Rouf, M.A. and Islam, M.M.M. 2006. Water quality and management of shrimp culture in Southwest coastal areas of Bangladesh. *Khulna University Studies*, 7(1): 91-98

Khulna University Studies, 7(1): 91-98, 2006

RESEARCH ARTICLE LIFE SCIENCE

WATER QUALITY AND MANAGEMENT OF SHRIMP CULTURE IN SOUTHWEST COASTAL AREAS OF BANGLADESH

M.A. Rouf * and M.M. Majedul Islam

Fisheries & Marine Resource Technology Discipline, Khulna University, Bangladesh 9208

KUS-05/44-081205

Manuscript received: December 8, 2005; Accepted: May 4, 2006

Abstract: The shrimp industry of Bangladesh is facing severe problems and results less production. A study was conducted under a DFID-funded research project (TROPECA) to investigate the issue during 2004. The study was done in an aquatic system of Dumuria *Upazila* of Khulna district comprising a river (semi diurnal tidal system), a canal and 10 shrimp ponds. Shrimp culture practices within the study area were mostly extensive to improved extensive system. Shrimp were being produced without proper pond preparation, water management, fry nursing, and feed management due to a lack of technical knowledge. There were also concerns about the risks associated with the consequence of higher levels of financial investment. Consequently, production rates were low, averaging only 191 kg ha^{-1} in the system. Entrance of untreated river water in the pond having less depth (<0.5 m) was considered as a major cause of shrimp mortality. The studied water qualities were within an acceptable range for shrimp during grow-out period except NH_3-N and total nitrogen, which were exceptionally high throughout the aquatic system. River water, used as input water of shrimp farm, itself contained high level of NH_3-N and dominated the water quality of the system. Therefore, a sustainable use of river water with measures to control the NH_3-N should be encouraged where farm should be prepared with adequate depth (2.5-3.5 ft) and provided with adequate fertilizer and feed in order to minimize the shrimp mortality in this region.

Key words: Water quality, *Penaeus monodon*, shrimp culture management, Bangladesh coast

Introduction

Shrimp farming has become one of the Asia's fastest growing industries (Chang, 1990). More than 85% of world's farmed shrimp is produced in coastal areas of the Asia-Pacific region with Bangladesh being the fifth largest producer in the world (Anon, 2002). Since the early seventies shrimp culture in the coastal region of Bangladesh has been expanding significantly. In the fiscal year 2001-2002, shrimp production reached to 0.464 mt/ha, which was only 0.177 mt ha^{-1} in the fiscal year 1991-92 (Anon, 2003). Despite rapid expansion and intensification of shrimp farming in Bangladesh, water and sediment qualities and their implications in shrimp production as well as the impacts of farm effluents on the receiving ecosystem remains poorly understood (Islam *et al*., 2004*)*. So, as an obvious effect of rapid unplanned expansion of shrimp farming in Bangladesh, especially with present level of intensification based on different inputs, the industry has faced severe disease problems.

Many problems and needs appear to be linked to the number and intensity of farms in a given coastal area, or the ability of the area to assimilate waste materials (Macintosh and Philips, 1992). Moreover, the excessive amount of dissolved nitrogen and phosphorus resulted from shrimp farms would give problem when there are intensive aquaculture operations at a unique coastal site. So, information on effluent loading is also needed for development of environmental capacity modeling.

Corresponding author:* email : <roufku@yahoo.com>

DOI: https://doi.org/10.53808/KUS.2006.7.1.0544-L

Several studies stated the picture of shrimp farming in Bangladesh. (Dev, 1998; Islam, *et*, *al*., 2004; Wahab *et al.*, 2000; 2001; 2003; Rouf and Ali, 2005). But still area specific shrimp culture study is required for planning and management of the shrimp sector development in Bangladesh.

In the present study, water quality and managerial operation of ten shrimp (*P. monodon)* ponds were investigated in the Southwest coastal areas of Bangladesh. Efforts were made to identify the main issues for low production and mortality in the traditional shrimp culture as well as to develop a guideline for the sustainable management. Sampling was conducted in a local system for whole culture cycles. Volunteer farmers were involved in record keeping on farming practice and farm performance. These were then compared with farm practice and performance of farmers from wider area.

Materials and Methods

Study site**:** The present study was conducted at Kathaltala, Dumuria *Upazila* of Khulna district of Bangladesh, throughout the year 2004. Two stations from the Teligati river (semi diurnal tidal system), two from canal (river connected) and ten shrimp ponds were selected for weekly sampling. Surveys in the greater Khulna region (Khulna, Satkhira and Bagerhat) were also conducted to verify the results.

