

METABOLISM AND BIOMASS OF WATER HYACINTH-DOMINATED PONDS  
AND CANALS IN THE VICINITY OF GAINESVILLE, FLORIDA

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RESUME

*Nous avons étudié la répartition de la biomasse, la productivité, la respiration et la transpiration de la jacinthe d'eau et de communautés végétales aquatiques en dix stations, tant en conditions flottantes que non flottantes. Toutes les stations étaient eutrophes et entourées d'agro-écosystèmes ou d'écosystèmes urbains.*

*La biomasse par unité de surface de la jacinthe d'eau varie de 660 à 3.000 g/m<sup>2</sup> et est en corrélation linéaire avec la teneur en éléments nutritifs. Une hypothèse de travail consista dans l'effet multiplicateur possible du courant sur la concentration en éléments nutritifs, régulateur de croissance et de répartition de biomasse dans les communautés à jacinthe d'eau. Une corrélation linéaire négative fut trouvée entre la biomasse des racines et celle de la partie exondée de la plante. Un faible rapport des biomasses racine / partie exondée est caractéristique des emplacements à courant rapide où les plantes se développent rapidement et paraissent posséder une valeur plus élevée du turn-over que celle des plantes croissant en eaux calmes à dépôts organiques épais.*

*La vitesse de photosynthèse nette diurne, combinée pour quatre espèces de macrophytes aquatiques varie de manière exponentielle à l'intensité lumineuse, suggérant une photo-adaptation élevée. Des mesures préliminaires en deux stations différentes suggèrent que la productivité des communautés à jacinthe d'eau réagit au même effet synergétique du courant sur la concentration nutritive. La présence d'un tapis flottant de jacinthe d'eau à la surface d'une*

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pièce d'eau modifie la dynamique de la production de biomasse et de l'oxydation dans la colonne aqueuse en réduisant la vitesse de production sous le tapis, créant ainsi de grandes quantités d'eau organique et diminuant la capacité d'oxydation de l'eau. Cet effet résulte de la diffusion de l'oxygène produit par la photosynthèse des feuilles de la jacinthe d'eau. Deux processus compensent toutefois ce manque d'oxygène. La première voie proposée est l'apport d'oxygène atmosphérique à la colonne aqueuse via les espaces gazeux et les racines de la jacinthe d'eau; le second processus est la diffusion continue d'oxygène atmosphérique au travers de l'interface air-eau. Tandis que ces mécanismes allègent la demande en oxygène de la couche sous-jacente d'eau, la haute production de matière organique par les macrophytes et les apports de la végétation littorale ainsi que ceux des champs voisins soumis à l'agriculture augmentent la demande en oxygène, amenant une accumulation de la matière organique, un maintien à un niveau faible mais stable de l'oxygène et l'existence d'anaérobiose pendant certaines périodes de la journée. Dans des conditions à flux continu d'eau les accumulations de matières organiques peuvent partiellement être exportées, réduisant ainsi la demande en oxygène. Les taux annuels de productivité et de respiration en eau libre et sous tapis de jacinthe d'eau furent respectivement de 405 et 687 et de 300 et 696  $g O_2/m^2$ . La productivité annuelle du tapis fut de 727  $g O_2/m^2$  et la respiration de 641  $g O_2/m^2$ .

#### ABSTRACT

We have investigated the distribution of biomass, productivity, respiration, and transpiration in water hyacinth plants and communities in flowing and non-flowing conditions at 10 sites. All sites were nutrient rich and surrounded by agricultural or urban systems. Water hyacinth biomass per unit area ranged from 660 to 3,000  $g/m^2$  and was linearly correlated with nutrient eutrophication. We postulate a possible multiplicative effect of water flow on nutrient concentration as regulator of growth and biomass distribution in hyacinth communities. An inverse linear relationship between root biomass and above water plant parts was found. Low root-to-high above water biomass ratio was characteristic of high water flow areas where plants developed quickly and appeared to have a higher rate of turnover compared with plants growing in still waters over thick organic mats. The combined net daytime photosynthesis rates of four species of aquatic macrophytes responded exponentially to light intensity suggesting high light adaptation. Preliminary measurements from two different habitats suggested that the productivity of water hyacinth communities responded to the same synergetic effect of water flow on nutrient concentration. The presence of the hyacinth mat over a water body alters the dynamics of biomass production and oxidation in the water column by decreasing the rate of production below the mat, contributing large amounts of organic matter, and decreasing the oxidation capacity of the water. This effect is due to the atmospheric diffusion

of the oxygen produced by the photosynthesis of water hyacinth leaves. However, two mechanisms compensate for this loss oxygen. One is the proposed pathway of atmospheric oxygen to the water column via the air spaces and roots of the water hyacinth, and the other is the continuous diffusion of atmospheric oxygen through the air-water interface. While these mechanisms alleviate the oxygen demand of the underlying water, the high production of organic matter by macrophytes and imports from littoral vegetation and adjacent agricultural fields add to the oxygen demand resulting in the accumulation of organic material, maintenance of low but stable oxygen levels, and the occurrence of anaerobiosis during certain times of the day. In environments with continuous water flow the organic loads may be partially exported thus reducing the oxygen demand. Annual rates of productivity and respiration in open water and under a hyacinth mat in  $g O_2/m^2$  were respectively : 405 and 687; and 300 and 696. The annual productivity of the mat was  $727 g O_2/m^2$  and respiration was  $641 g O_2/m^2$ .

## INTRODUCTION

In many parts of the tropical world, the landscape is spotted with a variety of water bodies whose dominant vegetation are aquatic macrophytes. In north central Florida, this variety of ecosystems includes lakes, ponds, rivers, canals, roadside ditches, marshy areas, and reservoirs. In many of these systems, the water hyacinth (*Eichhornia crassipes*) is the dominant species and sometimes covers the entire surface. The physiognomy of these hyacinth communities is a function of season and location and wide variations in the size, shape, and color of plants may be observed. This study started as an effort to quantify the changes in biomass content and distribution of different water hyacinth communities and with the idea of comparing oxygen production and consumption below hyacinth mats with that of adjacent open waters. Later, it evolved into a detailed study of gas exchange of aquatic plants in natural and man-disturbed environments. We report the results of biomass studies in 10 water hyacinth populations and of studies of the dissolved oxygen dynamics in a farm pond dominated by this plant.

## METHODS

Ten hyacinth populations representing a wide plant habit and habitat range were selected for biomass studies. At each location a square meter of plants was harvested and a water sample taken. The water was analyzed for phosphates, organic nitrogen plus ammonia,

sodium, potassium, and iron by the Soils Department Analytical Laboratory at the University of Florida. All plants were counted and ten from each sample were selected for dissection into the following plant parts : leaves, petioles, ligules, stolons, flowers, roots, stems, and dead material. Flowering stalks were included with the stolons. After separation, plant parts were oven-dried at 100° for 24 hours and weighed.

The study sites, with one exception, were all in the immediate vicinity of Paynes Prairie just south of Gainesville, Florida (U.S.A.). They were identified as follows :

1. *Paynes prairie*. Roadside drainage canal 1 m deep on the west bank of State Road 441 (SR-441) at Paynes Prairie. This drainage canal received runoff from surrounding grazing land and was completely dominated by water hyacinth.
- 2 & 3. *SR-23-A* and *SR-23-B*. This was a small pond (1.1 ha) by State Road 23 located 1.7 km north of Paynes Prairie and 1.7 km west of SR-441. Its water surface was 95% covered by water hyacinth plants 0.15 - 0.75 m in height. Water depth at the sampling points was 1 m.
4. *River Styx*. Samples were taken at the intersection of the river with State Road 346. Plants were growing on the edge of the river at a depth of 0.76 m.
5. *Gordon's Pond*. This is a farm pond located 5.07 km south-west of Gainesville on State Road 121 at the north western edge of Paynes Prairie. Its area varied with the season but average 4 ha. Hyacinths covered 95% of its water surface area and maximum depth was 1.5 m. Most plants did not exceed 25 cm in height. This system was also selected for the gas exchange and plant growth studies.
6. *Lake Wauburg*. This community was located on a drainage canal that runs under SR-441 5 km south of Paynes Prairie. The canal connected two lakes on opposite sides of the road. Plants were 0.75 m tall, covered all the water surface, and were sampled at a depth of 1 m.
7. *Lake Alice*. This lake was located on the campus of the University of Florida and received sewage from a treatment plant. Plants were harvested from the south side of the lake where they covered all

the water surface and grew to a height of 1 m. Continuous sewage input maintains a slow but steady flow through this lake. Plant growth was measured at this site.

