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Effects of Chemical and Biological Weed Control on the Ecology of a South Florida Pond

J. R. CASSANI AND W. E. CATON[1]

ABSTRACT

A combination of herbicides and hybrid grass carp were utilized for control of hydrilla in a sub-tropical urban pond (1.2 ha surface area). Selected water quality parameters and non-target communities were monitored for 15 months prior to the herbicide treatment and for 20 months afterward. Hybrid grass carp were stocked 3 months after a partial herbicide treatment at a rate of 380 fish ha^{-1} or approximately 25 kg fish metric ton^{-1} vegetation (FW) resulting in a rapid elimination of all submersed macrophytes. Aquatic macrophytes, primarily southern naiad, replaced hydrilla as the dominant species and became problematic 15 months after the fish were stocked. Only 2.6% of the hybrid grass carp originally stocked were recovered after 19 months. Phosphorus, nitrogen, turbidity and chlorophyl a levels increased sharply the first month after stocking but returned to near pre-treatment levels the next month. Diversity indices for phytoplankton during pre- and post-treatment periods were not significantly different ($p < .05$) except for diatoms which decreased significantly during the post-treatment period. Seasonal trends in zooplankton density remained similar throughout the study except that rotifer abundance greatly increased three months after hybrid grass carp were stocked but decreased to pre-treatment levels five months later. In addition, zooplankton became significantly more diverse during the post-treatment period. The Chlorophyceae, Cyanophyceae, Copepoda (nauplii), Copepoda and Rotifera demonstrated significant ($p<.05$) negative correlations with aquatic plant biomass. Six of the nine major macroinvertebrate taxa encountered demonstrated similar or increasing trends in seasonal abundance after the control applications when macrophyte densities were low to moderate (0.4-1.2 kg m^{-2}) compared to pre-treatment levels of 2.0-3.0 kg m^{-2}.

Key words: Hydrilla, water quality, macroinvertebrates, plankton, aquatic macrophytes, hybrid grass carp, chemical control.

INTRODUCTION

Integrating chemical and biological control agents for managing aquatic macrophytes is a desirable approach in that plant densities might be manipulated with greater precision[2]. The use of herbivorous fish, (i.e. grass carp, *Ctenopharyngodon idella* Val. or hybrids there-of), combined with a limited initial herbicide treatment is a relatively new concept in the area of aquatic weed management.

The objective of this study is to determine the practicality with regard to efficacy and environmental impact of an integrated management approach using hybrid grass carp (*Ctenopharyngodon idella* X *Hypophthalmichthys nobilis* Rich.) combined with an aquatic herbicide (Diquat with copper) to manage vegetation in an urban south-Florida pond.

STUDY SITE

Lake Jasmine, a eutrophic pond located in Lee County, Florida, (26°North Latitude, 81°West Latitude) has a surface area of 1.2 ha, a maximum depth of 3.0 m during the summer months and an approximate volume of 23,000 m^3. The basin was artificially created and collects surface drainage from a densely populated residential area in Lehigh, Florida. The species composition of the submersed macrophyte community was initially, dominated (>90% bottom area) by hydrilla (*Hydrilla verticillata* (L.f.) Caspary) but also included southern naiad (*Najas guadalupensis* (Spreng.) Magnus) and Chara (*Chara* sp.).

METHODS

Water samples were collected monthly from November 1980 to October 1983. Sampling was conducted for 15 months prior to any control measures as background data. The water column was sampled with a Kemmerer water sampler at two deep-water stations and results for the parameters tested were the average of the values of both stations. Samples were analyzed for conductivity, temperature, dissolved oxygen, total alkalinity, pH, turbidity, total phosphorus, ortho phosphorus, nitrate, nitrite, ammonia nitrogen and chlorophyl a.

Dissolved oxygen and temperature was determined at half-meter intervals with a Y.S.I. Model 57 Dissolved Oxygen Meter. Conductivity was measured with a Y.S.I. Model 33 S-C-T Meter. Total alkalinity was determined by titrating with 0.02N sulfuric acid using Brom Cresol Green-Methyl Red as an indicator. A Corning pH meter 5 was used for pH determinations. Turbidity was measured with a spectrophotometer and expressed as Formazin Turbidity Units. Total phosphorus ("acid hydrolyzable") was determined by acid hydrolysis with oxidative digestion and ortho phosphorus ("reactive") by using ascorbic acid as a reducing agent. Nitrate measurements were performed by modifying the cadmium reduction method using gentisic

[1]Lee County Hyacinth Control District, P. O. Box 06005, Fort Myers, Florida 33906.

[2]Sutton, D. L. 1979. Final report to the Florida Department of Natural Resources on the Project: A combination of herbicides and the herbivorous white amur fish for aquatic weed control. Ft. Lauderdale, Fl: Agri. Res. Center, Univ. of Florida. 48 pp.

acid in place of 1-naphthylamine. Nitrites were determined using the diazotization method with chromotropic and sulfanilic acid as the indicator. The Direct Nesslerization Method was used for measuring ammonia nitrogen. Chlorophyl a was determined by spectrophotometry after acetone extraction (1).

