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R.J. Rippingale
N.A. Smith

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AQUATIC PLANTS FOR THE TERTIARY TREATMENT OF WASTEWATER

R.J. Rippingale* and N.A. Smith*

ABSTRACT

Much literature is available on the use of aquatic plants in the treatment of wastewater. However, since conditions for plant growth differ from place to place, it is necessary to establish the effectiveness of this type of treatment for each locality. A programme to test the effectiveness of aquatic plants in improving the quality of secondary effluent from a wastewater treatment plant near Perth was conducted for twelve months. Eleven ponds, each of $10m^3$ capacity, were constructed at the plant and were continuously supplied with secondary effluent. Three plant species were established in the ponds, **Lemna** sp. (Duckweed), **Myriophyllum aquaticum** (Parrot's Feather or Water Milfoil) and **Typha orientalis** (Bullrush) and some ponds were left without macroscopic plants. **Lemna** and **Myriophyllum** were harvested weekly and the results of both plant analysis and water analysis in the ponds indicated substantial nitrogen reduction in the tertiary effluent.

* School of Biology Western Australian Institute of Technology, Kent Street, South Bentley, Western Australia, 6102

* Present Address Hutt Valley Drainage Board. Private Bag Low Hutt. New Zealand.

INTRODUCTION

The Need for Tertiary Treatment

Finite water resources and the ever increasing demand for water justifies research and development of technology for upgrading the quality of wastewater effluent. If the quality of secondary effluent can be upgraded it may be acceptable for discharge to rivers or for aquifer recharge without environmental damage or for re-use in irrigation or industry.

Approximately 90% of all treated wastewater from Perth is discharged to the ocean. This water, some 3.7×10 m^3 $year^{-1}$, represents almost 25% of the potable water supplied within the metropolitan area.

The nitrogen and phosphorus content of this wastewater has the potential to cause environmental deterioration. Bacteria and viruses limit the re-use potential in certain circumstances but removal methods for these, such as lagooning and chlorination, are well known and in common use.

Wastewater treatment is expensive and attempts to reduce these costs by devising processes which use little mechanical equipment and no chemical additives are worthwhile. This paper discusses an investigation into the use of macroscopic aquatic plants in the removal of nitrogen and phosphorus from secondary effluent.

Aquatic plants are natural users of soluble nutrients and the concept of harnessing and controlling this natural water treatment process is attractive. The plants most effective in rapid nutrient uptake are capable of out-competing other plants and establishing monocultures which themselves detract from environmental quality. For this reason these plants are regarded as weeds and may be restricted by legislation. Research efforts in Western Australia must be restricted to the use of plants which will not be any threat to the environment.

Literature is available on work from various countries, including Australia, on the use of macroscopic plants in wastewater treatment. However, in any area there are particular patterns of climate, endemic species, aspects of water quality and biological interactions between species such that research findings from one locality are not necessarily valid for others. Their applicability can only be validated by local studies. The climate of the Perth area provides ideal conditions for experimenting with plant growth for tertiary treatment. Mild winter conditions usually permit continuous plant growth throughout the year.

Overseas Studies

Many overseas studies have concentrated on the use of **Eichhornia crassipes** (Water Hyacinth) for treating wastewater. This plant grows rapidly over water surfaces and is a nuisance weed in many places. For this reason its use could not be considered in the present study because of the risk of infesting local waterways. In South Carolina USA, **Typha** was found to be more productive and to remove more nutrients from a given area than **Eichhornia** (Boyd 1971). In Saskatchewan, Canada, **Scirpus sp.** and **Typha** were both found to reduce nitrogen and phosphorus effectively (Lakshman, 1978). In New Zealand, studies on **Typha sp.**, **Myriophyllum aquaticum** and **Alternanthera sp.** showed that **Typha** most effectively removed nutrients (Gifford 1979, 1980; Oliver 1979, 1980, 1981). In Michigan USA **Typha** and **Lemna** were used to effectively reduce capital costs in tertiary wastewater treatment (Sutherland and Bevis 1979). Other studies have shown that **Eichhornia** and **Lemna** complement each other when grown in the same system by each growing most strongly in different seasons (Wolverton and McDonald 1981), and various workers have shown the effectiveness of different plants in removing contaminants from wastewater treatment (Golueke 1981; O'Brien 1981; Sherwood et al. 1981; Stowell et al. 1981).