8. *Bivens Arm*. Plants were collected east of SR-441 which crosses adjacent to the west bank of the lake. Hyacinth coverage was 100%, plant height was 0.75 m and nutrient input to the lake from nearby farming operations was considerable. Plant growth was measured at this site.
9. *Sewage Plant*. A hyacinth population was established experimentally in the holding ponds of the University of Florida's sewage treatment plant. Ponds were 1 m deep and had a high rate of water flow. Plants grew to a height of 1 m and covered the surface entirely. An effort was made to study the biomass distribution of parent and daughter plants in this site.
10. *South Creek*. This system was located about 500 km south of Gainesville near the north western boundary of Everglades National Park. Plants were sampled at a creek meander within the Oscar Scherer State Park. The biomass distribution of parent and daughter plants was also determined at this site.

Rates of oxygen consumption and production in open water and under hyacinth mats in Gordon's Pond were calculated from diurnal curves of dissolved oxygen and temperature. The methodology and timing for dissolved oxygen and temperature determinations is discussed by ULTSCH (1973). Dissolved oxygen values were converted to a meter square basis multiplying by depth, corrected for diffusion using the dome method (COPELAND and DUFFER 1964), and analyzed according to the methods advanced by ODUM and HOSKIN (1958).

The metabolism of the hyacinth plants and other aquatic macrophytes was measured with an infrared CO<sub>2</sub> gas analyzer (Beckman Model 215) in the field under natural conditions and in a large aquaria on the roof of McCarty Hall at the University of Florida. The uptake and production of CO<sub>2</sub> and rates of water loss were measured utilizing an open system similar to the one described by ODUM *et al.* (1970). Each experiment lasted for a 24-hour period.

	Average % of total biomass	
	Mean	Standard error of the mean
Petioles	36.0	4.4
Leaves	16.9	1.7
Stems	7.6	0.7
Roots	24.0	3.8
Dead Matter	8.2	2.0
Ligules	3.9	0.5
Flowers	0.8	0.4
Stolons	2.5	0.7
Leaves + Petioles	53.3	5.4
Total Biomass (g/m <sup>2</sup> )	1859.	294.

Tabl. I : Biomass distribution in water hyacinth plants from nine populations in north central Florida.

## RESULTS AND DISCUSSION

### Biomass Distribution in the Water Hyacinth.

Table I summarizes the mean biomass distribution for 90 plants from nine different populations. Approximately half of the plant biomass occurred in the leaves and petioles, 25% in roots and about 8% each in stems and still-attached dead matter. These proportions varied significantly from population to population as illustrated for the relationship between root and above water parts on figures 1 and 2. The figures show three populations clustered at each extreme of the lines and four intermediate populations. Lake Wauburg, Lake Alice and the Sewage Plant populations were at the low root-to-high above water biomass extreme. Gordon's Pond, SR-23-A, and Paynes Prairie were at the high root-to-low above water biomass extreme and the others (Bivens Arm, SR-23-B, River Styx, and South Creek) were clustered in the middle.

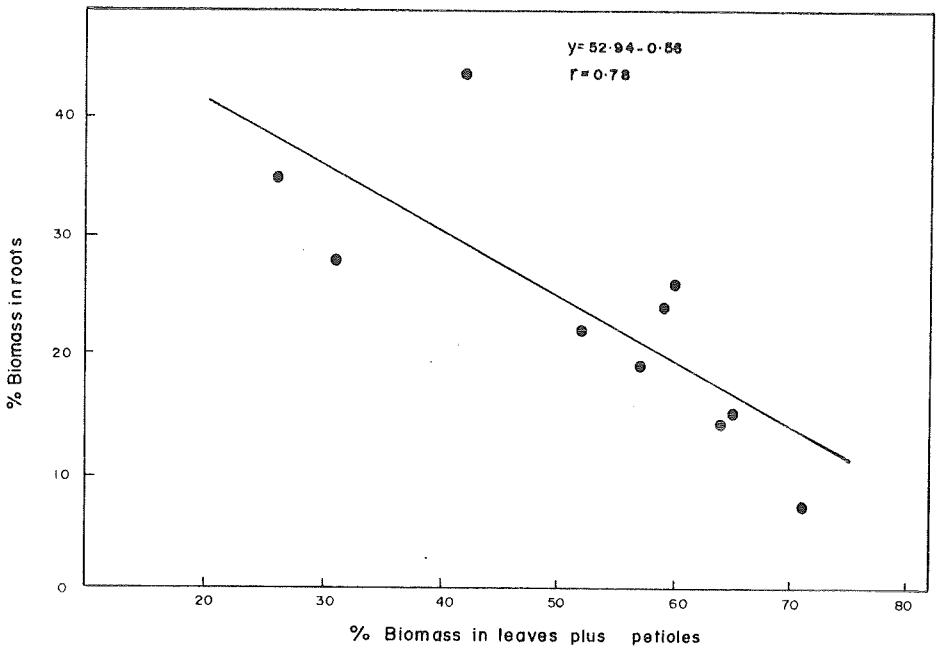


Fig. 1 : Linear relationship between percent of the total plant weight in root biomass and percent biomass above water (leaves plus petioles). Each point represents the mean of 10 plants from different populations.

In terms of quantity of root matter per plant, a Duncan's multiple range test ( $P < 0.01$ ) failed to separate the populations in these three groups.

We believe that water flow and nutrient concentration may act synergistically to account for the observed differences in root and above water biomass distribution in plants. Under lotic conditions compared with standing water, more nutrients come in contact with the submerged roots. Sites with high water flow have lower root biomass and higher above water biomass compared with sites where waters are still. Under lentic conditions, energy allocation to root structure (at the expense of lower above water biomass) has adaptive significance. Hyacinth growth studies by MORRIS (1974) in Paynes Prairie confirmed these findings.

Of interest is the apparent variation in biomass distribution between plants located within 40 meters of each other in the same habitat (SR-23-A and B). The lower root proportion in SR-23-B is due to an underwater spring, a characteristic of many ponds in the karst

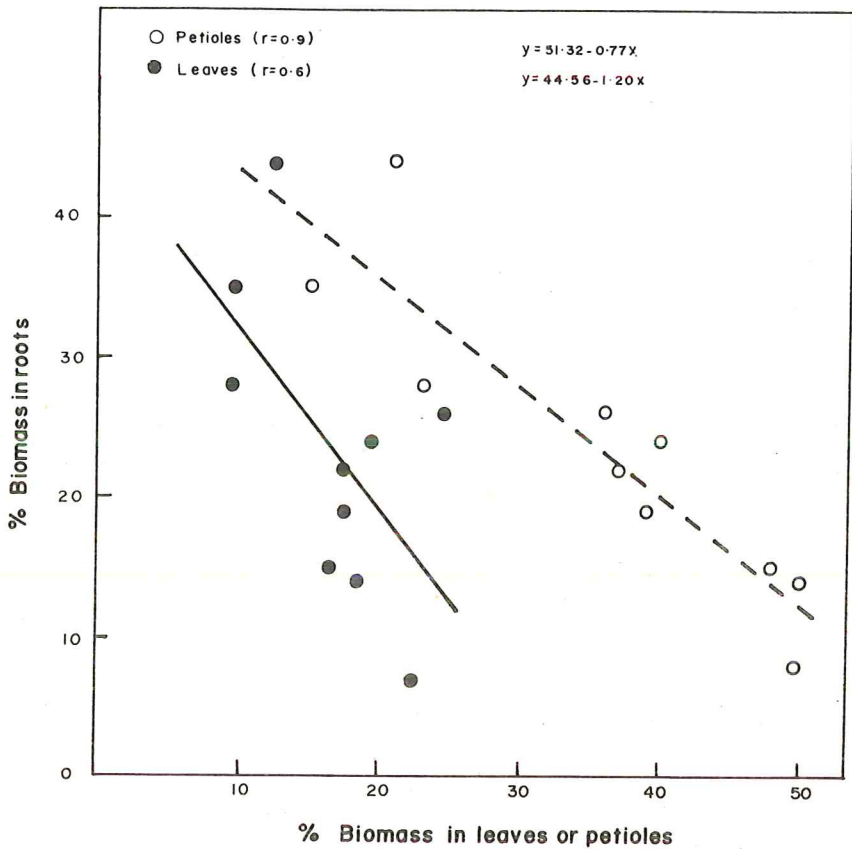


Fig. 2 : Linear relationship between the percent of the total plant weight in root biomass and the percent in leaves (solid line) and petioles (dashed line). Each point in a given curve represents the mean of 10 plants from different populations.