Phytoplankton and zooplankton were sampled monthly at both stations, from the top two meters (ea. 80% of maximum depth) of the water column with a 4.2 *l* Kemmerer. Each sample was filtered through a Wisconsin style plankton bucket (80 micron mesh) and was concentrated and preserved with Lugol's solution (1%). Phytoplankton density per taxa was determined by counting four random strips at 200X with a Sedgwick-Rafter Counting cell (1 ml). Zooplankton were enumerated and identified by examining 3 ml of concentrate with a Sedgwick-Rafter cell at 100X.

Macroinvertebrates were sampled monthly with multiplate artificial substrate samplers (AS) and with an Ekman dredge. The AS samplers consisted of 11 square plates 75mm X 75mm having a total surface area of 1303 cm^2. Four stations were established at each shallow (<1.0m), mid-depth (1.5-2.0m) and deep (>2.0m) level, with one AS sampler at the bottom and one tied mid-way between the pond bottom and surface. The AS samplers were carefully placed in plastic bags under water and returned to the laboratory where they were rinsed and scraped for attached invertebrates. Invertebrates were stored, sorted and identified in 70% ethyl alcohol. The AS samplers were reassembled and returned the following day.

Four Ekman dredge samples (232 cm^2) were collected at each of three open, deep-water stations. Samples were washed in the field using a washing bucket with a U.S. Standard No. 30 sieve (0.595 mm openings). Dredge samples were collected monthly until January 1983 after which samples were collected bi-monthly. Sampling for all parameters was usually done between 0900 and 1100 hours.

Vegetation biomass was determined monthly by taking 25 (20.8/ha) random samples with a cylindrical sampler having a cutting area of 0.25 m^2. The sampler, weighted with lead, was connected by rope to a boom and winch assembly at the bow of an air boat and was allowed to free-fall to the water surface and through the water column. Samples were removed under water and carefully placed in nylon mesh bags. The sample was washed in the field and placed in a plastic bag for transportation to the laboratory where the macrophytes were sorted by species and spun in a nylon bag at approximately 500 rpm for 5 minutes to determine fresh weight (FW).

During February, 1982, approximately 30% of the pond surface area was treated with an underwater injection of inverted diquat and copper (6,7 - Dihydro-dipyrido [1,2-a:2′, 1′-C] pyrazinediium dibromide, monohydrate and copper triethanolamine complex) at rates of 3.0 and 2.3 kg a.i. ha^{-2} respectively.

Prior to stocking the pond with hybrid grass carp, three exclosures were constructed with one inch mesh polyethylene netting as a check on feeding activity by the fish. Each exclosure excluded 4 m^2 of pond bottom and the water column above it, from feeding by hybrid grass carp. All of the vegetation in the exclosures was collected by hand under water and washed and weighed in the same manner as described above. The exclosures were sampled at six month intervals starting November, 1982.

During May 1982, 457 hybrid grass carp ($\bar{x}$ total length = 275.0 mm±6.5 mm 95% CI, n=71) were stocked at a rate of 380 fish ha^{-1}. The hybrid grass carp were produced by Malone and Son, Inc. during 1981 and were approximately 11 months old at the time of stocking. Assuming an average weight of 220 g/fish, 24.8 kg of fish were stocked per metric ton (FW) of vegetation or 83.75 kg ha^{-1}.

To determine hybrid grass carp survival, the pond was treated with Rotenone (>3 ppm) during December 1983.

RESULTS AND DISCUSSION

During the pre-treatment period (Nov. 1980 through Jan. 1982) estimated vegetation biomass remained relatively high with minor monthly variations between 2 and 3 kg m^{-2} (Figure 1). The herbicide treatment in February 1982 brought about a rapid decline in hydrilla density, and by May, the month hybrid grass carp were stocked, the hydrilla biomass estimate was less than 0.4 kg m^{-2}. By May 1982, most of the vegetation appeared as fresh regrowth despite a decline in biomass, with a greater proportion of *Utricularia* (24%) after March 1982. During the June sampling period, numerous hydrilla fragments were observed on the pond surface indicative of hybrid grass carp feeding activity. By July no submersed macrophytes remained indicating that the initial stocking rate was too high. Observations of hydrilla regrowth in the exclosures and subsequent sampling of them indicated that the hybrid grass carp were very likely responsible for the vegetation disappearance outside the exclosures. Average plant biomass (kg m^{-2}) inside the exclosures for the 02-XI-82, 23-V-83 and 01-XI-83 sampling dates were 1.9, 8.4 and 5.7 respectively. Vegetation density outside the exclosures never exceeded 1.5 kg m^{-2} during the post-treatment period (Figure 1). In February 1983 aquatic vegetation began to regrow in the pond and continued to increase with southern naiad becoming the dominant species. Hydrilla remained monotypic in the exclosures indicating that hybrid grass carp were selectively feeding on hydrilla on the outside or that the harvesting for weight determination every 6 months in the enclosures stimulated hydrilla regrowth from propagules remaining in the hydrosoil. Southern naiad is one of several species preferred by hybrid grass carp (5), however tender hydrilla shoots sprouting from tubers may have been more preferred.

