Turkish Journal of Fisheries and Aquatic Sciences 9: 91-98 (2009)

Influence of Salinity and Management Practices on the Shrimp (*Penaeus monodon*) Production and Bacterial Counts of Modified Extensive Brackishwater Ponds

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Received 16 June 2008
Accepted 14 January 2009

Abstract

The influence of salinity and management practices on the production of *Penaeus monodon* and changes in the counts of total heterotrophs (THCs), presumptive vibrios (PVCs) and luminous vibrios (LBCs) in nine modified extensive brackishwater ponds was investigated for one crop period, ranging from 102 to 132 days. The THCs ranging from 10^4 to 10^6/ml pond water and 10^5 to 10^7/g pond sediment and PVCs from 10^2-10^5/ml pond water and 10^3-10^6/g pond sediment were recorded. The LBCs were detected only in high saline ponds in the range of 10^2-10^4/ml pond water and 10^3-10^5/g pond sediment. The results of the bacterial counts of low (4-9 ppt), medium (9-15 ppt) and high (15-26 ppt) saline shrimp ponds indicated that the THCs, PVCs and LBCs of water samples are influenced by salinity and their counts increased with increase in salinity. Although the production/ha among the ponds did not vary much ($P>0.05$), the farmers were to extend the culture period by about 12-18 days in low saline and 20-30 days in medium saline ponds compared to high saline ponds to attain a harvest size of 29-30 g. The results clearly indicated the positive effect of optimum salinity on the growth and the overall health status of shrimp, despite the higher counts of heterotrophs, vibrios and luminous vibrios in pond water and pond sediment.

Keywords: *Penaeus monodon*, total heterotrophs, *Presumptive vibrios, Luminous vibrios*, shrimp production.

Introduction

Over the last decade, Indian shrimp farming industry has transformed from a traditional shrimp trapping system to a capital oriented semi-intensive system due to ever increasing consumer demand, high foreign exchange and stagnation in the wild catch. The country possesses huge brackishwater resources of over 1.2 million hectare (ha) suitable for shrimp farming; however, the total area brought under cultivation was just 157,000 ha. West Bengal is bequeathed with rich resources for aquaculture in India. It has cosmic potential for commercial farming of shrimps. Currently, around 58,000 ha are under culture in West Bengal. These brackishwater areas were reported to have salinity fluctuating between 2 and 32 ppt. The aquaculture production of shrimp in West Bengal increased from 12,370 t during the year 1990-1991 to 41,000 t in 2006-2007 (Anon, 2007). The dominant species under culture are *Penaeus monodon* followed by *Fenneropenaeus indicus* and *Metapenaeus* spp.

Rapid development of shrimp culture has been accompanied by the occurrence of diseases induced both by natural and man-made environmental changes. The important pre-disposing factors leading to disease outbreaks in shrimp culture are adverse environment, high stocking density, nutritional deficiency, inadequate aeration, insufficient water exchange, heavy algal blooms, physical injury and presence of high numbers of virulent pathogens (Alavandi *et al*., 1995). Bacteriology of cultured shrimp and the environment in Texas (Vanderzant *et al*., 1971), Sri Lanka (Fonseka, 1990), South-East Asian countries (Peranginangin *et al*., 1992; Sung *et al*., 2001) and South India (Sharmila *et al*., 1996; Otto *et al*., 1999) have been reported. The baseline data on bacteriological aspects of West Bengal penaeid shrimp pond environment under optimal to sub-optimal growth conditions are scanty. Therefore, this study was taken up to investigate the changes in bacterial counts of modified extensive shrimp grow-out ponds with varied salinity regime.