region of Florida. These springs accelerate water flux and promote higher growth rates in small pockets within habitats where conditions normally lead to lower growth rates. The sites were originally selected for the visible differences in the size of plants. The populations from South Creek and River Styx were growing on free flowing bodies of water but their biomass distribution was intermediate between the two flow extremes. Since nutrient concentrations were also high in both localities, we find no easy explanation for differences in response of these populations. However, since the flux of water currents may have shifted the plants from one place to another, it is unlikely that stable conditions developed in any one spot. Low biomass per unit area in these populations may have been also due to export by water currents.

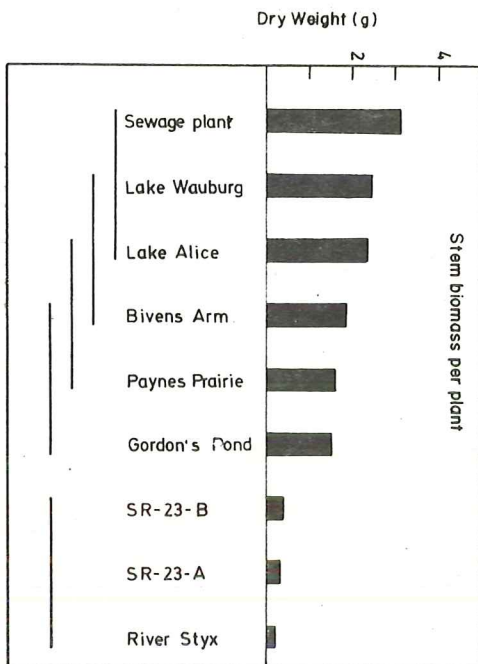


<u>South Creek</u>	Parent		Daughter	
	Mean	(SE)	Mean	(SE)
Leaves	3.15	0.86	0.69	0.33
Petioles	6.64	2.64	1.73	0.86
Roots	4.06	2.01	0.65	0.26
Stolons	0.70	0.11	0	0
Stems	0.92	0.42	0.24	0.13
Ligules	0.27	0.10	0.10	0.04
Dead matter	3.38	1.72	0.22	0.15
Flowers	0	0	0	0
Total	16.71	6.26	3.45	1.58
 <u>Sewage Plant</u>				
Leaves	2.55	0.20	1.02	0.20
Petioles	2.94	0.24	1.23	0.27
Roots	1.53	0.50	0.36	0.11
Stolons	0.40	0.14	0.30	0.04
Stems	0.36	0.05	0.15	0.03
Ligules	0.21	0.06	0.09	0.02
Dead matter	0	0	0	0
Flowers	0	0	0	0
Total	8.10	0.79	3.20	0.70

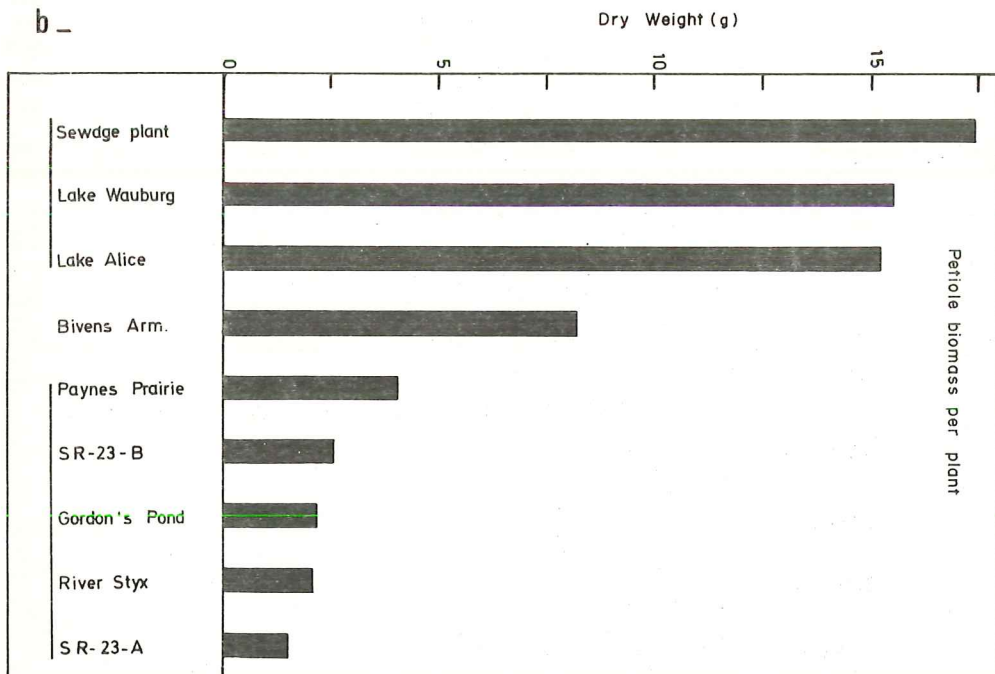
Tabl. II : Comparison of biomass distribution (g dry weight) in parent and daughter plants.

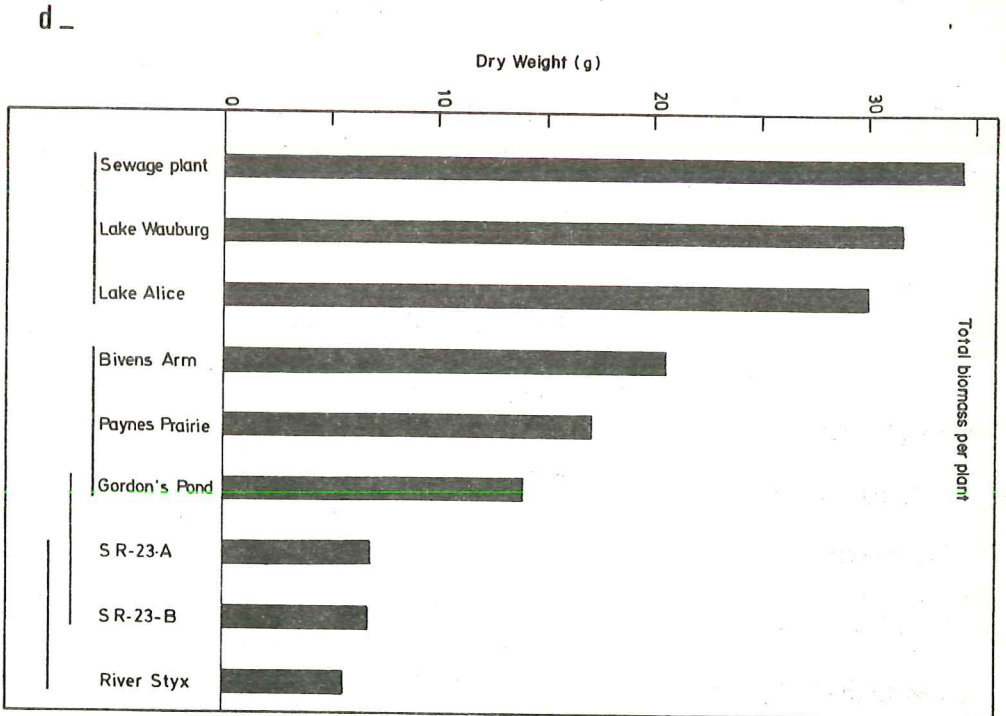
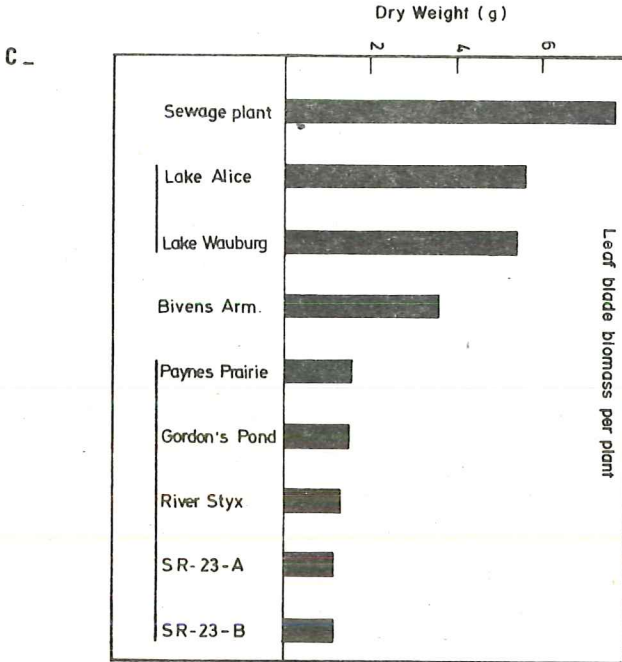
Fig. 3 (see following page) : Mean biomass content per plant in the form of stems (a), petioles (b), leaves (c), and total plant weight (d) in nine different hyacinth populations. Note the changes in the biomass scale. The lines under the bars unite populations whose differences in biomass content were not statistically significant ( $P < 0.01$ ).

