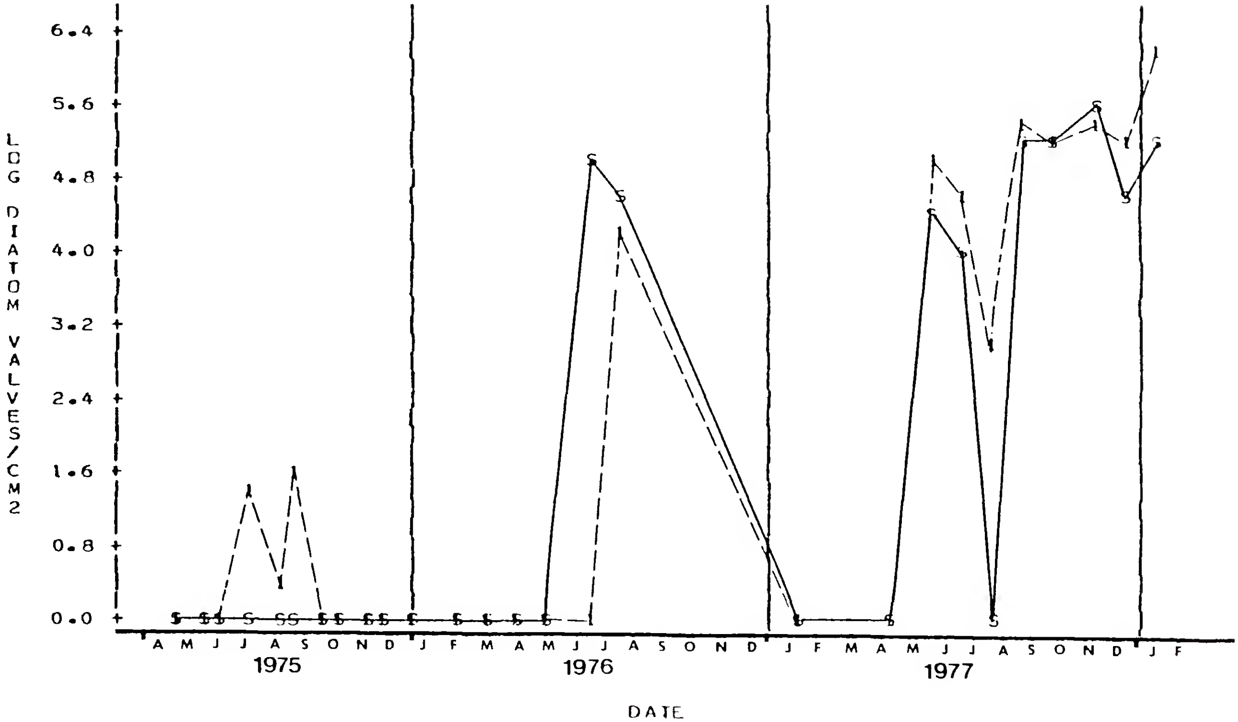


Figure 119. Pond Three Stephanodiscus astrea var. minutula, expressed as number of diatom valves/cm^2 in $\log_{10}$ (——— = pond surface, —·—— = one meter depth).

It was found to be negatively correlated to percent total vegetation cover in all the pond surfaces and depths. *S. astrea* var. *minutula* was negatively correlated to total phosphate-phosphorus and available phosphate-phosphorus in all the pond surfaces and depths, except the surface of Pond One. *S. astrea* var. *minutula* was also negatively correlated to carbon dioxide in the surfaces and depths of Ponds One and Three.

This diatom was positively correlated to water temperature, bicarbonate, soluble salts, calcium, and *Oscillatoria subbrevis* in the surface of Pond One, and negatively correlated to *Oscillatoria limnetica*. *S. astrea* var. *minutula* was positively correlated to water temperature, pH, soluble salts, calcium, specific conductivity, and *Oscillatoria subbrevis* and negatively correlated to *Oscillatoria limnetica* at a one meter depth in Pond One.

This diatom was positively correlated to dissolved oxygen, pH, nitrate-nitrogen, and calcium, and negatively correlated to water temperature in the surface of Pond Two. *S. astrea* var. *minutula* was positively correlated with pH, soluble salts, nitrate-nitrogen, calcium, total blue-green algae, and total *Oscillatoria* at a one meter depth. *S. astrea* var. *minutula* was positively correlated to pH, soluble salts, nitrate-nitrogen, calcium, specific conductivity, and total *Oscillatoria* at a two meter depth.

S. astrea var. *minutula* was positively correlated to dissolved oxygen, soluble salts, total blue-green algae, *Microcystis* *aeruginosa, Oscillatoria subbrevis,* and total *Oscillatoria* in the surface of Pond Three. It was positively correlated to soluble salts, specific conductivity, total blue-green algae, *Oscillatoria subbrevis,* and total *Oscillatoria* at a one meter depth.

Stepwise multiple regressions selected total phytoplankton as the best possible model for the surface of Pond One but no significant model was found at the one meter depth. No significant model was found in the surface of Pond Two. The best one meter depth model in Pond Two was percent total vegetation cover, while calcium, magnesium, and Secchi disk disappearance was the best two meter depth model. No significant models were found for the surface or depths of Pond Three.

Synedra ulna (Nitzch) Ehr.

This periphyton diatom species reached a surface maximum of 8.24×10^4 valves/cm^2 and a one meter maximum of 2.36×10^4 valves/cm^2 in Pond One (Fig. 120). *S. ulna* reached a surface maximum of 4.52×10^3 valves/cm^2, a one meter maximum of 181.0 valves/cm^2, and a two meter maximum of 311.0 valves/cm^2 in Pond Two (Fig. 121). This diatom species attained a surface maximum of 1.42×10^4 valves/cm^2 and a one meter maximum of 88.0 valves/cm^2 during the study in Pond Three (Fig. 122).

