# Response Of Aerobic Community Metabolism To Chemical Treatment Of Aquatic Macrophytes[1]

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## ABSTRACT

Following application of a 6,7-dihydrodipyrido(1,2-*a*:2′,1′-*c*) pyrazidiinium ion (diquat) and 7-oxabicyclo(2,2,1) heptane-2,3-dicarboxylic acid (endothall) herbicide mixture to control the submersed macrophyte egeria (*Egeria densa* Planch.) in Chickahominy Reservoir, Virginia, daily oxygen consumption by the aquatic community regularly exceeded daily community oxygen production in areas of moderate and heavy macrophyte density. Subsequent recovery aided by phytoplankton increases returned these areas to approximate equilibrium within 6 to 7 weeks. Treatment did not alter the pattern of aerobic community metabolism in an area of light macrophyte growth. Community oxygen consumption 6 weeks after treatment indicated that 24 to 76% of the macrophyte biomass lost from the water column in an area of heavy growth may have been aerobically decomposed.

## INTRODUCTION

The success of an aquatic plant management program depends not only on control of the nuisance macrophyte, but also on avoidance of detrimental side-effects. Fish mortality and degraded aesthetics caused by dissolved oxygen depletion sometimes follow chemical treatment of dense stands of submersed macrophytes. Dissolved oxygen problems occur when the aerobic metabolism of an aquatic community becomes severely unbalanced. The response of aerobic community metabolism, the relationship between all photosynthetic production and total aerobic respiration, is an important consideration in evaluating an aquatic plant

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management program. However, only a few studies of herbicide application have included direct measurements of primary production and respiration. Fish (6), using single day diurnal dissolved oxygen (DO) curves, found that the rate of photosynthesis was less in a treated area than in an untreated area 9 months after treatment. Walsh et al. (10), employing diurnal DO curves and DO based light and dark bottles, found that the majority of total gross production shifted to the phytoplankton after treatment. Brooker and Edwards (5), using calculations from continuous DO curves, reported that both gross production and community respiration declined after treatment. The following study of aerobic community metabolism, part of a larger study of herbicide application in an aquatic environment (2, 3, 4), is an effort to more fully understand oxygen dynamics in a stressed aquatic community.

## STUDY AREA AND SAMPLING PERIODS

Chickahominy Reservoir, a 1,100-ha water supply, is located just above tidal influence near Richmond, Virginia. Lush vegetation surrounding the reservoir is dominated by yellow water lily (*Nuphar advena* Ait.), swamp loosestrife (*Decadon verticillatus* (L.) Ell.), and bald cypress (*Taxodium distichum* (L.) Richard.). Before herbicide treatment on 10 July 1973, the extensive littoral area of the reservoir was infested with the submersed macrophyte egeria. The reservoir receives nutrient enrichment from development in its drainage basin; nitrate has been observed to range from $<0.01$ to 1.19 mg per liter and orthophosphate from 0.17 to 1.18 mg per liter in the major tributary (9). Before treatment, the egeria had a strong influence on the DO in the reservoir. Dissolved oxygen during the day ranged from $<1$ to 7 mg per liter in areas of dense growth. Open areas of the reservoir had higher DO (7 to 10 mg per liter). Treatment consisted of a 1:1 mixture of commercial formulations of potassium endothall and diquat dibromide applied as a surface spray from an airboat to reach a target concentration of approximately 0.3 mg per liter of the combined active ingredients at an average depth of 1.7 m.

During the research period (beginning the month of treatment and continuing for 1 year) total aerobic community metabolism, aerobic metabolism of the phytoplankton assemblage, and phytoplankton numbers were studied at five stations (Figure 1). Total aerobic community metabolism was measured daily during most of the summer of treatment and for 10 days the following summer. Measurements were taken at stations representing three different degrees of pretreatment macrophyte densities. The heavy growth station was a small inlet 1 m deep that was filled to the surface with egeria before treatment. The moderate growth station was an old creek channel 1 to 3 m deep that had thick peripheral growth with clear center before treatment. The light growth station was an open area 1 to 2 m deep where pretreatment macrophytes were sparse and did not reach the surface.

Aerobic metabolism of the phytoplankton assemblage was evaluated at weekly intervals at the moderate growth station during the summer of treatment and twice the following summer. Additionally, phytoplankton metabolism measurements were taken in two adjacent bays twice at the end of the first summer and twice the following summer. The adjacent bays were approximately 1 m deep and had similar dense growths of egeria. One bay was treated, one was not.