a \_



b \_





The distribution of biomass in parent and daughter plants still attached to the parent are shown in table II. Leaves and petioles developed first and initially constituted 70% of the daughter biomass. Later, as other plant parts developed (roots, stems and stolons) this percentage decreased.

The differences in the amount of biomass per plant part per population was tested for statistical significance using Duncan's multiple range test ( $P < 0.01$ ). Flower, attached dead biomass, and ligule biomass differences were calculated but not reported here. Although no significant difference was observed in the amount of stolon biomass in the nine populations that were tested, statistical differences were observed at the 99% level of significance in stem, petiole, leaf, and total biomass per plant of each population (Fig. 3). Populations behaved in accordance with the same general trend discussed for figure 2. Three populations were consistently in the higher biomass per plant part range while three others consistently were clustered in the lower range. The groupings correspond with those discussed earlier and are

<u>Population</u>	<u>Density Plants/m<sup>2</sup></u>	<u>Total</u>	<u>Live</u>
		<u>Biomass</u>	<u>Biomass</u>
		<u>g/m<sup>2</sup></u>	
Lake Wauburg	103	3,262	2,999
Paynes Prairie	148	2,545	2,063
Gordon's Pond	165	2,305	1,938
Lake Alice	75	2,257	2,170
Biven's Arm	101	2,082	1,844
Sewage Plant	54	1,861	1,786
SR-23-B	154	1,048	976
SR-23-A	101	699	679
River Styx	120	673	658

Tabl. III : Plant density and total and live biomass in nine water hyacinth populations in north central Florida. Data were collected on July, 1970.

explained by the same multiplicative interaction of flow and nutrient levels.

To further document the role of nutrients on hyacinth vigor, multiple linear regression analysis was performed to test if there was a relationship between nutrient levels in the water and total live plant biomass per unit area (Tabl. III). Results yielded insignificant correlation with any of the nutrients and elements monitored in the water quality analysis. However, when all the nutrients and elements

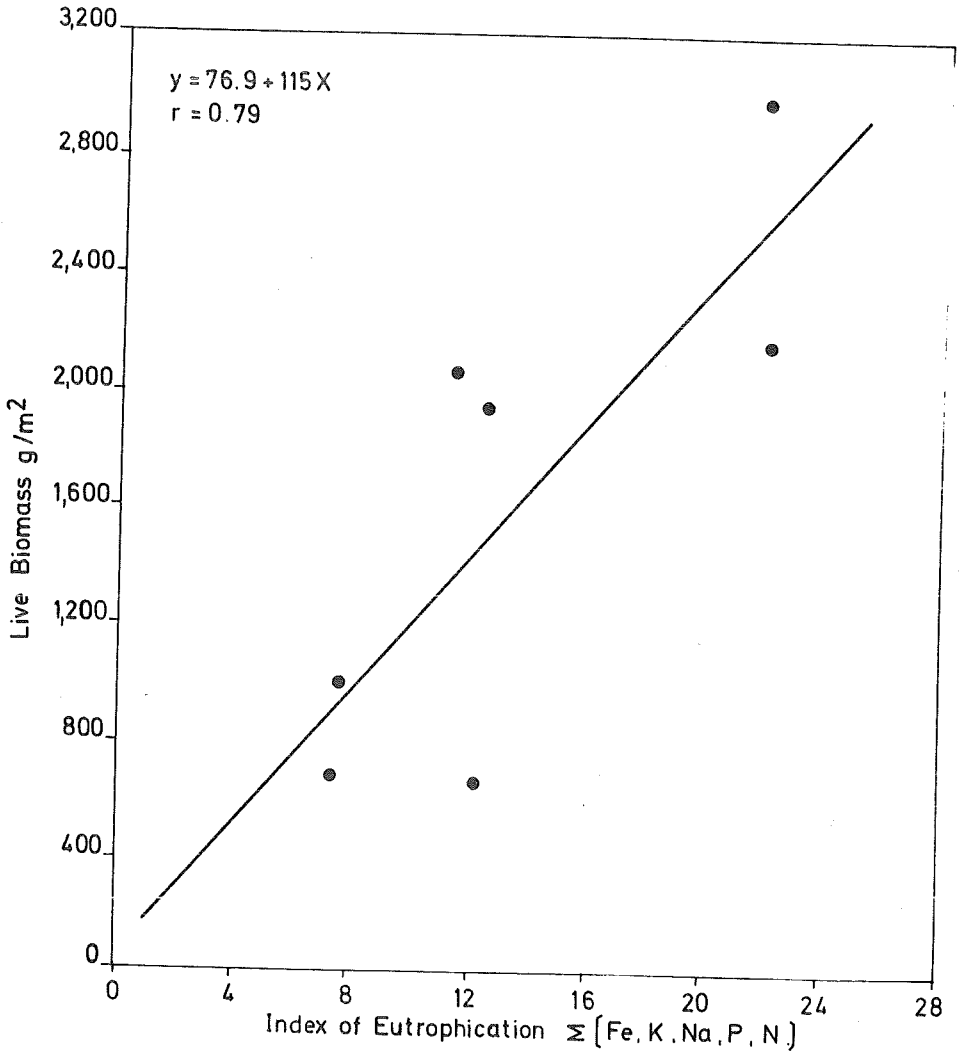


Fig. 4 : Linear relationship between live plant biomass per square meter and an index of water eutrophication.

Site	Time of year	Leaves	Petioles	Ligules	Roots	Stems	Stolons	Flowers	Dead Matter
Gordon's Pond	July	1.53	2.17	1.03	5.00	1.46	0.29	0.28	2.22
	November	0.82	1.60	0.22	4.23	1.18	--	--	5.50
	Change	-0.71	-0.57	-0.81	-0.77	-0.28	-0.29	-0.28	+3.28
Lake Wauburg	July	1.57	4.04	0.71	4.86	1.59	0.62	0.55	3.26
	November	1.65	6.92	0.31	2.62	3.83	0.15	0.11	17.15
	Change	+0.08	+2.88	-0.40	-2.24	+2.24	-0.47	-0.44	+13.89
Lake Alice	July	5.57	15.14	1.25	4.47	2.34	0.17	--	1.16
	November	5.59	14.91	1.09	2.02	3.21	0.87	0.11	3.81
	Change	+0.02	-0.23	-0.16	-2.45	+0.87	+0.70	+0.11	+2.65

Tabl. IV : Biomass distribution in plants from three water hyacinth populations at two times of the year (July and November, 1970). All values represent dry weight in grams.