Shrimp farming techniques and management**:** The quantity and quality of inputs (feed, fertilizer and water exchange) and production were recorded during the study period without any interruption to the farm activities. Various issues related to management, growth and disease prevalence were closely monitored and observed with a participatory approach.

Pond preparation started in January after completion of paddy culture (from August to December). A periphery canal near the border of the farms was dug and the soil was used for making dike to store water for their farm. The canal was used as nursery pond (locally known as *tob*) for shrimp fry. The farmland was ploughed and left for 7-10 days under sunshine and then lime (CaO) was applied. After 7 to 10 days of liming inorganic (mainly Urea and TSP) and organic fertilizer (cow dung) was applied at a rate given in table 1.

After 7-10 days of fertilization water was introduced by allowing the water level of high tide to enter into the ponds during the new or full moon. No particular stocking density was maintained. Stocking varied from farm to farm and average stocking density was 13,782 PL ha^{-1}(1.37 PLm^{-2}). PL stocking continued from March to June with every lunar phase by 6-8 spells and stocking completed before the rainy season. Monoculture of shrimp was not observed in the site. Though tiger shrimp, *Penaeous monodon* was the target species, some other species, especially fresh water prawn, *Macrobrachium rosenbergii* (during rainy season) and finfish species like tilapia, *Oreochromis mossambicus* and persia, *Liza parsia* were used to stock. A number of other shrimp and finfish species also enter into the ponds with tidal inflow of water. Fry nursing in nursery pond (*tob*) was a common practice especially at early spells i.e., before the rainy season. Duration of nursing was varied and usually it was for one month. Fry acclimatization was not practiced properly.

There were inlet and outlet facilities used for receiving and discharging the water where spring tide used for water inlet and neap tide for water outlet. Most of the river or canal side farms exchange farm water frequently with tide, but water exchange was rare in the farms located far from the river or canal. Some farmers occasionally added only river water allowing high tide to maintain water level in the ponds.

Frame survey in the wider area**:** A questionnaire survey considering 60 randomly selected shrimp farms was carried out in the wider area (3 coastal districts - Khulna, Satkhira and Bagerhat) with a view to cross check the managerial issues recorded in the study area.

Water sampling and monitoring**:** Weekly water quality monitoring throughout the year was conducted in 10 selected shrimp ponds and 4 stations of river (station 1 and 2) and water supply canal (station 3 and 4) to observe water quality dynamics. Separate sampling during both high and low tide was also considered. The parameters studied weekly were temperature (°C), depth (cm), salinity (ppt), pH, dissolved oxygen (mgl^{-1}), biological oxygen demand (BOD) (mgl^{-1}), ammonia nitrogen (NH_3-N) (mgl^{-1}) and total phosphate (TP) (mgl^{-1}). Water samples were collected fortnightly from pond inlets and outlets throughout the shrimp growing cycle to determine total nitrogen (TN) (mgl^{-1}) and total phosphorus (TP) (mgl^{-1}).

Water pH was recorded directly by using a digital pH meter (pHep+ by HANNA). Salinity was measured by a hand refractometer (ATAGO S/Mill-E). Dissolved oxygen (DO) was measured on the spot by a digital DO meter (DO-5510, Lutron). The NH_3-N and TP were measured by using a water test kit (HACH). Total nitrogen was estimated by micro Kjeldahl method (APHA, 1998) and total phosphorus by digestion followed by direct spectrophotometric reading. Biological oxygen demand (BOD_5) was analyzed in the lab by Winkler titrimatric method.

Results

***Growth and yield performance*:** The average stocking density of *P. monodon* in 10 farms was 13,782 PL ha^{-1} and average yield was 190.9 kg ha^{-1}. The survival rate was between 40 and 52% (average, 46.7%) and the individual weight at harvest ranged between 24.3 and 32g (average, 27.62g). The range of total production was 150-798 kg ha^{-1} with an average of 384.1 kg ha^{-1}. The main target species, *P. monodon* constituted 49.7 % of the total yield. The average production of fresh water prawn, *M. rosenbergii* was 99.8 kg ha^{-1} (26%), and average production of the fin fishes was 93.4 kg ha^{-1} (24.3%) (Table 1).

Table1. Infrastructure and management issues of the shrimp ponds under investigation.