Australian Studies

Weir (1976) examined various alternatives for nutrient sinks and found **Typha** to be effective in nutrient uptake. **Typha** also proved to be very digestible and rated better than lucerne as a stock food.

Mitchell (1978) stressed the value of aquatic plants in wastewater treatment and suggested the use of several types, including **Typha**, **Phragmites australis** (Common Reed) and **Eleocharis sphacelata** (Spike Rush). Jackson and Gold (1981) described preliminary trials at the University of New South Wales with wastewater treatment using various aquatic plants, concluding that **Typha** and **Myriophyllum** were the most promising.

In Victoria, the Dandenong Valley Authority is presently investigating the use of aquacalture systems with **Lemna**, **Myriophyllum** and **Cotula coronopifolia** (Water Button). The CSIRO Division of Irrigation Research at Griffith is working on the treatment of rural wastewater by aquatic plants using **Phragmites australis** and **Scirpus validus** (Great Bullrush).

The Present Study

In the middle of 1981 discussions were held with engineers from the then Metropolitan Water Board to consider developing a local research programme on the use of aquatic plants in wastewater treatment. Westfield wastewater treatment plant was chosen as a site because land was available, qualified operators and chemists were in attendance and effluent could easily be delivered to a trial site.

Westfield treatment plant is a conventional diffused air activated sludge plant treating on average 7400m day of wastewater from a predominantly residential catchment. The effluent is usually not nitrified, most of the nitrogen being present as ammonia.

At the time of the study, secondary effluent from Westfield was either sprayed onto pasture or pumped into lagoons to allow infiltration into the sandy soil. The study was designed to consider the effectiveness of aquatic plants in improving the quality of this secondary effluent. Three plants were selected for study, Typha orientalis, Lemna and Myriophyllum aquaticum. Figure 1 shows the relative size and position in the water of the three chosen plants.

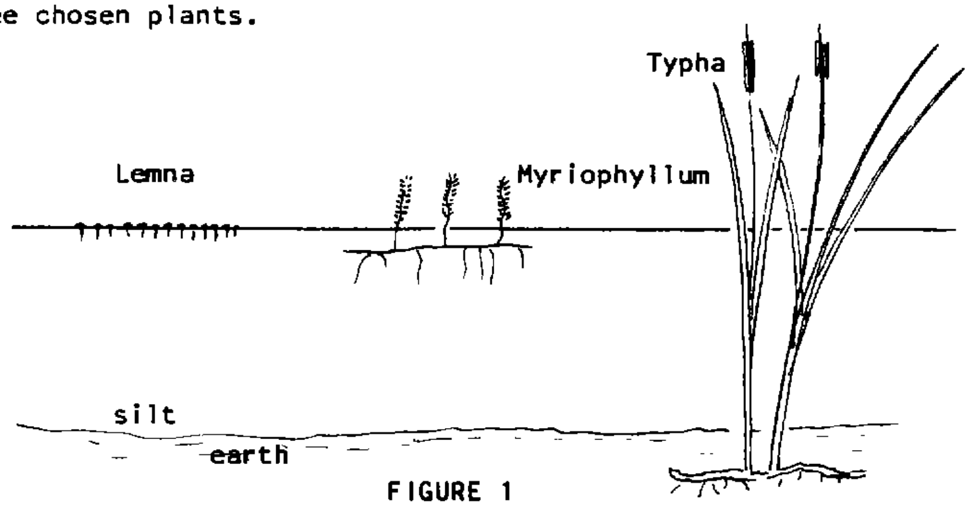

FIGURE 1

SKETCH OF AQUATIC PLANTS USED IN TRIALS

To investigate the plants' growth patterns and their potential to reduce the nutrient level of secondary effluent, experimental ponds were constructed. These ponds were continuously supplied with secondary effluent and the nutrient removal efficiency estimated from analysis of the nutrient content of the harvested plants and the quality of water entering and leaving the ponds.

