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Physicochemical characteristics in relation to pollution and phytoplankton production potential of a brackishwater ecosystem of Sundarbans in West Bengal

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Abstract: The environmental characteristics of Jagannath canal of Sundarbans estuarine complex of West Bengal monitored during March 1995 to February 1997 showed significant seasonal variation. Vertical attenuation coefficient of incident light (K^t = 14.41) in the canal was observed to be influenced by the high load of non-photosynthetic suspended particulate matter which was highest during monsoon months. Photosynthetic pigment seemed to be of very little importance. Salinity (0.26-9.54‰) showed an exceptional seasonal pattern with the lowest value during early winter. The concentrations of different nutrients were found to be considerably higher and the ratios of different nutrients were highly variable than the normal ratio required in the aquatic ecosystem. About 93% of the phytoplankton production can be expected from the ambient concentrations and atomic ratios of carbon, nitrogen and phosphorus. The deteriorating condition of the system was indicated by the high under saturation of dissolved oxygen, high chemical oxygen demand and high level of total ammonia preferably in the premonsoon season.

Resumen: Las características ambientales del canal Jagannath del complejo estuarino de Sundarbans, Bengala Occidental, monitoreado durante marzo de 1995 a febrero de 1997, mostró una variación estacional significativa. Se observó que el coeficiente de atenuación vertical de luz incidente (K^t = 14.41 en el canal está influenciado por la alta carga de materia particulada suspendida no fotosintética, la cual alcanzó su máximo durante los meses de monzón. El pigmento fotosintético pareció tener muy poca importancia. La salinidad (0.26-9.54‰) mostró un patrón estacional excepcional, con el valor más bajo a principios de invierno. La concentración de diferentes nutrientes fue considerablemente mayor, y los cocientes entre diferentes nutrientes fueron más variables que el cociente normal requerido en el ecosistemas acuático. Se puede esperar que aproximadamente 93% de la producción fitoplanctónica se derive de las concentraciones ambientales y de los cocientes atómicos de carbono, nitrógeno y fósforo. La gran subsaturación de oxígeno disuelto, la alta demanda de oxígeno químico y el alto nivel de amoníaco total preferentemente en la estación premonzónica indicaron la condición deteriorada del sistema.

Resumo: As características ambientais do canal de Jagannath no complexo estuarino do Sunderbans na Bengala ocidental, monitorizado entre Março de 1995 a Fevereiro de 1997, mostrou uma variação estacional significativa. O coeficiente de atenuação vertical da luz incidente (K^t = 14,41) no canal foi observada ser influenciado pela elevada carga de partículas

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suspensas não fotossintéticas, a qual foi mais elevada durante os meses de monção. Os pigmentos fotossintéticos parecem ser de muito pouca importância. A salinidade (0,26-9,54 ÅÒ) mostrou um padrão estacional excepcional, tendo atingido o valor mais baixo durante o início do inverno. Foi observado que as concentrações dos diferentes nutrientes eram consideravelmente altas e que os ratios dos diferentes nutrientes eram muito variáveis para além do ratio normal requerido nos ecossistemas aquáticos. Cerca de 93% da produção de fitoplâncton pode ser esperado tendo em atenção as concentrações e os ratios atómicos do carbono, azoto e fósforo. A deterioração das condições do sistema foi indicada pela elevada sub-saturação do oxigénio dissolvido, elevada procura de oxigénio químico e alto nível de amónia total, principalmente na estação de pré-monção.

Key words: Jagannath canal, phytoplankton, pollution, Sundarbans, water quality.

Introduction

The brackishwater of Sundarbans estuarine system of West Bengal encompasses several rivers and canals. One of the most important canals is the Jagannath canal which originates from the Bidyadhari river near Kulti. The upstream of the canal is divided into several arteries. Sewage of Calcutta Metropolitan Corporation (CMC) is mixing with the brackishwater of Bidyadhari river at Kulti and flows north-eastward through the canal during high tide (Ghosh 1989). These waters are being used to feed an estimated 3,600 ha shrimp culture impoundments (locally called bhery) of various sizes (0.5-25 ha), which have been developed along the banks of the canal and its arteries. Thus, the Jagannath canal ecosystem has great importance for aquaculture. Monitoring of such an ecosystem is very essential for predicting the potentiality of its water for using in aquaculture. Several investigations have been carried out on the hydrobiology of such waterbodies *viz.*, Kulti estuary of Sundarbans (David 1959), Cochin back waters (Vijayan *et al.* 1976), estuarine waters of Goa (Sankaranarayanan *et al.* 1978), retting zones of backwater of Kerala (Abdul Azis & Nair 1978), and Poonthura estuary (Anila Kumari & Abdul Azis 1992). In the present communication, the quality of water of the Jagannath canal, in relation to pollution and primary production potential is discussed.

