ECOLOGICAL CONDITIONS FOR SUCCESSFUL CULTURE OF FISH IN SEWAGE POND EFFLUENTS

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Abstract

The principal parameters affecting survival and growth of fish in sewage effluents are temperature, pH and dissolved oxygen content. Measurement of these parameters over a period of one year on the oxidation pond at Blenheim, New Zealand showed considerable fluctuation, with dissolved oxygen in particular falling below tolerance levels for most fish species.

When a separate experimental pond was constructed in which a longer retention time of sewage water and slower rate of admission of raw sewage was allowed, conditions became suitable for survival and growth of *Carassius auratus*, *Retropinna retropinna* and *Salmo gairdneri*.

The ecological conditions over a period of nine months are compared for the main oxidation pond and the experimental pond and some conclusions drawn for the successful ecological management of sewage effluents to permit fish culture.

1 INTRODUCTION

The ponding of sewage as a method of waste treatment is now regarded as the most economical in many countries such as the United States, India, Germany and New Zealand (Sickle, 1970; Malone, 1969; Jhingran, 1972; Hicks, 1958; Ferrier and Ralston, 1970). In New Zealand, since the introduction of the Waters Pollution Act in 1953, more than 40 communities and institutions have oxidation ponds (New Zealand Department of Health, Annual Report, 1968). The reasons for the general acceptance of oxidation ponds for waste treatment are low capital costs, insignificant operating costs and the production of effluents of acceptable sanitary quality.

The ponding of sewage in oxidation ponds is designed to convert organic nitrogen, phosphate, sulphur and other plant and animal nutrients into inorganic salts of these elements and to reduce faecal coliform bacteria in the treated sewage to a level accepted by local health authorities. The chemical process involved is one of biological oxidation and success of the system requires maintenance of an aerobic regime in the pond.

In the investigation of the hydrobiology of a biological oxidation pond in Blenheim, New Zealand, it was observed that although bacterial risk may be reduced significantly by treatment of sewage in the pond, the effluent is still eutrophic in its effect and causes weed problems upon release into the Opawa river. Serious eutrophication may also cause nuisance algal blooms and oxygen depletion in that river. In order to prevent the development of these conditions in the receiving water it is necessary to crop the excessive organic production and nutrients in the oxidation pond. A number of methods may be employed: (1) tertiary treatment of the effluent to remove phosphate, nitrate, carbonate and other nutrients; (2) harvest of algae in the pond for animal feed; (3) fish culture to crop excessive organic production. The first method is technically difficult and expensive; the second is feasible only when problems of harvesting techniques and consumer preference can be solved. The third method is probably the least expensive.

Fish culture in oxidation ponds has been practised in India with appreciable fish production (Jhingran, 1972). In the oxidation ponds attached to the Bhilai township in India, primary ponds and secondary ponds are used profitably for the production of air-breathing fish and carps respectively (Chatterjee et al, 1967). Fisheries which use sewage water as fertilizer are quite common in West Bengal in India (Jhingran, 1972). In Malaysia fish culture ponds of considerable size (80 m x 40 m x 1.5 m) receive the domestic sewage of man, pigs and cows. Fish, usually carps, use all the available food in the pond and may reach commercial size within a year (Teoh, 1969). The Munich sewage scheme uses a fish pond to salvage some of the waste material in sewage. Sewage water is sprayed into the pond in which the sewage is diluted 3 or 4 to 1 with fresh water. A good rate of fish production - 500 lb per acre (550 kg/ha) - is reported (Hickling, 1971). In New Zealand fish culture in oxidation ponds has never been practised. However, eels and carps of good size have been frequently found in Pukekohe Borough oxidation pond and Auckland sewage oxidation pond (Beca and Airey, 1967).

The feasibility of using fish culture to crop the organic production in the Blenheim oxidation pond was therefore investigated. Experiments were carried out in an experimental pond which was fed regularly with oxidation pond water with a dilution of approximately 1 to 5. Various types of local fish such as goldfish, *Carassius auratus*, common smelt, *Retropinna retropinna*, rainbow trout, *Salmo gairdneri*, etc. were reared in the experimental pond.

The ecological parameters investigated are air and water temperature, secchi disk transparency, dissolved oxygen, pH, phosphate, biological oxygen demand, phytoplankton, zooplankton and bacterial populations. At the same time the hydrobiological study in the oxidation pond, which had been carried out for 8 months prior to the fish culture study, was continued for comparison with the hydrobiological parameters of the experimental pond.