<u>Site</u>	<u>Month</u>	<u>Plant Density Number/m<sup>2</sup></u>	<u>Living Biomass</u>	<u>Dead Biomass</u>	<u>Total Biomass</u>
Gordon's Pond	July	165	1940	363	2305
	November	112	901	616	1517
	Change % Change	-53 -35	-1038 -53	+252 +70	-787 -34
Lake Wauburg	July	148	2063	482	2545
	November	101	1574	1732	3306
	Change % Change	-47 -32	-488 -24	+1249 +260	+761 +30
Lake Alice	July	75	2170	87	2257
	November	38	1056	144	1201
	Change % Change	-37 -50	-1114 -51	+57 +66	-1056 -47

Tabl. V : Biomass distribution in three water hyacinth communities at two times of the year (July and November, 1970).  
All biomass values represent dry weight in g/m<sup>2</sup>.

were added and the sum considered an index of eutrophication, a correlation coefficient of 0.79 was obtained (Fig. 4). The data for Bivens Arm was not included in the calculation due to possible error in the water analysis. A better correlation may be obtained when water flow information for these sites becomes available.

### Biomass Dynamics.

Table II shows some of the changes in the distribution of biomass in the life cycle of a water hyacinth. Similar changes occurred in whole hyacinth mats as illustrated in tables IV and V which contain comparative data from three sites taken at two times of the year. Data for July represent the peak of the growing season while those for November represent conditions one month after the end of the growing season. The reduction in live biomass is accompanied by a dramatic increase in dead matter. This organic material contributes to the formation of the typical hyacinth-mats and to the increase in oxygen demand in the water column. In flowing waters, much of the detritus is exported. In stagnant water such as that in Gordon's Pond, conditions for export are insignificant and large accumulations of dead matter form an essentially continuous mat.

Figure 5 shows the results of petiole elongation studies. In Gordon's Pond, the population exhibited little elongation while higher rates were observed in the other two populations. The stagnant conditions in Gordon's Pond and the thick organic mats may have limited plant growth and turnover. In environments where water flow flushes away plants and organic matter away, populations may remain in a younger state and exhibit rapid elongation rates. As the leaves age, growth is reduced, mortality occurs, and a new leaf is produced. New leaf blades expand quickly but our measurements were not frequent enough to document this rapid expansion. After the initial expansion, leaf elongation does not occur.

Our elongation studies were hampered by the fragility of the hyacinth plant. Any slight change in the position of the leaf caused its subsequent mortality. Handling of petioles also caused mortality since they could not overcome the slight bending that resulted from the tagging and measuring operation. The individual water hyacinth seems to be a very sensitive plant. However, as leaves died, new ones replaced



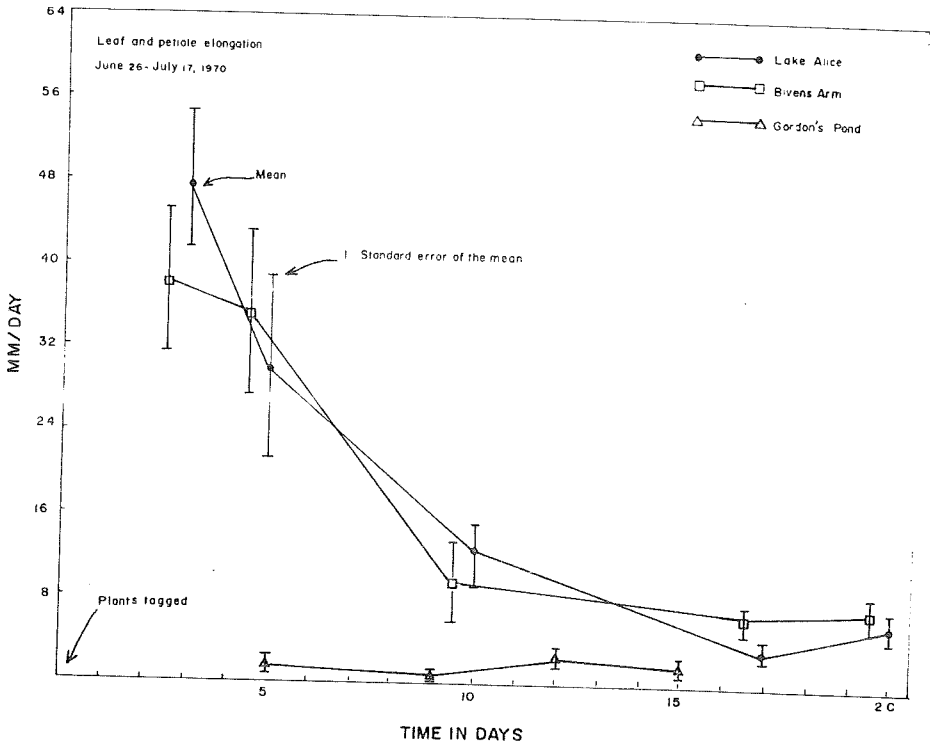


Fig. 5 : Rates of petiole elongation in three water hyacinth communities during a period of 20 days in the growing season.

the dead ones very quickly. Efforts to measure root elongation resulted in negative numbers probably as a result of grazing by aquatic animals.

#### Plant Productivity and Dissolved Oxygen Dynamics in the Water Column.

Net daytime photosynthesis, nighttime respiration and transpiration of hyacinth populations were measured in Gordon's Pond (Fig. 6) and Lake Alice. Rates for individual plant and community determinations are summarized in table VI. These plant communities represented habitat differences that were expected to influence hyacinth growth characteristics. In the calm waters of Gordon's Pond, small plants grew slowly

<u>Species</u>	<u>Date and Time</u>	<u>N</u>	<u>Mean Pn</u>	<u>Max Pn</u>	<u>Efficiency of Pn (% total light)</u>	<u>N Rni</u>	<u>Mean Rni</u>
<i>Hydrocotyle rannunculoides</i>	July 14, 1971 11:00 AM - 2:30 PM	5	0.46	0.61	0.61	-	-
<i>Typha latifolia</i>	July 15, 1971 12 N - 8:00 PM	13	0.41	0.59	0.79	-	-
<i>Nelumbo lutea</i>	July 14-15, 1971 5:00 PM - 10:00 AM	10	0.08	0.19	0.23	23	0.41
<i>Eichhornia crassipes</i> (above water)	August 17, 1970	12	0.44	-	4.0	12	0.04
<u>Community</u>	<u>Date</u>	<u>Total Pn</u>	<u>Total Rni</u>	<u>Efficiency of Pn (% total light)</u>	<u>Evapotranspiration (1) <math>\text{gH}_2\text{O}/\text{m}^2 \cdot \text{day}</math></u>	<u>LAI</u>	
Hyacinth Mat at Gordon's Pond (including dead matter)	July 6-7, 1971	2.97	2.62	0.5	1,219	1.7	
Hyacinth Mat at Lake Alice (above water)	August 14, 1970	16.97	1.72	4.0	3,300	3.2	

(1) Potential evapotranspiration was 4,890  $\text{gH}_2\text{O}/\text{m}^2 \cdot \text{day}$ . Photosynthetic and respiratory values for species are in  $\text{gC}/\text{m}^2$  leaf surface-hour. Each measurement (N) lasted 1/2 hour. Corresponding values for communities are reported in  $\text{gC}/\text{m}^2$  ground area-day. Each value represents a 24-hour experiment.

Tabl. VI : Net daytime photosynthesis, its efficiency, and nighttime respiration rate summaries for some aquatic macrophyte species and communities.

