Conservation

A FRESH WATER WASTE RECYCLING-AQUACULTURE SYSTEM

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ABSTRACT: *A system is described in which the nutrients in treated wastewater are removed by passing the effluent through a culture of aquatic weeds. The incremental growth of the weeds is fed to a culture of grass carp and fresh water shrimp* (Macrobrachium). *Projections are made for large-scale nutrient removal efficiencies and the accompanying aquaculture yields in the commercial application of such a system.**

EUTROPHICATION is one of Florida's most pressing environmental problems. Its fresh water lakes, rivers, and canals are being enriched from domestic, agricultural, livestock, food processing, and other kinds of organic wastes. Such waters often become choked with vegetation which makes them unsightly, impassible, and almost useless or valueless for commercial or recreational purposes. The pattern can be reversed only by the removal of plant nutrients (nitrogen, phosphorus) from these wastewaters prior to their discharge or drainage into natural receiving waters. The existing physical and/or chemical methods of nitrogen and phosphorus removal are costly, both in terms of monetary considerations and energy demand. They often are not very effective (Antonucci and Schaunburg, 1975). Biological nutrient removal systems, although not well developed, give promise not only of being more economical to operate but of producing potential valuable crops of plants or animals as a by-product (Ryther et al., 1972). A waste recycling-marine aquaculture system has been developed, tested, and evaluated on a pilot scale by the senior author at Woods Hole, Mass. (Ryther, 1977). The principles of that system would appear to be applicable to fresh water environments, where the need for a satisfactory solution is more critical than in the marine environment.

A joint project was initiated in 1975 with the Florida Game and Fresh Water Fish Commission to develop a fresh water waste recycling-aquaculture system at the Harbor Branch Foundation aquaculture facility. The plan was to pass secondary sewage effluent through ponds containing macroscopic fresh water algae or higher plants (i.e., "aquatic weeds") at concentrations and rates that would enable the vegetation to remove the inorganic nutrients from the effluent. The effluent could then be discharged to the receiving waters and not cause eutrophication.

Nutrient removal by the aquatic vegetation is not, however, the complete answer, since it would not differ from the eutrophication of natural waters. The new growth of the aquatic plants must be removed. One possibility is to use an aquaculture system, feeding the plants to an appropriate aquatic herbivore.

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The grass carp or white amur (*Ctenopharyngodon idella*) feeds upon macroscopic aquatic vegetation. An exotic species, its general introduction into Florida is restricted. Any research with grass carp in the State must be performed under the supervision of the Florida Game and Fresh Water Fish Commission. The grass carp is a voracious feeder upon a wide variety of aquatic plants (Michewica, Sutton, and Blackburn, 1972). When it was introduced in reservoirs and impoundments in Arkansas, it was highly efficient in removing and controlling vegetation (Bailey, 1975). It should therefore be suited for a fresh water waste-recycling-aquaculture system as proposed above. One disadvantage is that it does not now have market value as human food in the United States and might be useful only as a source of fish meal. It could be argued that its role in a waste recycling system to prevent or reverse eutrophication of Florida's waters is important enough that additional value of the product of the system is inconsequential or simply a bonus. However, in view of the rising price of fish meal, its value for that purpose could also be significant. Also, the species may not always be unpopular as a food fish.

The experiments were performed in two 11 × 4 × 0.6 m (25,000 l) PVC-lined earthen ponds, which were filled with fresh (well) water. One pond was inoculated with the fresh water macroscopic alga *Chara* sp. Undiluted secondary effluent from the Harbor Branch Foundation's activated sludge waste treatment plant was passed through the pond at a rate of 500 l/day, providing a turnover rate of 2% of the pond vol per da.

The experiment was initiated on March 3, 1975 and was terminated on August 29, 1975. During that period, the concentrations of nitrogen, measured as ammonium, nitrite, and nitrate, and of phosphate-phosphorus were measured in the pond influent (i.e., the secondary sewage effluent from the treatment plant) and in the pond effluent. Ammonia was measured by the method of Solorzano (1969), nitrite and nitrate by the method of Wood et al. (1967), and phosphate by the method of Murphy and Riley (1962).

