Journal of Environmental Sciences Vol.16, No.3, pp.466—470, 2004

ISSN 1001—0742
CN11—2629/X

Article ID: 1001-0742(2004)03-0466-05 **CLC number**: X503.2; X142 **Document code**: A

Environmental impact of aquaculture-sedimentation and nutrient loadings from shrimp culture of the southeast coastal region of the Bay of Bengal

Biplob Das[1,*], Yusuf Sharif Ahmed Khan[2], Pranab Das[2]

(1. Department of Earth and Atmospheric Sciences, 1—26 Earth Sciences Building, University of Alberta, Edmonton, Alberta T6G 2E3, Canada. E-mail: bdas@ualberta.ca; 2. Institute of Marine Sciences, University of Chittagong, Chittagong 4331, Bangladesh)

Abstract: Nutrient loadings were measured for surface seawater and bottom sediments of semi-intensive and improved extensive shrimp culture pond, adjacent estuary, and fallow land in the south-east coastal region of Bangladesh during August, 2000—January, 2001 to evaluate the impact of shrimp culture. The mean levels of nutrients found in the pond surface water were 108.780 mg/L for $CaCO_3$, 0.526 mg/L for NH_4^+-N, 3.075 wt% for organic carbon, 7.00 mg/L for PO_4-P, 5.57 mg/L for NO_3-N, and 7.33 mg/L for chlorophyll-a. The maximum mean value of H_2S(0.232 mg/L) was found in estuarine water. Nutrients loading were found to be decreased with distance from the shrimp farm discharge unit in estuarine water. The mean level of organic matter, total nitrogen, and organic carbon were found in higher concentrations in sediments of cultured pond compared to bottom soil of adjacent fallow land at the same elevation. Extractable Ca values were found in higher concentration(550.33 ppt) in adjacent fallow land, as the shrimps for molting in shrimp ponds use extractable Ca. The relation between seawater H_2S value and sediment pH ($r = -0.94$); sediment organic carbon and sediment pH values ($r = -0.76$), sediment total nitrogen and sediment pH ($r = -0.74$) were found to be highly negatively correlated. Whereas the relation between seawater H_2S value and sediment total nitrogen ($r = 0.92$), water NH_4^+-N and sediment pH ($r = 0.66$) were found to be positively correlated. The results revealed that load of nutrients at eutrophic level in estuarine water, and decrease of soil pH; leading to acid sulphate soil formation indicates a negative impact of shrimp culture.

Keywords: environment; eutrophication; impact; nutrients; shrimp culture

Introduction

Small-scale coastal shrimp culture has been a traditional and sustainable practice in many countries. The levels and patterns of coastal shrimp culture practices vary according to the species cultured, sites, and methods of farming. There is, however, a trend towards intensification, which is usually derived by the market forces and competitive use of the resources. This trend is expected to continue for the foreseeable future although at present a large proportion of coastal shrimp culture is still extensive or semi-intensive. In Asia most brackish water farms collectively cover a large area, but are individually small and poorly managed. The majority of existing coastal shrimp culture is undertaken for profit rather than subsistence farming.

Bangladesh is uniquely endowed with the diversity of very rich and extensive inland and marine fishery resources. In the overall agro-based economy of the country, the contribution of fishery is very promising and important for earning foreign currency, alleviating poverty and improving nutritional status of the people. Fishery sector contributes 4.7% in the national production and 14% of the agricultural income. In the financial year 2001—2002, 5.98% of the export earning came from frozen food sector, among them 4.5% came from shrimp alone. The traditional shrimp culture in Bangladesh is quite old, but from early seventies when demand and price of shrimp in the world market became very high, coastal shrimp culture started expending in the mangrove and polder areas (Khan, 1996). From eighties intensification of monotype shrimp culture began, particularly in Cox's Bazar and Satkhira areas. Now three modern types of shrimp culture viz. extensive, improved extensive and semi-intensive methods are being practiced in the coastal areas of Bangladesh, and major species cultured is *Penaeus monodon* and *Macrobrachium rosenbergii*.