The cause for a shift from dominance by hydrilla to southern naiad after the control applications was unexpected. The actual reason(s) for this are unknown to us, however, underwater observations indicated that the hydrosoil had become very floculant, apparently due to the decomposition of the vegetation. Several studies have demonstrated a negative effect of high organic content of sediments on hydrilla growth (2, 3, 6). By August 1983 the vegetation (primarily southern naiad) had reached an estimated density of 1.2 kg m^{-2}, a level arbitrarily determined

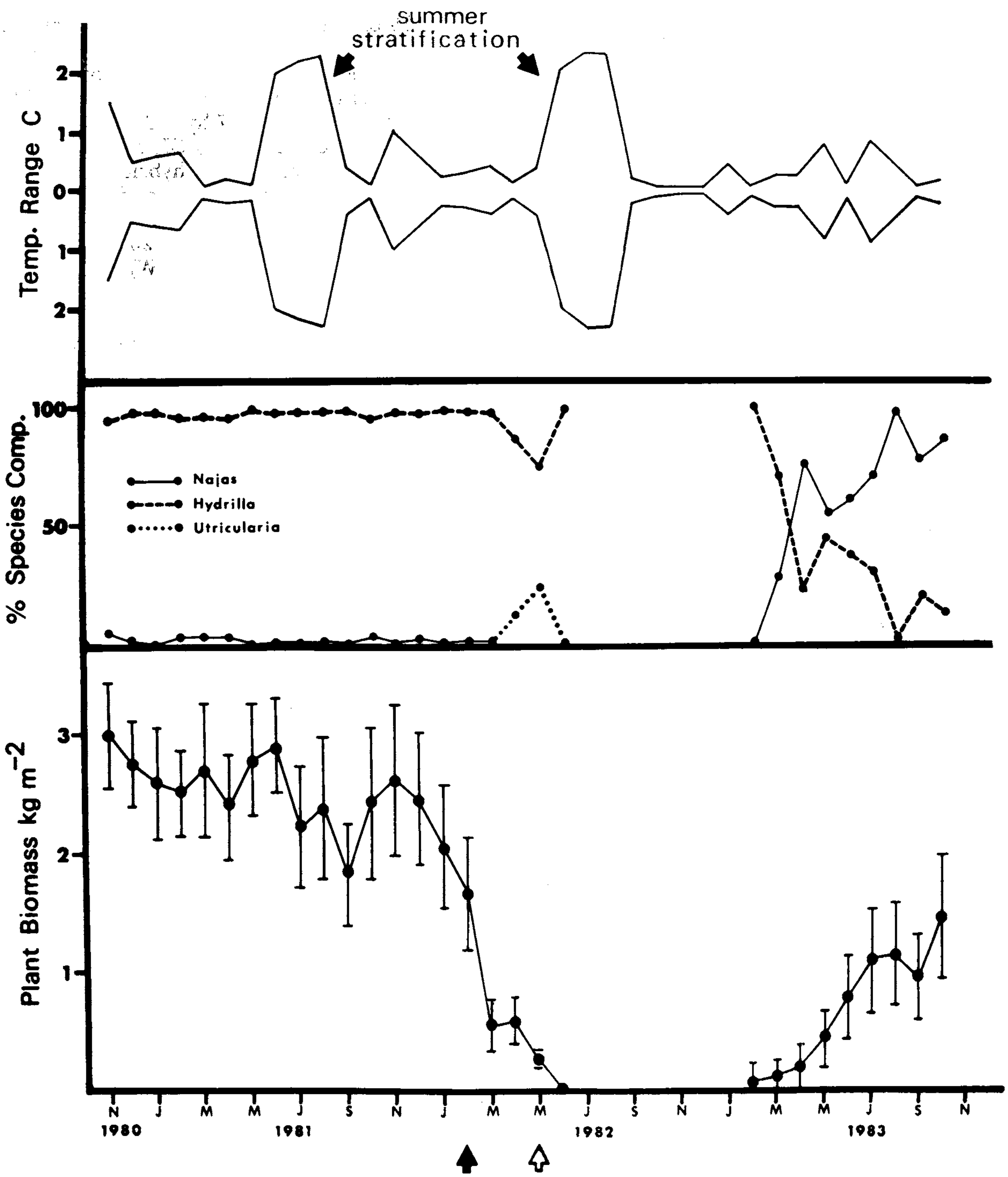

Figure 1. Vegetation biomass, submersed macrophyte species composition and temperature ranges through the water column for Lake Jasmine. Vertical bars on mean monthly biomass are 95% confidence intervals. FW = fresh weight, solid arrow = herbicide treatment, open arrow = fish stocking.

as problematic. The control period (veg. < 1.2 kg m^{-2}) after hybrid grass carp were stocked was determined to be 15 months.