S. ulna was commonly found in the pond surfaces during cool water periods before and after hyacinth disappearance.

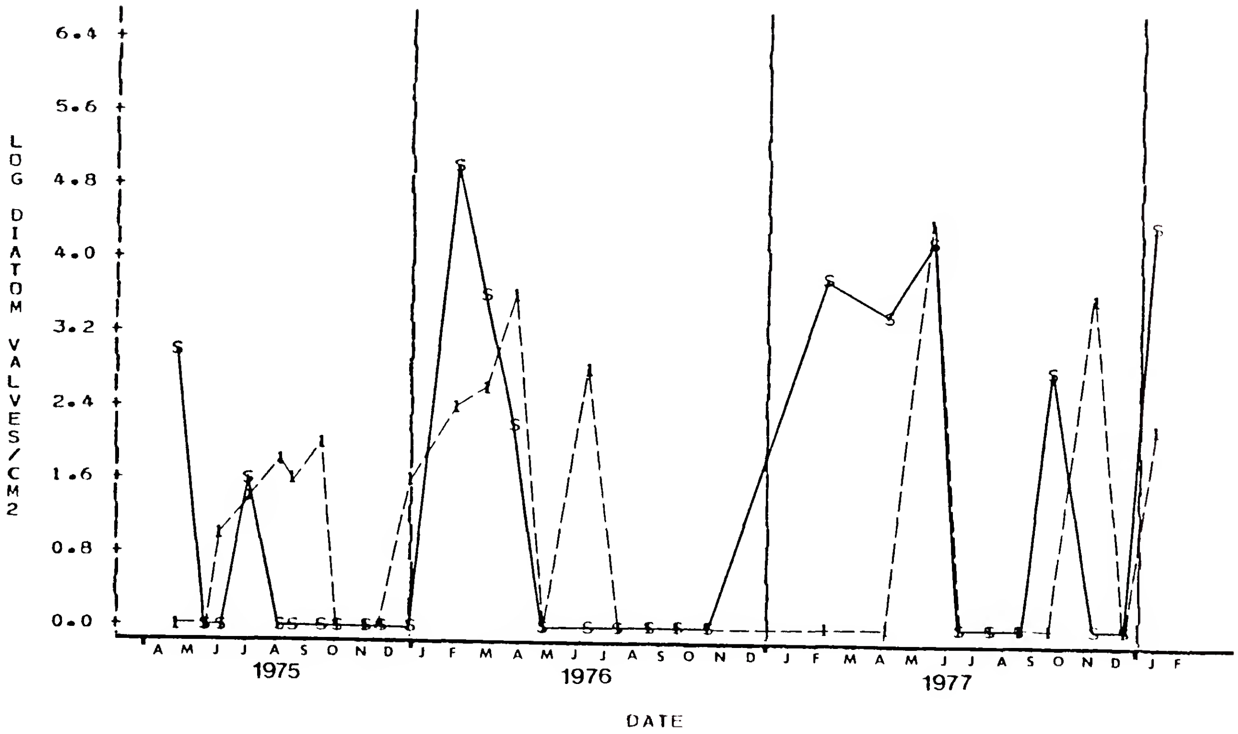


Figure 120. Pond One Synedra ulna, expressed as number of diatom valves/cm^2 in $\log_{10}$
(——— = pond surface, - - - - = one meter depth)

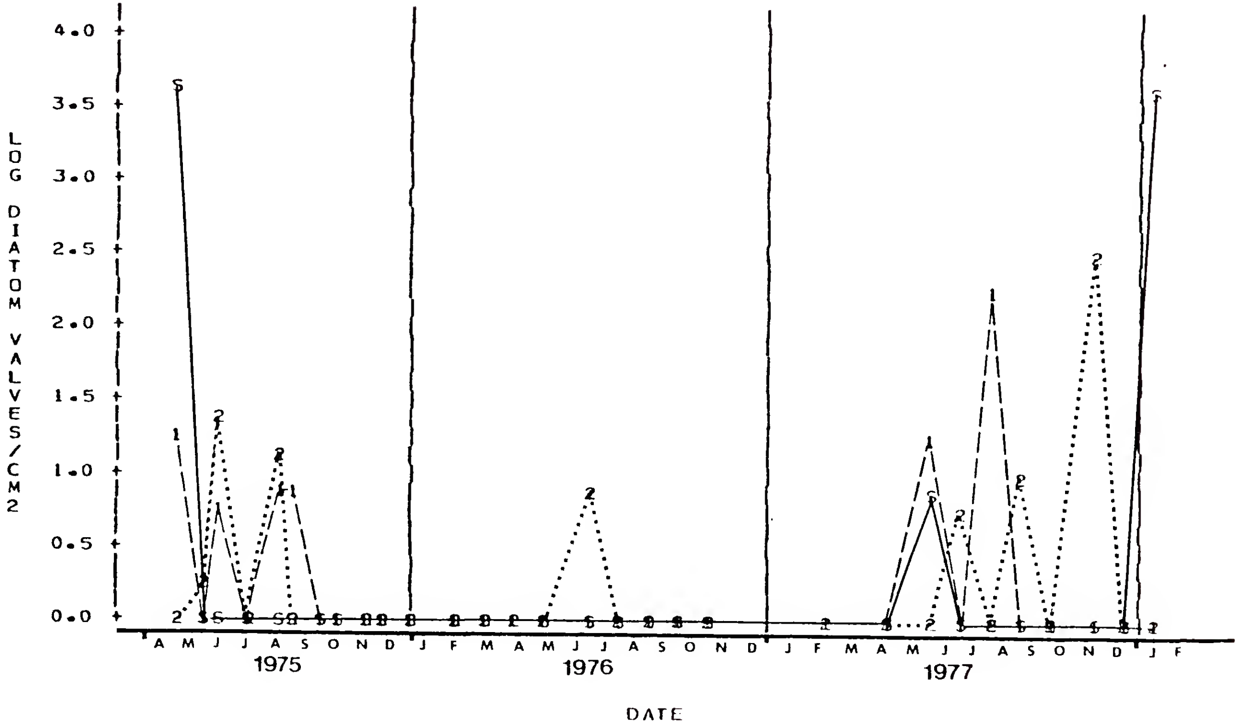


Figure 121. Pond Two Synedra ulna, expressed as number of diatom valves/cm2 in $\log_{10}$ (——— = pond surface, – – – = one meter depth, ········ = two meter depth).