MATERIALS AND METHODS

Construction of Experimental Ponds

Eleven ponds, each 6m x 2m with $10m^3$ capacity were constructed close to the final clarifiers at Westfield. Asbestos fencing provided dividing walls in a 6m wide trench to produce the ponds. The narrow ends of each pond were closed with sand embankments and each pond was lined with high density plastic membrane.

Effluent Feed

Secondary effluent was continually delivered to a header tank through a 32m polythene pipe connected to the effluent pumping mains. From this header tank the effluent gravitated through a 50mm PVC pipe to a distribution box where the flow was split evenly between the eleven ponds. Initially the rate of flow was adjusted to give a theoretical 7 day retention in the ponds in April 1983 the rate of flow was increased to give a theoretical retention of 4 days.

Inoculation with Plants

Three of the ponds were inoculated with each of Typha, Myriophyllum and Lemna and two left without macroscopic plants as controls. Green microalgae and a dense zooplankton developed in these ponds so they were controls only in the sense of having no macroscopic plants. Typha was collected from abundant stands in and around the treatment plant. Clumps of the plant were set into approximately 100mm of sand at the bottom of the pond.

Lemna was abundant on standing water in the area and soon appeared on the surface of the ponds. **Myriophyllum** did not occur nearby but an inoculum was obtained from an ornamental pool at the Western Australian Institute of Technology.

Harvesting

Regular harvesting of **Lemna** commenced six weeks after the initial inoculation and harvesting of **Myriophyllum** commenced ten weeks after inoculation. Several harvesting techniques were tried before the following method was adopted. **Lemna** was removed with a swimming pool leaf scoop until a loose cover of plants remained. Half of the **Myriophyllum** plants were removed with a rake and the remainder spread out to fill the pond. The plants were then weighed on site in a basket hanging from a 25kg spring balance after allowing a few minutes for most of the free water to drain off.

Samples of the harvested **Lemna** and **Myriophyllum** were taken to the laboratory for dry weight and nutrient content analysis.

Very slow growth was observed in the **Typha** that was planted. No harvests were taken and no further reference to the **Typha** pond is made in this report.

Effluent Quality Sampling and Analysis

Full Analysis of the secondary effluent received by the ponds was carried out regularly by the chemists at Westfield. The tertiary effluent from the experimental ponds was sampled weekly and analysed for ammoniacal, nitrite and nitrate nitrogen and less regularly for organic nitrogen and total phosphorus.

RESULTS

General

The trial ponds operated continuously for more than a year with approximately ten months of harvesting **Lemna** and **Myriophyllum**.

Water Quality

Figure 2 shows the results of total nitrogen analysis averaged for the three **Lemna**, the three **Myriophyllum** and the two control ponds. The reduction of total nitrogen varied from 10% to 50% depending on plant, season and flow rate through the pond.

The average reduction over the year was 26% for **Lemna** and 30% for **Myriophyllum**.

Total phosphorus analysis on the treatment plant effluent and the pond effluents showed varying concentrations between 6.8 and 10.2 $mg.l^{-1}$ with no significant trends discernible.