Materials and Methods

Study area and Farming Practices

In West Bengal, India, the North 24 Parganas, South 24 Parganas and East Midnapore districts have vast potential areas suitable for aquaculture, where shrimps are cultured by extensive, modified extensive and semi-intensive methods. Modified extensive brackishwater grow-out ponds culturing *Penaeus monodon* in three locations of Contai region (Lat 21°48' N, Long 87°45' E), East Midnapore district were selected on the basis of salinity regime and categorized as low saline (4-9 ppt), medium saline (9-15 ppt) and high saline (15-26 ppt) ponds. Three each of low saline ponds in Rasulpur, medium saline ponds in Korpura and high saline ponds in Petuaghat along the Rasulpur River, with varied management

practices, were sampled for bacteriological and physicochemical analyses between 2002 and 2003. The details of farming and management practices followed in these modified extensive shrimp grow-out ponds are tabulated in Table 1.

Collection of Pond Water and Pond Sediment

Samples of water and sediment from nine *P. monodon* grow-out ponds with varied salinity were collected on monthly intervals for one crop period ranging from 102 to 132 days. The final sampling was, however, done either on the previous day of harvest or just prior to harvest. Pond water samples were collected in sterilized polypropylene bottles of 250 ml capacity at a depth of about 20 cm. Pond sediment was collected at four places, viz., near the inlet, close to outlet, pond center and close to feeding tray in each pond using sterilized plastic corers and transferred immediately to a U-V sterilized polythene bag and mixed thoroughly. All the samples were placed in insulated containers and brought to the laboratory within 12-18 h of collection. Samples of pond water and pond sediment for physicochemical analyses were also collected separately as above from each pond.

Physico-chemical Analyses

The physico-chemical parameters of water such as temperature by mercury thermometer, transparency by Sacchi disc, pH by digital pH meter (Hanna, Portugal), salinity by refractometer (Erma, Japan) and redox potential or oxidation-reduction potential (ORP) by ORP meter (Hanna, Portugal) were measured at site. The dissolved oxygen (DO) was determined by Winkler's method (APHA / AWWA / WEF, 1998). The total organic carbon (TOC) content of sediment was determined by the method of Walkley and Black (1934). Soil pH was measured by sediment pH meter (ESICO, India).

Bacteriological Analyses

The enumeration of bacterial population of pond water and sediment samples was by spread plating. Aliquots (0.1 ml each) of water samples diluted in 1% saline were spread on to the nutrient agar (NA), seawater complex (SWC) agar and thiosulphate citrate bile salt sucrose (TCBS) agar, respectively for the enumeration of total heterotrophic counts (THCs), luminous bacterial counts (LBCs) and presumptive vibrio counts (PVCs) as described elsewhere (Abraham *et al*., 2003; Abraham and Palaniappan, 2004) and incubated at 30±2°C for 24-48 h to count the colony forming units (cfu). Likewise, the thoroughly mixed sediment sample from each pond was diluted in 1% saline and aliquots (0.1 ml each) of suitably diluted sediment samples were spread on to NA, SWC TCBS agar, respectively for the enumeration of THCs, LBCs and PVCs

Monitoring of Shrimp Health Status

About 50 shrimps were collected, on each sampling day, using four throws of cast net at different sites of a pond. The shrimps were examined at site for behavioural changes, abnormalities, gross and clinical signs of diseases (Lightner, 1977) and their severity (Lightner, 1993).

Shrimp Production and Determination of Food Conversion Ratio

The details on average body weight, survival percentage and shrimp production from the modified extensive low saline (4-9 ppt), medium saline (9-15 ppt) and high saline (15-26 ppt) grow-out ponds were collected from the farm records. The food conversion ratio (FCR) was calculated by dividing the total feed consumed on dry weight basis (kg) by growth in terms of wet weight gain (kg).

Statistical Analyses

The results of the bacterial counts were processed by log transformation. ANOVA and simple correlation were carried out using Microsoft Excel Statistical Package.