Twelve hybrid grass carp were recovered after renovation of Lake Jasmine in December 1983, 19 months after stocking. The average total length and weight of the fish recovered was 507.4 mm ± 23.5 mm 95% CI and 1389.9 g ± 21.1 g 95% CI. The twelve fish remaining had increased in length an average of 232.4 mm and represented only 2.6% of the number originally stocked. Since escapement was impossible, the poor survival was probably due to removal by angling since these fish were observed to readily take a variety of cut and natural baits. Also, fish were reported to have been removed in this manner from several other sites where hybrid grass carp were stocked. Predation by largemouth bass (*Micropterus salmoides* (Lacepede)) was unlikely since the pond was renovated with rotenone prior to the introduction of hybrid grass

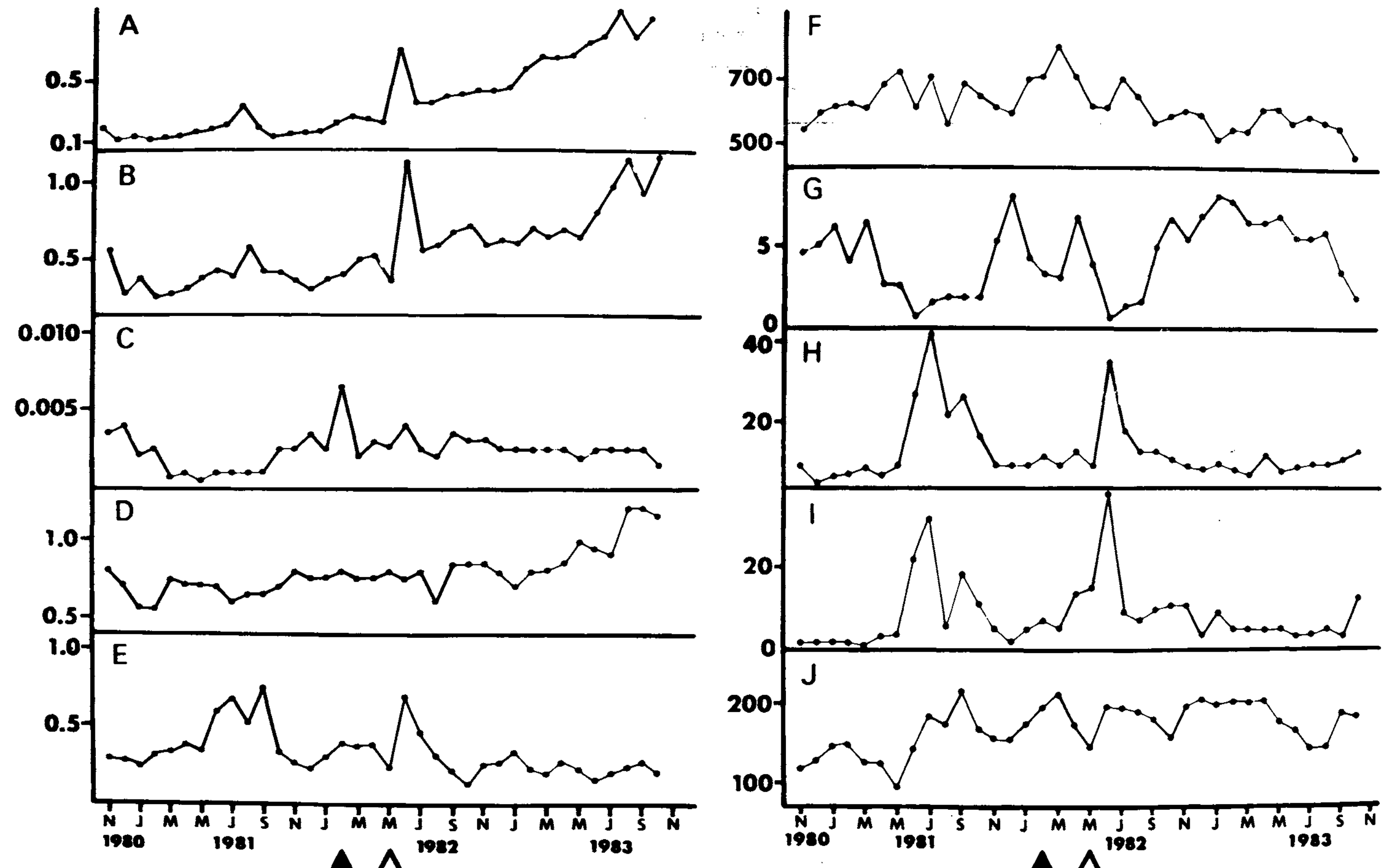

Figure 2. Water quality parameters for Lake Jasmine: A, x̄ ortho phosphorus (ppm); B, x̄ total phosphorus (ppm); C, x̄ nitrite (ppm); D, x̄ nitrate (ppm); E, x̄ ammonia nitrogen (ppm); F, x̄ conductivity (mhos/cm); G, x̄ dissolved oxygen (ppm); H, x̄ turbidity (FTU); I, x̄ chlorophyl a (mg/m^3); J, x̄ total alkalinity (ppm calcium carbonate). Solid arrow = herbicide treatment, open arrow = fish stocking.

carp. Poor recovery (11%) of hybrid grass carp was also reported from two central Florida lakes although considerably smaller (18 to 26 g) fish were originally stocked (13). If not for the population reduction, hybrid grass carp would probably have continued to contain vegetative regrowth.