Phytoplankton were counted at the heavy and moderate growth stations once before treatment, daily the week after treatment, weekly throughout the rest of the summer, and once during the following summer. Phytoplankton numbers were enumerated in adjacent bays on a monthly basis from the end of the first summer until the end of the study.

## METHODS AND MATERIALS

The diel DO pulse modification (7, 11) of Odum's (8) diurnal DO curve method of measuring community production and respiration was used in the routine monitoring of total aerobic community metabolism. The diel DO pulse modification involves simplifying the diurnal curve to include only the high and low points in the daily oxygen regime. Diurnal curves consisting of DO determinations taken at 2-hr intervals beginning at dawn and continuing into night were conducted regularly to verify high and low points and substantiate values calculated from the diel pulses.

All DO determinations were made by the azide modification of the Winkler method (1). Samples for DO analysis were taken within 1 m of the surface with a Kemmerer bottle and were accompanied by temperature readings. Total aerobic community metabolism calculations include only the top meter of the water column. During the summer at all stations the top meter roughly corresponded with both the epilimnion and the photic zone as determined by temperature profiles and light extinction measurements.

Total aerobic community metabolism, calculated from the diel DO pulses and the diurnal DO curves, was expressed as a series of daily oxygen budgets. Net production of oxygen during the day was calculated from the accumulation of DO between morning and evening corrected for diffusion. Consumption of oxygen during the night was calculated from the diffusion corrected decline of DO between evening and morning. The difference between daytime oxygen production and nighttime oxygen consumption yielded the 24-hr oxygen budget for the community.

Determination of a gas exchange rate complicates diffusion correction of DO curve-based measurements of community metabolism. Welch (11) evaluated some methods proposed for measuring gas exchange rates in biological systems and concluded that arbitrary assignment of values was an acceptable approach to the problem. In terms of the diffusion constant K($g\ O_2\ m^{-2}\ hr^{-1}$ at 100% departure from saturation), Welch used values of $K = 0.1$ for calm days and $K = 0.3\text{-}0.5$ for windy days. Oxygen budgets in Chickahominy Reservoir were measured using diel DO pulses calculated with three different K's (0.10, 0.25, 0.40) to represent a realistic range within which true values would be expected to correspond. A $K = 0.25$ was used when calculating oxygen budgets from diurnal DO curves.