Issues	Applications
Pond size (ha)	0.2 – 2.4
Depth (m)	0.8 – 1.17
Water exchange	Tidal exchange
Inlet-outlet	Same gate
Average stocking density (No./m^2)	1.37 (multiple spell stocking)
Fry nursing	Only for first spell stocking
Rearing period	4 – 5 months
Supplementary feed	Irregular use
Formulated feed	Rarely used
Natural feed	Mostly used
Survival rate (average)	46.7%
Average weight (g)	27.62
Lime used	200-300 kg ha^{-1}
Urea and TSP used	An equal rate of 60-80 kg ha^{-1}
Cow dung used	500-1000 kg ha^{-1}.
Gross production	(kg ha^{-1}yr^{-1})
P. monodon	190.9 (49.7%)
M. rosenbergii	99.8 (26.0%)
Fin fish	93.4 (24.3%)
Total	384.1 (100%)

***Farmer's view in wider area*:** The high rate (average 60%) of mortality was often noticed in the study areas. Farmers linked this mortality to both disease and management issues. Most of the farmers blamed the frequent water exchange from river and canal, which may contain microbes and pollutants responsible for disease occurrence. Most of the farmer used to exchange farm water traditionally using tidal level of the adjacent river (70%) and canal (12%). As no or very limited supplemental feed was used, most of the farmers were obliged to fill ponds with river or canal water as they thought the water carry natural food and also to fill up the evaporation and leaching loss. Only a few farmers (8%) (Fig. 1) were not willing to fill the farms with river water considering that the water causes shrimp mortality. The reddish color, oily layer and off odor/smell of water was considered to be bad for farm and responsible for disease outbreak. On the other hand greenish water and growth of hydrophytes (*Ruppia maritima*), locally called "*cata saola*" was considered to be good for farm water environment. It was also reported that mortality was less in the farms having *Ruppia maritima* and considered as a wonderful source of food and shelter for shrimp in the dry season.

Inadequate water depth (<1ft) was reported as a major problem for shrimp culture. Most of the farmers were not able to maintain optimum (2.5-3 ft) depth of water in shrimp farms as it involved high capital investment. Excessive salinity with low water depth caused shrimp mortality. Occurrence of saline bubbles and salt coagulation in the pond bottom was also reported as a cause of shrimp mortality. Some farmers (10 %) reported that hatchery produced shrimp PL might be a cause of huge mortality (Fig-1) but ensuring the quality of fry is out of farmers' capacity. Sixty eight percent (68%) of the surveyed farms did not use any supplemental feed (Fig. 2) and relied on natural feed. Only 18% farmers used cereal and 6% home made feed. During grow out period, 16% farmers used Lime+Urea+TSP+Cowdung, getting highest production (273.6 kg ha^{-1}). Another 16% used Lime+Urae+TSP also obtained similar production. A medium level production (200.6 kg ha^{-1}) was obtained without any use of fertilizer but 50% respondent preferred not to use fertilizer at that stage. Production became higher to some extent in the improved extensive system where lime and fertilizer were used.

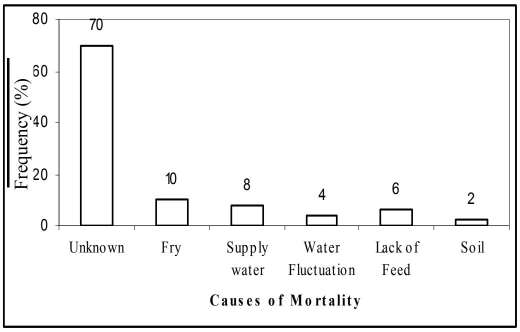

Fig. 1. Causes/source of shrimp mortality in the ponds

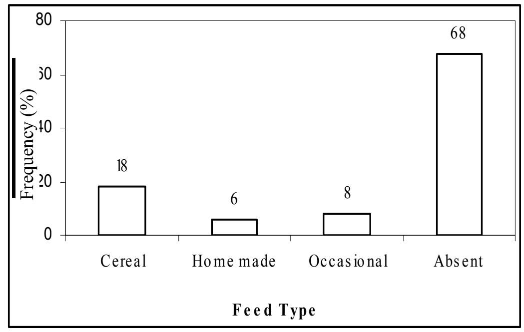

Fig. 2. Proportion of used feed in the ponds

White spot, lesion in body, spoilage of appendices and reddish color were generally observed in shrimp after death. Sometimes no detectable symptom was observed in a dead shrimp. Shrimp mortality used to occur at any stage and any season. But most of the farmers (60%) reported that 44-66 grade shrimp (15-23 g) was more vulnerable than higher (less than 44) grades (Fig. 3). Forty percent of the farmers reported that mortality was more frequent in the month of May-June (Fig. 4) when there is heavy rainfall in the area.