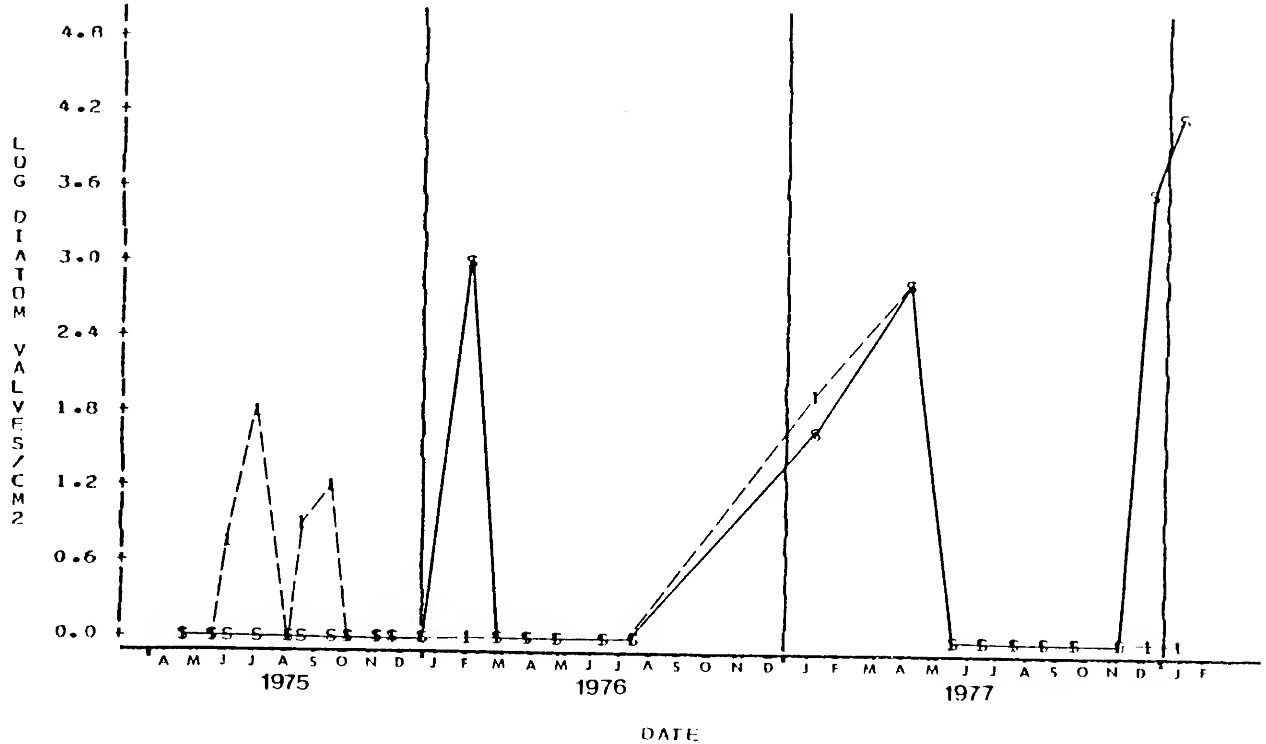


Figure 122. Pond Three Synedra ulna, expressed as number of diatom valves/cm2 in log10
(——— = pond surface, - - - - = one meter depth)

However, it was not limited to cool water periods in the pond depths and was commonly found during summer.

This planktonic and periphyton diatom species was positively correlated to dissolved oxygen and nitrate-nitrogen in the surface of Pond One, and negatively correlated to total phytoplankton, total blue-green algae, *Oscillatoria limnetica,* and total *Oscillatoria.* *S. ulna* was positively correlated to nitrate-nitrogen and negatively correlated to total phytoplankton, total blue-green algae, and total *Oscillatoria* at a one meter depth in Pond One.

This diatom was positively correlated to dissolved oxygen in the surface of Pond Two and negatively correlated to potassium. *S. ulna* was positively correlated to bicarbonate, carbon dioxide, specific conductivity, potassium, total blue-green algae, total *Oscillatoria,* and *Oscillatoria limnetica* at a one meter depth. There were no significant correlations found at a two meter depth in Pond Two.

S. ulna was negatively correlated to percent total vegetation cover and water temperature in the surface of Pond Three. This diatom was positively correlated to percent total vegetation cover, potassium, and Secchi disk disappearance, and negatively correlated to total green algae at a one meter depth.

No significant models were found for this diatom in any of the pond surfaces or depths.

Water Hyacinth Length

The total length of water hyacinths from petiole tip to root tip (Table 1) was measured for a three month period at the beginning of the study in Pond One (control pond) and Pond Two (treatment pond).

Table 1. Water Hyacinth Length (meters)

Date	Pond One (control)	Pond Two (treatment)
April 8	0.7	0.5
April 22	0.7	0.6
*May 14	—	0.8
June 6	1.3	0.4
June 29	1.0	0.3

*date of chemical treatment of Pond Two hyacinths.

Herbicide was applied to the treatment ponds (Ponds Two and Three) on May 14, 1975, as a means of controlling the water hyacinth populations. Table 1 shows that the treatment pond hyacinths were at their maximal length on treatment day and decreased in length in following weeks. This decrease in length was due to wilting and dying of the chemically treated plants. The control pond plants increased in length until June 13, 1975, at which time they were at maximal length. Actively growing hyacinths increased in length very quickly during spring until water temperatures and air temperatures had increased considerably. These and other restraining factors, such as limited surface area, were associated with a decrease in the water hyacinth growth rate.

Water Hyacinth Biomass

Determinations of water hyacinth fresh and dry weights per M^2 of pond surface were made in Pond One (control pond) and Pond Two (treatment pond) before and after herbicide application, for a three month period at the beginning of the study in 1975 (Table 2).