Other studies utilizing grass carp in natural systems and of a similar size to our hybrid fish have demonstrated faster growth, more fish surviving for a longer period of time and provide control for a longer period at lower stocking rates (9, 12, 17, 18, 19).

Effects on Water Quality and Plankton. A number of water quality parameters demonstrated trend shifts after application of the herbicides and stocking of hybrid grass carp. Total and ortho-phosphorus concentrations increased sharply after the fish were stocked but dropped to near pre-treatment levels the month after, with a gradual and continual rise in subsequent months (Figures 2A and 2B). Phosphorus concentrations (total and ortho) showed highly significant ($p<.001$) negative correlations with macrophyte denstity as might be expected when nutrients are recycled back into the water column during and after macrophyte decomposition (Table 1). Nitrate levels did not peak sharply after the control applications but did rise gradually thereafter (Figure 2D). A significant negative correlation also occurred between nitrate levels and macrophyte density (Table 1). Nitrite and ammonia concentrations were evidenced by a trend toward stability after the control applications as compared to the background data (Figures 2C and 2E).

The mean dissolved oxygen concentration (Figure 2G) dropped sharply in May 1981 and May 1982, the month when summer stratification occurred. During the summer of 1983, thermal stratification was slight and dissolved oxygen levels remained high through the entire summer. The low macrophyte density during the post-treatment period facilitated "mixing" by wind and rain and resulted in little or no thermal stratification compared to the pre-treatment period (Figure 1). The pH levels were from 7.3 to 8.3 pre- and 7.6 to 8.3 post-treatment respectively.

In response to increased nutrient availability, the density of blue-green algae dominated by *Chroococcus pallidus*, peaked seven months after the control applications but rapidly dropped in December 1982 possibly resulting from regrowth of naiad and cooler water and remained at levels similar to those of the pre-treatment period until October 1983 when the study was terminated (Figure 3). The blue-green algae were dominated by the genera *Chroococcus, Oscillatoria* and *Lyngbya* before and after the control applications. Green algae (Chlorophyceae) increased during Jan.-June 1981 and 1982 and remained at relatively high levels during the winter 1982 post-treatment period (Figure 3).

TABLE 1. CORRELATION COEFFICIENTS (r) CALCULATED WITH VEGETATION BIOMASS AS THE DEPENDENT VARIABLE (* = $p < .05$, ** = $p < .01$, *** = $p < .001$)

Chemical parameter	(r)	Macroinvertebrate	(r)	Plankton	(r)
PO_4 (total)	–0.56***	*Chaoborus* (D)[1]	0.16	Chlorophyceae	–0.45**
PO_4 (ortho)	–0.57***	Chironomidae (AS)	–0.51**	Bacillariophyceae	–0.23
NO_2	–0.24	Chironomidae (D)	0.15	Cyanophyceae	–0.34*
NH_3	0.19	Ostracoda (AS+D)	–0.25	Copepoda (nauplii)	–0.33*
NO_3	–0.35*	Oligochaeta (AS+D)	–0.16	Copepoda	–0.33*
Chlorophyl a	–0.13	*Callibaetis* (AS)	–0.33*	Rotifera	–0.51**
Specific conductance	0.02	*Caenis* (AS)	–0.38*	Cladocera	–0.25
Total alkalinity	–0.70***	*Orthotrichia* (AS)	–0.54***		
Turbidity	0.07	Libellulidae (AS)	0.35*		
Dissolved oxygen	–0.26	Zygoptera (AS)	–0.29		

[1](D) = dredge, (AS) = artificial substrate

Tetraedron spp. and *Ankistrodesmus* spp. were numerically the dominant taxa during both pre- and post-treatment periods, with *Chlamydomonas* spp. becoming a co-dominant during the post-treatment period. Both the green ($p<.01$) and blue-green algal populations ($p < .05$) were negatively correlated with macrophyte biomass (Table 1). The highest diatom density (primarily *Synedra*) occurred during May 1982 when the fish were stocked, but rapidly dropped the following month and remained at relatively low levels for the rest of the study.

No significant ($p<.05$) differences were found among Shannon-Weaver diversity indices for phytoplankton groups before and after the control applications except for the diatoms which were significantly less diverse during the post-treatment period (Table 2).