Materials and methods

To have a complete feature of the hydrography of Jagannath canal, three stations were chosen (Fig. 1). The detailed hydrography of the canal was studied monthly from March 1995 to February 1997. Temporary field laboratories were set up in each station to carry out quick analysis of the hydrological parameters. Due to shallow depth of 4.2-6.04 m (Saha *et al.* 2001) and heavy turbulence, the vigorous mixing of water allowed no vertical stratification of the canal water. Hence, surface water was monitored as a representative of

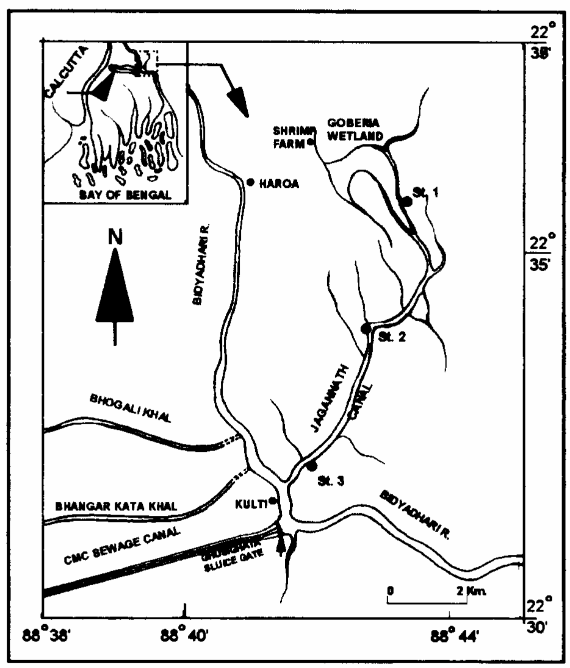

Fig. 1. Sampling stations in the Jagannath canal of Sundarbans in West Bengal. (*Inset*: map of lower West Bengal).

the whole water column. Water samples for the physicochemical parameters (except DO) and chlorophyll *a* were collected by a clean bucket. The water sample for analyzing dissolved oxygen (DO) was directly taken from the canal into 300 ml BOD bottles without agitation and fixed with manganous sulphate and alkaline potassium iodide immediately after collection. Temperature of water was recorded using a standard mercury thermometer, pH by Scan 2 digital pH meter which was calibrated by standard buffers before every use and transparency by a Secchi disc. The euphotic depth (D') was determined from the extinction coefficient (K_t) of water which was estimated from the formula K_t = 1.44/Secchi depth in meter as applicable for turbid water (Holmes 1970). Chlorophyll *a* content of phytoplankton was estimated by acetone extraction method. The extinction coefficient due to chlorophyll (K_c) was calculated by following Riley (1956). Suspended particulate matter (SPM), salinity, free carbon dioxide, alkalinity, DO, chemical oxygen demand (COD) and nutrients were determined by following standard methods (APHA 1992; Strickland & Parsons 1968). Dilution factor of water was calculated by following Yentsch (1975). The monthly rainfall data was collected from the Meteorological Department of Calcutta. Statistical analyses following Snedecor & Cochran (1968) were employed to find out the spatial and temporal variations and correlation among different parameters.

Results and discussion

The Jagannath canal is a mixed type of waterbody with semi-diurnal tides, having a high spring tide level of 5.50 ± 0.38, 5.75 ± 0.26 and 4.63 ± 0.34 m during premonsoon (March-June), monsoon (July-October) and postmonsoon seasons (November-February), respectively. Analysis of variance revealed that station-wise variations of all the parameters except suspended particulate matter (SPM), transparency, dissolved oxygen (DO), nitrate-nitrogen and ammonium-nitrogen were not significant, but all the parameters exhibited distinct seasonal variations. However, the data collected from three stations have been pooled into mean and presented here.