This paper discusses the major ecological parameters that affect fish growth in the experimental and oxidation ponds. Fish growth in the experimental pond is dealt with in a separate paper.

2 METHODS

2.1 Field

The field work was conducted from 29 March 1971 to 3 November 1972. Samples were taken at monthly intervals from inlet, outlet, middle of the oxidation pond and later from the experimental pond when fish culture experiment was started. A modified Ruttner water sample which has a capacity of 750 ml was employed.

Potentiometric methods for measuring water temperature, dissolved oxygen and pH as mentioned in Golterman (1969) were followed.

Samples for phytoplankton analysis were fixed with 4 percent formalin immediately after collection (Welch, 1948). Zooplankton were sampled with a Clark-Bumpus plankton sampler equipped with a conical nylon plankton net of 200 mμ pore size. The cod end of the net was tied to a 250 ml milk bottle, the contents of which was poured into a preserving jar. Formol-alcohol (40 percent commercial Formalin + 70 percent ethyl alcohol) was used as a preservative.

2.2 Laboratory

The haemocytometer method for blood cell count (Armstrong, 1969) was modified for use in phytoplankton cell count. A volume of the fixed phytoplankton sample was concentrated by a centrifugation at 400 RPM for 15 minutes. The supernatent was pipetted off until only 1 - 2 ml of sample was left at the bottom of the centrifuge tube. The phytoplankton pellet was resuspended in the remaining supernatent and a drop of the suspension transfered to the haemocytometer chamber for counting.

Zooplankton biomass was estimated by the settling method according to Welch (1948).

3 RESULTS

Data on ecological parameters are present in figures 1 and 2. Data from the oxidation pond are based on samples taken from the middle of the pond where mixing was considered to be uniform and ecological conditions were intermediate between the inflow and outflow sites. As the differences in vertical distribution of measured parameters were negligible only the results of surface samples are treated here.

3.1 Phytoplankton Population of the Oxidation Pond

As shown in Fig. 1 (A), the phytoplankton population fluctuated widely in 1971 and exibited very clear-cut maxima and minima. The fluctuations were not as great in 1972 and the population tended to stabilize at a certain level after April 1972. The difference between the maxima and minima in 1971 was as great as 1 million cells per ml. The pattern of fluctuations in 1971 did not seem to follow seasonal changes. Maxima occurred in mid winter of 1971 when temperature was low and light period was short whereas in 1972 the phytoplankton population roughly followed seasonal evolution with maxima in mid summer; minima, however, took place in autumn instead of winter. A seasonal succession of phytoplankton was observed throughout the study period. Each genus attained a high level at different times of the year as shown by the following table:

Table 1 Seasonal succession of phytoplankton in Blenheim oxidation pond

Year	Month	Dominant phytoplankton	Sub-dominant phytoplankton
1971	29 March	Closterium	Nil
	29 April	Closterium	Nil
	31 May	Chlorella	Chodatella
	30 June	Chlorella	Chodatella
	29 July	Chlorella	Chodatella, Scenedesmus
	30 August	Chlorella	Scenedesmus
	27 September	Chlorella	Scenedesmus, Micractinium
	2 November	Closterium	Navicula
	1 December	Euglena	Chlorella, Closterium

Year	Month	Dominant phytoplankton	Sub-dominant phytoplankton
1972	5 January	Euglena	Chlorella Navicula
	26 January	Chlorella	Scenedesmus Chodatella Micractinium
	29 February	Chlorella	Micractinium Scenedesmus Chodatella
	22 March	Chlorella	Oocystis Scenedesmus Chodatella
	26 April	Ankistrodesmus	Chlorella Chlorococcum
	30 May	Chlorella	Schroederia Chodatella
	3 June	Schroederia	Chlorella Micractinium
	31 July	Chlorella	Ankistrodesmus Chlorococcum
	31 August	Chlorella	Schroederia Ankistrodesmus
	4 October	Chlorella	Ankistrodesmus Closterium
	3 November	Closterium	Ankistrodesmus Chlorella

3.2 Phytoplankton Population of the Experimental Pond

Comparatively, the phytoplankton population of the experimental pond was much lower than that of the oxidation pond between November 1971 and November 1972. Maxima were observed in August 1972 (late summer). The seasonal succession of the phytoplankton population in the experimental pond was as follows:

Table 2 Seasonal succession of phytoplankton in experimental pond

Year	Month	Dominant phytoplankton	Sub-dominant phytoplankton
1971	November	Navicula	Nil
	December	Ankistrodesmus	Navicula
1972	5 January	Schroederia	Nil
	26 January	Schroederia	Nil
	29 February	Schroederia	Navicula
	22 March	Navicula	Chlorella
	26 April	Navicula	Chlorella
	30 May	Navicula	Ankistrodesmus
	3 June	Chlorella	Micractinium Schroederia
	31 July	Navicula	Schroederia Chlamydomonas
	31 August	Schroederia	Chlorella Scenedesmus
	4 October	Chlorella	Ankistrodesmus Chlorococcum
	3 November	Schroederia	Nil

3.3 Zooplankton Population

Zooplankton populations in the oxidation pond fluctuated greatly between 1971 and 1972 (Fig.1). No appreciable zooplankton were present in the pond between April and August 1971. In 1972 a bloom of *Daphnia* occurred on 25 April and a bloom of *Bosmina* was first observed on 3 November. Two blooms of rotifers also occurred in September 1971 and 1972 respectively.

In the experimental pond the zooplankton population (Fig.2) (mainly *Daphnia*) was generally higher than that in the oxidation pond. Copepods dominated on 31 July and 31 August, 1972.

3.4 Water Temperature

Water temperature in the oxidation pond fluctuated seasonally with a range between 8.8°C and 21.0°C in 1971 and between 7.0°C and 23.5°C in 1972 (the winter in 1972 was one of the coldest in recent years).

Water temperatures in the experimental pond also followed seasonal fluctuations with a range of temperature between 5.0°C and 22.0°C.

3.5 Transparency

Transparency values in the oxidation pond varied greatly in 1971 but remained rather constant in 1972. Fluctuations correlated very well with the changes in phytoplankton density. Generally, low transparency values were associated with dense populations of *Daphnia*. The transparency values also showed that only the upper part of the pond (0-40 cm below surface) was penetrated by light in most of the months of the year. This accounted for the lack of rooted vegetation in the oxidation pond.

Transparency values in the experimental pond remained quite constant between 5 January and 30 May but dropped to below 15 cm between 3 July and 31 August when there was an increase in the phytoplankton population.

3.6 Dissolved Oxygen

Wide variations in dissolved oxygen content were noted in the oxidation pond between 1971 and 1972. There were several occasions (29 April, 31 May, 1971 and 22 March, 1972) when the pond was nearly anaerobic.

Dissolved oxygen in the experimental pond varied between 4 and 14.0 ppm. Anaerobic conditions were not noted during several diurnal observations; this strongly favours the culture of fish.

3.7 pH

Very significant differences in pH were noted between 1971 and 1972 in the main oxidation pond. pH values in 1971 were above 7 while in 1972 there were three occasions (22 March, 31 August and 4 October) when the pH of the pond water was below 7. pH values higher than 9 (30 August, 1971 and 26 January, 1972) were observed when phytoplankton was abundant and zooplankton was negligible.

The pH in the experimental pond fluctuated between 7 and 8.8. No acidic condition was detected. Again, high pH values were correlated with high phytoplankton populations.

4 DISCUSSION

Suitable regimes of water temperature, dissolved oxygen and pH, an adequate supply of food and absence of pathogenic bacteria are essential to good fish growth. In investigating bacterial contamination of water in the experimental pond it was observed that faecal coliform bacteria and faecal streptococcus, which were introduced into the pond during monthly filling, were reduced to a very insignificant level (less than 10 colonies per 100 ml sample in most analyses) after a retention period of 3-4 weeks. No pathogenic bacteria were detected when water samples from the pond were plated out on selective medium such as MacConkey's agar.

4.1 Water Temperature

Water temperature has long been known as a limiting factor in the growth of fish since as in other poikilotherms, body temperature is dependent on ambient temperature. Lavrovsky (1967) reported the optimum range of temperature for the growth of the rainbow trout to be between 16-18°C. However, he noted that this species may continue to feed at temperatures up to 24°C and can tolerate short rises of temperature of up to 28°C. Carp stop feeding at about 10°C and become torpid at about 5°C, but they flourish and grow rapidly in tropical waters at 28-32°C (Hickling, 1971). Rainbow trout were observed to stop feeding at about 8°C (lower limit).

In the present investigation the temperature regime in the experimental pond (Fig.2) (5 - 22°C) was suitable for the growth of rainbow trout as they will continue to feed within this range except for July-August. This temperature regime was also suitable for the growth of goldfish, Carassius auratus during 9 months of the year. A winter growth check was detected in goldfish kept in cages in the experimental pond, which agrees with earlier observations on carps (Hickling, 1971). The optimum range of temperature for common smelt, Retropinna retropinna, is unknown; however, as they are temperate water fish they should be able to live and grow within the range of temperature in the experimental pond. This is confirmed by our investigation on the growth rate of this species (see Slack and Teoh, 1972).