Table 2. Water Hyacinth Biomass (kg/M^2 dry weight)

Date	Pond One (control)	Pond Two (treatment)
April 8	2.9	2.2
April 22	3.4	2.9
*May 14	6.1	3.0
June 6	5.4	1.7
June 29	3.4	1.2

*date of chemical treatment of Pond Two hyacinths.

The control and treatment ponds both had maximal dry weight biomass on May 14, 1975, and both decreased in the following weeks. Pond One had a maximal fresh weight biomass of 57.7 kg/M^2 (573 tonnes/hectare), and maximal dry weight biomass of 6.1 kg/M^2 (60.7 tonnes/hectare) on May 14, 1975. The treatment pond biomass decreased rapidly (and eventually reached zero) as the herbicide application killed the water hyacinths, and sediments (decaying plant material) sank to the pond bottoms. The biomass of actively growing water hyacinth populations increased rapidly while water and air temperatures were favorable (cool) and surface area was not limiting. Once water and air temperatures increased and the surface area was totally occupied, growth rates (and biomass) decreased. Note that the biomass was always greater in the control pond than in the treatment ponds even before herbicide application. This was probably due to nutrient availability which was influenced by pond interconnections. Pond One is mostly fed by a small stream. Pond Two is largely fed by overflow from Pond One, and Pond Three is mostly fed by overflow from Pond Two. All three ponds are partially fed by small springs and runoff. It is reasonable to assume that the water hyacinths in all three ponds were removing nutrients in substantial quantities and therefore the nutrient levels of outflowing water would be significantly reduced. Thus, water reaching Pond Two would have lower nutrient concentrations than that flowing originally into Pond One since nutrients were removed by the Pond One water hyacinths (and other producer communities).

Sediment Accumulation

The amount of sediments accumulating beneath actively growing water hyacinth populations (Pond One, control pond) and beneath chemically treated populations (Pond Two, treatment pond) is shown in Table 3.

Table 3. Sediment Accumulation Beneath Actively Growing Water Hyacinths (Pond One), As Compared to Chemically Treated Water Hyacinths (Pond Two). Measured in kg/M^2 Deposited Over an Eight Month Period (May 14, 1975, to Jan. 12, 1976).

	Replicates	Drained Fresh Weight	Dry Weight
Pond One	1	2.871	0.114
	2	5.990	0.322
	Average	4.431	0.218

Table 3 (continued).

	Replicates	Drained Fresh Weight	Dry Weight
Pond Two	1	10.024	0.716
	2	10.823	0.549
	3	9.783	0.613
	Average	10.210	0.626

Sediment accumulation in terms of dry weight in kg/M^2 was much greater (almost triple) beneath chemically treated hyacinths than beneath actively growing hyacinth populations. If the original dry weight biomass of the hyacinth populations is considered (Table 2), the sediment accumulation from chemically treated hyacinths was almost six (5.8) times greater than that of the actively growing hyacinths since the biomass of the control pond was double that of the treatment pond when herbicide application occurred (May 14, 1975).

The dry weight of sediments deposited below actively growing hyacinths (control pond) averaged 0.218 Kg/M^2 of pond bottom. This accounts for approximately 3.6 percent of the original hyacinth biomass available at the beginning of the study (6.1 kg/M^2 dry weight). The remaining 96.4 percent of the control pond hyacinth biomass can be accounted for in three ways: (1) biomass remaining within living hyacinth mats floating on the pond surface, (2) biomass entering aquatic or terrestrial food chains (detritus or living plant material being eaten), and (3) biomass being decomposed either aerobically on the pond surface or anaerobically from the sediment pans (on the pond bottoms).

The results of this study suggest that sediment accumulation beneath actively growing hyacinth populations is significant

(3 to 6 percent), and that the majority of the hyacinth biomass remains within the floating hyacinth mat. The amount of biomass lost to aquatic food chains and decomposition could not be determined by this study. However, the highly anaerobic conditions normally found beneath growing hyacinth populations suggests a minimal loss of biomass to aquatic food chains (due to lack of dissolved oxygen, resulting in small zooplankton populations) and aerobic decomposition. Anaerobic decomposition would seem to account for a significant (but not large) loss of biomass since the sediment layers of such hyacinth ponds quickly increase in thickness. Under natural conditions such shallow hyacinth ponds are normally short-lived, eventually becoming marshlands through the process of aquatic succession. This natural process is hastened by the rapid sediment accumulation found beneath floating aquatic plants such as water hyacinths and pennywort.

The dry weight of sediments deposited below chemically treated hyacinths (treatment ponds) averaged 0.626 kg/M^2 of pond bottom. This accounts for approximately 20.9 percent of the original hyacinth biomass available at the beginning of the study (3.0 kg/M^2 dry weight). The remaining 79.1 percent of the original biomass can be explained in two ways: (1) biomass entering food chains or (2) biomass being decomposed. No significant amount of biomass was left on the pond surfaces eight months after herbicide application. Since large, thick, floating mats of decaying organic matter were found on the treatment pond surfaces for many months, it is highly probable that much organic matter (biomass) was aerobically decomposed and lost directly to the atmosphere. The large populations of rhizopodal protozoans found feeding upon the mats of decaying organic material probably consumed significant amounts of organic material. Aerobic conditions began to return to the pond depths after the floating mats of decaying organic material broke up and sank. Other zooplankton populations then began to flourish, many of which were dependent upon detrital material for food sources.

In summary, both actively growing and chemically treated hyacinths deposited significant amounts of sediments. Three to six times more sediment accumulation occurred after hyacinths had been chemically treated, but this was still much less than might be expected. Much of the biomass contained within the once-living hyacinth mat was apparently lost to aerobic decomposition and aquatic food chains. Only 20.9 percent of the original biomass could be accounted for in the sediments below such chemically treated populations as compared to 3.6 percent for actively growing hyacinth populations.