The temperature of the canal water varied from 19.6 to 33.47°C with almost same temperature during premonsoon and monsoon seasons, but a drastic decline in temperature was observed in postmonsoon season (Fig. 2). Highest rainfall was recorded during monsoon season (Fig. 2). The canal water was highly turbid due to tide induced current which carried sewage mixed water to the canal, discharge of effluent from aquaculture impoundments and resuspension of bottom particles due to turbulence of water. The mean suspended particulate matter of station 1, 2 and 3 were 106.98 ± 67.91, 131.54 ± 69.64 and 158.21 ± 75.24 mg l^{-1} respectively. Significantly high load of SPM ($F = 27.568$; $P<0.01$) near the origin of the canal (St. 3) and gradual decline in the upstream indicates gradual settling of SPM with the upward movement of water. The observed high load of SPM during monsoon months (Fig. 3) is associated with the land drainage due to high rainfall during this period. The extinction coefficient (K_t) of downwelling radiation is a function of water molecules and dissolved and suspended particulate materials (Strickland 1958). K_t varied from 8.76-26.52 and showed very strong correlation ($r = 0.950$; $P<0.001$) with SPM. The extinction coefficient due to chlorophyll (K_c) was 0.21-0.37 comprising only 1.00 to 2.73% of the total extinction

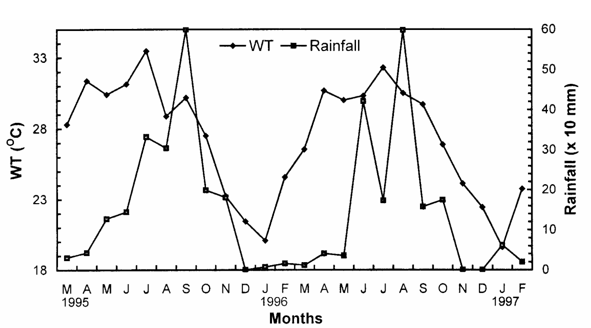

Fig. 2. Rainfall and temperature of water (WT) of Jagannath canal.

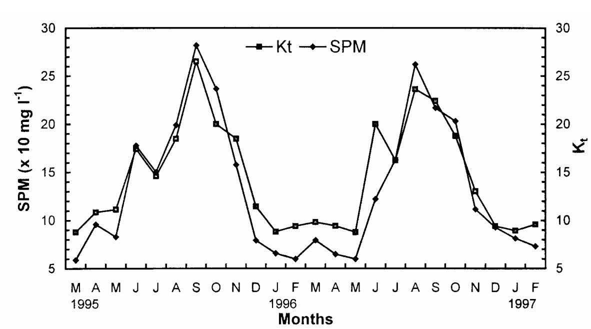

Fig. 3. Suspended particulate matter (SPM) and extinction coefficient of light (K_t) of Jagannath canal.

coefficient. Considering the extinction coefficient for pure seawater as 0.035 as reported by Ryther (1963), it can be inferred that non-photosynthetic particles were mainly responsible for inhibiting penetration of solar radiation into the canal. The turbidity of water inhibited penetration of incident light and limited the euphotic depth within a narrow range of 0.075 to 0.228 m, with a mean of 0.158 ± 0.01 m. This condition is not conducive for photosynthetic production of the system.

The salinity was highest (9.54‰) during premonsoon season, which gradually declined to almost zero during November-December (Fig. 4). This is an exceptional feature of the Jagannath canal ecosystem and associated waterbodies. The same pattern of seasonal salinity variation was observed in Kulti estuary from which the canal originates (David 1959). Generally, salinity level of most of the rivers decreases to minimum during monsoon season as recorded in the Hugli estuary (De *et al.* 1991). But, lower tidal amplitude during postmonsoon months and freshwater inflow did not allow salinity of this canal water to rise even after rainy season. This is also confirmed by high dilution factor during postmonsoon months (Fig. 4).