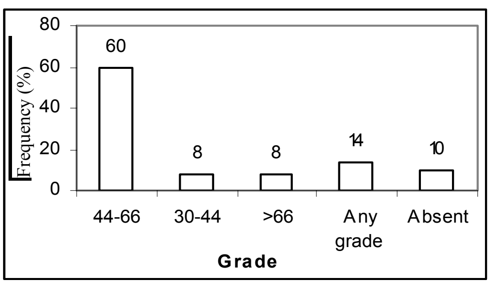

Fig. 3. Shrimp mortality stage (grade) in the culture ponds

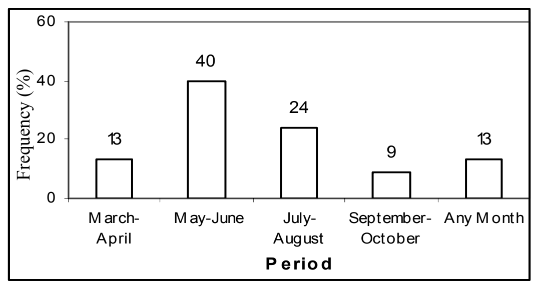

Fig. 4. Shrimp mortality period in the ponds

***Water quality parameters*:** Temperature, salinity, DO, pH and BOD did not show significant variation among river, canal and ponds (Fig. 5). In the month of January salinity was 0 ppt. Significant gradual increases of salinity in the water were recorded from February (1ppt) to June (15 ppt), followed by a gradual decline to 1 ppt recorded in December. The average salinity of the 10 ponds remained relatively low from January to June and became higher after June than that of river and canal (Fig. 5a).

The dissolved oxygen concentrations fluctuated mostly between 4 and 7.5 mg l^{-1}. DO concentrations of pond was usually higher than that of river and canal except during January to March, when 4 of the ponds were dried for preparation and little amount of water was remained in other 6 ponds (Fig. 5b).

The pH value of river, canal and ponds were relatively higher (7.5- 8) during April to October compared with the rest of the year. The average water pH in the culture ponds was slightly higher in most periods of the year compared with river and canal (Fig. 5c).

The average BOD of the river, canal and ponds varied mostly between 1.7-2.5 mg l^{-1} (Fig. 5d). The highest BOD level (4 mg l^{-1}) was recorded from one pond in November and the lowest value of 0.8 mg l^{-1} was found at river (station 1) in December. The average BOD contents of the river, canal and pond water was 2.1±0.88 mg l^{-1} during the study period.