Results

Physico-Chemical Parameters

The range and mean values of physico-chemical parameters of low, medium and high saline shrimp grow-out ponds are presented in Table 2. The temperature of pond water ranged between 28 and 32.5°C in all systems with a mean of about 31°C. The dissolved oxygen (DO) values varied from 5.84 to 7.10 mg/L in low and high saline ponds and from 4.02 to 6.10 mg/L in medium saline ponds. The pH and transparency values of water samples were observed to vary between 7.02 and 8.80, and 15 and 62 cm, respectively. The redox potential values were always above +49 mV, with a maximum of +246 mV. The pond sediment pH and TOC values varied between 6.80 and 9.30, and 0.11 and 0.86%, respectively (Table 2).

Bacteriology

The results of the THCs, LBCs and PVCs of pond water and pond sediment samples of low, medium and high saline modified extensive shrimp grow-out ponds are presented in Tables 3-5. The low saline ponds recorded THCs in the range of 2.85×10^4-7.40×10^5/ml pond water and 1.06×10^6-1.94×10^7/g

Table 1. Details of *Penaeus monodon* farming in the brackishwater modified extensive culture system of West Bengal, India

Particulars	Low saline ponds (4-9 ppt)			Medium saline ponds [a] (9-15 ppt)			High saline ponds (15-26 ppt)		
	Pond 1	Pond 2	Pond 3	Pond 1	Pond 2	Pond 3	Pond 1	Pond 2	Pond 3
Pond area (ha)	0.20	0.40	0.40	0.0992	0.1285	0.11	0.28	0.38	0.35
Source water	Rasulpur River	Rasulpur River	Rasulpur River	Rasulpur canal	Rasulpur canal	Rasulpur canal	Rasulpur River[b]	Rasulpur River[b]	Rasulpur River[b]
Numbers stocked	20,400	40,000	40,000	11,700	17,800	11,200	24,000	36,000	36,000
Stocking density (no/m^2)	10.20	10.00	10.00	11.79	13.85	10.18	8.57	9.47	10.29
Source of seed	Hatchery and wild	Hatchery and wild	Hatchery and wild	Hatchery and wild	Hatchery and wild	Hatchery and wild	Hatchery	Hatchery	Hatchery
Aeration[c]	+	+	+	-	-	-	+	+	+
Water exchange (%)[d]	5	5	5	0	0	0	5-10	5	5-10
Feed, Brand	CP Aqua, Water Base	Water Base	CP Aqua	CP Aqua	Avanti	Wockhardt	Water Base	CP Aqua	CP Aqua
Feeding method (numbers)	Feed trays (3)	Feed trays (4)	Feed trays (4)	Feed trays (2) and broadcast	Feed trays (2) and broadcast	Feed trays (2) and broadcast	Feed trays (3)	Feed trays (4)	Feed trays (4)
Water depth (m)	1.00	1.00	1.20	1.80	2.00	1.70	1.00	1.00	1.10

a: Filling and draining by pumping as there were no inlet and outlet; b: Lower reaches of Rasulpur River; c: By pumping; d: Need based, after one month of stocking

Table 2. Range and mean values of physicochemical parameters of shrimp culture ponds during culture operation

