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Sediment Oxygen Consumption in Freshwater Fish Pond Ecosystems

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ABSTRACT

The sediment oxygen consumption rates of fish ponds under different management practices with reference to organic matter and biotic components as also primary production rates in the overlying water column are presented. The mean sediment oxygen consumption rates in natural ponds and those under extensive, semi-intensive and intensive management practices were 2.54, 3.02, 2.88 and 2.69 g O_2 m^{-2} d^{-1}, comprising 44.55, 58.95, 40.54 and 37.35% of the gross primary production respectively. The chemical oxygen demand was 51.28, 58.62, 66.68 and 64.54% of total oxygen consumption respectively, in the four systems, and the biotic oxygen consumption accounted for the remaining fractions.

INTRODUCTION

The sediment layers in an aquatic ecosystem virtually regulate the productivity of the overlying waters for they can be nutrient sources or sinks, depending on the pH, Eh, organic carbon content, bacterial and other biotic activities, etc. The surface sediment oxygen consumption is an important indicator of the rate of oxidation processes as well as biological activity (Edwards and Rolley 1965, Pamatmat 1971, Granell 1978). This aspect has received much attention in the temperate waters for assessing the amount of oxygen consumed by the sediment for stabilisation of organic matter, thus exerting a demand on the oxygen budget of the systems (Hargrave 1972, Granell 1979). In view of its significance in the community metabolism (Olah et al. 1987, Saha et al. 1991), the sediment oxygen consumption has been investigated by a rapid survey of ponds under different management practices (natural, extensive, semi-intensive and intensive culture). The paper discusses the results in relation to primary production and other chemical and biotic conditions of the pond ecosystems.

MATERIAL AND METHODS

Twentyfour non-drainable perennial fish ponds in and around the Central Institute of Freshwater Aquaculture fish farm (20° 11' 6" - 20° 11' 45" N Latitude, 85° 50' 52" - 85° 51' 35" E Longitude) were selected for this study. The study was made during July-November 1991 and sampling was done during 0800-1700 hr. The ponds were categorised into natural (6 village ponds with no structures or swamps under reclamation), extensive (3), semi-intensive (12) and intensive (3) systems, based on the prevalent management measures (Table 1).

Table 1. Management regime of fish ponds

Parameter	Natural (6)	Extensive (3)	Semi-intensive (12)	Intensive (3)
Area, ha	0.2 - 2.0	1.8 - 2.2	0.02 - 0.40	0.08
Water depth, m	2.0 - 4.0	2.5 - 4.0	1.0 - 2.5	1.5 - 2.0
Water source	Spring & surface runoff	Seepage & canal	Seepage & canal	Seepage & canal
Stocking density (no. of carp fingerlings ha^{-1})	1000-2000	2000-4000	6000-10000	15000-25000
Organic manuring (t cowdung ha^{-1} yr^{-1})		4	10	20

Standard methods were employed for analysing water quality parameters like dissolved oxygen, pH, ammonia-nitrogen, nitrate-nitrogen, phosphate-phosphorus, net plankton collected through bolting silk cloth (No. 25, mesh size 64 μm), benthic fauna, sediment organic carbon (APHA-AWWA-WPCF 1981), heterotrophic bacterial counts (Collins and Lyne 1985) and dehydrogenase activity (Casida et al. 1964). Gross primary production, community respiration and production efficiencies were calculated, using the diel oxygen curve data with three measurements (McConnel 1962, Natarajan and Pathak 1985).

The oxygen uptake by the sediment layers from the overlying water column in an undisturbed core is considered to be a reliable index of the total sediment oxygen consumption comprising chemical and biotic oxygen demand (James 1974, Edberg 1976). Accordingly, undisturbed sediment cores were collected in four PVC tubes (40 cm, 3 cm dia) with the overlying water being intact. Set 1 with replicate tubes was kept for measuring the total oxygen consumption in which the initial oxygen concentration in the water medium was measured using an oxygen meter (WTW, OXI-191) before plugging the tube. In the second set, saturated solution of mercuric chloride was added to a final concentration of 3 mg l^{-1} and oxygen values measured. The tubes were incubated in dark for two hours, whereafter the dissolved oxygen levels were measured. The differences between the initial and final oxygen levels gave a measure of the total oxygen uptake in the first set and chemical oxygen demand in the second. Further the difference in the values between the two sets gave the biotic oxygen demand. The volume of water in the different tubes and diameter of the tubes were considered for computing the oxygen consumption rates as g O_2 m^{-2} d^{-1}. The data were subjected to suitable statistical analyses.

RESULTS

Hydrobiological Conditions

The salient features of different categories of ponds are presented in Table 1. 1 Though increasing organic loading was the primary feature of intensification of culture practices, organic accumulations were high in the natural system due to allochthonous organic input in terms of human and cattle washings and leaf litter fall over many years. It may be mentioned that the organic enrichment of the ponds was basically a function of age rather than area or water depths.