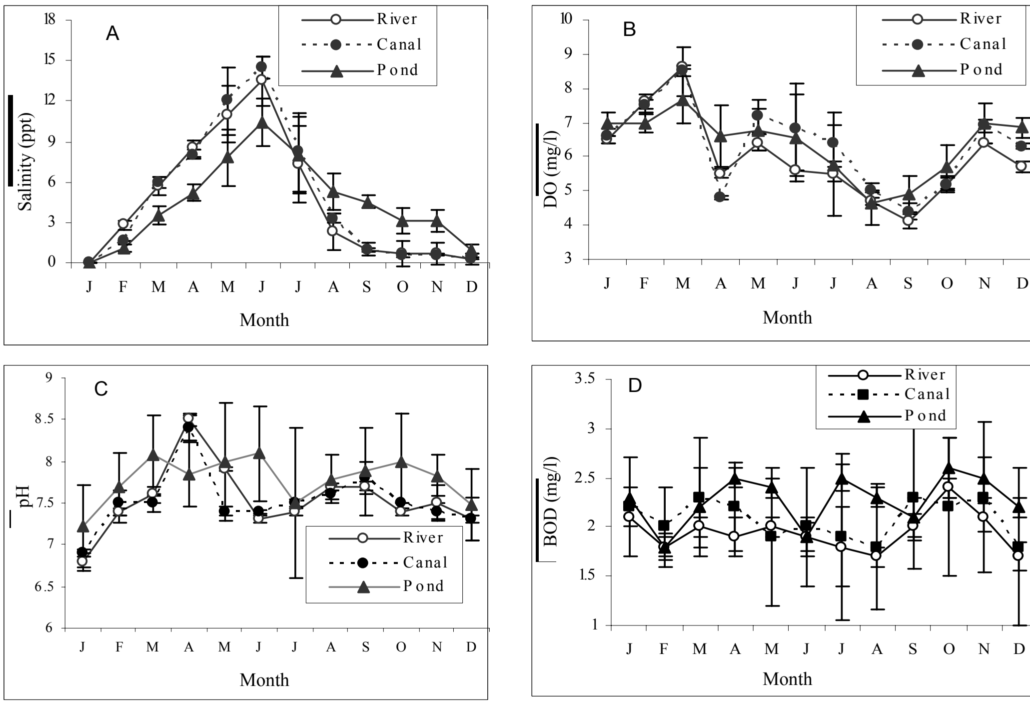

Fig. 5. Monthly changes in the selected physico-chemical parameters (mean±SD) of water throughout the year in river, canal and culture pond. A: salinity (ppt), B: DO (mg l^{-1}), C: pH and D: BOD (mg l^{-1}).

Nutrient dynamics

***Seasonal water nutrient variation*:** The TP and total NH_3-N concentration did not show significant variation among river, canal and ponds (Fig. 6). The TP concentrations were mostly between 0.5-0.7 mg l^{-1} with the exception in the month of October, where slightly increased values were recorded (0.73-0.96 mg l^{-1}). The concentrations of total NH_3-N were ranged between 0.5-0.8 mg l^{-1} during non-culture period (October to February). Significant gradual increases (up to 2.2 mg l^{-1}) were recorded during shrimp culture period from March to September. The highest value (2.2 mg l^{-1}) was recorded from the canal.

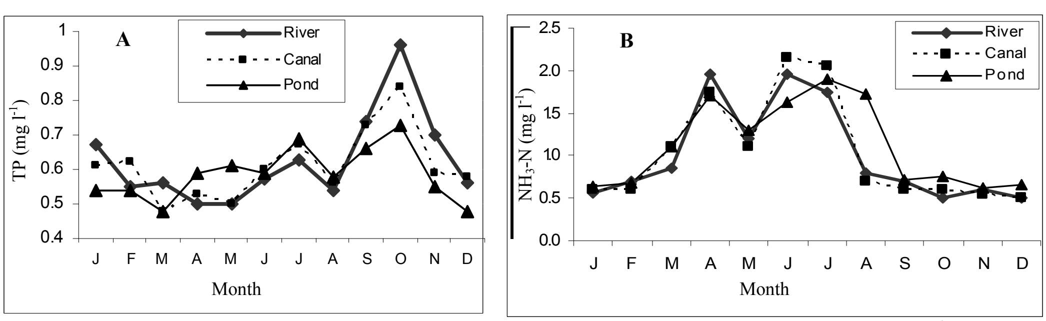

Fig. 6. Fluctuation of water nutrients throughout the year in river, canal and ponds. Average monthly data of A for TP (mg l^{-1}) and B for NH_3-N (mg l^{-1}).

Fluctuation of nutrients in shrimp grow-out ponds: The concentration of total Nitrogen and total Phosphorus in supply and discharge water showed the same pattern. The concentrations were low during first two months (February and March). Then the concentration increased from 0.15 mg l^{-1} to 0.25 mg l^{-1} for total phosphorus and from 1.3 to 4.3 mg l^{-1} for total nitrogen (Fig. 7). The concentration of TN and TP were higher in the supplied (inlet) water than discharged (outlet) water in the first few months of culture cycle. In the later months, however, TN and TP were higher in outlet than inlet water. The average TN and TP concentration of inlet water was slightly higher than that of outlet or discharged water (excluding the final drainage).