DISCUSSION

Emulsamine E-3 (the oil soluble amine of 2,4-D) proved to be an efficient means of controlling dense growths of water hyacinths. However, under high nutrient conditions (such as in these citrus ponds), regrowth of hyacinths or other aquatic weeds can be expected to occur. Only by monthly monitoring and occasional herbicide applications to fringe or regrowth areas can control of floating aquatic plant populations be achieved.

Large floating mats of decaying organic material were found on the treatment pond surfaces for several months after herbicide application. These floating mats decomposed aerobically and eventually broke up and sank to the pond bottoms. Open water conditions were then established and water quality slowly improved.

A drawdown of Ponds Two and Three, started during June 1976 (one year after herbicide application), was done to remove the nutrient-rich water contained in the ponds after chemically treating the aquatic vegetation, and to consolidate and oxidize the thick sediments on the pond bottoms. The water levels in Ponds Two and Three were re-established in January 1977, by which time the sediments in both ponds had consolidated considerably and water quality had significantly improved. Very few floating aquatic weed problems later arose in the treatment ponds, except for small marginal fringes of water hyacinths, pennywort, alligatorweed, or duckweed, which were easily controlled by herbicide application from a hand sprayer or by manual collection.

Refer to Table 4 for a summation of the changes in chemical and physical parameters and to Table 5 for a summation of the changes in the biological populations during the major phases of this study.

Very little light reached the pond surfaces and depths while dense, actively growing, floating mats of water hyacinths were present. Light penetration into the pond depths gradually increased after hyacinth disappearance and as water quality improved. Light penetration increased during cool water temperature periods (winter) as the water hyacinth populations decreased their total surface coverage due to frost damage.

Water hyacinth biomass (standing crop) determinations showed that actively growing populations produced up to 57.7 kg/M^2 (573 tonnes/hectare) fresh weight and 6.1 kg/M^2 (60.7 tonnes/hectare) dry weight.

Actively growing water hyacinth populations produced an average of 0.218 kg/M^2 dry weight sediments while dying chemically treated hyacinths produced 0.626 kg/M^2 dry weight over an eight month period. The chemically treated hyacinth populations produced almost six times more sediments than did the actively growing hyacinth populations after taking into account the biomass differences in the original populations. The use of herbicides to kill undesirable floating mats of aquatic plants, such as water hyacinths

Table 4. Relative Change in Chemical and Physical Parameters During the Major Phases of the Study: (a) Beneath Actively Growing Water Hyacinth Mats, (b) Beneath Chemically Treated Hyacinth Mats; and Under Open Water Conditions (c) Year One After Treatment, and (d) Year Two After Treatment.
N-None, L-Low, M-Medium, H-High

Parameter	(a) Growing Hyacinths (1975)	(b) Dying Hyacinths (1975)	(c) Open Water Year One (1976)	(d) Open Water Year Two (1977)
pH	L	L	H	H
CO_2	H	M	L	L
HCO_3^-	H	M	M	L
Turbidity	L	M-H	L-H	L-M
Soluble Salts	L	M	M	M-H
Specific Conductivity	*L	*L-M	M	H
Potassium	L	H	M	M
Available Phosphate-P	L-M	H	M	L-M
Calcium	L	M	M	M-H
Magnesium	M	M	M	M
Surface Dissolved O_2	L-N	L	L-H	M-H
1M Dissolved O_2	L	L-N	L-M	L-H
Water Temperature (annual range)	L	*L-M	M	H
Sedimentation	M	H	*L	*L-N
Light Penetration at 1M Depth	L	*L-M	M	M

*estimated value

Table 5. Relative Change in Biological Populations During the Major Phases of the Study: (a) Beneath Actively Growing Hyacinth Mats, (b) Beneath Chemically Treated Hyacinth Mats; and Under Open Water Conditions (c) Year One after Treatment, and (d) Year Two after Treatment.
N-None, L-Low, M-Medium, H-High

Parameter	(a) Growing Hyacinths (1975)	(b) Dying Hyacinths (1975)	(c) Open Water Year One (1976)	(d) Open Water Year Two (1977)
Total Phytoplankton	M	L-M	H	H
Green Algae	M	N	L-H	M-H
Blue-Green Algae	H	L-H	L-H	L-H
Total Zooplankton	H	L	M-H	M
Rhizopodal Protozoans	H	M-H	L-M	L
Rotifers	L-M	L	H	M
Crustaceans	M	N-L	L-M	M
Periphyton Diatoms				
Surface Density	L-M	L-H	M-H	L-H
1M Density	L	L-M	M-H	M-H
Surface Species Diversity	M	L	M-H	M-H
1M Species Diversity	M-H	M	M	L-M
Number of Species (Surface)	M	L	M	M-H
Number of Species (1M)	H	M-H	L	L-M

and pennywort, caused a larger sediment load to be deposited on the pond bottoms than would usually be caused by normal plant growth. Although herbicide application caused an increased sediment loading, its environmental impact was much less than might be expected. Only 20.9 percent of the original biomass could be accounted for in the sediments below chemically treated populations (as compared to 3.6 percent under actively growing populations). Much of the biomass contained in the chemically treated mat was probably lost to aerobic decomposition during periods when large floating mats of dead and decomposing organic materials were found on the pond surface or to aquatic food chains.

The three ponds studied were typically populated and dominated by those organisms generally associated by many researchers with highly eutrophic conditions. Hutchinson (1967) described this type of phytoplankton assemblage as a "mixed eutrophic" type, composed of diatoms (mainly *Melosira* and *Stephanodiscus*), Chlorococcales, Myxophyceae, and Euglenophyta. Stoermer and Yang (1970) found that *Fragilaria capucina* var. *mesolepta* and *Melosira granulata* var. *angustissima* (phytoplankton and periphyton diatom dominants in this study) required high levels of nutrients and were, therefore, typical of highly eutrophic lakes. Butcher (1947) described *Gomphonema parvulum* (a periphyton diatom dominant in this study) as being an indicator of organic pollution.