Coastal shrimp culture, once allowed to take place e.g., Chakaria Sundarban, destroyed mangrove forest area, the overall ecology including the naturally rich flora and fauna, denuded nursing and breeding ground of many marine lives. Shrimp cultural activities exposed the dormant acid sulfate soils, resulting in acidification(Mahmood, 1995). Clearance of mangroves for shrimp culture is not only causing colossal habitat, aquatic resources, and bio-diversity, but also increasing soil erosion, vulnerability to cyclonic storms and tidal bore. Salinity intrusion in surrounding areas has been another ecological as well as socio-economic disaster in some areas. In the past coastal people used to earn their livelihood from salt production in the saltpans during dry season and traditional polyculture of shrimp with finfish with or without paddy, thus used to live in very close harmony with environment. But with the expansion and intensification of shrimp culture from seventies in different habitats like mangrove forests, saltpans, paddy fields, and other agricultural land, changed the land use pattern in the coastal

* Corresponding author

area. Bangladesh has lost more than 50% of the mangroves particularly by leasing out of the mangrove marshes for shrimp culture from 1977, and the damage done to the mangrove forests is colossal and irreparable (Khan, 1996). Recently natural shrimp fry as well as shrimp brood production have been greatly reduced; and ore offshore fishing grounds are situated opposite to the great Sundarbans forest. These clearly indicated the importance of the conservation of mangrove ecosystem (Mahmood, 1995).

Shrimp culture in Bangladesh still depends primarily on stocking of wild post-larvae. It has been estimated that about 3000 million fry of tiger shrimp (*Penaeus monodon*), which are about 98% of the present requirement are being caught from the coastal water by different types of gear. The fry collectors destroy about 92 other organisms for one tiger shrimp fry while sorting out the tiger fry, thus causing enormous loss to other shrimps, fishes, and zooplanktons. Mahmood and Saikat (Mahmood, 1995) observed that for a single tiger shrimp fry, the fry collectors destroy 14 other shrimp fry, 21 fish fry and 4631 other zooplanktons.

Semi-intensive shrimp farms are now using fishmeal, trash fish, crustaceans, and mollusks with artificial feed, as a result fresh and brackish water snails and mussels are at great risk. With intensification of culture practice the requirement of water increase; 30% — 40% of pond water is exchanged per day for semi-intensive culture mainly to remove the waste metabolites, direct discharge of which pollutes the surrounding water. The waste disposal through shrimp pond effluent, in the form of dissolved metabolites and particulate matter as well as smaller quantities of chemicals, micro-organisms and other detritus, derived largely from the feed, fertilizer, and faeces is increasing with the intensification of shrimp culture. Use of fresh diets like crushed mollusks and trash fish increases nitrogen loads (Wickine, 1984), therefore bring about a higher waste load to the environment. Again, the amount of feed wasted plays an important role in the total waste load. However, the nutrient and organic wastes influence the quality of effluent discharged from shrimp farms and the subsequent impact on external environment (Pullin, 1993). The use of chemicals as feed additives; disinfectants, pesticides, algaecides, molluscides, chemotherapecutant, lime, and fertilizer are also likely to contribute the environmental damage. The present study is aimed at evaluating the nutrients loading to the environment through shrimp cultural activities in the southeast coastal region of Bangladesh.

1 Materials and methods

1.1 Sampling area

The investigated area, Bakkhali River Estuary is situated between 22°32′N and 91°52′E. There are about 15 semi-intensive and 11 extensive shrimp farms on the bank of the investigated Bakkhali River. The ponds are selected on the basis of the farming practices. A semi-intensive shrimp (*Penaeus monodon*) farm, Beximco Fisheries Ltd. and an improved extensive farm, Chand Mian Shrimps, situated on the bank of the Bakkhali River Estuary, Cox's Bazar, Bangladesh were selected for the present study. Three ponds (B_1, B_2, and B_3) of Beximco Fisheries Ltd., three ponds (E_1, E_2, and E_3) of Chand Miah Shrimps were randomly selected water and' sediment sample collection. Three stations of fallow land (F_1, F_2, and F_3) between these farms randomly selected for soil sample collection at the same elevated of the cultured ponds. Six stations R_1 (0 km), R_2 (1 km), R_3 (2km), R_4 (3 km), R_5 (4 km), and R_6 (5 km) were randomly selected on the distance from the mouth of the estuary, to collect surface water samples. Dry season (August, 2000—January, 2001) was chosen for sample collection, as the shrimp farms are in full operation during this period.