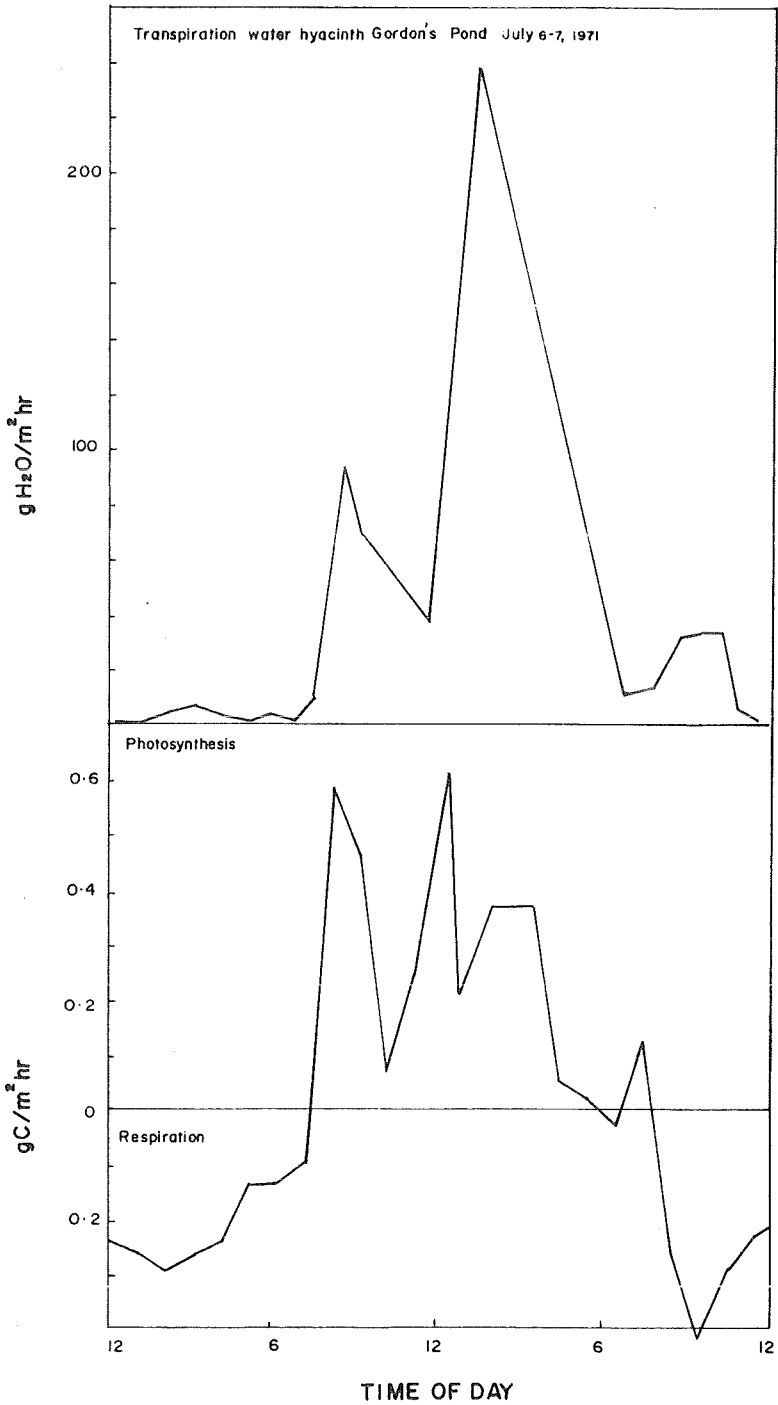


Fig. 6 : Diurnal rates of net daytime photosynthesis, nighttime respiration, and transpiration of the water hyacinth community at Gordon's Pond. Rates are summarized in table VI.

over very thick organic mats. In Lake Alice, where water flow occurred and organic mats were thinner, the structural development of the canopy was greater as evidenced by the higher leaf area index (LAI). Metabolic differences between these sites were magnified by transplanting Lake Alice plants to a large tank prior to the measurements of gas exchange.

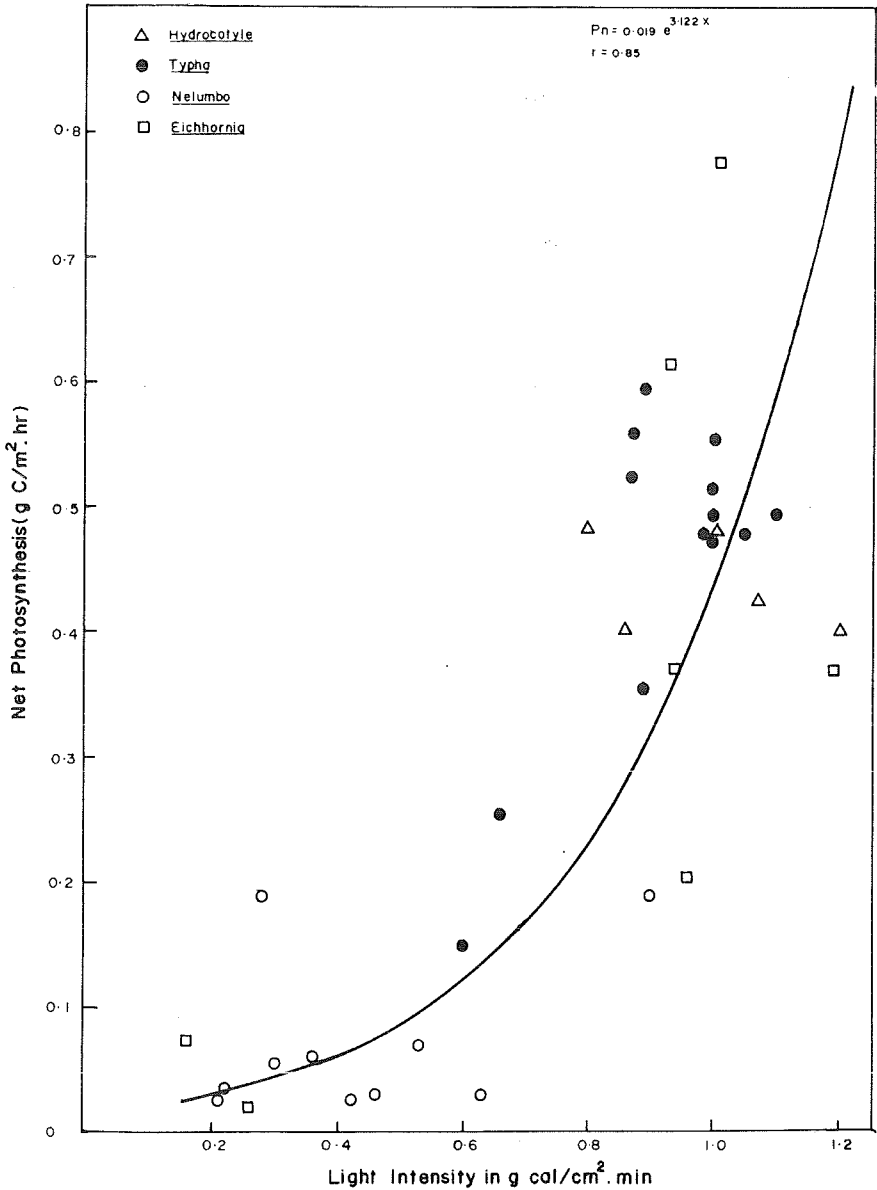


Fig. 7 : Exponential relationship between rates of net daytime photosynthesis ( $P_n$ ) in four species of aquatic plants and total light energy incident on the plants. For each percent increase in light energy, there is a 1.7% increase in net daytime photosynthesis.

Thus, the respiration of the mat was reduced in comparison to the plants at Gordon's Pond which were measured in situ. In spite of the measured differences, the rates of net daytime photosynthesis were high in both populations and exceeded nighttime respiratory consumption. The hyacinth community in Gordon's Pond exhibited lower rates of productivity and higher rates of respiration than the plants from Lake Alice.

Table VI also contains comparative data for the mean rates of net daytime photosynthesis, and nighttime respiration of hyacinths and other aquatic macrophytes that were studied during the same time period at Paynes Prairie. It appears that all these species behave like sun adapted plants but lack of sufficient data precluded the completion of light-photosynthesis curves for each species. A plot of light vs rate of net photosynthesis for all aquatic macrophyte species studied fitted an exponential function with a correlation coefficient of 0.85 (Fig. 7). This suggests that during the summer growing season in nutrient-rich aquatic environments light is the limiting factor to plant productivity.

