

AERATION AS A TOOL TO IMPROVE WATER QUALITY AND REDUCE THE GROWTH OF *HYDRILLA*

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Abstract—Aeration of artificial, model lake systems was studied as a tool to improve water quality and to control the growth of a nuisance aquatic weed, *Hydrilla verticillata* (L.F.) Royle, which has been recognized as a plant pest since the mid-1960s. Aeration decreased the growth of *Hydrilla* by 20% fresh weight and 18% dry weight on average after 21 days. The effect was due to the oxygenation of the water and not the mechanical effect of the bubbles, as verified by studies using pure nitrogen. Aeration also affected water quality. Inorganic carbon decreased; nitrate-nitrite-nitrogen decreased, more slowly in test systems than in control systems; dissolved oxygen increased to saturation within 24 h and pH increased 0.5–1.5 unit over the period of study. Phosphate-phosphorus concentration was unaffected. The concentrations of zinc, calcium and iron decreased as well. The effect of aeration upon *Hydrilla* growth appears to be correlated with a decrease of iron. After 7 days, iron concentrations decreased to less than 20 ppb. Iron toxicity is proposed as the mechanism responsible for creating a limiting condition for *Hydrilla* growth.

INTRODUCTION

Restoration of degraded aquatic habitats has been an important subject for all involved in resource management. Several methods and combinations of methods have been employed in lake improvement projects; among these is mechanical aeration (Dunst, 1974). The effects of aeration of lakes and ponds have been extensively studied by Kerr (1970) and Fast (1971). Destratification (pumping the lower waters to the surface) by various mechanical means has been reviewed and studied by Strecker *et al.* (1977). Lorenzen & Fast (1977) have evaluated various aeration and circulation techniques and updated the work of Hogan *et al.* (1970). Aeration efficiency of the various devices has been evaluated by Carr & Martin (1978). Nutrient inactivation by the addition of chelating agents of various kinds has also been evaluated by Peterson *et al.* (1974). More recently, a combination of aeration and nutrient inactivation techniques has been employed by Laing (1974) and Bateman & Laing (1977) to improve water quality of Lake Weston, Orlando, Florida, a eutrophic lake receiving sewage plant effluent. A non-toxic, soluble calcium compound was added to make phosphorus unavailable for plant assimilation. Trent & McArthur (1974) reported in a series of preliminary pond experiments that water quality could be improved and aquatic weed growth impaired by this technique. They claimed 100% control of growth of *Hydrilla* and blue-green algae for 6 months in 2-acre ponds.

Conclusions about the primary effects of aeration, however, have varied considerably. Riddick (1957) concluded that some of the effects of artificial destratification on impoundments include: (1) oxidation and precipitation of iron and manganese; (2) leveling off of pH in the range 6.7 to 7.3; (3) reduction of carbon dioxide; (4) reduction in color; (5) increases in bicarbonate alkalinity and (6) elimination of most algal blooms. Kerr (1970), on the other hand, concludes that iron and manganese may increase by as much as 10 orders of magnitude and that concentrations of $\text{NO}_3\text{-N}$, $\text{NH}_3\text{-N}$ and $\text{PO}_4\text{-P}$ are drastically reduced in the lower depths during induced aeration without significant increases in the surface waters.

The experiments conducted here were an attempt to reconcile some of the divergent data present in the literature by examining the effect of aeration on the macronutrients carbon, nitrogen, phosphorus, iron, calcium and magnesium. Other trace metals were studied to follow the effects of oxidation upon their availability. Furthermore, the use of aeration as a method to control the growth of the rooted, submerged aquatic plant, *Hydrilla verticillata* was examined. This plant has been the subject of aquatic plant research and control studies in Florida for the past 8 years, although it was a recognized nuisance as early as 1960. The expenditure of over 15 million dollars annually by Florida for the control of *Hydrilla* and another aquatic plant, water hyacinth, *Eichhornia crassipes* (Mart.) Solms, suggests a need for alternative techniques for the control of this weedy species.