1.2 Sampling procedure

Hydro-biological and soil sampling were done fortnightly intervals from all the ponds and the estuary. Samples were collected between 9:00 am to 12:00 am. Soil sample for chemical analysis were collected from the surface of the pond bottom. A column of soil 15 cm deep from the soil-water interface was trapped by a Van Veen-grab sampler covering an area of 0.026 m^2 in each cast. Soil samples of adjacent plain fallow land were collected at the same elevation of the cultured ponds (2 m). The number of soil samples collected from each pond and each station of adjacent fallow land varied from 15 to 20. The samples are then mixed to make a homogenous sample.

Surface water samples were collected from at 15—20 cm depth. The samples were then transferred into the plastic bottle covered with black sheet and kept on ice until returned to the laboratory. Collected water samples were filtered ($<$ 0.5 μm pore-size) to remove zooplankton and other unwanted debris. The filtered samples were preserved at -20℃ for days until further analysis.

1.3 Preparation of samples

The soil samples collected from different ponds and stations were air-dried, powdered, and passed through a 2 mm mesh sized sieve. Before analysis, soil samples were finally dried in an oven at 150℃ for 24 h. All the determinations were replicated thrice and the mean values were used to obtain representation of each pond and each station.

1.4 Method of water analysis

Dissolved oxygen (DO) was determined following Azide modification of Winkler's method (Lind, 1979). Salinity was determined with a digital refractometer, temperature with a centigrade thermometer, pH with pen pH meter, and transparency with a secchi disc. Electrical conductivity (EC) was measured with EC meter which ranged from 0 to 10000 μmhos/cm (Model RB 3R 104, SER, 58833), $CaCO_3$ by EDTA Titrimetric method. Organic carbon (OC) were determined according to Jackson (Jackson, 1958), NH_4^+-N by Neslerization method, PO_4^+-P by Stannous chloride method, and chlorophyll-a as described by Ketchum (Ketchum, 1969). NO_3-N was measured by UV Spectrophotometric method and H_2S as described by Kelly *et al* (Kelly, 1987). Chlorophyll-a measurement protocol as described by Marker *et al*. (Marker, 1980) was followed. Chlorophyll-a contained within suspended particles were collected by filtration of water samples onto 47-mm Whatman glass-fiber filters (GF/F) under low vacuum and extracted 24 h in 96% ethanol at room temperature. Chlorophyll-a concentration was determined spectrophoto-metrically with a UV4-100 spectrophotometer (Unicam, Ltd.). The absorbance of the extract at 665 nm was corrected for the background absorbance in the near infrared (750 nm), and converted to chlorophyll-a concentration from the equation as described by Marker *et al*. (Marker, 1980).

1.5 Method of soil analysis

Soil texture was determined according to Bouyouco's hydrometer method. pH was measured with soil pH meter, organic matter (OM) from loss on ignition, organic carbon (OC) were determined according to Jackson (Jackson, 1958), total nitrogen (TN) by Micro-Kjeldahl digestion and distillation procedure, available phosphorus by the extracted with Bray and Kurtz No. 2 extract (0.03 mol/L NH_4F in 0.10 mol/L HCl) followed by spectrophotometric determination according to $SnCl_2$ reduced molybdophosphoric blue colour method (Jackson, 1958). Extractable Ca, Mg, Na, and K was measured by 1 mol/L NH_4OAC, pH 7.0 ± 0.1 saturation and Fe by 1 mol/L NH_4OAC, pH 4.6 saturation followed by atomic absorption spectrophotometry.