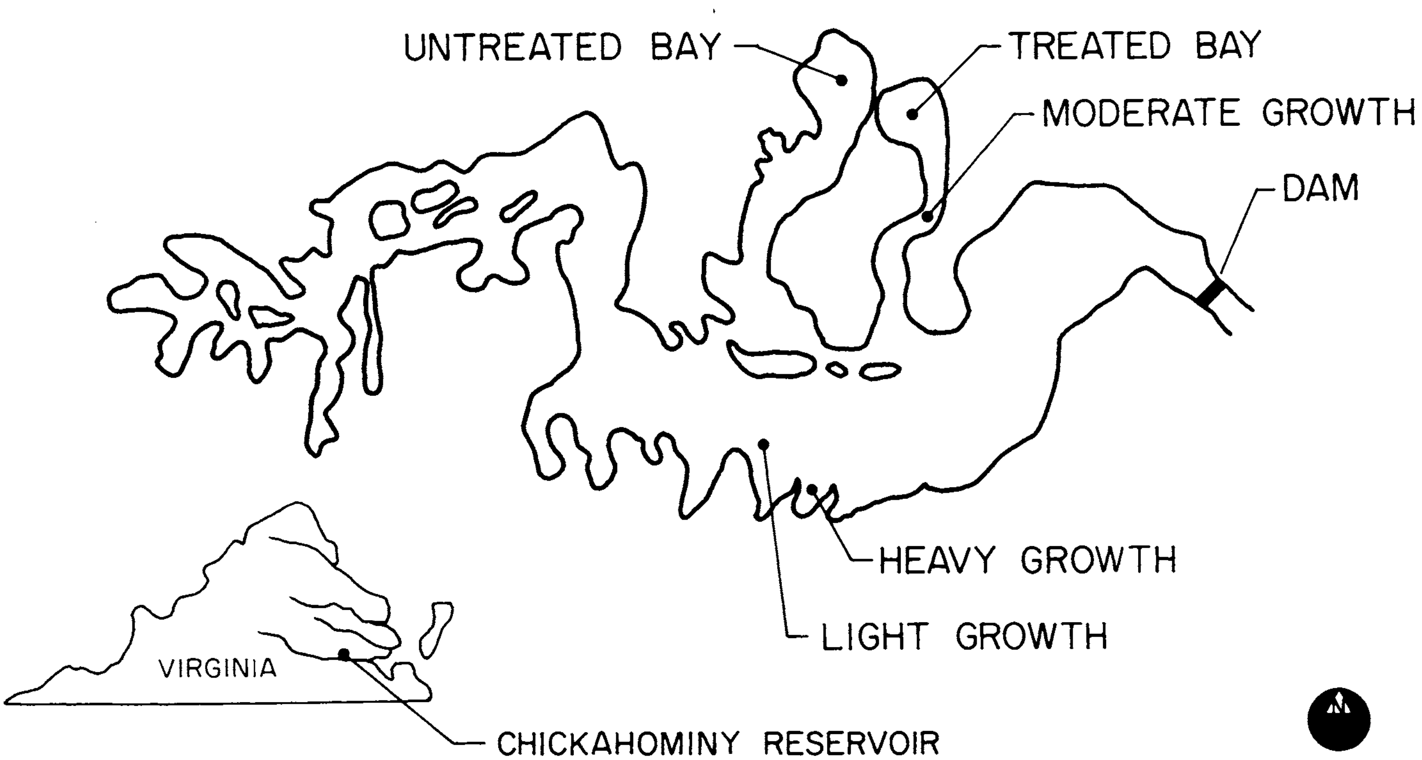

Figure 1. Map of Chickahominy Reservoir indicating locations of the five sampling stations (scale: heavy and light growth stations are separated by approximately 1 km).

During the summer of treatment, daily solar radiation measurements were obtained from Virginia Institute of Marine Science, Gloucester Point, Virginia, approximately 45 km from Chickahominy Reservoir. The following summer, solar radiation was measured at the site with a recording pyrheliometer.

The contribution of the phytoplankton assemblage to total aerobic community metabolism was measured in the top meter of the water column with DO based light and dark bottles. The bottles were exposed during the entire period of community net production indicated by the diurnal DO curves. Nighttime respiration (extrapolated from the rate of DO consumption in the dark bottles) was subtracted from net production (DO accumulation in the light bottles during exposure) to give a 24-hr oxygen budget for the phytoplankton assemblage. At the moderate-growth station duplicate series of bottles were set and the results averaged. During the comparisons of the treated and untreated bays a set was run in each bay.

Surface samples of lake water for phytoplankton enumeration were preserved with Lugol's solution. Cell-clumps in unconcentrated subsamples were strip counted in a nannoplankton cell. The algae were identified to genera during enumeration. The data were pooled into numbers per ml of blue-green algae (Cyanophyta), green algae (Chlorophyta), and other algae (all others).

## RESULTS AND DISCUSSION

Beginning the day after treatment, the stations with heavy and moderate macrophyte growth displayed consistently negative oxygen budgets; i.e., community oxygen consumption regularly exceeded community oxygen production (Figure 2). Approximate equilibrium between days with positive and days with negative oxygen budgets was reached 6 to 7 weeks after treatment. This balance was still in effect a year later. The dashed regression lines (oxygen budgets against days after treatment) of the heavy and moderate growth stations have negative intercepts and slopes significantly different from zero at $P<0.005$ (t-test of the regression), substantiating periods of consistently negative oxygen budgets and trends toward recovery. Net community oxygen consumption, represented by negative oxygen budgets after treatment, was supported by diffusion from the atmosphere maintaining DO at levels sufficient to prevent fish mortality. The light growth station showed no posttreatment change in the pattern of its daily oxygen budgets. The light growth regression line has a positive intercept and the slope does not significantly deviate from zero. This indicates a slight, steady predominance of positive oxygen budgets.

Consistently negative oxygen budgets at the heavy and moderate growth stations after treatment are probably due to the cessation of macrophyte photosynthesis and the beginning of bacterial degradation. The subsequent recovery, however, is not due to macrophyte regrowth because the macrophytes disappeared from the water column in 6 weeks and did not reappear until the following spring (2). Return of total aerobic community metabolism to equilibrium was probably due in part to gradual loss of dead plant material from the water column and in part to increases in numbers and productivity of phytoplankton. At the heavy and moderate growth stations, phytoplankton numbers increased after treatment and returned to pretreatment levels the following summer (Figure 3). The 24-hr oxygen budgets of