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EXPERIMENTAL

Several studies were done in order to evaluate the effects of aeration upon water chemistry and upon growth of

Table 1. Description of studies assessing aeration effects

Study No.	Objective	Components			
		Air	N ₂	Hydrilla	Sediment
1	Evaluate aeration effects on selected chemical characteristics in lake-simulation systems	Yes	No	No	Yes
2	Evaluate aeration effects on <i>Hydrilla</i> growth and selected chemical characteristics	Yes	No	Yes	Yes
3	Compare <i>Hydrilla</i> growth response in aerated and non-aerated systems	Yes	No	Yes	Yes
4	Evaluate significance of physical disturbance to overall aeration effectiveness	No	Yes	Yes	Yes
5	Evaluate significance of sediment to overall aeration effectiveness	Yes	No	Yes	No

Note: The forced addition of air is termed aeration; the forced addition of N₂ is termed nitrogenation.

Hydrilla. A brief description of the studies is given in Table 1. Methods are discussed below.

Two 55-gal. (208 l.) polyethylene barrels were used for all studies. Equal volumes of sand and peat (28.4 l.) were used to simulate a lake bottom. Sand was obtained from a local construction company and peat was obtained from a peat bog located in northwest Tampa. The growth medium consisted of well water (162 l./barrel) obtained from a calcitic/dolomitic formation of the Floridan Aquifer. Water was added carefully so as not to stir up the sediment. *Hydrilla*, harvested from a natural lake in Tampa, was brought to the laboratory, washed thoroughly with tap water to remove periphyton and detritus and rinsed with deionized water. The plants were maintained for 2 to 3 days in tap water before use.

Approximately 100, 300, 200 and 300 g fresh weight *Hydrilla*/barrel was used in studies 2, 3, 4 and 5, respectively. The barrels were lighted by four 48 in. Westinghouse fluorescent bulbs (F40CW) 15 cm above the water surface on a 14L:10D cycle. Aeration was achieved using air stones and house air at a rate of 0.24 lb min⁻¹. Nitrogenation (Study 4) was accomplished using water-pumped nitrogen at a similar rate. All studies were run at 23 ± 2°C.

Water samples were taken from the top and bottom of the water column at various intervals, and stored at 4°C in the dark in 22 × 105 mm Kimax or Pyrex test tubes. Following analyses for carbon, NO₃-NO₂-N and PO₄-P, samples were acidified with 0.1 N HCl in preparation for metals analyses. Tests were performed in triplicate, and the mean for the pooled barrel represents the mean ± SD for 6 determinations. Analytical methods are summarized in Table 2.

RESULTS AND DISCUSSION

In each case in which *Hydrilla* was subjected to

aeration, the plant declined in mass and in general appearance. Decreases in fresh wet and dry weights of at least 10%, and often greater than 20%, occurred (Fig. 1). In non-aerated systems (stagnant and nitrogenated), increases in plant weight of about 20% or greater were observed. Signs of plant deterioration in the aerated systems appeared after 10 to 14 days of aeration. At this time, leaves and stems turned a copper-brown color and decayed tissue was visible. Prior to this period, plants appeared healthy and exhibited an increase of fresh weight.

The effects observed in the aerated systems apparently are a consequence of chemical rather than physical changes. Nitrogenation, while producing a bubble pattern similar to that in aeration, failed to bring about a significant decrease in plant weight, in fact, a 17% increase was noted (Fig. 1).

The presence of sediment in the lake simulation studies did not alter the pattern of *Hydrilla*'s response to aeration. In Study 5, identical to Study 2 except in lacking sediment in the lake-simulation system, plant weight decreased by 12 to 20% (Fig. 1).

The information suggests that the growth-inhibiting effect of aeration on *Hydrilla* results from chemical changes in the water contained in the lake-simulation systems rather than from mechanical disturbance of the water column or from sediment-related changes.

In evaluating data from analyses made on the water in the growth systems, several trends in the concentrations of selected constituents became obvious.