2 Results and discussion

Hydrobiological parameters of semi-intensive, extensive and estuarine water are shown in Table 1. It was observed that the descending order in respect of mean concentration level of H_2S was found as semi-intensive ponds < extensive ponds < estuarine water as 0.113 mg/L, 0.213 mg/L and 0.232 mg/L respectively. The higher concentrations of H_2S value in estuarine water might be due to eutrophic levels of nutrients (NH_4^+-N, NO_3-N, and PO_4-P) that are used by the primary producers causing lower DO level. Discharge of organic waste increase the consumption of O_2 by the sediment and can result in oxygen depletion of the bottom water and formation of H_2S gas (Rosenfeld, 1979). A reduction in the concentration in DO in water passing through shrimp farms has also been reported (Rosenthal, 1983). The present findings are in well agreement with the statements of the above authors.

Table 1 Hydrobiological parameters of water samples collected from shrimp ponds and estuarine water

	Sample	Temperature, ℃	Transparency, cm	DO, mg/L	pH	Salinity, ppt	H_2S, mg/L	$CaCO_3$, mg/L	NH_4^+-N, mg/L	OC, wt%	PO_4-P, mg/L	NO_3-N, mg/L	Chlorophyll-a, μg/L
Semi-inten	B_1	29.50	51.47	8.94	7.88	27.01	0.011	107.90	0.50	3.163	7.0	5.5	7.5
sive pond	B_2	29.71	53.11	9.75	7.90	27.17	0.011	109.54	0.54	3.172	6.9	5.7	7.3
	B_3	29.76	51.84	8.97	7.87	27.35	0.012	108.90	0.58	2.890	7.1	5.5	7.2
Extensive	E_1	28.86	44.00	6.36	6.19	27.80	0.024	89.91	0.41	2.640	6.5	5.0	6.9
pond	E_2	28.98	44.09	6.30	6.98	27.66	0.020	91.18	0.49	2.370	6.0	4.7	6.8
	E_3	28.99	39.73	6.15	6.75	27.42	0.020	88.64	0.48	2.380	6.1	4.8	6.9
Estuarine	R_1	28.92	39.17	6.02	6.72	27.51	0.027	61.12	0.49	2.710	6.2	4.9	6.5
water	R_2	28.03	37.92	6.05	6.09	27.62	0.025	59.21	0.47	2.110	5.8	4.8	6.5
	R_3	28.39	40.26	5.98	6.02	27.03	0.025	58.09	0.48	2.090	5.7	4.7	6.3
	R_4	28.71	40.07	6.00	6.07	27.52	0.024	58.21	0.45	1.921	5.5	4.5	6.1
	R_5	28.90	38.98	6.07	6.51	27.49	0.020	57.99	0.43	1.750	5.5	4.5	6.1
	R_6	28.19	40.02	6.10	6.27	27.39	0.018	55.23	0.40	1.720	5.3	4.4	6.0

The mean level of $CaCO_3$ value was found in higher concentration (108.78 mg/L) in the semi intensive ponds. The ascending order was as $CaCO_3$ in semi-intensive pond (108.78 mg/L) > in extensive pond (89.91 mg/L) > in estuarine water (50.31 mg/L). Tseng (Tseng, 1987) noted that the Ca concentration of soil and water is important for molting and growth of shrimps. So the shrimp farmers use lime ($CaCO_3$) in the shrimp ponds in semi-intensive system. The mean level of NH_4^+-N (0.526 mg/L), NO_3-N (5.57 mg/L) and OC (3.057 wt%) values are found in higher concentration in semi-intensive pond as supplemented feed is used in shrimp ponds and addition of fecal substances from shrimps. The ascending order was as NH_4^+-N (0.526 mg/L), NO_3-N (5.57 mg/L) and OC (3.057 wt%) in semi-intensive ponds > NH_4^+-N (0.46 mg/L), NO_3-N (4.83 mg/L) and OC (2.46 wt%) in extensive ponds > NH_4^+-N (0.453 mg/L), NO_3-N (4.63 mg/L) and OC (2.15 wt%) in estuarine water. The mean levels of PO_4-P (7.0 mg/L) and chlorophyll-a (7.33 μg/L) value were found in higher concentration in semi-intensive ponds, as phosphate fertilizer is used for algal production in shrimp ponds. Moreover, phosphate compounds are added as additives in feed. An increase in phytoplankton biomass attribute to nutrient enrichment by shrimp farming from a archipelago in Finland (Isotalo, 1985). Increasing nutrients can lead to ecologically undesirable consequences and there is possibility that waste released from shrimp/fish farms could stimulate the growth of species harmful to farm stock (Nishimura, 1982). The present findings are well agreed with them. The ascending order is as, mean level of PO_4-P (7.0 mg/L) and chlorophyll-a (7.33 μg/L) in semi-intensive ponds > mean level of PO_4-P(6.2 mg/L) and chlorophyll-a(6.86 μg/L) in extensive ponds > mean level of PO_4-P(5.67 mg/L) and chlorophyll-a(6.25 μg/L) in estuarine water. The level of H_2S, $CaCO_3$, NH_4^+-N, NO_3-N, OC, PO_4-P and chlorophyll-a(Fig. 1) were found to decrease from the mouth of the estuary to downstream. The results are similar to the findings of Ketchum(Ketchum, 1969). The results indicated nutrient loadings at eutrophic levels in estuarine water and could reduce the natural productivity of this area. Imai(Imai, 1971) demonstrated that the culture of 50000—60000 shrimps reduced the amount of seston by 76% to 95%. It is therefore possible that the siting of shrimp farm in coastal areas could reduce the natural productivity.