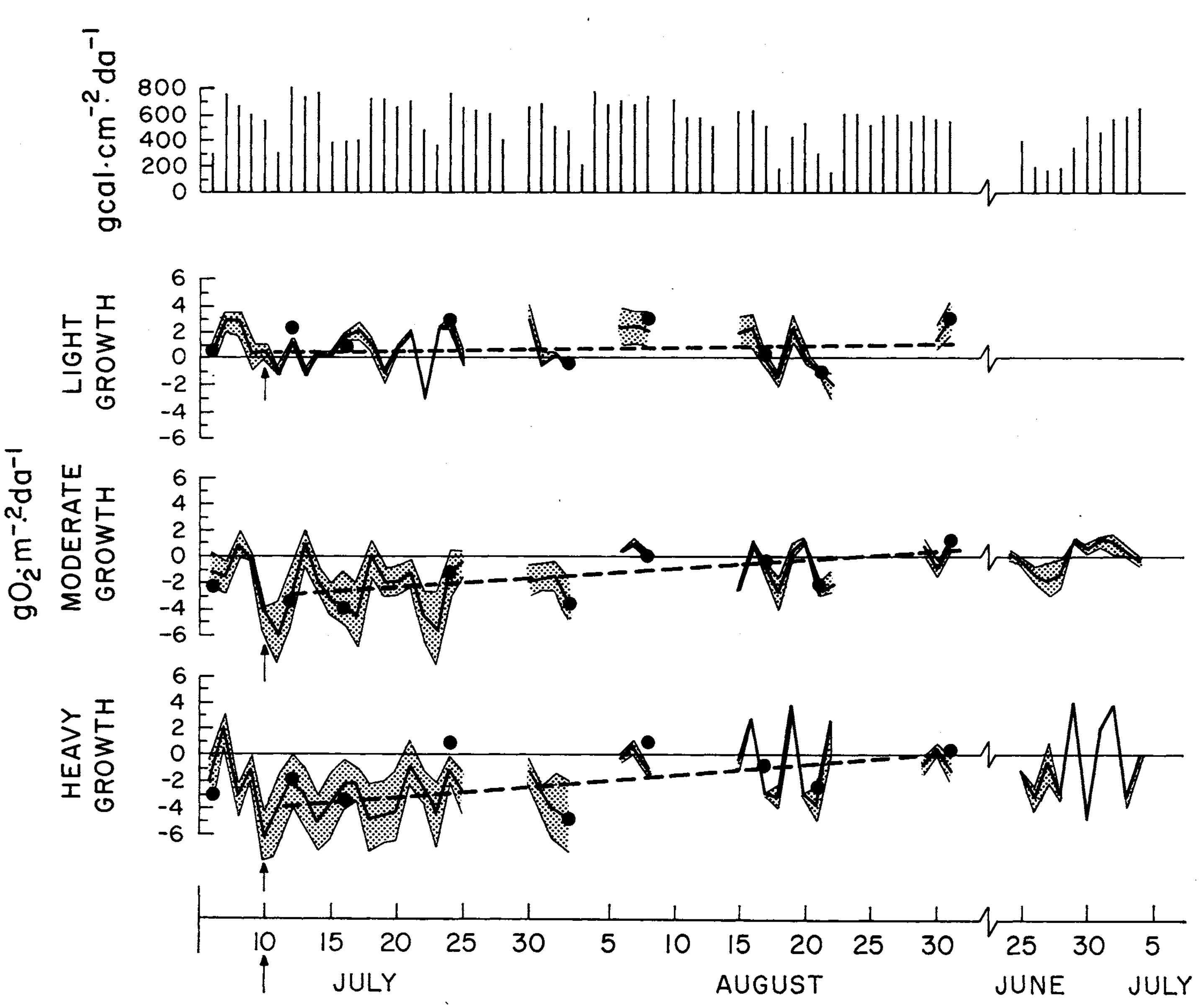

Figure 2. Upper graph shows incident solar radiation. Lower graphs present aerobic community metabolism as daily oxygen budgets at three stations. The solid line represents oxygen budgets calculated from diel DO pulses with $K = 0.25$ The shaded area represents the possible range of oxygen budgets with K equaling from 0.10 to 0.40. The heavy dots indicate oxygen budgets measured by diurnal DO curves with $K = 0.25$. The heavy dashed line is the regression of oxygen budgets (from diel DO pulses, $K = 0.25$) on days after treatment.