The periphyton diatom communities showed typical spring and fall maximum densities and lower (and fluctuating) densities during summer after hyacinth disappearance. This type of general diatom distribution was described by Round (1960), Castenholz (1960), and Patrick and Reimer (1966). While most investigators have found the spring or early summer diatom blooms to be of greater proportions than the fall blooms (e.g. Castenholz, 1960), the opposite situation occurred in all three citrus ponds during this study. The dominant periphyton diatoms commonly found during the study included *Achnanthes exigua* var. *heterovalvata, A. hungarica, Cyclotella Meneghiniana, Eunotia curvata, E. pectinalis, Gomphonema affine* var. *insigne, G. gracile, G. parvulum, Melosira granulata* var. *angustissima, Navicula confervae, N. minima, Nitzschia amphibia, N. palea, Stephanodiscus astrea* var. *minutula,* and *Synedra ulna.*

The cyanophyte species (*Oscillatoria limmetica, O. subbrevis Anabaena spiroides, A. Schermer,* and *Microcystis aeruginosa*) composed the major portion of the total phytoplankton standing crop in this study. Pearsall (1932), in regard to phytoplankters associated with eutrophic conditions, suggested that the Cyanophyta generally showed a positive correlation with high concentrations of organic matter, as did Prescott (1939). Hutchinson (1967) suggested that cyanophyte blooms occurred in fairly hard water, warm temperatures, and reasonable sodium levels. Under these conditions, blue-green algae out-competed other algal forms for inorganic and organic nutrients. Nutrients such as phosphates, nitrates, and ammonia could have diffused from the organic bottom muds, particularly at the warm temperatures experienced in this study.

Other factors which also could have contributed to the dominance of the blue-green algae in the study ponds include the ability of certain members of the Cyanophyta to produce iron-selective chelators (Murphy and Lean, 1976), the ability of some members of the group to excrete substances inhibitory to other algae (Keating, 1978), and the increased efficiency of carbon dioxide utilization by certain blue-green algae (Shapiro, 1973).

Total phytoplankton was found to be maximal during cool water periods when light penetration was increased and minimal during warm water periods under actively growing hyacinth mats when light penetration was decreased. Total phytoplankton decreased after the hyacinth mats were chemically treated due to decreased light penetration and foul water quality conditions and later increased after open water conditions were established. Total phytoplankton was minimal during cool water periods and maximal during warm water periods after hyacinth disappearance.

Blue-green algae were prevalent throughout the year beneath actively growing hyacinth populations but decreased rapidly when hyacinth populations were dying after herbicide application. Blue-green algae populations were minimal during cool water periods and maximal during warm water periods after hyacinth disappearance (open water conditions).

The phytoplankters most commonly found under actively growing water hyacinth populations were *Oscillatoria limnetica*, *Ulothrix* spp., unidentified green unicells, total green algae, and phytoplanktonic diatoms such as *Fragilaria capucina* var. *mesolepta* and *Melosira granulata* var. *angustissima*. These phytoplankters reached maximal populations during cool water periods when light penetration was maximal. Other phytoplankters such as *Euglena* spp. and *Eudorina* spp. did well under foul water conditions while floating mats of dead and decaying water hyacinths were found on the pond surfaces.

Certain phytoplankters such as *Microcystis aeruginosa*, *Fragilaria capucina* var. *mesolepta*, *Melosira granulata* var. *angustissima*, and *Synura uvella* grew well while water quality was improving after hyacinth disappearance. Phytoplankters that thrived under open water conditions with improved water quality were *Anabaena Schermer*, *Anabaena spiroides*, *Oscillatoria subbrevis*, and *Volvox* spp.

Periphyton diatom densities were found to be negatively correlated to percent total vegetation cover. Periphyton diatoms beneath the actively growing water hyacinth mats were found to be maximal during cool water periods and minimal during warm water periods when large hyacinth mats shaded the pond surfaces. Periphyton diatom populations were minimal in the pond depths until the water hyacinths disappeared and water quality (and light penetration) improved. Surface populations were many times denser than the corresponding populations in the pond depths before hyacinth disappearance. Diatom populations in the pond depths increased significantly after hyacinth disappearance and often surpassed the corresponding surface densities. They showed typical spring and fall maximum densities and lower fluctuating densities during summer.

Periphyton diatom densities were positively correlated with light penetration. Light penetration eventually increased as the hyacinths died back during cool water periods (winter) or were removed by chemical treatment. Periphyton diatom and phytoplankton populations increased in the pond surfaces and depths as light penetration increased.

The one and two meter depth periphyton diatom populations were sensitive to changes in light penetration (positive correlation). Light penetration was dependent upon percent total vegetation cover, total phytoplankton, and turbidity. Changes in water temperature caused corresponding changes in the total phytoplankton population which effected light penetration. Increased water temperatures during summer led to increased phytoplankton populations (mostly blue-green algae). These increased phytoplankton populations caused corresponding decreases in light penetration which effected the densities and species diversities of the periphyton diatom populations in the pond depths. Total phytoplankton populations decreased during winter due to the lower water temperatures and periphyton diatom populations increased due to increased light penetration.

It is clear that light penetration is directly related to the relative abundance of phytoplankton. As the phytoplankton standing crop increased, the light penetration decreased. Maximum phytoplankton standing crops were present during the summer months (mostly blue-green algae), as were the smallest values for light penetration. According to Patrick and Reimer (1966), when light penetration becomes a limiting factor, bottom periphyton diatom community structure is easily altered. The surface periphyton diatom communities show this relationship to phytoplankton concentrations and light penetration but not as well as do the periphyton communities in the pond depths. The surface communities only appear to be effected by major phytoplankton concentration changes. This was as expected since these diatom communities would be less affected by changes in light penetration.

Data from this study suggest that distributions of phytoplankton and periphyton are limited and effected by many interrelated factors, the most important of which are light penetration, water temperature, and nutrient concentrations. These environmental factors seemed to determine which phytoplankters were best suited for these ponds. The favored phytoplankton populations grew and effected the periphyton diatom communities by altering light penetration. The amount of hyacinth cover also had profound effects upon the producer communities since increased hyacinth populations would decrease light penetration.