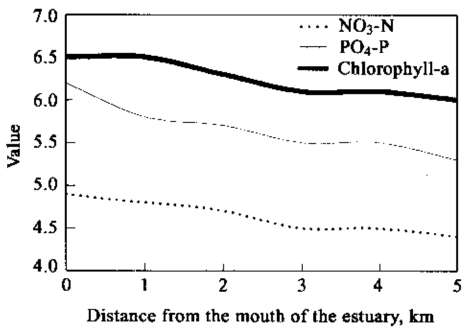

Fig. 1 Levels of NO_3-N(mg/L), PO_4-P(mg/L) and chlorophyll-a(μg/L) with distance from the mouth of the Bakkahali River Estuary, Bangladesh

Textural classes of sediment samples are shown in Table 2, and physico-chemical parameters along with nutrient values are shown in Table 3. It was observed from the present findings that mean OM values(2.49 wt%), total nitrogen (TN) value(0.141 wt%), and organic carbon values(1.32 wt%) are in higher concentration in semi-intensive ponds, as most of the supplemental feeds are sedimented and the faecal matter were produced from shrimps. The ascending order is as OM(2.49 wt%), TN(0.141 wt%) and OC(1.32 wt%) in semi-intensive ponds > OM (1.24 wt%), TN (0.099 wt%) and OC (0.93 wt%) in extensive ponds > OM(0.91 wt%), TN(0.075 wt%) and OC(0.54 wt%) in estuarine water. Mean available P value (20.5 ppt) was found in higher concentration in semi-intensive ponds, as fertilizers were used in shrimp farms. Extractable Ca value (346.33 ppt) are found in lower concentration in semi-intensive ponds, as sediment Ca is used by the shrimps for molting (Tseng, 1987).

Table 2 Textural classes of sediment samples

	Sample	Sand, %	Silt, %	Clay, %
Semi-intensive pond	B_1	65	13	22
	B_2	65	14	21
	B_3	66	13	21
Extensive pond	E_1	57	17	26
	E_2	55	19	26
	E_3	57	18	25
Fallow land	F_1	65	13	22
	F_2	65	14	21
	F_3	65	13	22

Table 3 Different parameters of sediment samples collected from shrimp ponds and different points of fallow land

	Sample	pH	EC, μmhos/cm	Salinity, ppt	OM, wt%	Total nitrogen, wt%	Available P, ppm	OC, wt%	Extractable Na, ppt	Extractable K, ppt	Extractable Ca, ppt	Extractable Mg, ppt
Semi-intensive pond	B_1	6.89	16.65	24.48	2.30	0.139	19.66	1.43	5964.64	549.91	311.18	705.00
	B_2	6.92	17.22	21.98	2.20	0.141	21.16	1.10	6111.82	584.00	365.73	709.09
	B_3	6.83	16.22	21.40	2.98	0.144	20.68	1.43	6183.18	600.00	362.09	703.64
Extensive pond	E_1	5.50	13.39	21.10	1.17	0.097	18.21	0.92	6921.02	497.98	442.20	739.91
	E_2	5.32	14.02	22.29	1.52	0.100	17.89	0.87	6730.51	529.21	420.93	723.42
	E_3	5.29	13.92	20.07	1.02	0.099	19.00	0.99	6532.46	510.46	452.34	740.91
Fallow land	F_1	6.20	12.62	14.39	0.95	0.066	17.88	0.49	7307.36	489.18	549.00	807.09
	F_2	6.15	12.59	15.31	0.89	0.097	17.26	0.57	7089.82	475.91	545.00	801.91
	F_3	6.14	12.84	15.25	0.89	0.063	17.53	0.55	6855.00	510.45	557.27	788.61