As depicted in Fig. 5, pH of water (7.26-8.77) was found to be alkaline throughout the study period and the highest pH was encountered during monsoon months, when free carbon dioxide was almost nil. Highest concentration of free carbon dioxide (2.86 ± 0.58 mg l^{-1}) was observed during postmonsoon season. Total alkalinity of water varied from 121.21 to 185.06 as mg l^{-1} $CaCO_3$ (Fig. 6) and made up of mostly by bicarbonates (91.90-100%). The alkalinity level revealed the latent capacity of water for bioactivity. Total carbon dioxide calculated from free carbon dioxide and total alkalinity varied from 110.03-156.18 mg l^{-1}.

The dissolved oxygen (DO) concentration (Fig. 7) ranged from 3.41 to 5.66 mg l^{-1} with the highest mean concentration (5.33 ± 0.33 mg l^{-1}) during monsoon season, which agrees with the observations of Zingde & Desai (1980) in Mahim creek and

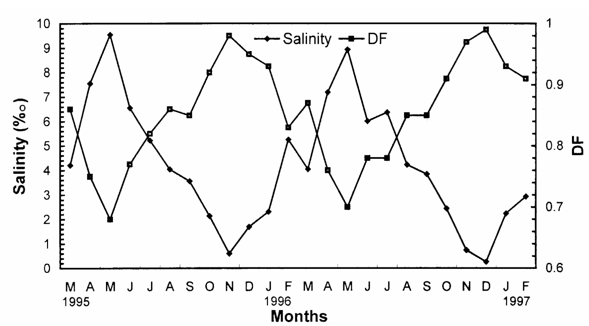

Fig. 4. Salinity and dilution factor (DF) of water of Jagannath canal.

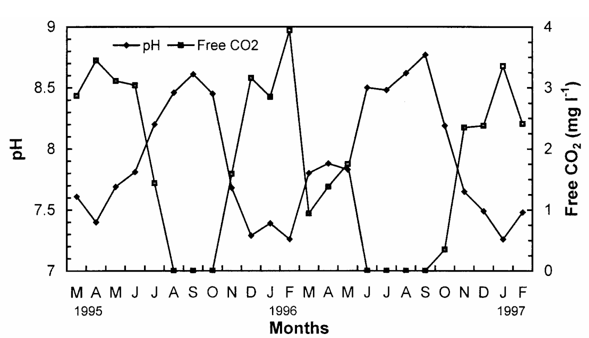

Fig. 5. pH and free carbon dioxide of water of Jagannath canal.

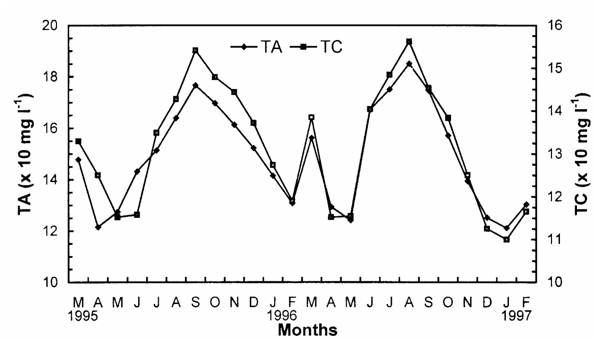

Fig. 6. Total alkalinity (TA) and total carbon dioxide (TC) of Jagannath canal.

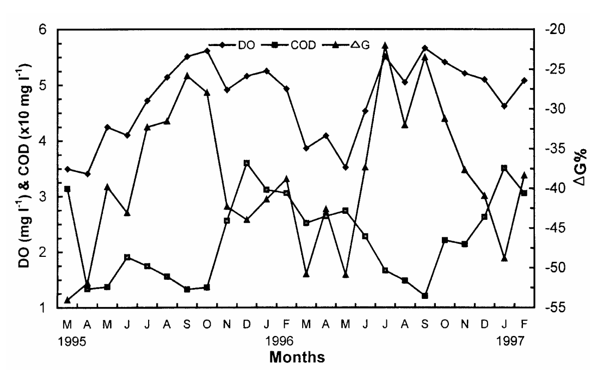

Fig. 7. Dissolved oxygen (DO), chemical oxygen demand (COD) and oxygen saturation anomaly (ΔG) of water of Jagannath canal.