the phytoplankton assemblage at the moderate growth station showed a brief slump after treatment. Within 3 weeks oxygen budgets increased to three times pretreatment levels (Figure 3). The initial decline in phytoplankton oxygen budgets accompanied by rising phytoplankton numbers is puzzling. These data may result from exaggerated bacterial oxygen demand in the water caused by the release of particulate and dissolved reduced carbon from the newly killed macrophytes. A bloom of phytoplankton accompanied by positive oxygen budgets for the phytoplankton assemblage was evident in the treated bay in August (Figure 4). During the same period, the untreated bay had less than half the phytoplankton and the oxygen budget of the phytoplankton assemblage was negative (Figure 4). The untreated bay showed an increase in phytoplankton numbers in September during the natural decline of egeria. Following a winter decline, phytoplankton numbers increased in the treated bay, but did not reach the bloom conditions of the previous summer. The fact that phytoplankton numbers in the untreated bay had not reached the previous August levels by June of the following year indicated that some of the phytoplankton increases in the treated areas may have been the result of seasonal effects and were not solely in response to the removal of macrophyte competition.

Uniform pretreatment macrophyte infestation and shallow depth at the heavy growth station made it possible to estimate the degree of aerobic decomposition of the treated macrophytes. Berry[3] sampled egeria at six sites in the heavy growth station 3 days preceding and 6 weeks after treatment. An average of 3,097 g wet weight (185 g ash-free

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[3] Berry, C. R. 1975. Unpublished data.