There was an obvious seasonal succession in both numbers and kinds of producer organisms present throughout the study period. Water temperature and light penetration appear to be the most important factors effecting the producer communities during spring and fall. The cool water temperatures and maximal light penetration values found during these periods were quite conducive to diatom growth. Prescott (1939) and Round (1960) described light penetration and water temperature as crucial factors determining algal periodicities, while Stoermer and Kopecynska (1967) suggested that water temperature could possibly be the single controlling factor. Patrick and Strawbridge (1963) described the early spring diatom plankton populations as occurring after a temperature rise which makes growth possible while many nutrients have accumulated over the winter. Large populations formed, under such conditions, composed of a few species (*Fragilaria capucina* var. *mesolepta*, and *Melosira granulata* var. *angustissima* in this study) which can grow at low water temperatures. After water temperatures increase in summer, this dominance of the diatom population by a few species is less likely to occur since more species are able to grow and thrive under such favorable conditions.

Nutrient analyses of pond water suggest that nutrients were, most likely, not limiting to producer communities since abundant nutrients were available throughout the study. Abundant nutrients were held in reserve in the bottom mud layers of the ponds and were released from the decaying organic matter (most of which was originally derived from dead water hyacinths). These bottom layers were anaerobic throughout most of the study, at least until water quality conditions improved. According to Hutchinson (1967), similar bottom layers released nutrients such as phosphates and possibly nitrates or ammonia during periods of high water temperature. Dissolved oxygen, pH, specific conductivity, and soluble salts increased, while available phosphate-phosphorus, total phosphate-phosphorus, and carbon dioxide concentrations decreased after hyacinth disappearance. Bicarbonate, potassium, calcium, and magnesium concentrations stayed fairly stable.

Periphyton diatom species diversity indices (Shannon-Weaver) suggested that the surface diatom communities were usually less diverse than those communities in the pond depths. This relationship was particularly evident when water hyacinth populations were actively growing. These results suggest an increasing diversity of the diatom flora with depth. Hostetter and Stoermer (1968), in their study of the vertical distribution of periphyton diatoms in Lake West Okoboji, Iowa, also found an increased diatom diversity with increased depth. They suggested that this was best explained in terms of physical factors subject to very small changes in the relatively stable bottom environment of deep lakes. For example, diatoms living in deeper waters would be subjected to less extreme temperature fluctuations and light intensity changes than those living in shallower environments. Whether or not such mechanisms were responsible for the increased diatom diversity in the pond depths of this study is uncertain since Ponds One, Two, and Three were only one to three meters in depth and small in surface area.

The surface periphyton diatom communities were normally quite diverse beneath actively growing hyacinth populations. The species diversities decreased dramatically in the surfaces of all three ponds during hyacinth treatment and remained low while the dying hyacinth mats were still present. Pond One surface species diversities remained fairly low (as compared to those beneath growing hyacinth populations) after open water conditions were established while Pond Two and Three surface species diversities attained fairly high but fluctuating levels (comparable with the species diversities found before hyacinth treatment).

These changes in periphyton diatom community species diversity indices were influenced by light penetration, water temperature, and total phytoplankton. Light penetration seemed to be the major factor influencing species diversity beneath actively growing hyacinth populations (which act efficiently in shading the ponds from the sun). As light penetration decreased with increasingly depth, the species diversity increased (negative correlation). Factors other than light penetration (such as water temperature and total phytoplankton) also became important in effecting species diversity after open water conditions were established. For example, blue-green algae populations flourished during warm water periods after hyacinth removal, thereby decreasing light penetration and effecting species diversity.

Zooplankton populations were highly variable in composition and size during the study. Total zooplankton was found to be positively correlated to total phytoplankton in all three ponds. Stepwise mulitple regressions selected such parameters as total phytoplankton, dissolved oxygen, water temperature, and percent total vegetation cover as those which describe the best model for total zooplankton.

The most prevalent zooplankters found throughout the year beneath actively growing water hyacinth populations were rhizopodal protozoans, which included *Arcella* spp., *Centropyxis aculeata*, and *Difflugia bacillifera*. These were also the most abundant zooplankters after hyacinth treatment when the water hyacinth mats were dead and decaying and oxygen concentrations were minimal. These protozoans thrived under foul water conditions, apparently needing little dissolved oxygen and feeding upon the roots or other detritus originating from the water hyacinth populations. These zooplankton species were no longer found after open water conditions became established and water quality improved. Stepwise multiple regressions selected percent total vegetation cover as the best possible model for all the rhizopodal protozoan species (*Arcella* spp., *Centropyxis aculeata*, and *Difflugia bacillifera*) in all three ponds.

Other zooplankters were also found under actively growing water hyacinth populations but were maximal only during early spring when the hyacinth populations were minimal, dissolved oxygen concentrations were maximal, and water temperatures were low. Such zooplankters included *Cyclops* spp., nauplii larvae, *Ceriodaphnia* spp., *Chydorus* spp., chironomid larvae, and various rotifer species.

The bulk of the total zooplankton population on most sampling dates was composed of rotifers. They were found throughout the year before and after hyacinth disappearance. Rotifers were maximal during early spring and minimal during summer beneath actively growing hyacinths. The opposite was true after hyacinths had disappeared and open water conditions were established. Several rotifers, such as *Brachionus havannaensis*, *B. plicatilus*, and *Polyarthra* spp., were commonly found comprising very large populations under such open water conditions.

Total rotifers was found to be positively correlated to total phytoplankton in all three ponds. Stepwise multiple regressions selected total phytoplankton as the best model for Pond One and water temperature as the best model for Ponds Two and Three. Stepwise multiple regressions selected parameters such as percent total vegetation cover, total phytoplankton, water temperature, pH, and dissolved oxygen, as the best models for the major rotifer species found during this study.