Copepod populations increased during the summer months of 1981, 1982 and 1983, but no dramatic shift in this trend was observed after the control applications (Figure 3). The rotifer population increased dramatically starting in August 1982, two months after submersed vegetation had been eliminated and rapidly dropped to pre-treatment levels by January 1983 (Figure 3). The rotifer community was dominated by *Karatella cochlearis* during the pre-treatment period and by *Brachionus havanaensis*, *B. angularis*, *K. cochlearis* and ploimate rotifers during the post-treatment period.

The tremendous increase in the rotifer community appears to be at least an indirect response to the macrophyte decline and elimination. The phantom midge (*Chaoborus*) population, a zooplankton predator (10, 14), went from abundant to rare at the same time the rotifer population increased (Figure 4A). Another possibility for the dramatic increase in rotifers may be that rotifers, especially monogonatid spp. (i.e. *B. havanaensis*, *B angularis* and *K. cochlearis*) prefer open water as opposed to vegetated areas (14, 20). The Cladocera were relatively uncommon and showed no distinct trend in abundance or occurrence (Figure 3). The Copepod ($p<.05$) and rotifer ($p<.01$) populations demonstrated significant negative correlations with macrophyte density. Shannon-Weaver diversity index was significantly ($p<.05$) higher for total zooplankton during the post-treatment period (Table 1).

Data from other studies on northern and central Florida lakes relating changes in water quality, phytoplankton and macroinvertebrate population dynamics associated with the use of grass carp for weed control, are difficult to compare because of variations in climate, watershed, trophic state, target plant, nutrient buffering capacities, stocking rates and other variables (8, 16)[3,4,5,6]. The value of this study is that biotic and abiotic parameters were monitored with respect to drastic changes (heavy→none→moderate) in aquatic macrophyte density. Few if any other studies have monitored changing conditions of these types especially in a relatively small, subtropical, urban pond. Variations in water quality parameters in central and northern Florida lakes stocked with grass carp, reported by Leslie, *et al.* (9), generally resemble our data in that dissolved oxygen levels remained higher and for a

TABLE 2. SHANNON-WEAVER DIVERSITY INDICES FOR PHYTOPLANKTON AND ZOOPLANKTON 15 MONTHS BEFORE AND AFTER THE START OF THE CONTROL APPLICATION.

Taxa	Pre-treatment (11/80 through 1/82)	Post-treatment (2/82 through 5/83)
Cyanophyceae	1.152	1.103
Chlorophyceae	1.374	1.478
Bacillariophyceae	1.409	0.934[1]
Dinophyceae	0.134	0.257
Chrysophyceae	0.059	0.053
Euglenophyceae	0.323	0.314
Total Phytoplankton	2.036	1.928
Total Zooplankton	0.857	1.345[1]

[1]Significant difference at the $p<.05$ level as determined by a t-test.

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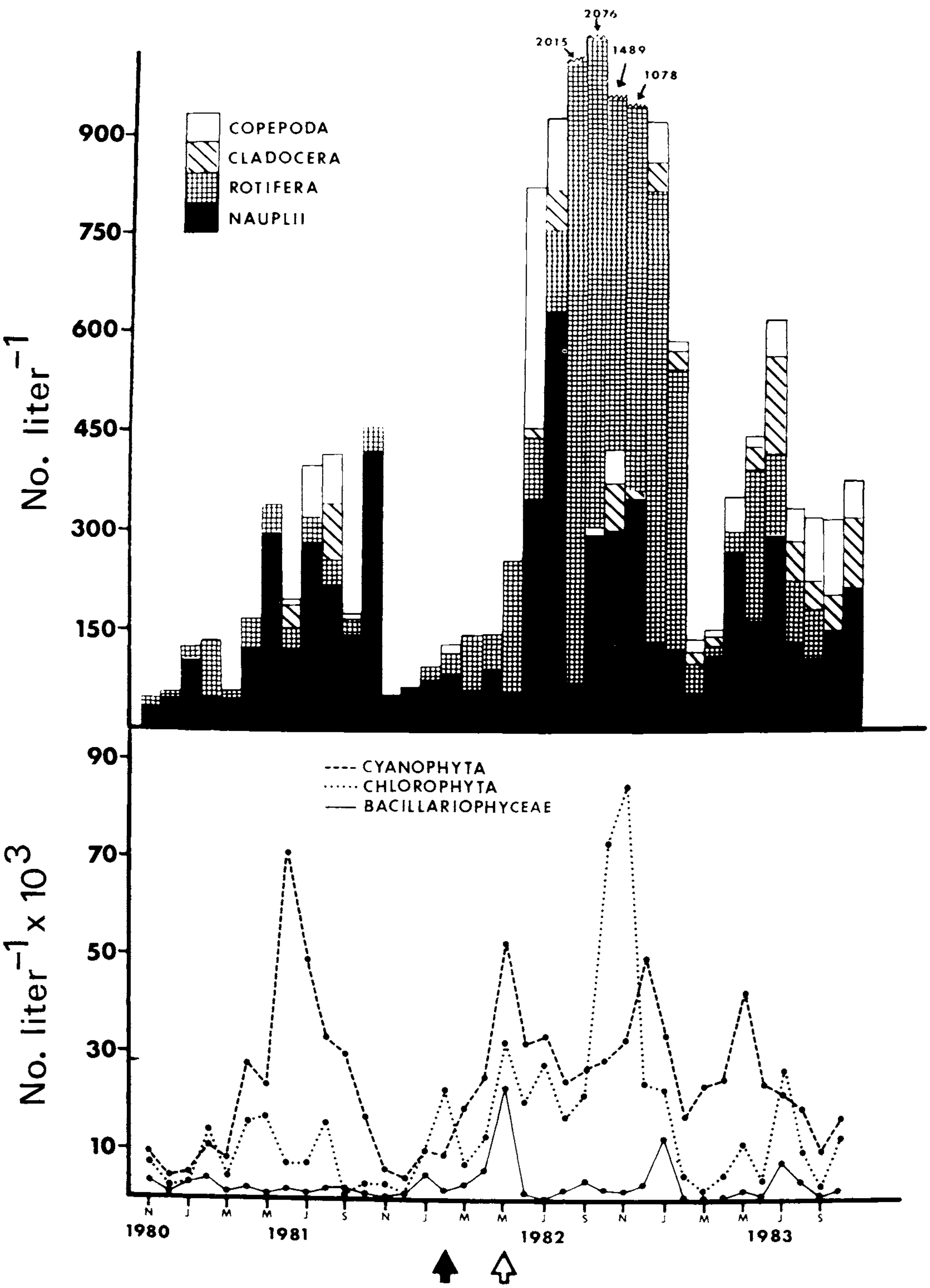