Table 2. Summary of analytical methods

Constituent	Method or instrument
NO ₃ -NO ₂ -N	Cadmium reduction (Technicon Auto Analyzer II)
PO ₄ -P	Ascorbic acid reduction (Technicon Auto Analyzer II)
DO	Polarographic probe method (YSI 57)
pH	Chemtrix 40E
Carbon, Total and Inorganic	Combustion and infrared analysis (Beckman 915 carbon analyzer)
Fe	Technicon Auto Analyzer II
Other metals	Atomic absorption spectrophotometry (Perkin-Elmer 103)

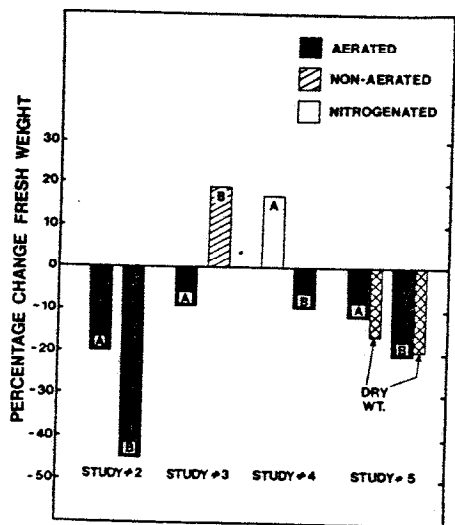


Fig. 1. Effect of aeration, non-aeration and nitrogenation on the fresh weight (percentage change) of *Hydrilla*.

Inorganic carbon decreased in every case (Figs. 2-5), most noticeably in Studies 3 and 4. Total carbon remained the same or decreased only very little, while organic carbon increased in aerated systems. No correlation could be detected between the organic:inorganic carbon ratio and the decline in plant weight.

Nitrate-nitrite-nitrogen remained unchanged in the aerated systems lacking *Hydrilla* (Fig. 2) but did decrease at a steady rate in the presence of the plant (Figs. 3-5). The concentration of $\text{NO}_3:\text{NO}_2\text{-N}$ decreased more slowly in the aerated system having *Hydrilla* than in the non-aerated or nitrogenated systems (Figs. 4 and 5), possibly reflecting a stress relating to nitrate uptake by the plant.

As expected, dissolved oxygen concentration in aerated systems exceeded that in both non-aerated and

nitrogenated systems. At no time were oxygen concentrations approaching toxic levels recorded.

Values of pH were higher overall in the aerated systems than in non-aerated systems. Values ranged from 6.2 to 7.5 and from 6.1 to 6.7 for aerated and non-aerated systems, respectively.

No change in dissolved phosphate concentrations occurred as a result of aeration.

Concentrations of iron were affected markedly by aeration. In aerated systems without *Hydrilla*, iron declined from approximately 1.2 ppm to less than 0.2 ppm in 21 days. In Study 2, iron decreased to undetectable levels early in the study, then increased significantly by Day 20 (due, perhaps, to iron release from decaying plants). In Study 3, iron concentrations in aerated and nonaerated systems were similar until Day 11 when concentrations in aerated systems decreased dramatically, reaching undetectable levels by Day 18. At this time, non-aerated systems contained slightly more than 0.1 ppm iron. It is apparent that aeration brings about a rapid decrease in iron concentrations in the water column.

Two mechanisms of iron removal immediately came to mind to explain the results just described: (1) uptake and incorporation by *Hydrilla* and (2) precipitation of compounds such as FeCO_3 or FeOOH . In an effort to determine which mechanism was operating under our experimental conditions, iron analyses of the plant, sediment and water were done and a mass balance for iron in the lake-simulation systems was prepared. Under aerated conditions, the concentration of iron associated with the plant increased from 4.2 mg g^{-1} dry weight to 33.0 mg g^{-1} dry weight after 21 days. In the absence of aeration, iron concentration changed from 4.2 mg g^{-1} dry weight to 16.0 mg g^{-1} dry weight of plant. This gain in plant-associated iron in the aerated systems is depicted in