The zooplankton populations observed during this study were very dependent upon the producer communities either directly or indirectly. The several main components of the zooplankton communities found beneath actively growing water hyacinth popu-ations were rhizopodal protozoans (which were found throughout the year until hyacinth disappearance) and crustaceans and rotifers (which were found mostly during the spring). Rhizopodal protozoans apparantly depended upon root materials and other detritus originating from the overlying water hyacinths as their food source. The rotifers and herbivorous crustaceans apparently were reliant upon phytoplankters, phytoplanktonic diatoms, and detrital material as their food sources. The rarely observed carnivorous crustaceans were probably dependent upon herbivorous zooplankters as a food source.

The rotifers and herbivorous crustaceans, which constituted the majority of zooplankters during this study, were positively correlated with total phytoplankton. Zooplankton population increases followed shortly after phytoplankton population increases.

As previously mentioned, phytoplankton population changes were affected by such factors as water hyacinth vegetation cover, water temperature, and light penetration. Therefore, changes in these parameters would cause changes in the phytoplankton populations which would eventually affect the size and composition of the zooplankton populations.

No significant correlations were found between the zooplankton populations and the periphyton diatom populations. This is not to imply that such correlations and interrelationships do not exist but only that they are apparently not of major importance.

CONCLUSIONS

Heavy infestations of water hyacinths or other mat-forming, free-floating, aquatic weed populations in small stagnant farm ponds can be controlled (killed and removed) by the use of Emulsamine. Dense populations of aquatic weeds adversely alter the water quality and composition of aquatic plant communities below them due to competition for nutrients, the shading effects of the vegetation, and constant sediment accumulation from dead and decaying plant parts.

The poorest water quality conditions were evident during warm water periods when hyacinth growth, surface coverage, and shading effects on the underlying water column were maximal. These factors minimized light penetration, and thereby severely limited the phytoplankton and periphyton producer communities. Zooplankton populations were also minimal in response to the low phytoplankton populations.

Below actively growing hyacinths, conditions were more suitable for growths of phytoplankton, zooplankton, and periphyton during cool water periods. During such times of the year, hyacinths covered less surface area, allowing increased light penetration into the underlying water column. Even with this increased light penetration, water quality conditions were still poor, with high concentrations of suspended organic material, carbon dioxide, and bicarbonate, and low pH's and dissolved oxygen concentrations.

It is well known that in order to be effective, herbicide application to aquatic weed species must occur when the plants are actively growing. Since such weed control must occur during warm water periods, when water quality is poorest and submerged biological populations are minimal, the environmental impact of herbicide treatment on hyacinth mats in heavily infested small stagnant farm ponds was minimal. Although increased sediment accumulation occurred, and the water quality was somewhat reduced after herbicide treatment, a virtual biological desert normally existed beneath the hyacinths during warm periods of the year, and the impact upon existing plant and animal species at that time was minimal. Death of the hyacinths and disappearance of the hyacinth mats would most likely occur before the onset of cool water periods.

Water quality conditions remained poor while the chemically treated hyacinths were dying, and while the large floating mats of dead and decaying organic material were found on the pond surfaces. Only after these floating mats broke up and disappeared, did water quality begin to improve. This improvement of water quality may take several years to occur, depending upon the magnitude and duration of the hyacinth infestation.

During periods of dense hyacinth cover, competition for available nutrients between the various producer communities occurred constantly. Hyacinths apparently out-competed the phytoplankton and periphyton for nutrients during the warm water periods (rapid hyacinth growth, and minimal phytoplankton and periphyton growth), while the opposite situation apparently occurred during cool water periods. When hyacinths or other types of aquatic vegetation were chemically treated, nutrients bound in that plant material were released, leaving high nutrient levels in the ponds, and little competition for these nutrients. Such conditions, along with the environmental parameters previously described in this study, would seem to favor extensive and persistent blooms of the various blue-green algae species.

Blue-green algal blooms occurred in this study after hyacinth removal, but not as often or as large as expected. The author suggests that although water flow between ponds was minimal except during periods of heavy rains, there might have been sufficient flow to flush out excess nutrients, and inhibitory substances excreted by the blue-green algae. This may have caused the blue-green algae to be less favored for growth than other types of algae, especially the green algae.

The populations of aquatic organisms found during this study were typical of highly eutrophic conditions in northcentral Florida. These three citrus ponds are now devoid of aquatic weed problems, and are supporting large gamefish populations five years after the beginning of the study.

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BIOGRAPHICAL SKETCH

William Wallace Brower II was born July 17, 1948, in Akron, Ohio, to Ruth Elizabeth and Ralph Arthur Brower. William grew up in the Akron area, and developed into an enthusiastic student and sports participant. He graduated from Cuyahoga Falls High School in 1966.

William attended Bowling Green State University in Bowling Green, Ohio, where he majored in biology and minored in chemistry. He received his Bachelor of Science degree *Cum Laude* in 1970, and continued his study at Bowling Green for a master's degree in biology. William specialized in aquatic biology and phycology and received his Master of Science degree in 1973.

While at Bowling Green State University, William met Sharon Diane Parks, also majoring in biology. William and Sharon married in 1973, and she gave birth to their son, William Wallace Brower III, in 1979.

William entered the University of Florida in Gainesville, Florida, in 1973, where he studied botany in pursuit of the Doctor of Philosophy degree. Once again, William specialized in aquatic biology and phycology. He worked as a graduate teaching assistant for the Botany Department for two years, and as a graduate research assistant for the Agronomy Department for three years.

William accepted a teaching position at Brevard College, Brevard, North Carolina, in 1978. He is currently employed in his third year as a biology instructor, while completing *in absentia* his studies at the University of Florida.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Joseph S. Davis

Joseph S. Davis, Chairman
Professor of Botany

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

William T. Haller

William T. Haller
Associate Professor of Agronomy

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Frank G. Nordlie
Professor of Zoology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

David S. Anthony
Professor of Botany

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Richard C. Smith
Professor of Botany

This dissertation was submitted to the Graduate Faculty of the Department of Botany in the College of Liberal Arts and Sciences and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 1980

Dean, Graduate School