The mean concentrations of total inorganic nitrogen (ammonia, nitrite, and nitrate) and phosphorus entering the pond were 2889 μmoles/l (40 ppm) and 187 μmoles/l (6.2 ppm) respectively. The mean concentrations of these nutrients in the water leaving the pond were 498 μmoles N/l (6.9 ppm) and 25 μmoles P/l (0.8 ppm) giving an efficiency of nitrogen and phosphorus removal of 83 and 87% respectively (Table 1). The ratio, by atoms, of nitrogen to phosphorus in the wastewater entering the pond was 15:1, very close to that present in most algae, which accounts for the similarity in the removal efficiency of both nitrogen and phosphorus. In purely domestic sewage effluent (in contrast to that of the laboratory complex at Harbor Branch Foundation), the N:P ratio is typically 5-7:1 by atoms due to the phosphorus contributed by household detergents (Ferguson, 1968). Aquatic plants can remove the nitrogen from domestic sewage effluent but they will leave one-third to one-half of the phosphorus. Since nitrogen is limiting, the lack of N is an effective deterrent to further plant growth in the environment (Ryther and Dunstan, 1971, Goldman et al., 1974).

Based on the results of the preliminary experiment described above, an area

TABLE 1. Nutrient removal efficiency in *Chara* pond.

	$NH_4^+ + NO_2^- - NO_3 - N$ (μmoles/liter)	$PO_4^{\equiv}$-P
Influent	2889	187
Effluent	498	25
% removal	83	87

of 60 acres of *Chara* pond culture would be needed to perform tertiary sewage treatment (nutrient removal) at the efficiencies observed (83-89%) on a wastewater loading of one million gallons per da (1 MGD), the avg output of a community of 10,000 people. It is, however, unrealistic to extrapolate the results of one small preliminary experiment to fullscale operation. Choice of the pond size, sewage flow rates, and other operating parameters was purely empirical and did not necessarily reflect the optimal performance efficiencies.

In an adjacent pond of the same size and construction as the *Chara* pond, 28 juvenile (20 g) grass carp (Fig. 1) were stocked on April 8, 1975. These fish were fed the harvest (growth) of the *Chara* at a rate of 1-2 kg *Chara* per da. One of the difficulties encountered in the experiment was that the *Chara* could not be routinely removed from the pond and weighed. Handling apparently damages the fragile alga and seriously depresses its growth for a period of one or more wk. Thus, growth of *Chara* and removal of incremental growth for feeding to the grass carp had to be estimated.

During a period of 161 da (4/8-9/3), the grass carp were fed 170 kg of *Chara* and increased in size from 21 to 180 gm/fish, a total biomass increase of 4.5 kg, a conversion efficiency of only 2.6%. The latter is not impressive since efficiencies of 10-20% (wet wt food:wet wt fish) are not uncommon in fish culture, but it may not be unusual in a voracious herbivore such as grass carp that consumes vast quantities of vegetation. A large fraction of the food eaten is rejected as undigested organic wastes (Stanley, 1974). This phenomenon is, in fact, the basis for the highly successful polyculture practice in mainland China, in which organic wastes from the grass carp serve, directly or indirectly, as food for several other fish species grown together in the same pond (Bardach, Ryther, and McLarney, 1972).

In cognizance of the potential food value of the wastes from the inefficient grass carp, approximately 75 juvenile fresh water shrimp (*Macrobrachium rosenbergi*) were stocked in the grass carp pond on April 23, 1975. In the ensuing 146 days (4/23-9/15) these crustacea grew from 1.7 gm to 19.7 gm/shrimp. At the end of the test period 66 individuals were recovered for a survival of 88% and a biomass increase of 1.2 kg. By that time, the shrimp had reached adult, marketable, size and sexual maturity, gravid females being noted in the population.