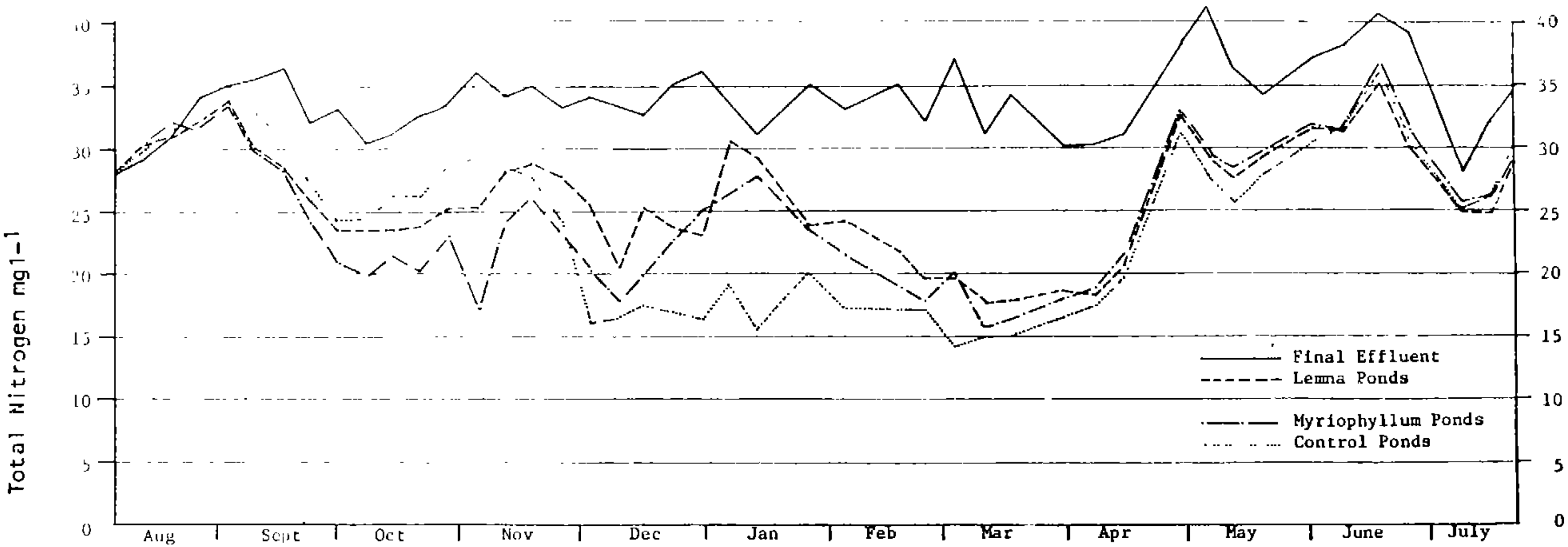

FIGURE 2

THE TOTAL NITROGEN ($mg1^{-1}$) IN THE WATER RECEIVED BY THE EXPERIMENTAL PONDS (THE FINAL EFFLUENT) COMPARED WITH THE TOTAL NITROGEN LEAVING THOSE PONDS BY OVERFLOW.

Harvested Plants

(a) Yield

The wet harvest quantities of **Lemna** and **Myriophyllum** are shown in Figure 3. Dry weight measurements on samples of the plants gave an average dry weight of 6% for **Myriophyllum** and 10% for **Lemna.**

Using these figures the dry weight harvest for eacth plant was calculated as follows:

Annual Averages (based on 10 months of harvesting)

Lemna

0.05 kg dry wt m^{-2} $week^{-1}$
(71 kg ha^{-1} day^{-1})

Myriophyllum

0.120 kg dry wt m^{-2} $week^{-1}$
(172 kg ha^{-1} day^{-1})

Peak Season

Lemna (Dec to Feb)

0.08 kg dry wt m^{-2} $week^{-1}$
(114 kg ha^{-1} day^{-1})

Myriophyllum (Feb)

0.195 kg dry wt m^{-2} $week^{-1}$
(279 kg ha^{-1} day^{-1})

Low Season

Lemna (Apr to May)

0.03 kg dry wt m^{-2} $week^{-1}$
(43 kg ha^{-1} day^{-1})

Myriophyllum (June to July)

0.074 kg day wt m^{-2} $week^{-1}$
(105 kg ha^{-1} day^{-1})

(b) **Nitrogen and Phosphorus Content of Plants**

The nitrogen and phosphorus content in dried plant tissues was established after digestion of samples. The mean results of five analyses for nitrogen and two for phosphorus were:

Lemna	6.5% N	1.5% P
Myriophyllum	3.8% N	0.9% P

(c) **Nitrogen and Phosphorus Removal by Harvested Plants**

The quantity of nitrogen and phosphorus removed from each pond in the harvested biomass of plants was calculated from the figures of total production and percentage nitrogen and phosphorus in the dry weight. The average daily nutrient removal calculated over 10 months harvesting is shown below:

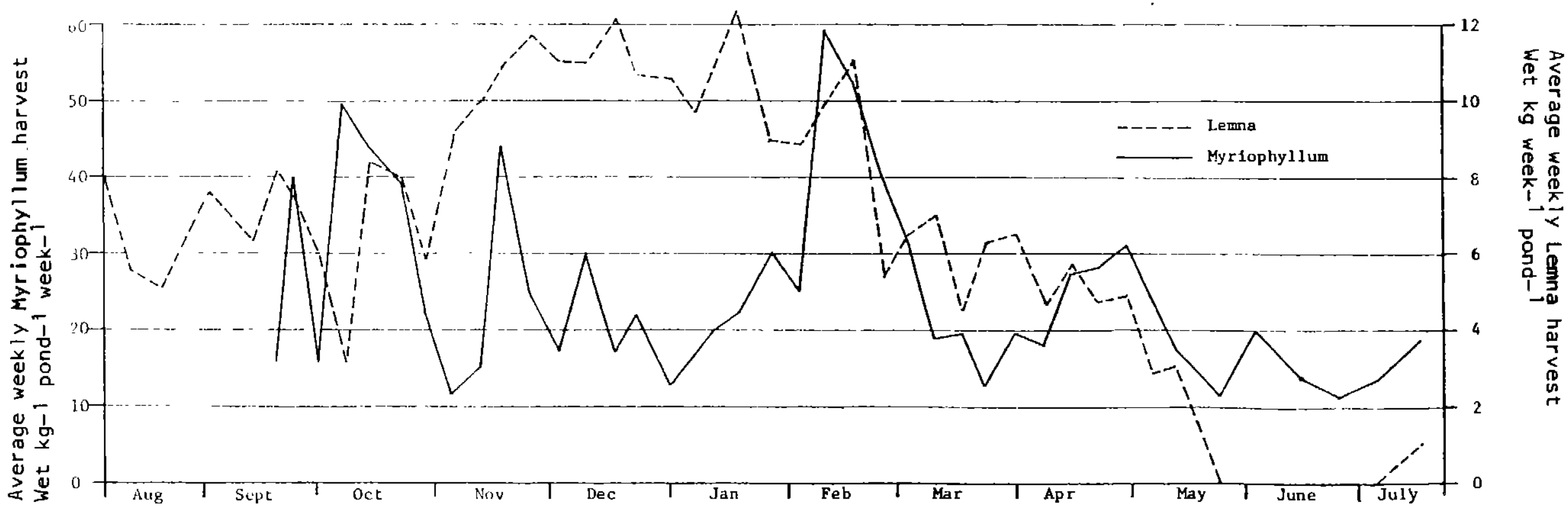

FIGURE 3

THE AVERAGE WEEKLY WET WEIGHT HARVEST FROM THREE PONDS GROWING LEMNA AND THREE PONDS GROWING MYRIOPHLLUM.

Lemna

	(4.6 kgN ha^{-1} day^{-1})
	(1.07 kgP ha^{-1} day^{-1})
Myriophyllum	(6.5 kgN ha^{-1} day^{-1})
	(1.5 kgP ha^{-1} day^{-1})

With 7 days retention in the ponds and 4 days retention in the ponds the amount of water passing through the ponds each week was $10m^3$ and $17.5m^3$ respectively. The theoretical nitrogen and phosphorus depletion from the water by plant growth for the two flow rates is as follows:

	7 Day Retention	4 Day Retention
Lemna ponds		
	3.8 mg N $Litre^{-1}$	2.2 mg N $litre^{-1}$
	0.92 mg P $litre^{-1}$	0.52 mg P $litre^{-1}$
Myriophyllum pond		
	5.5 mg N $litre^{-1}$	3.1 mg N $litre^{-1}$
	1.3 mg P $litre^{-1}$	0.7 mg P $litre^{-1}$