The linear relation between water H_2S value and soil pH ($r = -0.94$) and soil OC and soil pH($r = -0.76$), soil total nitrogen value and soil pH($r = -0.74$), were highly negative correlated in semi-intensive pond. The linear relation between water NH_4^+-N and soil pH ($r = +0.66$), water H_2S value and soil total nitrogen($r = +0.92$) were highly positively correlated in semi-intensive pond. The results indicated that the soils are going to be acidic due to unplanned feeding and fertilizing in the shrimp ponds which agreed with the findings of Mahmood and Saikat(Mahmood, 1995).

3 Conclusions and recommendations

Planned and properly managed aquaculture development is productive use of the coastal zone if undertaken within the boarder framework of integrated coastal zone management plans, according to national goals for sustainable development and in harmony with international obligations. The likely consequences of coastal aquaculture developments on the social and ecological environment must be predicted and evaluated, measures formulated in order to contain them within acceptable, pre-determined limits. Coastal aquaculture activity must be regulated and monitored to ensure that impacts remain within pre-determined limits and to signal when contingency and other plans need to be brought into effect to reverse any trends leading towards unacceptable environmental consequences. Keeping all these in view, the following recommendations are made:

The allocation of potential sites and the selection of forms of coastal aquaculture practice should be preceded by adequate survey and evaluation.

The zonation approach is one of the effective means of assigning priorities and limiting development activities to specific areas or zones. The priority activity in a particular zone acquires " predominant use" status. Other "permitted uses" should be accommodated, but only as long they do not jeopardize the predominant use. Remote sensing and geographical information systems should be effectively used for this purpose, especially to determine changes in resource use over time.

Environmental impact assessment (EIA) process (social, biological, chemical and physical environment) should be applied to all major aquaculture proposals.

In selecting an appropriate site for shrimp culture it should be considered, in addition to the socio-economic consideration, the biophysical requirements of the cultured organism, the characteristics of the site and the culture methods to be used. In evaluating the characteristics of the site, essential physical, chemical and biological variables should be considered. These include coastline morphology and bathymetry, water temperature and salinity, flushing time, sediment particle size, water movement, dissolved oxygen, dissolved inorganic nutrient, sedimentary redox-potential and organic content, natural resources and their use, wildlife, planktonic biomass and species composition, and bacterial population.

Properly sited and managed aquaculture activities should not result in unacceptable ecological change. Nevertheless, whenever change occurs a number of measures should be used to minimize it.

The concept of environmental capacity should be applied to the control of pollution and assumes that coastal ecosystems have differing quantifiable capacities to assimilate the discharge of a contaminant and provide trophic and non-trophic resources (GESAMP, 1986).

The use of mangroves along the shorefront or fringing riverbanks for aquaculture should be discouraged in view of their significant contribution to coastal stability preventing soil erosion, and their role as valuable habitats. The use of river basin mangrove should be guided by the recommendations from national mangrove committees, which have been established in some nations with rich wetland resources.

It should be emphasized that every movement of species to and from aquaculture sites, even within the same general area, should be strictly controlled through inspection and certification.

The accumulating effects of discharges on the coastal environment should be greatly reduced by the enforcement of site and contaminant specific effluent standards (e.g., for suspended solids, nutrients, and BOD). Levels to be adopted should be within the assimilative capacity of receiving ecosystems (GESAMP, 1986).

All aquaculture products should be confirmed with safety standards for seafood before they are allowed for human consumption. Depuration and appropriate storage and preservation facilities need to be established to ensure the adequate quality of products.