The idea that water hyacinths transpire more water than evaporates from a free water surface (TIMMER and WELDON, 1967) was not confirmed by the transpiration rate experiment at Gordon's Pond. The rate of evapotranspiration was lower in the hyacinth community than in the open water (Tabl. VI). The open water value was calculated from the potential evapotranspiration reported by a nearby U.S. Weather Bureau station. A possible explanation is that plants reduce evapotranspiration by means of stomatal control and modification of microclimate.

The annual production and consumption of dissolved oxygen in the water column below water hyacinth mats and in open water areas is presented in figure 8. Figure 9 shows the diffusion rates used to correct individual oxygen diurnals. Diffusion rates, with the exception of a few daylight hours, contributed significant amounts of oxygen to the water column. During certain days, dissolved oxygen values increased at nighttime suggesting a great deal of patchiness in the distribution of dissolved oxygen.

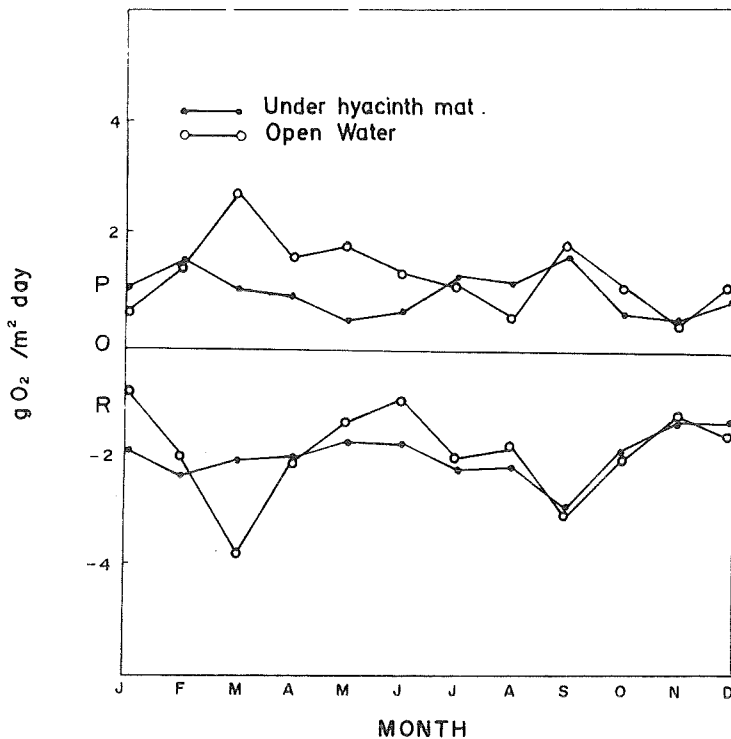


Fig. 8 : Monthly rates of oxygen production and consumption in Gordon's Pond. Values are corrected for diffusion and thus reflect rates of net daytime productivity and nighttime respiration in open water and below a hyacinth mat. Notice that during most of the year, respiration exceeds productivity. The annual productivity and respiration in open water were 405 and 687  $\text{gO}_2/\text{m}^2$ . Under the hyacinth mat the corresponding values were 300 and 696  $\text{gO}_2/\text{m}^2$ .

The dynamics of oxygen and organic matter in Gordon's Pond are summarized in the two models in figure 10. All the numbers, with the exceptions of those with question marks were collected in this study.

Dissolved oxygen in open water (Fig. 10-a) depends on the oxygen produced in situ plus that which originates from atmospheric diffusion. That respiration exceeded productivity in the open water, suggests the import of organic material from surrounding hyacinth communities or overland runoff. No estimates of organic storage were made in this zone. The open water environment was oxygenrich as a result of contribution by photosynthesizing submerged plants. This zone becomes low in dissolved oxygen only during periods of very high temperature (ULTSCH, 1973) and when dissolved  $\text{CO}_2$  and nutrient concentrations are low.

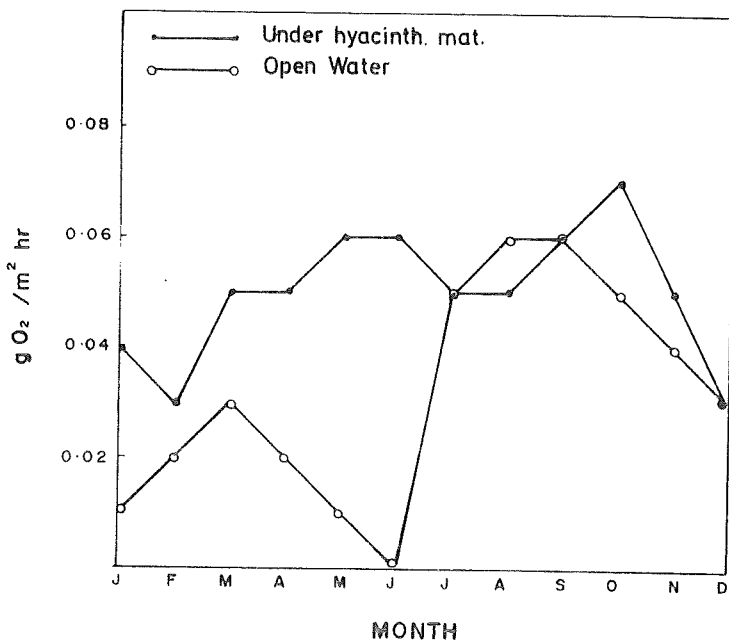
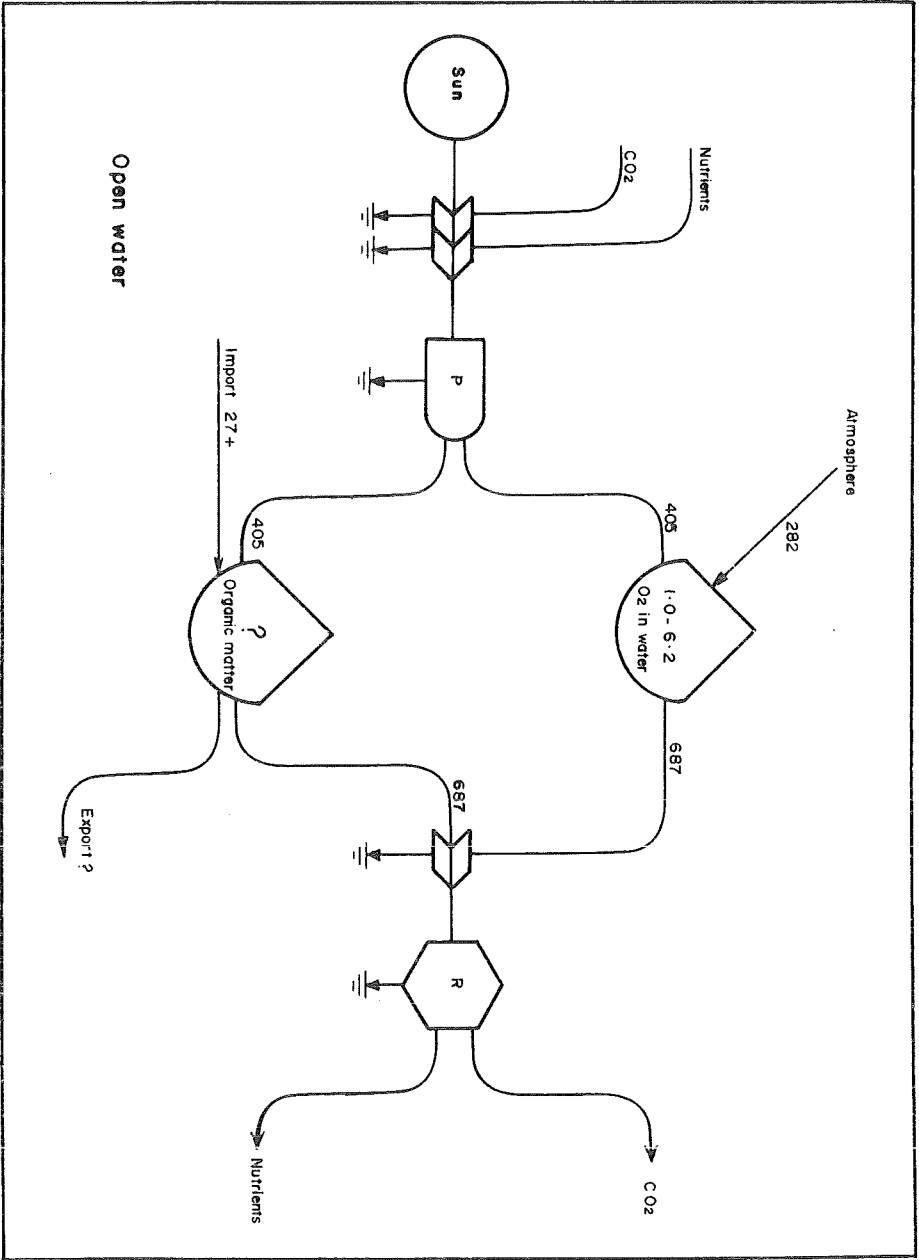