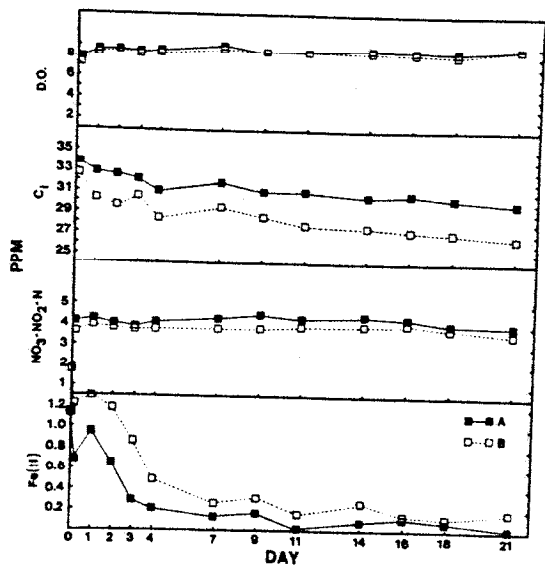


Fig. 2. Changes in selected chemical constituents measured during Study 1. Concentrations are expressed in ppm.

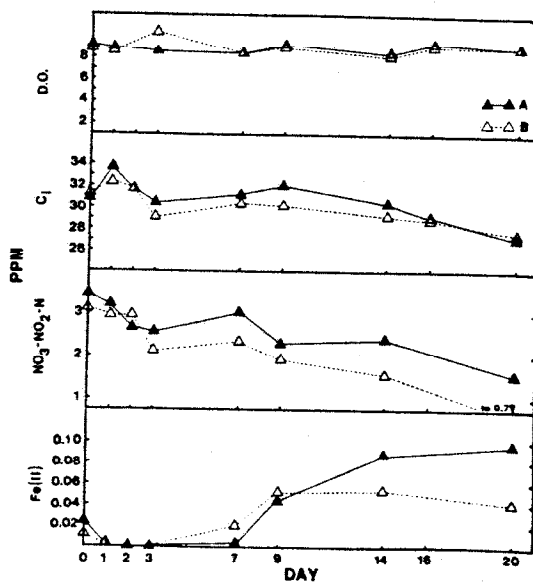


Fig. 3. Changes in selected chemical constituents measured during Study 2.