The combined yield of 5.0 kg of grass carp and 1.3 kg of *Macrobrachium* per 33 m² pond is equivalent to a production of 1,700 lbs/acre for 6 mo or 1.7 tons/

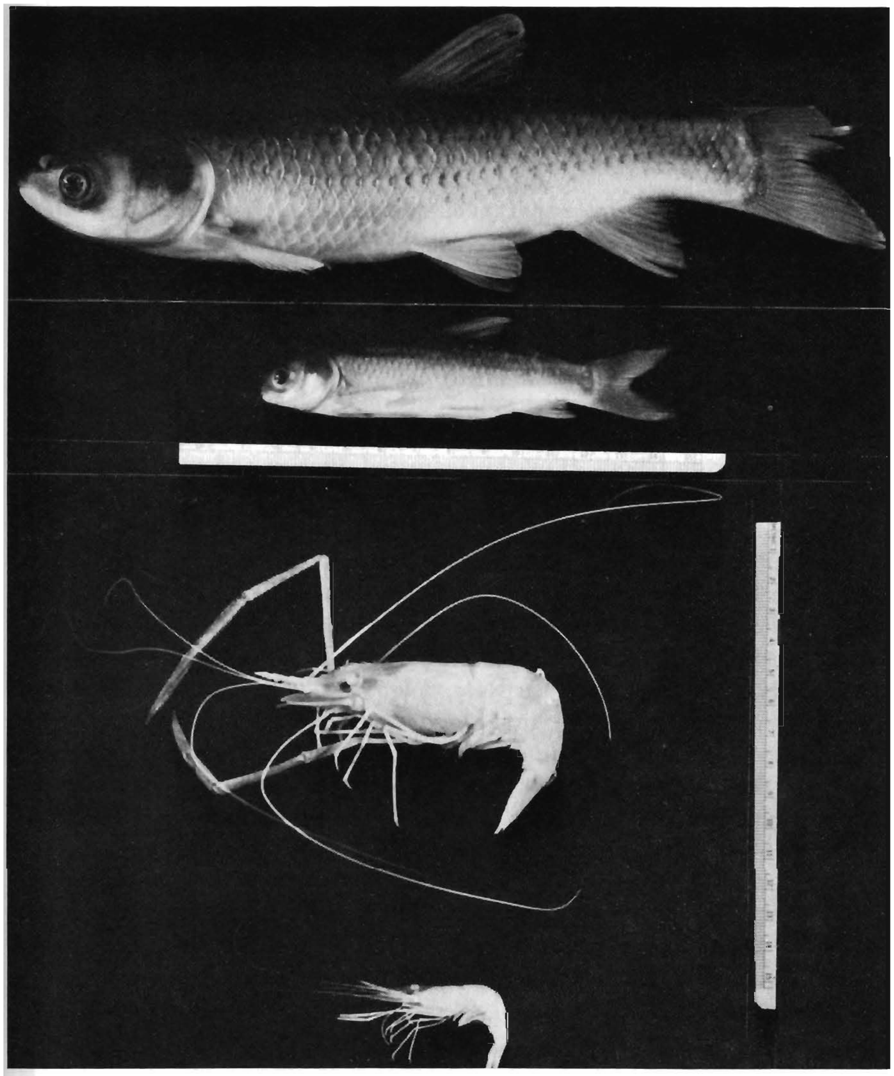

Fig. 1. Growth of grass carp (*Ctenopharyngodon idella*) in 161 days and freshwater shrimp (*Macrobrachium rosenbergi*) in 146 days in pond fed *Chara* harvest.

acre/yr (assuming year-round production at essentially the same rate), an extremely high yield for an aquaculture system based on natural food. More properly, however, the area required for the food production (the *Chara* pond) should also be included, making the production equivalent to 1,700 lbs/acre/yr, which is still an impressive figure.

Problems encountered with the fresh water system include the difficulty in maintaining and handling the alga *Chara* without retarding its growth. The plant has a natural tendency to fragment into small pieces that do not survive or grow in the culture. Since the grass carp apparently feed and grow equally well on a wide variety of plant species it is probable that one or more other species of algae or higher plants would be more successful in the culture system. A new experiment has recently been initiated using the common water weed *Egeria (Elodea) densa*, a plant which appears to be somewhat more hardy and more easily handled than *Chara* and is equally well accepted by the grass carp (Stanley, 1974a, b).