Better public awareness of the need for good seawater quality in the production of aquaculture should be provided to control undesirable inputs to the local environment.

Incentives such as, concessionary lease of wetlands, tariff exemption on feeds and equipment, energy subsidies and depreciation allowances on facilities and deterrents such as, taxes on land and water uses and effluent discharge should be encouraged aqua culturists to make more efficient use of resources and take full responsibility to mitigate or to minimize environmental change.

Identification of the spatial and temporal trend in a particular variable should be aided by reducing variations due to seasonality and sampling and method error. Since monitoring is only a means to an end, the results obtained should be used to modify the operation if the change in a variable exceeds or falls below the predetermined.

References:

Allan G F, Greg B M, 1992. Effects of pH and salinity on survival, growth and osmoregulation in *Penaeus monodon* Fabricius[J]. Aquaculture, 107: 33—47.

GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1986. Environmental capacity-An approach to marine pollution prevention [R]. Rep Stud GESAMP, (30): 49.

GESAMP (IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP Joint Group of Experts on the Scientific Aspects of Marine Pollution), 1986. Long-term consequences of low-level effects of marine contamination: An analytic approach[R]. Rep stud GESAMP, (40): 14.

Imai T, 1971. Aquaculture in shallow seas: Progress in shallow sea culture[M]. Tikto Koseishi, Kozeoku (Translated by the US National Marine Fisheries Service and republished in 1977 by American Publ. Co. Pvt. Ltd., New Delhi).

Isotolo I, 1985. The impact of the fish farming in the state of the Stroom area in Kustavi (in Finish)[M]. Vesihallit Mon Sarja.

Jackson M L, 1958. Soil Chemical Analysis[M]. Englewood Cliffs. N. J. USA: Perntice-Hall Inc.

Kelly C A, Rudd J W M, Hesslein R H *et al*., 1987. Prediction of biological acid neutralization in acid sensitive lakes[J]. Biogeochemistry, 3: 129—140.

Ketchum B H, 1969. Eutrophication of estuaries. In: Eutrophication: causes, consequences[M]. Washington: National Academy Press. 197—209.

Khan Y S A, Hossain S, 1996. Impact of shrimp culture on the coastal environment of Bangladesh [J]. International Journal of Ecology and Environmental Sciences, 22: 145—158.

Lind O T, 1979. Handbook of common methods in limnology[M]. Missouri: C. U. Mosby Company. 199.

Mahmood J U, 1987. Studies on semi-intensive and traditional culture systems of Bagda shrimp, *Penaeus monodon* Fabricius, 1798 in brackish water ponds of Cox's Bazar with reference to hydrobiology and bottom soil of the ponds. M. Sc. Thesis [D]. Institute of Marine Sciences, University of Chittagong, Bangladesh.

Mahmood N, Saikat S Q, 1995. On acid sulphate soils of the coastal aquaculture ponds of Bangladesh[J]. Pak J Mar Sci, 4: 39—43.

Marker A F H, Nusch E A, Rai H *et al*., 1980. The measurement of photosynthetic pigments in freshwaters and standarisation of methods: conclusions and recommendations[J]. Arch Hydrobiol Beih Ergebn Limnol, 14: 91—106.

Pullin R SV, Rosenthal H, Maclesan J L, 1993. Environment and aquaculture in developing countries[C]. ICLARM Conf Proc, 31: 359.

Rosenfeld J K, 1979. Implications of transplantations to aquaculture and to ecosystems[C]. FAO technical conference on aquaculture. Rome, FAO, FIR: AQ/Conf. 76/E. 67: 19.

Rosenthal H, 1983. Coastal aquaculture and water quality in protected bay of Japan[C]. Copenhagen, ICES, C.M. 1983/E: 22. 22.

Tseng W Y, 1987. Shrimp mericulture. A practical manual [M]. Taiwan Province: Chien Cheng Publisher. 305.

Wickins J F, 1984. The role of hypercapnic sea water on growth and mineralization in Penaeid prawns[J]. Aquaculture, 41:37—48.

(Received for review May 20, 2003. Accepted July 8, 2003)