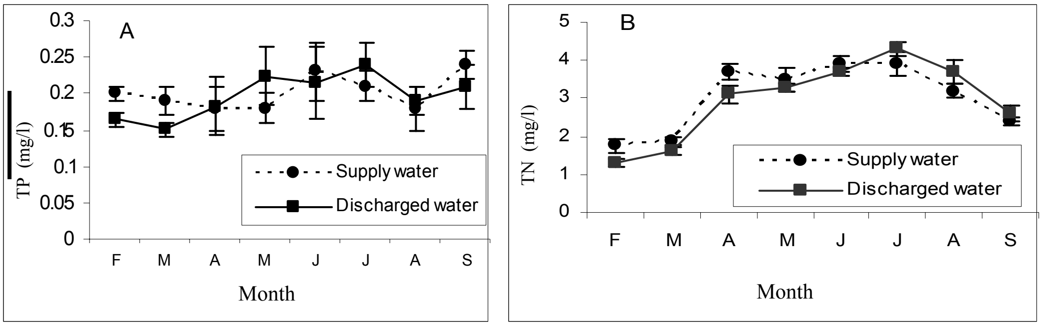

Fig. 7. Changes of water nutrients in three shrimp ponds throughout the growing cycle. Values (mean±SD) are for Total Phosphorus (mg l^{-1}) and Total Nitrogen (mg l^{-1}).

Discussion

***Culture technique and yield*:** Shrimp production (average 100-200 kg ha^{-1}) in the ponds was low due to some management as well as socio-institutional problems. In terms of pond preparation, farmers dug a canal inside the levees, took little initiative for dyke preparation, used lime and fertilizer in some extent but ploughed the land very rarely and were not worried about the black mud in pond bottoms. Pond bottom with acidic and anoxic soil makes the shrimp farm vulnerable. Another major and severe problem was pond depth. Farm and '*tob*' depth was ranged between 0.3-0.9 m and 0.9-1.17 m respectively. The effective water depth of most farms during culture periods never exceeded 0.4 m. Such low water depth prevents the water flow, creates spike of any water parameters and ultimately reduces the survivability of shrimp.

Stocking density was very low in most of the farms. The present study showed that the stocking density of 7,410-10,868 piece ha^{-1} produced 105-156 kg $ha^{-1}yr^{-1}$of shrimp. But optimum density of stocking is 15,000-20,000 piece ha^{-1} for extensive method. A production of 191-288 kg $ha^{-1}yr^{-1}$ with stocking density of 13,782-18,525 piece ha^{-1} was noticed in one of farms in the study area.

Optimum production also depends largely on using feed and fertilizer that was not properly practiced. Some of the farmers did not use feed and fertilizer at all while others used fertilizer without following any recommended dose. In addition, the feed that they used was not balanced and adequate. A few number of supplementary feed ingredients like rice bran, boiled rice and wheat bran was used in the farm that necessarily did not contain all the nutrients. Some of them used fishmeal occasionally. As no or very limited supplemental feed was used, farmers mostly relied on natural feed by maintaining water exchange and using fertilizer. In addition, they did not have any other options except river water to compensate for the evaporation and leaching loss. Insufficient natural feed brings malnutrition, a common phenomenon, causing diseases and lower growth of shrimp.

Frequent water exchange is a usual practice in the present shrimp culture system in the study area. But it is often noticed that highly turbid river water is used in the pond that may hinder the growth of plankton and ultimately made the farm environment unsuitable creating mortality and consequent low production.

There is a practical difficulty in maintaining standard pond depth. Farmers usually get lease of a land for 1-3 years only for seasonal shrimp farming, in which owner cultivates paddy during the off season. Thus, to compromise with owners' paddy cultivation in the same land, a farmer cannot dig the land too much for shrimp farming. There is a shrimp farmers association that focuses only the large-scale farmers (>5 ha) but a lot of small-scale farmers (<5 ha) who have no association and not registered with the (due to complicate system) fisheries department. The small-scale farmers even do not get any technical or administrative support from respective authority.

***Water quality parameters*:** Water quality of river, canal and ponds remain nearly similar throughout the year. It may due to the traditional nature of the culture system where input is very less as well high rate (3273% per cycle) of water flashing (Rouf, 2005). Consequently, river water has a major influence on the water quality of the ponds. The optimum conditions for *P. monodon* were summarized by NACA (Anon, 1994) and these are salinity, 10-20 ppt; dissolved oxygen, 3.8-5.0 mg l^{-1} and pH 7.5-8.