The atmospheric and water temperatures during the study period were in the range of 26.7-33.8 °C and 28.6-30.2 °C respectively. With no significant difference between the ponds, the range of values of water quality parameters were: dissolved oxygen 3.3-6.2 mg l^{-1}, pH 7.55-7.90, total alkalinity 82.33-100 mg $CaCO_3$ l^{-1}, NH_4-N 0.03-0.62 mg l^{-1}, NO_3-N 0.11-0.24 mg l^{-1}, P_2O_5 0.005-0.025 mg l^{-1}.

The mean net plankton counts were 6913, 8870, 15,431 and 18,787 per liter in the natural, extensive, semi-intensive and intensive culture systems respectively (Fig. 1). The plankton were represented by *Oscillatoria, Merismopedia* (Myxophyceae), *Melosira, Cyclotella, Diatoma, Synedra, Navicula, Pinnularia, Gomphonema, Gyrosigma, Asterionella, Amphora, Nitzschia* (Bacillariophyceae), *Pediastrum, Botryococcus, Ankistrodesmus, Scenedesmus, Spirogyra, Kirchneriella, Selenastrum* (Chlorophyceae), *Starurastrum, Closterium, Cosmarium, Euastrum* (Desmidaceae) among phytoplankton, and *Brachionus, Keratella, Asplanchna, Filinia, Hexarthra, Polyarthra* (Rotifera), *Moina, Ceriodaphnia, Bosmina, Macrothrix* (Cladocera) and *Diaptomus, Cyclops* (Copepoda) among zooplankton.

The mean density of macroinvertebrates in the four types of ponds were 5888 1953, 2062 and 13,652 individuals m^{-2}. The common forms encountered were oligochaetes, dipteran larvae, hemipterans, odonates, gastropods and bivalves. The mean representation of Diptera in the four types of ponds were 39.4, 47.0, 22.1 and 57.6% of the total whereas the oligochaetes were 15.3, 10.7, 37.4 and 29.4%, and the gastropods were 33.9, 34.6, 31.0 and 13.1% respectively.

Primary Production

The mean gross primary production in the natural, extensive, semi-intensive and intensive culture systems was 6.3, 5.1, 7.3 and 7.0 g O_2 m^{-3} d^{-1} respectively. Of this, the respiration alone accounted for 78.4, 87.1, 83.1 and 83% respectively. (Fig. 1). The mean production rates were computed as 2.36, 1.93, 2.73 and 2.62 g C m^{-2} d^{-1} respectively, in the four types of ponds and thus, the respective production efficiencies worked out to 1.25, 1.02, 1.45 and 1.39%.

Sediment Characteristics

The mean organic carbon content of the sediment in natural, extensive, semi-intensive and intensive culture ponds was 1.40, 1.10, 1.12 and 1.50% respectively. The respective heterotrophic bacterial counts were 363, 401, 392 and 317 x 10^3 g^{-1}. The dehydrogenase activity, an indicator of total microbial activity was 0.52, 0.44, 0.52 and 0.49 mg triphenyl formazone g^{-1} sediment $24h^{-1}$ (Fig. 1). The lower bacterial count as well as dehydrogenase activity in the extensive culture system was possibly related to the utilization of organic matter.

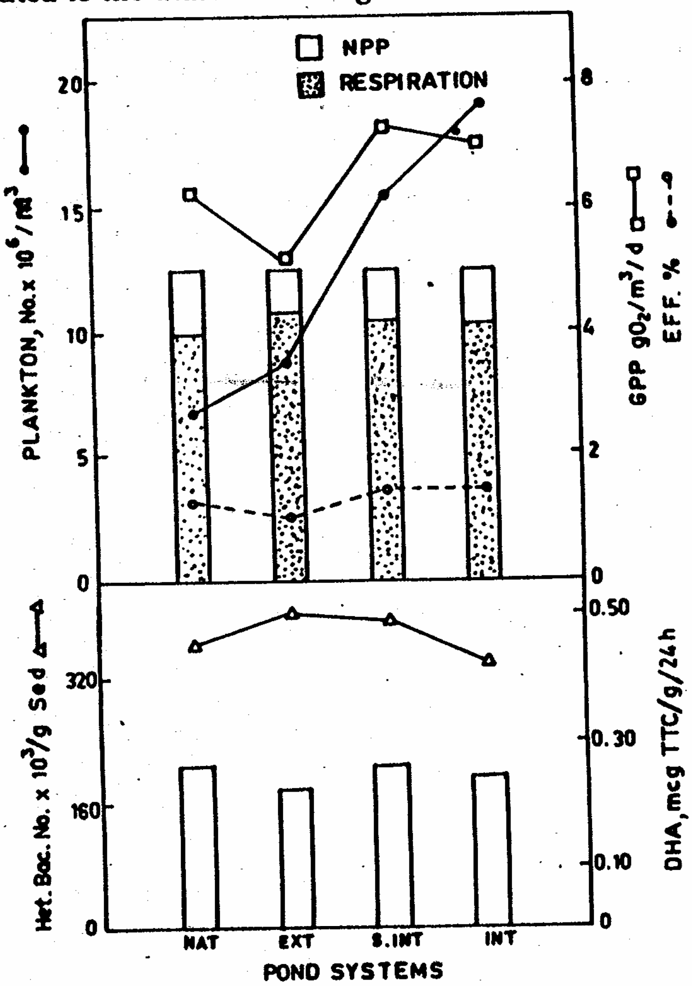

Fig. 1. Net plankton, primary production, sediment heterotrophic bacterial counts and dehydrogenase activity in ponds under natural, extensive, semi-intensive and intensive culture systems