Anila Kumari & Abdul Azis (1992) in Poonthura estuary. The oxygen saturation anomaly (Δ G%) of the canal calculated by the expression of Weiss (1970) was always negative -54.03 to -22.07 indicating under saturation of DO in the system. Generally, variation in DO are largely governed by photosynthesis, respiration, mineralization and decomposition activities in water. It was observed through primary production study (Saha *et al.* 2001) that there was no net production of oxygen even in the euphotic depth of the canal. Hence, the availability of DO may be the out come of turbulence of water and diffusion from the atmosphere. The observed lower DO concentration was due to pollution resulting from the sewage disposal from Calcutta Metropolitan Corporation (CMC) (Ghosh 1989). This is confirmed by the high demand of oxygen required for the stabilization of various inorganic and organic substances as revealed by 12.08-35.96 mg l^{-1} of chemical oxygen demand (COD), which is considered more scientific than the traditional concept of biochemical oxygen demand (BOD) for determining the organic load of a waterbody (De 1995). However, this situation suggests the deteriorating condition of the Jagannath canal ecosystem. The worst situation of DO was observed during premonsoon months. This may be due to enhancement of decomposition of organic materials and increase of bacterial activity by the high temperature during this period. The same situation was reported by Vijayan *et al.* (1976) in Cochin backwaters. David (1959) estimated the oxygen demand of sewage by half hour digestion in $KMnO_4$ at 100°C and estimated COD of 16.16, 20.75 and 16.75 mg l^{-1}, respectively at high and low tides at the outfall of sewage at Kulti and the sewage discharge gate at low tide during 1954-55. Undoubtedly, the present COD level of sewage of the outfall area has increased to several folds due to rapid industrialization of CMC in the last 30 years (Mondol *et al.* 1994). This may influence the COD level of Jagannath canal.

Fig. 8 depicts that the concentrations of all forms of inorganic nitrogen were observed to be lowest and that of silicon were highest during monsoon months. This may be attributed to the dilution of sewage water by the silica loaded freshwater during this period in the estuarine waters of Sundarbans ecosystem (Ghosh *et al.* 1992). The observed negative relationship of rainfall with nitrate-nitrogen and ammonium-nitrogen and positive relationship with silicate-silicon strengthen this opinion. The excessive silicate concentration in association with freshwater influx and land run off was also observed in Cochin backwaters (Qasim *et al.* 1969). The silicate concentration also showed negative relationship ($r = -0.4647$; $P < 0.05$) with salinity, which was also noticed earlier in Vellar estuary (Chandran & Ramamoorthi 1984). Phosphate-phosphorus showed highest concentration during premonsoon months. The general distributions of NO_3-N, NO_2-N, NH_4-N, PO_4-P and SiO_2-Si were within the range of 23.99-60.87, 2.62-8.92, 9.33-31.70, 4.79-10.33 and 82.55-180.67 µg-at l^{-1}, respectively and all values are higher than that of Hugli estuary (Ghosh *et al.* 1992) and world wide average for river water (Liss 1976). The level of ammonium-nitrogen in this canal was alarming high consisting of about 30% of the total dissolved inorganic nitrogen (DIN), which may be due to decomposition of sewage and under saturation of DO, because ratio of DIN:NH_4-N was primarily a function

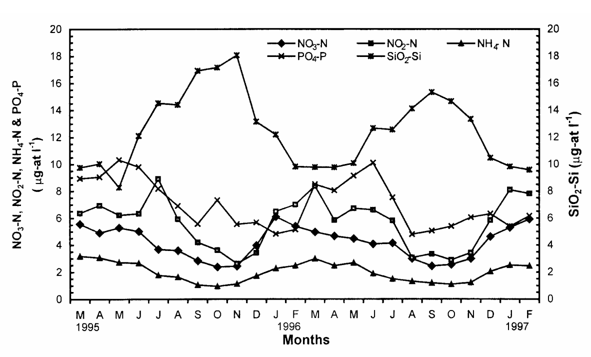

Fig. 8. Concentration of NO_3-N (x 10), NO_2-N, NH_4-N (x 10), PO_4-P and SiO_2-Si (x10) of water of Jagannath canal.