Figure 3. Mean densities for the major phytoplankton and zooplankton communities in Lake Jasmine. Solid arow = herbicide treatment, open arrow = fish stocking.

longer period of time during the summer months, total and ortho phosphorus concentrations demonstrated gradual long-term increases, and chlorophyl a returned to levels similar or lower than the pre-treatment period after a relatively brief peak associated with vegetation removal. Our results for turbidity indicated a sharp rise after the control applications but rapidly returned to relatively low levels instead of remaining high.

Effects on Macroinvertebrates. Seasonal occurrence and density data for the nine major taxa encountered are illustrated in Figure 4. Four groups, chironomidae AS, *Callibaetis* (AS), *Caenis* (AS) and *Orthotrichia* (AS), demonstrated significant negative correlations with macrophyte density (Table 1). Ironically, nymphs of several species in the genera *Callibaetis, Caenis* and *Orthotrichia* have been reported as preferring lentic habitats with submersed

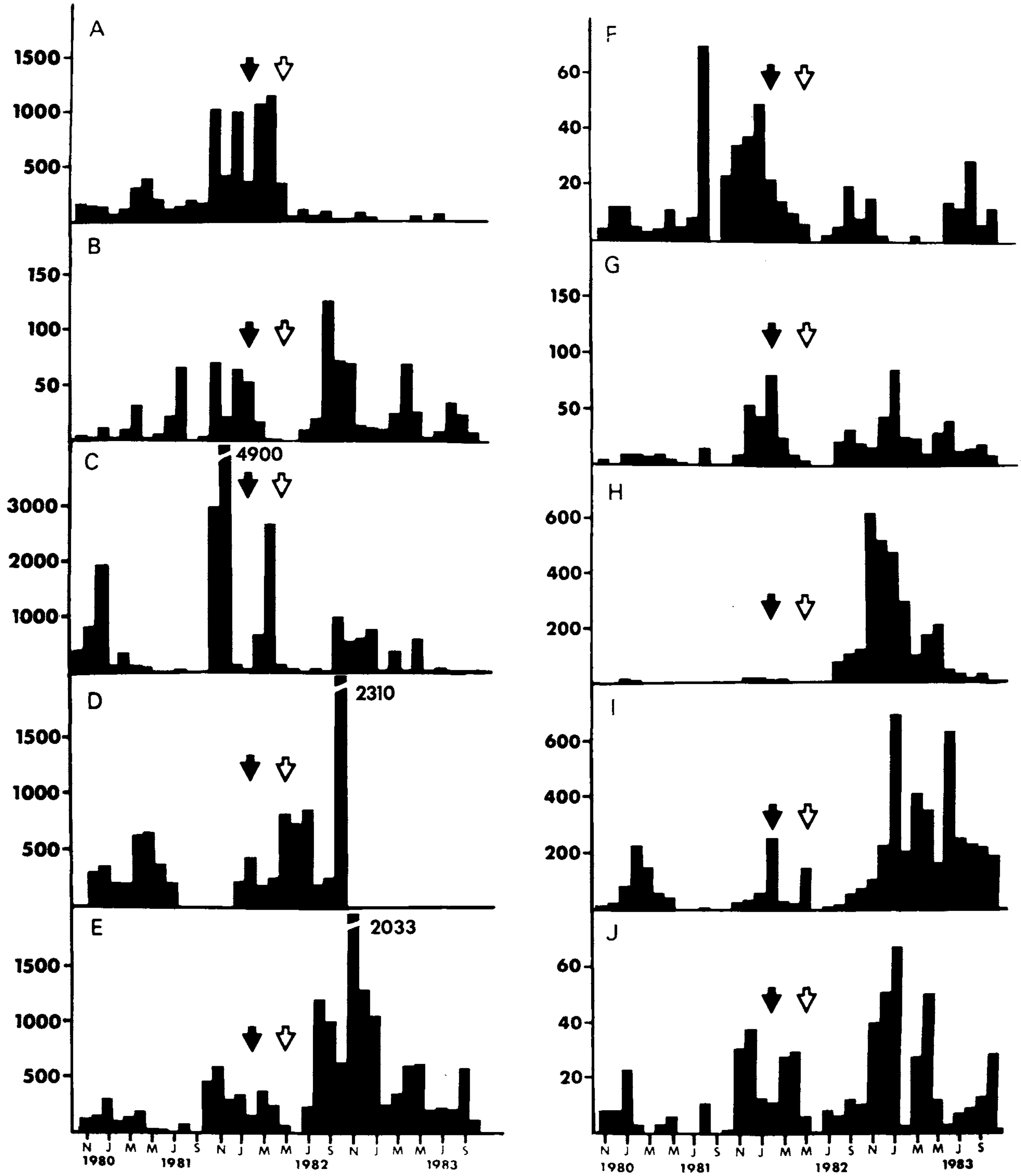

Figure 4. Population fluctuations (no. m^{-2}) for the major macroinvertebrate groups in Lake Jasmine. A, Culicidae, *Chaoborus punctipennis* (dredge); B, Oligochaeta (AS); C, Chironomidae (dredge); D, Ostracoda (dredge); E, Chironomidae (AS); F, Libellulidae (AS); G, Zygoptera (AS); H, Hydroptilidae, *Orthotrichia* sp. (AS); I, Caenidae, *Caenis* sp. (AS); J, Baetidae, *Callibaetis* sp. (AS). Solid arrow = herbicide treatment, open arrow = fish stocking, (AS) = artificial substrate.

macrophytes (7, 21). However, Rabe and Gibson (15) reported that *Callibaetis* preferred vegetated sites but also occurred regularly in denuded locations. Other factors including water quality, predator prey relationships and niche diversification, that can be directly or indirectly affected by macrophyte density must also be considered when discussing site selection by macroinvertebrates. Our data suggest that most macroinvertebrate groups, especially those known to be associated with aquatic macrophytes, were equally or more abundant at low to moderate macrophyte densities (0.4-1.2 kg m^{-2}) than at higher levels (2.0 kg m^{-2}). Poor water quality as an indirect effect of high macrophyte density is probably responsible for the shift in the abundance of certain macroinvertebrate groups. This effect was especially pronounced with the *Orthotrichia* sp. after the control application (Figure 4H).