Sediment Oxygen Consumption

The average sediment oxygen consumption in the four types of ponds was recorded to be 2.54, 3.02, 2.88 and 2.69 g $O_2\,m^{-3}\,d^{-1}$ (Fig. 2). Oxygen content in the overlying water column ranged from 2.03 to 8.73 mg l^{-1}, indicating its availability for uptake by the sediments at any time. The chemical oxygen consumption in the total in the four types of ponds was 51.3, 58.6, 66.7 and 64.5%, the remaining being the biological consumption. The sediment oxygen uptake was equivalent to 44.5, 58.9, 40.5 and 37.3% of the gross primary production in the four types of ponds and accounted for 57.7, 67.7, 49.7 and 45.5% of the community respiration (Fig. 2).

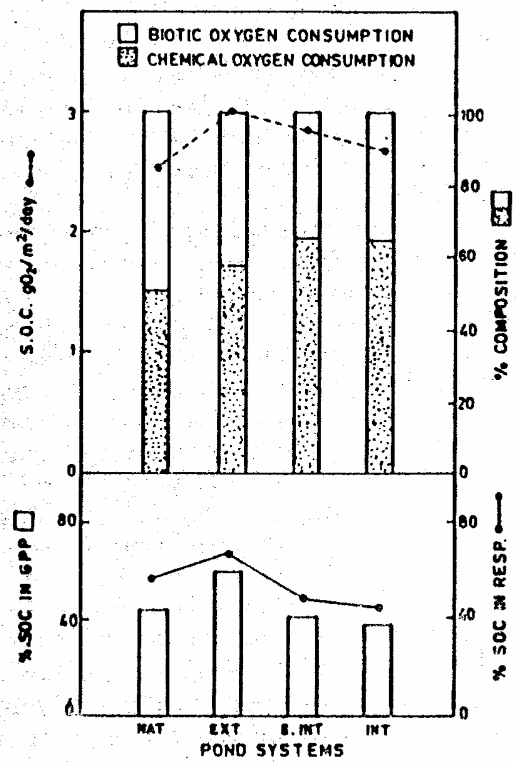

Fig. 2. Sediment oxygen consumption and its properties in the gross primary production and respiration in ponds under natural, extensive, semi-intensive and intensive culture systems.

The multiple correlation analysis showed that sediment oxygen consumption was significantly correlated with organic carbon, bacterial counts and density of benthic organisms ($R_{1.234}$ = 0.81, $P < 0.01$) and with organic carbon, gross primary production and benthos density ($R_{1.234}$ = 0.91, $P < 0.01$). While organic carbon content of the sediment contributes to the sediment oxygen uptake, the bacterial activity and density of macroinvertebrates account for the biotic oxygen consumption.

DISCUSSION

A comparison of the data obtained in this study with those reported earlier shows that the primary production and production efficiency were within the range of values observed in other Indian freshwarters (Srinivasan 1992, Ayyappan et al. 1990). The high rates of respiration not only indicate an active energy transfer to the secondary trophic level, but also the intensity of heterotrophy and the importance of allochthonous organic matter in the functioning of these systems (Kalbe 1972, Barko et al. 1977). The dominance of chemical oxygen uptake indicates high amounts of reduced substances and low oxidation-reduction potentials, as suggested by Teal and Kanwisher (1961) and Hargrave (1973). A similar situation was observed by Olah et al. (1987) in rural non-drainable ponds of eastern India. Further, the values of sediment oxygen consumption observed in the ponds were similar to those observed by Hargrave (1973) and Edberg (1976) and indicate active sediment-water interactions. Higher values in the extensive culture system corroborate the earlier observation regarding the higher rate of utilization of organic matter.

The study shows that sediment oxygen uptake must be taken into consideration in the estimation of community metabolism of aquatic ecosystems, which has never been done in Indian studies. Since the diel oxygen curve method was employed in the present investigation without incubating samples in enclosures, it allows for a comparison of the community respiration that includes sediment oxygen uptake also, with the sediment respiration itself. The data reported here on sediment oxygen uptake in the four systems clearly reveal its importance in the oxygen budget of the fish pond ecosystems. This assumes significance in the context of oxygen depletion in ponds causing fish mortality.

Further, while the rates are conducive for effective sediment-water interactions in the ponds under extensive culture system, measure like manual/mechanical raking of pond bottom and bioturbation would reduce organic matter accumulation in natural and intensive culture systems. The effects of stirring the pond bottom on increased bacterial activity and mineralisation rates have already been assessed (Granéli 1978, Ayyappan et al. 1990, 1991). The sediment-water interface exerts a regulatory influence on the productivity of the overlying waters and its assessment and management serve as an index and tool for improving production efficiency in fish pond ecosystems.

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