DISCUSSION

Figures of dry weight harvest from the experimental ponds are based upon regular wet weighing of harvested material (Fig.3) and three estimates of the dry weight content of samples of both species. At each harvest, every attempt was made to leave a comparable amount of plant material in the ponds to provide for growth before the next harvest, the object being to achieve a maximum sustainable yield. No quantitative experiments were carried out to determine how much plant material should be left but after a few weeks our subjective judgement was that **Lemna** ponds should be left with a loose cover over half of the surface and that **Myriophyllum** should be spread loosely over the entire surface. More experimental work could test these judgements. The quantity of plant material harvested can be regarded as the productivity of the pond during the inter-harvest period. The figures obtained can then be compared with those from other studies. Gifford (1980) reports the productivity of **Myriophyllum** as 16.5 Dry wt tonnes ha^{-1} $year^{-1}$. Boyd (1971) reports 192 tonnes ha^{-1} $year^{-1}$ for **Typha** and 54.7 tonnes ha^{-1} $year^{-1}$ for Eichhornia. After extrapolating from the $12m^2$ of our ponds to the larger area the productivities measured at Westfield were 20 tonnes ha^{-1} $year^{-1}$ for **Lemna** and 62 tonnes ha^{-1} $year^{-1}$ for **Myriophyllum.**

Whilst extrapolations are necessary to permit comparisons, their validity must always be in some doubt. The methods of harvesting plants from a large area could not be the same as from a small pond where care can be taken to avoid individual plants becoming unproductive through senescence. Also, patterns of water circulation and the effects of wind could alter the growth of plants in large ponds. Despite these reservations the results show that biomass production can occur throughout the year under local conditions, albeit with seasonal peaks (Fig 3.), and that the quantities obtained are roughly comparable to that which is achieved elsewhere.

The estimates of the nitrogen and phosphorus content of harvested **Lemna** and **Myriophyllum** can be coupled with the total harvest figures to estimate the total amounts of nutrients removed from the effluent in the biomass. The figures obtained can be compared with other published data. Gifford (1980) gives a figure for nitrogen removal which can be calculated to 1.6 kg N ha^{-1} day^{-1} for New Zealand conditions and Golueke (1981) gives 22 kg N ha^{-1} day for Eichhornia. The present figure of 6.5 kg N ha^{-1} day^{-1} for **Myriophyllum** and 4.6 kg N ha^{-1} day^{-1} for **Lemna** indicate significant nitrogen removal. Since the phosphorus content of biomass is substantially less than the nitrogen content a lower rate of removal of phosphorus is to be expected.

Extrapolating further from these data on nitrogen and phosphorus removal by harvest it possible to calculate the expected depletion of these elements from the pond water caused by plant growth. These calculated figures are shown in section c above.

Ideally these figures would relate well to the actual data (Fig 2) on differences in nutrient levels of the water entering and the water leaving the ponds. In fact the ecosystem of the ponds removed more nitrogen than could be accounted for in the harvested biomass. Nitrogen reduction in the control ponds can be explained by the growth of micro green algae and zooplankton which were continually lost in the overflow.

The movement of nitrogen within the ponds may have been affected by a number of factors. The pattern of water circulation within each pond was not known and the presence of the plants may well have affected this circulation. The dense stem and root systems of **Myriophyllum**, occupying the upper 20 cm of the water column, probably restricted the movement of water in the upper part of the profile. In contrast, in the 'control' ponds, with the surface exposed to the wind, circulation would be much greater. Oxygen and temperature profiles were taken in each pond on a number of occasions.

While 'control' ponds, containing phytoplankton maintained high levels of dissolved oxygen, ponds with dense stands of **Myriophyllum** or **Lemna** became deoxygenated, indicating limited circulation.

Since the type of plant present in the ponds greatly affected the temperature and oxygen profile the mobility of nitrogen would be expected to be different in different ponds. In anaerobic conditions nitrogen may be removed from the system by denitrification, while in aerobic ponds more rapid conversion of ammonia to nitrate can be expected.

Although the removal of plant biomass unarguably removes nutrients from effluent the level remaining in the effluent is still high in relation to the objectives of improving water quality. Further reduction in nutrient levels may be achieved by increasing the water residence time in the ponds. However, if this is done, a limiting point must eventually be reached after which further reduction in the availability of nutrients to plants inhibits their growth and so becomes self defeating. Experiments are presently underway to measure the effect of diluted effluent on the growth response of **Myriophyllum** and lemna. Further work will be carried out using Typha when plants are better established in the experimental ponds.

CONCLUSION

It has been shown that the nitrogen level of secondary effluent can be reduced by the cultivation of Lemna and Myriophyllum. Further investigations are warranted to include other species of plants, to optimize harvesting techniques and to find economic uses for the biomass.

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