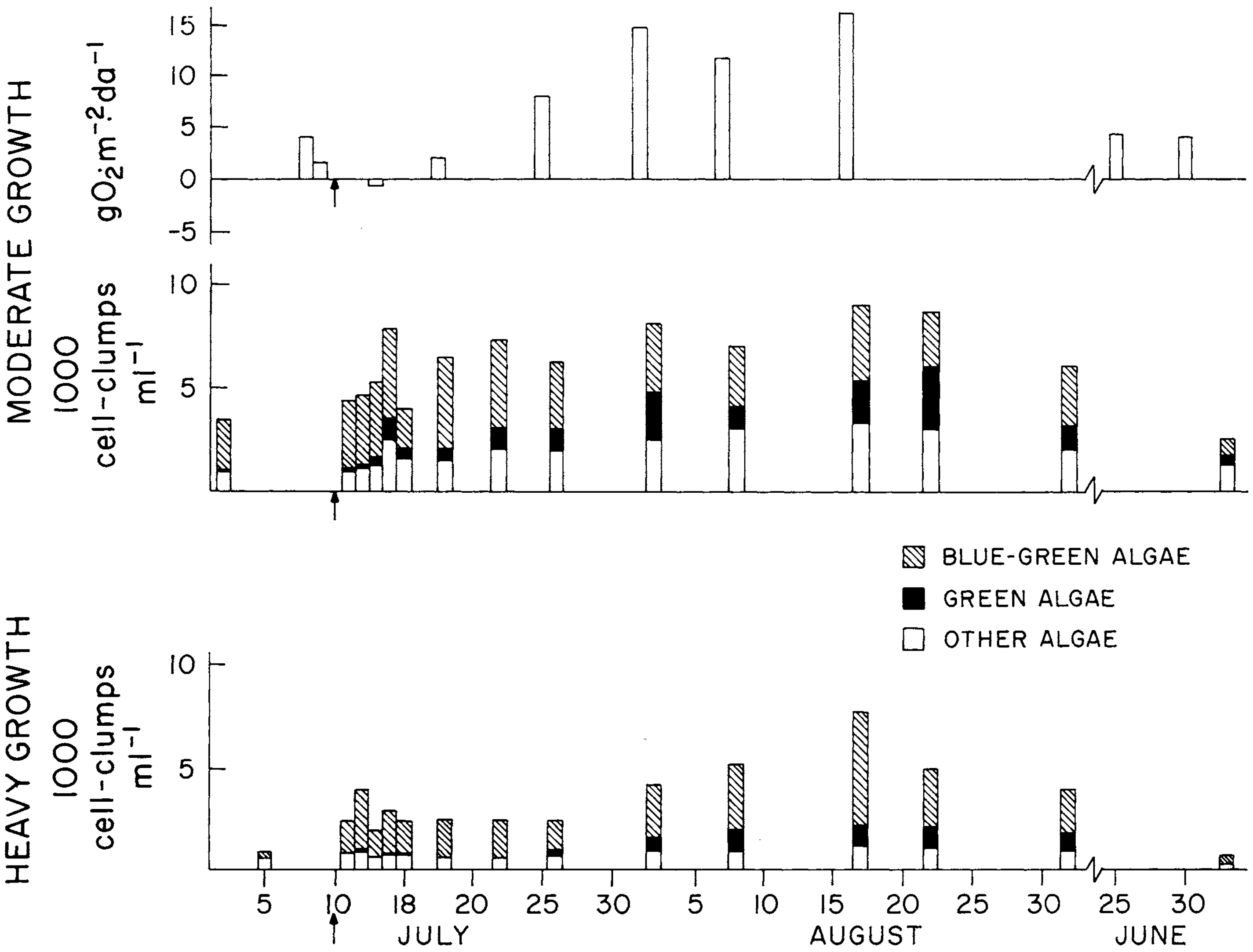

Figure 3. Oxygen budgets for the phytoplankton assemblage and phytoplankton numbers measured at the moderate macrophyte growth station. Phytoplankton numbers only measured at the heavy macrophyte growth station.

dry weight) of egeria per m$^2$ was lost from the water column during the 6 weeks following treatment decreasing the pretreatment biomass by 97%. Assuming ash-free dry weight to be $(CH_2O)_n$, there was a calculated loss of 6.2 moles per m$^2$ of reduced carbon compounds. Complete oxidation of this reduced carbon would require approximately the same number of moles of $O_2$ ($CH_2O + O_2 \rightarrow CO_2 + H_2O$). The possible range in number of moles of $O_2$ consumed per m$^2$ in the heavy growth station during the 6 weeks after treatment was calculated from the extremes in possible oxygen budgets (Figure 3) to be from 1.5 to 4.7 moles $O_2$ per m$^2$. Depending on actual diffusion between 24 and 76% of the macrophyte biomass that disappeared from the water column may have been broken down aerobically. The remainder contributed to the bottom sediments or were decomposed anaerobically.

The reduction of a large crop of macrophytes following a chemical weed control program in Chickahominy Reservoir (2) altered aerobic community metabolism in areas of moderate and heavy infestation. The return of aerobic community metabolism in the affected areas to equilibrium within 6 weeks, without a period of DO depletion, was an important factor in the overall impact of the project including the avoidance of fish kills, the stability of the macroinvertebrate community (3), and favorable public reaction (4).

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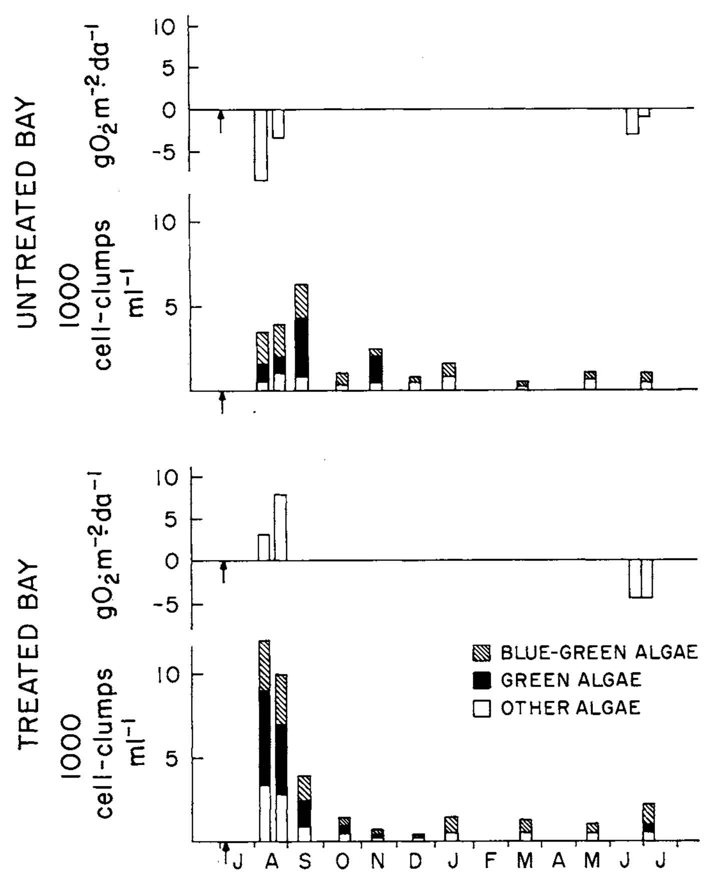

Figure 4. Oxygen budgets for the phytoplankton assemblage and phytoplankton numbers in two adjacent bays.

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