Another problem in our experiment was the development of dense phytoplankton blooms in the *Chara* culture. Discharge of effluent from the pond containing a dense population of phytoplankton would violate suspended solid standards and defeat the objectives of tertiary treatment, as mentioned above. In addition, the phytoplankton shaded and may have reduced the growth of the *Chara*. In the current experiment involving *Egeria*, this problem has been corrected by diluting the sewage effluent 50:1 with well water so as to provide a pond turnover rate of 1 vol per da, a rate of exchange too rapid to permit the establishment of a phytoplankton bloom. How this increased dilution and turnover rate will affect the efficiency of nutrient removal and the economics of the operation remain to be demonstrated.

Another approach to the same problem, not yet investigated, is the use of a filter-feeding herbivore in the plant culture to suppress the growth of phytoplankton. Possible candidates for this role are fresh water clams or mussels, the water flea (*Daphnia*) or other microcrustacea, or a phytoplankton-feeding species of finfish such as the silver carp (*Hypophthalmichthys molitrix*). Introduction of the latter, an exotic species, into Florida would present a problem.

The grass carp-*Macrobrachium* pond did not have any exchange of water during the 6-mo experiment. Aeration was provided to insure an adequate supply of dissolved oxygen, and nutrients were monitored to make sure that dangerous levels of ammonia did not accumulate. Surprisingly, the nutrient concentration did not increase in the pond for reasons that are not understood. However, a dense load of light brown particulate matter did accumulate in suspension in the pond. The origin and nature of the suspended matter, presumably related in some way to the excreted or defecated wastes of the animals, is now being investigated.

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LITERATURE CITED

Antonucci, D. C., and F. D. Schaunburg. 1975. Environmental effects of advanced wastewater treatment at South Lake Tahoe. J. Water Poll. Cont. Fed. 47:2694-2701.

Bailey, W. M. 1975. Operational experience with the white amur in weed control programs. Proc. Symp. Water Quality Management Through Biological Control, Gainesville, Florida, January 29-31, 1975. U. Florida Dept. Eng. Sci. Rept. No. Env. 07-75-1:75-84.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture. Wiley-Intersci. Publ. New York.

Ferguson, F. A. 1968. A nonmyopic approach to the problem of excess algal growths. Environ. Sci. Technol. 2:188-193.

Goldman, J. C., K. R. Tenore, and H. I. Stanley. 1974. Inorganic nitrogen removal in a combined tertiary treatment-marine aquaculture system. II. Algal bioassays. Water Res. 8:55-59.

MICHEWICA, J. E., D. L. SUTTON, AND R. D. BLACKBURN. 1972. The white amur for aquatic weed control. Weed Sci. 20:106-110.

MURPHY, J., AND J. P. RILEY. 1962. A modified single solution method for the determination of phosphate in natural waters. Anal. Chim. Acta 26:31-36.

RYTHER, J. H. 1977. Preliminary results with a pilot-plant waste recycling-marine aquaculture system. Pp. 89-132. *In* D'ITRI, Ed. Wastewater Renovation and Reuse. Marcel Dekker, Inc. New York.

———, AND W. M. DUNSTAN. 1971. Nitrogen, phosphorus, and eutrophication in the coastal marine environment. Sci. 171:1008-1013.

———, ———, K. R. TENORE, AND J. E. HUGUENIN. 1972. Controlled eutrophication. Increasing food production from the sea by recycling human wastes. BioScience 22:144-152.

SOLORZANO, L. 1969. Determination of ammonia in natural waters by the phenolhypochlorite method. Limnol. Oceanogr. 14:799-801.

STANLEY, J. G. 1974a. Energy balance of white amur fed *Egeria*. Hyacinth Contr. J. 12:62-66.

———. 1974b. Nitrogen and phosphorus balance of grass carp, *Ctenopharyngodon idella* fed *Elodea, Egeria densa*. Trans. Amer. Fish. Soc. 103:587-592.

WOOD, E. D., F. A. J. ARMSTRONG, AND F. A. RICHARDS. 1967. Determination of nitrate in seawater by cadmium-copper reduction to nitrite. J. Mar. Biol. Assn. U.K. 47:23-31.

Florida Sci. 40(2):130-135. 1977.