Two groups, the phantom midge (*Chaoborus punctipennis*) and the Ostracoda became rare or were not sampled at all shortly after the control applications (Figures 4A and 4D). Several studies have shown *Chaoborus* populations to increase after grass carp introductions (16)[6,7]. Relatively equal distribution of *Chaoborus* between vegetated and denuded areas of a lentic environment has also been reported (15). However, few if any studies have shown such drastic changes in macrophyte decline and reestablishment as ours did.

Another group demonstrating a seasonably decreasing trend after macrophyte dissappearance was the libellulid dragonflies (Figure 4F). The Libellulidae was the only group showing a significant ($p<.05$) positive correlation with macrophyte density. Several genera in the family are known to be associated with aquatic macrophytes (4, 11). A similar seasonal decline was not observed with the Zygoptera (Figure 4G).

As with most of the invertebrate groups, the chironomidae (AS) were most abundant during the winter months and demonstrated a trend toward greater densities after the control applications (Figure 4E). Chironomid densities for the dredged samples often fluctuated greatly possibly indicating an aggregated distribution in the hydrosoil in which the large fluctuations could be attributed to too few samples. The artificial substrate samplers were more efficient in collecting macroinvertebrates and most of the groups collected would not have been equally represented if sampling was done with the dredge alone. Species diversity indices were not determined for macroinvertebrate groups because identifications were not specific enough to account for species or in some cases genera level changes over time.

In conclusion, the overall impact of the control applications on the ecology of Lake Jasmine was considered to be short-term. Immediate effects were evident especially for the plankton and water quality data, however, most of the non-target biota sampled demonstrated similar or improving conditions during the post-treatment period when macrophytes were at low to moderate levels (0.5-1.2 kg m^{-2}) as compared to pre-treatment conditions when macrophyte density generally exceeded 2.0 kg m^{-2}. The level of macrophyte density could be linked either directly or indirectly to most of the observed changes occurring during this three year study.

Hybrid grass carp were capable of removing some vegetation, but poor survival attributed to removal by angling is a problem. Duration of control achieved with hybrid grass carp was not adequate for continued use due to economic considerations.

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