4.2 Dissolved Oxygen

Oxygen content of water may sometimes be a more important factor than either temperature or composition (Hickling, 1971). Carp acclimated to cold water may die of asphyxiation under thick ice cover in wintering ponds. Nicolskii (1963) also emphasized the losses to the fish industry due to oxygen depletion under thick ice cover

Lavrovsky (1967) observed that rainbow trout need 7-8.5 ppm of dissolved oxygen for optimum growth. However, short term decreases oxygen content down to 3.5-4 ppm are tolerated. Wunder (1936) classified carp, tench and crucian carp as fish which can survive oxygen saturation as low as 0.7 ppm.

The oxygen regime in the experimental pond ranged between 4 and 14 ppm which is good for the survival of goldfish, rainbow trout and possibly common smelt. The oxygen level at the bottom of the pond fell below 4 ppm on only two occasions; even then the concentration in surface waters was well over 4 ppm.

The oxygen regime in the oxidation pond, however, was not ideal for fish survival. In 1971, as shown in Fig.1, there were two occasions when the entire water column became anaerobic. Pond water was anaerobic on 22 March 1972 and on 31 July the oxygen level of the pond was below 4 ppm. Abundant bloom of phytoplankton may cause anaerobic condition in the pond especially during the night. Two of seven diurnal studies during phytoplankton blooms showed that oxygen concentration fell from 5 ppm during the day to 0.4 ppm at night (29 February 1972) and from 4.2 ppm to 0.6 ppm (26 April 1972). The oxygen regime in the oxidation pond is, therefore, not suitable for fish culture unless aerobic conditions can be maintained.

4.3 pH

Many experimental studies suggest that alkaline or neutral water is much more suitable for fish culture (Swingle, 1957; Depasse, 1956; Hickling, 1971). The disadvantages of having acid water are many: diminished food intake by fish, reduction in the population of other aquatic organisms which serve as food for fish, and loss of carbon dioxide which is essential for photosynthesis.

The pH of the experimental pond was ranged between 7.4 and 8.8. The pH of oxidation pond water was alkaline in 1971 but in 1972 there were three occasions when pond water showed an acidic reaction (Fig.1). This could probably be attributed to the higher rate of decomposition of organic matter which entered the pond at an uncontrolled rate. Maintenance of water pH at values above 7 through control of sewage input is therefore critical for successful fish culture

4.4 Food

The three species of fish in the experimental pond were all zooplankton feeders. However, as shown by laboratory experiment, goldfish can survive with a diet of phytoplankton although no growth is observed. The Daphnia population in the pond between November, 1971 and November, 1972 however, provided an abundant supply of food for the fish. Hence, a short food chain of Phytoplankton-zooplankton-fish had been established in the pond.

The zooplankton population of the oxidation pond. on the other hand, fluctuated greatly between 1971 and 1972. The zooplankton population was negligible for 5 months in 1971 and for 4 months in 1972. Furthermore, when zooplankton were present, the biomass, on ten out of twelve occasions, was much lower than that of the experimental pond.

It appears therefore that the three species of fish reared in the experimental pond would probably not be suitable for rearing in the oxidation pond. Since the phytoplankton population of the latter pond remained high during most of the year, herbivorous fish could probably be reared successfully.

5 CONCLUSIONS

The successful culture of three species of fish in the experimental pond which received sewage water at monthly intervals with a dilution of 1 to 5 may be attributed principally to:

(1) a suitable level of water temperature regime which ranged from 5^{o} - 22^{o}C

(2) an optimum range of dissolved oxygen content which ranged from 4 - 14 ppm

(3) a very suitable alkaline pH, and

(4) abundant supply of zooplankton which served as food for the fish

With the exception of the first, conditions mentioned above were not met in the Blenheim oxidation pond during the corresponding test period. If similar species had been reared in this pond, the fish would probably have died from asphyxiation, lack of food supply or lack of food intake. Even if the fish survived, growth would probably have been very poor.

The primary objective of this investigation, i.e., cropping the organic production of the oxidation pond, can therefore be achieved by directing the sewage effluents of the pond to a series of fish ponds built in its vicinity after appropriate dilution. It could also be achieved by culturing fish in the oxidation pond itself if conditions similar to those in the experimental pond could be maintained.

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