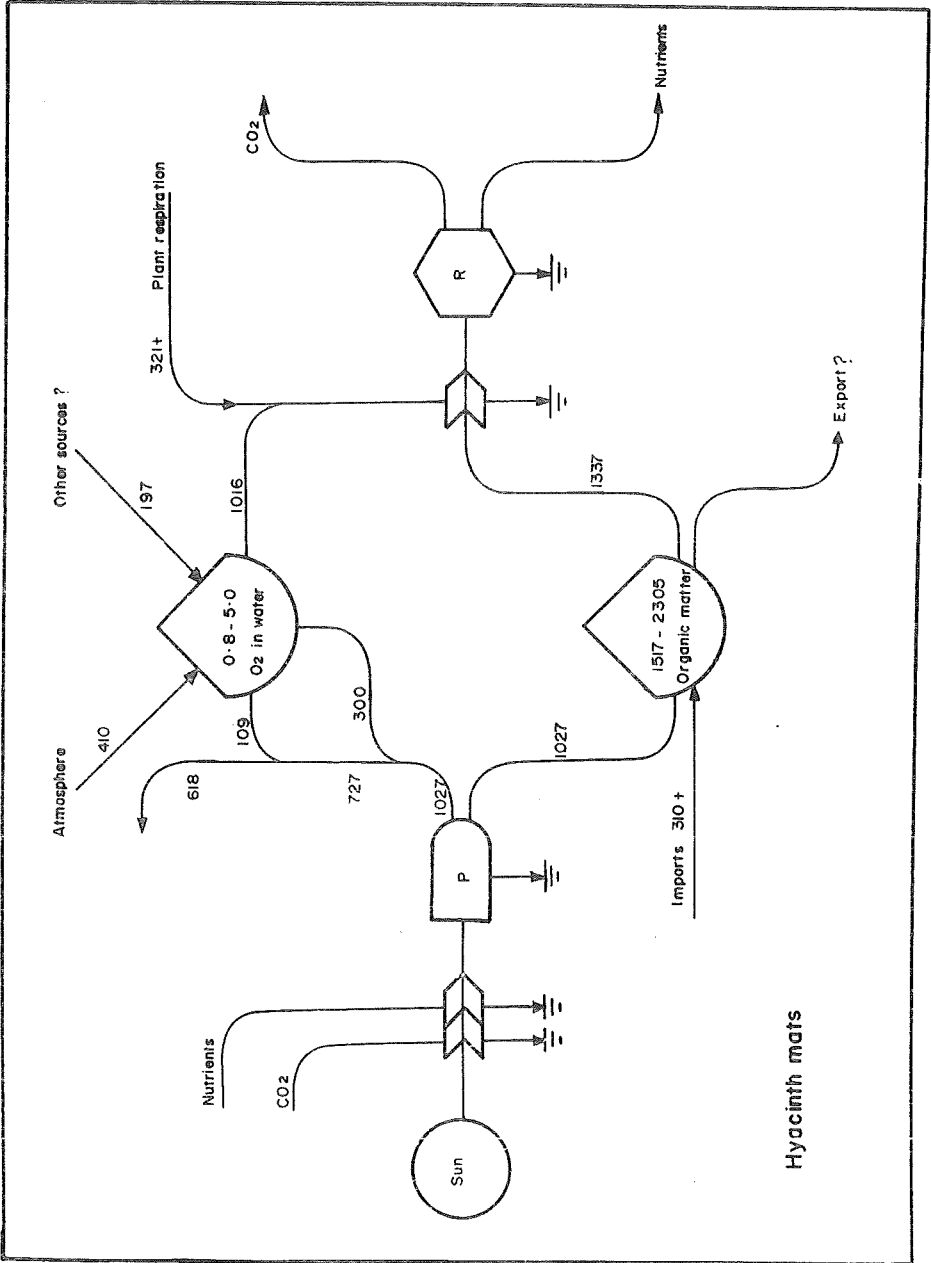
Fig. 9 : Monthly rates of oxygen diffusion into open water and through a water hyacinth. Annual rates of diffusion contributed more oxygen to the waters under the hyacinth mat than in situ photosynthesis (410 vs 300 gO<sub>2</sub>/m<sup>2</sup>) and a significant amount to the open water column (282 gO<sub>2</sub>/m<sup>2</sup>).

The dynamics of dissolved oxygen production and consumption are more complicated under the water hyacinth mat (Fig. 10-b). The mat may be twice as productive as the open water in spite of the time limitation of its productive period (March-October, ULTSCH, 1973). The hyacinth plants contribute significant amounts of organic matter to the water and increase the oxygen demand. However, since oxygen exchange between the atmosphere and the plants takes place mostly through stomata, it does not contribute much to the oxidation of organic matter

Fig. 10 (see following pages) : Models of oxygen and organic matter dynamics in open water (a) and water covered with a hyacinth mat (b). The tank represents oxygen or biomass storage, lines represent direction of flow, the circle represents solar energy input, the bullet-shaped symbol represents plant populations and the pointed symbol represents the multiplier relationship between two flows. Numbers over the lines are rates of flow in grams of organic matter or grams of dissolved oxygen per square meter per year. The numbers inside the tank represent grams per square meter.







in the water column. The model in figure 10-b shows a significant amount of oxygen escaping into the atmosphere. It also shows a 15% oxygen recycling into the water via hyacinth roots. This number is based on several observations related to CO<sub>2</sub> gas exchange. ULTSCH and ANTHONY (1973) have demonstrated that hyacinth roots may take up radioactive bicarbonate from the water and incorporate its carbon into dry matter. We have measured carbon dioxide concentrations of 70-210 ppm inside the air spaces of hyacinth petioles. In addition, the root zone of water hyacinth growing in anaerobic environments supports a rich invertebrate fauna. It is thus possible that some oxygen produced during photosynthesis diffuses through the system of air spaces of the water hyacinth and into the water column. The model assumes that at least half of the hyacinth respiration is supported by atmospheric oxygen. In spite of these oxygen sources, there still remains an unaccounted deficit of about 200 gO<sub>2</sub>/m<sup>2</sup> year for this habitat. This oxygen may originate from diffusion from adjacent open water, increased diffusion through hyacinth mats, through higher rates of photosynthetic oxygen recycling through hyacinth air spaces and roots, or by the photosynthesis of periphyton and algal mats growing on the water surface. As a result of this potential deficit, dissolved oxygen levels in this zone are very low and at times the water under the mat is anaerobic.

Our measurements suggest that the hyacinth zone required an import of organic material to account for the observed respiration. This import may be from surrounding agricultural areas and from littoral vegetation which also contributes to the pond's metabolism. Due to the location of the hyacinth mat, nutrient and carbon dioxide recycling within the mat may be more localized (closed) than in the open water. The lack of water flushing may cause lags in the mineral cycling and gas exchange and thus limit hyacinth growth and vigor.

The variation in plant biomass distribution and metabolism in the ponds and canals in the vicinity of Gainesville, Florida may be attributed to nutrient levels and to a possible synergetic effect between nutrient concentration and water flow. Hyacinth communities are successful in these environments due to their capacity to adjust morphologically and metabolically to the diversity of habitats in the region.

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