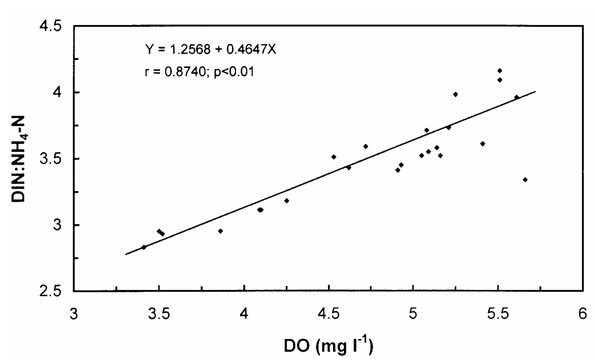

Fig. 9. Ratio of dissolved inorganic nitrogen (DIN) and NH_4-N as a function of dissolved oxygen (DO) in Jagannath canal.

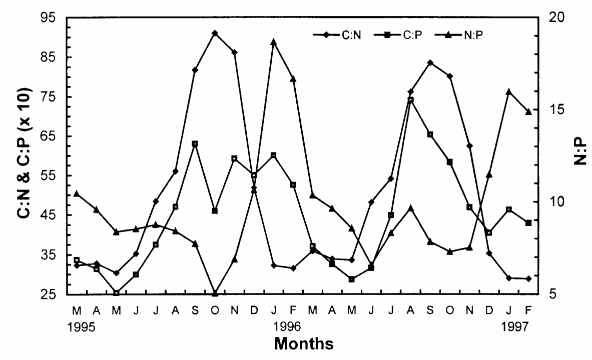

Fig. 10. Atomic ratio of different nutrients of Jagannath canal.

of dissolved oxygen (Fig. 9). The significantly high concentration of ammonium-nitrogen (21.17 ± 7.64 μg-at l^{-1}) near the origin of the canal and gradual decline in the upstream (18.96 ± 6.69 μg-at l^{-1}) and reverse distribution of nitrate-nitrogen indicates nitrification which is also correlated with the observed gradual increase in DO towards the upstream. The concentrations of phosphate-phosphorus were always observed to be above 0.32 μg-at l^{-1}, which can be considered sufficient enough to produce phytoplankton bloom (Sawyear *et al.* 1945). The concentrations of silicon were higher than the limiting concentration which lies below 1.78 μg-at l^{-1} (Riley & Chester 1971).

The atomic ratios of C:N of Jagannath canal water, which varied from 28.86-90.99 with a mean value of 50.45 ± 21.53 (Fig. 10) was higher than that of normal C:N of 6.62 (Redfield *et al.* 1963). Increase in C:N paralleled temporal variation of both inorganic carbon and inorganic nitrogen in that the highest ratio coincided with high inorganic carbon and low inorganic nitrogen. The variation in C:P (253.55-741.02) was also found to be higher than that of required ratio of 106 for the phytoplankton (Redfield *et al.* 1963). The highest C:P during monsoon months was due to the higher inorganic carbon content during this period. The N:P was highly variable and lower than the normal ratio of 16 (Redfield *et al.* 1963) almost throughout the study period. Among the three seasons, highest N:P was observed during postmonsoon. The fluctuation in N:P was closely related to the variation of inorganic nitrogen particularly nitrate-nitrogen. The low N:P supports Ryther & Dunstan's (1971) contention that phytoplankton production in the canal may not be phosphorus but nitrogen limited. However, phytoplankton do not become nitrogen limited as long as dissolved inorganic nitrogen (DIN) concentration remain above 0.24 μM (Caperon & Meyer 1972). Since DIN concentration of the canal was always above this value, it is unlikely that phytoplankton growth was nutrient limited in the Jagannath canal.

Production of phytoplankton in the aquatic system depends mainly on the availability and ratio of carbon, nitrogen and phosphorus. The expected production of phytoplankton from ambient concentrations of these nutrients was estimated by the growth factor law of Baule & Mitscherlich which has been modified by Verduin (1964). The calculation shows that about 93, 89 and 97% of the phytoplankton production would be expected from the ambient nutrient concentrations and their ratios during premonsoon, monsoon and postmonsoon season, respectively, if other conditions remain congenial.

Based on the above observations, it can be contended that the high tidal water of the Jagannath canal which is being used for aquaculture is considerably polluted. The high concentrations and ratios of different nutrients may lead to a situation of eutrophication but the high SPM and organic load may inhibit primary production by inhibiting penetration of incident light. The worst situation was observed during premonsoon season, when temperature was higher and DO reached the lowest level. Except this, the observed high ammonium concentration in conjugation with temperature and pH may create toxic environment, which may prove deleterious to the cultured species.

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