The average salinity of the ponds remained relatively low from January to June and became higher after June than that of river and canal due to the frequent farm water exchange or mechanism to keep the adequate saline water in the pond for shrimp culture. Although the salinity at initial stage and at the end of culture cycle was low (3-6 ppt) than the recommended lower limit. But the culture practice in this region is ideally adjusted with that salinity trend. The viability of *P. monodon* in low-saline water has been indicated by Saha *et al*. (1999). They observe, when salinity decreases after 60 days of culture (>5 ppt) to freshwater level (0.16 ppt), the growth rate and feed utilization of the shrimp stock were still satisfactory in semi-intensive pond. No significant variation in DO and pH among the farms was observed. The present DO and pH value represents the average of morning and noon record. So a lower level of DO and a higher level of pH might be in the system at afternoon. Chakraborti *et al.* (1985) stated that many variations in pH usually do not occur in shrimp farms owing to the buffering capacity of brackish water. More than 10 ppm of BOD is considered to be moderately and more than 20 ppm as to be highly polluted water (Paul, 1999). But a very negligible amount of BOD (mean, 2.1±0.88 mg l^{-1}) was recorded from river, canal and ponds during the present study, which generally indicates no organic pollution occurred in the river, canal and pond water.

Nutrient dynamics: The TP and NH_3-N concentrations showed similar trends in the river, canal and pond due to the excessive water exchange within the system. But there is prominent monthly or seasonal variation noticed in case of the NH_3-N. River waters itself and to some extent farming practice might be responsible for this variation. High range of NH_3-N might be due to the interception of oxidation process caused by less DO and high pH at afternoon in the system. Wahab *et al.* (2001) also recorded the minimum and maximum values of NH_3-N (TAN = NH_4^+-N + NH_3-N) as 1.08 mg l^{-1} and 2.43 mg l^{-1} in the pond. For successful production of *Penaeids*, the unionized ammonia (NH_3) which is toxic to fish and crustacean should not be more than 0.10 mg l^{-1} (Anon, 1994). Wahab *et al.* (2000) indicated peak concentrations in several shrimp farms due to increased pH in the afternoon ($p^H > 8.5$). In an experimental infection trial, addition of 2 ppm of total NH_3-N led to 40% mortality among *P. monodon* caused by WSSV (Wang *et al*., 1997). Allan *et al.* (1990) proved a growth reduction of 5% in *P. monodon* at 0.21 mg l^{-1} NH_3-N. Obviously, the ammonia peaks in the afternoon fluctuate within the sub-lethal range and consequently may have create stressing conditions for shrimp stocks (Wahab *et al.*, 2001). In the present study, the observed NH_3-N concentration (maximum 2.2 mg l^{-1}) in some ponds might have been a cause of disease outbreak. Burford and Longmore (2001) showed that low rate of nitrogen loss from denitrification, relative to high nitrogen input, results in high ammonia concentration in the water column.

Difference of nutrient concentration between supply and discharge water indicates the excessive water-flushing rate and minimum input in grow out ponds. River water itself rather than the shrimp farm practice has major influence on the dynamics. The overall data showed that inlet nutrient value was slightly higher than that of outlet or discharged value that indicates a net retention of nutrients in the pond ecosystem from the surrounding aquatic system.

Conclusion

Results of the present study suggest that the water quality in shrimp ponds and aquatic system during culture period were in acceptable range except the NH_3-N and TN, which come from the river water source. River water becomes more threatening for shrimp when urea or cowdung used in the shrimp pond. Lower pond depth (<1 ft) and lower nutrient input in terms of feed are the main concerns for the lower production rate in the study area. In order to overcome this problem, farmers should maintain adequate pond water depth (2.5–3.5 ft) and provide adequate fertilizers and supplemental feed to stoked animals. However, smaller units (1-5 ha) of farm with multiple depth ranges having separate nursing pond is highly recommended. In terms of water exchange, farm should be filled with river or canal water just after high tide or at the beginning of low tide to allow settlement of waste materials. If possible, having a reservoir to allow suspended particles of river water to precipitate is preferable. Farm effluents should not be discharged into freshwater areas or on to agricultural land. Accumulated sediment of ponds needs to be dug out and can be put on pond dikes or as earth-fill.

Integrated water exchange system must be developed considering the benefit of both small and large-scale shrimp farmers as well as paddy cultivators. Small-scale farmers may form an association, so that they may have access to information, and could address the problems in water management, marketing and local threats. Government should enact enforcement of the registration system for small-scale shrimp farms with training support.

Acknowledgements

The authors are grateful to DFID for providing funds to conduct the present work. They also acknowledge TROPECA project partners, Nautilus Consultants Co. Ltd. (UK), Uttaran (NGo), the Dumuria *Upazila* Fisheries officer and local farmers for their cooperation and active involvement in the study.

References

Allan, G.L.; Magurie, G.B. and Hopkins, S.J. 1990. Acute and chronic toxicity of ammonia to juvenile *Metapenaeus macleaya* and *Penaeus monodon* and influence of low dissolved oxygen levels. *Aquaculture*, 91: 265-280.