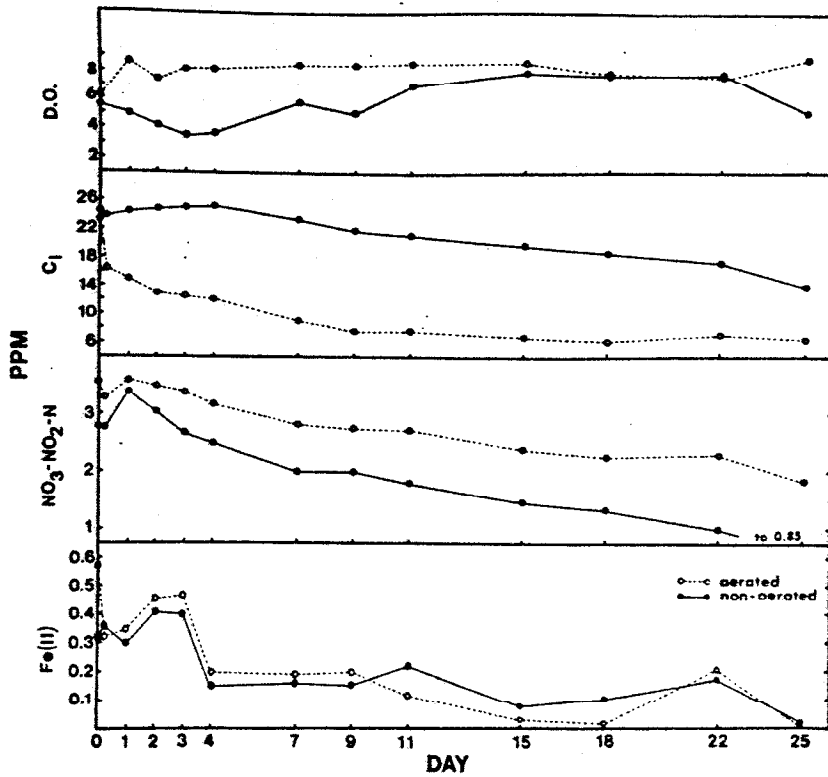


Fig. 4. Changes, selected chemical constituents measured during Study 3.

Fig. 6 in which it is shown that depletion of iron in the water was the result of a transfer of approximately 415 mg to *Hydrilla* and 312 mg to the sediments. In aerated systems, on the other hand, the sediments received a quantity of iron more than twice that transferred to the plant component. It has been reported that, relative to iron, *Hydrilla* is an "accumulator" plant with concentrations of 22 mg Fe g⁻¹ dry

weight of plant tissue being observed (Basiouny *et al.*, 1977). At this tissue concentration of iron, an increase of 25% in plant dry weight occurred, and it was concluded that *Hydrilla* possessed a mechanism enabling it to tolerate high iron concentrations. As already mentioned in the present study, plants grown under non-aerated conditions had a final iron concentration of 16 mg g⁻¹ dry weight and showed a weight gain of about 20%. However, the observed weight loss together with the obvious decay of plant tissue in the aerated systems strongly suggests an iron toxicity effect at the measured tissue concentration of 33 mg g⁻¹ dry weight.

The observation that plants in aerated systems became covered/impregnated with a rusty brown-colored material raises the question of the nature of the material and its role in the suggested iron toxicity

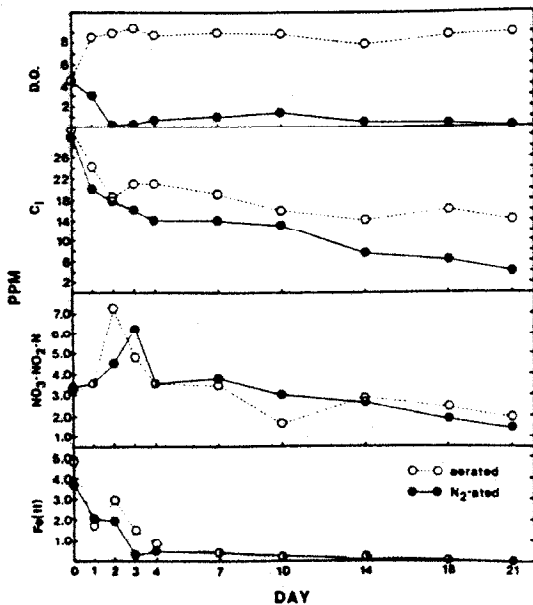


Fig. 5. Changes, selected chemical constituents measured during Study 4.

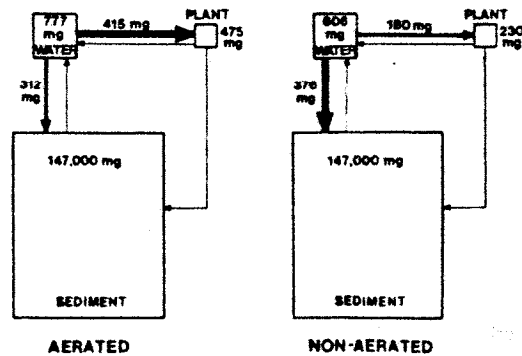


Fig. 6. Distribution of total iron between sediment, water, and plant for aerated and non-aerated systems.

effect. Only speculation can be offered at the present time; however, this material may represent precipitated iron compounds which may exert a negative effect on plant viability. Therefore, iron toxicity may be the result of a combination of enhanced iron incorporation by the plant as well as precipitation of iron-containing material on plant surfaces. Future investigations will shed light on this question.

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