Anon. 1994. *The Environmental Management of Coastal Aquaculture*. A study of shrimp culture in southern Thailand. Network of Aquaculture Centres in Asia-pacific, Bangkok, Thailand.

Anon. 1998. *Standard Methods for the Examination of Water and Wastewater*. 20th edn., APHA (American Public Health Association), Washington DC, USA.

Anon. 2002. *FAO Yearbook of Fishery Statistics*. Aquaculture Production, Vol. 90/2. Food and Agricultural Organization of the United Nations, Rome, Italy.

Anon. 2003. '*Motshya Pakkha'*. Proceedings, Department of Fisheries, Government of Bangladesh, Dhaka, Bangladesh.

Burford, M.A. and Longmore, A.R. 2001. High ammonium production from sediments in hypereutrophic shrimp ponds. *Marine Ecology Progress*, 224: 187-195.

Chakrabarti, R.K.; Ravichandran, P.; Halder, D.D.; Mondal, S.K. and Sanfui, D. 1985. Some physico-chemical characteristics of Kakdwip brackish water ponds and their influence on the survival, growth and production of *Penaeus monodon* (Fabricius). *Indian Journal of Fisheries*, 32: 224-235.

Chang, K.C. 1990. Asian shrimp aquaculture at cross-roads. *INFOFISH International*, 5/90: 40-47. In: Muthuwan, V., Nutrient budget and water quality in intensive marine shrimp culture ponds. August 1991, M.Sc. Thesis, Asian Institute of Technology, Bangkok.

Deb, A.K. 1998. Fake blue revolution: environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. *Ocean and Coastal Management*, 41: 63-68.

Islam, M.S.; Sarker, M.J.; Yamamoto, T.; Wahab, M.A. and Tanaka, M. 2004. Water and sediment quality, partial mass budget and effluent N loading in coastal brackishwater shrimp farms in Bangladesh. *Marine Pollution Bulletin,* 48: 471-485.

Macintosh, D.J. and Philips, M.J. 1992. Environmental considerations in shrimp farming. *INFOFISH International*, 6: 38-42.

Paul, G. 1999. *Paribes 0 Dushan* (Environment and Pollution). Dasgupta and Company, Ltd., India, 323 pp.

Rouf, M.A. 2005. Practical guideline for estimation and allocation of environmental capacity for aquaculture in tropical developing countries: A Case Study for South West Coastal Part of Bangladesh. Project Report of TROPECA. Khulna University-Nautilus Consultant Co. Ltd-Stirling University-AFGRP-DFID.

Rouf, M.A. and Ali, M.S. 2005. Shrimp (*Penaeus monodon*, Fabricius) culture in Satkhira coastal area of Bangladesh. *Journal of Subtropical Agricultural Research Development*, 3(2): 75-79.

Saha, S.B.; Bhatacharyya, S.B. and Choudhury, A. 1999. Preliminary observation on culture of *Penaeus monodon* in low-saline waters. NAGA, ICLARM Q. 22: 30-33. *In*: Wahab, M.A.; Bergheim, A. and Braaten, B. 2003. Water quality and partial mass budget in extensive shrimp ponds in Bangladesh. *Aquaculture,* 218: 413-423.

Wahab, M.A.; Bergheim, A. and Braaten, B. 2003. Water quality and partial mass budget in extensive shrimp ponds in Bangladesh. *Aquaculture,* 218: 413-423.

Wahab, M.A.; Bergheim, A.; Braaten, B.; Islam, M.S. and Rahman, M.M. 2001. Observation on some of the environmental parameters of selected shrimp farms in Khulna, Bangladesh. *Bangladesh Journal of Fisheries Research,* 5(1): 75-84.

Wahab, M.A.; Braaten, B. and Bergheim, A. 2000. Water quality in extensive and semi-intensive shrimp ponds in Bangladesh. Third Aquaculure Millenium Conference, 20-25 Feb. 2000, Bankok, Thailand, 7 pp.

Wang, C.S.; Tang, K.F.J.; Kou, G.H. and Chen, S.N. 1997. Light and electron microscopic evidence of white spot disease in giant tiger shrimp, *Penaeus monodon* and kuruma shrimp, *Penaeus japonicus,* cultured in Taiwan. *Journal of Fish Disease*, 20: 323-331.