Location of the ponds	Pond number	Parameters							
		Water						Sediment	
		Temperature (ºC)	Dissolved oxygen (mg/L)	pH	Salinity (ppt)	Transparency (cm)	Redox potential (mV)	pH	Total organic carbon (%)
Rasulpur, Midnapore (East) - Low saline	Pond 1	30.00-31.50 (30.9±0.63)	6.04-6.94 (6.61±0.39)	7.02-8.60 (7.93±0.81)	4.40-8.90 (6.68±1.27)	22.00-42.00 (32.25±8.42)	60.00-103.00 (74.25±19.47)	6.80-9.20 (8.40±1.10)	0.56-0.62 (0.58±0.02)
	Pond 2	30.00-31.00 (30.5±0.58)	5.84-6.70 (6.26±0.36)	7.50-8.80 (8.12±0.59)	4.20-9.00 (6.61±1.35)	20.00-43.00 (30.75±9.57)	59.00-71.00 (65.00±5.48)	6.80-9.30 (8.38±1.16)	0.50-0.65 (0.56±0.06)
	Pond 3	28.00-32.00 (30.75±1.89)	6.25-6.95 (6.67±0.30)	7.50-8.60 (7.93±0.50)	4.00-9.00 (5.98±1.39)	15.00-45.00 (27.00±12.75)	49.00-84.00 (74.25±16.94)	6.80-9.10 (7.88±1.15)	0.22-0.70 (0.43±0.24)
Korpora, Midnapore (East) - Medium saline	Pond 1	30.00-31.00 (30.43±0.32)	5.27-6.10 (5.68±0.35)	8.20-8.60 (8.30±0.19)	9.50-15.00 (11.82±2.28)	20.00-45.00 (30.85±10.78)	71.00-116.00 (101.75±10.73)	8.00-9.10 (8.34±0.42)	0.22-0.65 (0.41±0.17)
	Pond 2	30.20-32.10 (31.10±0.62)	5.25-5.95 (5.53±0.36)	7.62-8.55 (8.32±0.43)	9.50-15.00 (12.12±2.73)	23.00-45.00 (39.12±10.61)	69.00-110.00 (97.75±11.48)	8.10-9.10 (8.45±0.39)	0.24-0.57 (0.35±0.08)
	Pond 3	31.00-32.50 (31.75±0.57)	4.02-4.84 (4.35±0.30)	7.60-8.50 (8.10±0.31)	9.00-15.00 (12.25±1.56)	20.00-35.00 (29.85±2.36)	67.00-107.00 (87.81±15.69)	8.00-9.00 (8.43±0.36)	0.11-0.86 (0.34±0.19)
Petuaghat, Midnapore (East) - High saline	Pond 1	30.00-32.00 (31.10±0.78)	6.27-7.10 (6.78±0.36)	8.30-8.70 (8.50±0.18)	18.50-26.00 (21.88±3.08)	16.00-45.00 (30.75±11.87)	71.00-246.00 (120.75±83.73)	8.10-9.20 (8.43±0.52)	0.27-0.65 (0.46±0.19)
	Pond 2	30.00-32.00 (31.00±0.82)	6.25-6.95 (6.53±0.30)	7.60-8.80 (8.35±0.53)	19.50-25.00 (21.92±2.73)	23.00-45.00 (39.00±10.71)	49.00-200.00 (87.75±74.84)	8.20-9.10 (8.58±0.39)	0.22-0.27 (0.25±0.03)
	Pond 3	30.00-32.00 (31.00±0.82)	6.31-7.10 (6.58±0.35)	7.60-8.60 (8.10±0.48)	15.00-24.50 (21.00±4.18)	44.00-62.00 (53.50±8.06)	49.00-142.00 (81.25±43.65)	8.10-8.40 (8.23±0.13)	0.27-0.59 (0.43±0.18)

Table 3. Changes in the bacterial counts of low saline (4-9 ppt) brackishwater modified extensive shrimp ponds

Days of culture	Pond 1 (0.2 ha)			Pond 2 (0.4 ha)			Pond 3 (0.4 ha)		
	THC	PVC	LBC	THC	PVC	LBC	THC	PVC	LBC
Pond water	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml
0 – 7	3.05×10^4	$<1.00 \times 10^2$	$<1.00 \times 10^2$	7.25×10^4	$<1.00 \times 10^2$	$<1.00 \times 10^2$	3.50×10^4	$<1.00 \times 10^2$	$<1.00 \times 10^2$
30 – 37	2.18×10^5	2.00×10^2	$<1.00 \times 10^2$	4.10×10^4	$<1.00 \times 10^2$	$<1.00 \times 10^2$	2.85×10^4	4.00×10^2	$<1.00 \times 10^2$
60 – 67	1.11×10^5	2.20×10^2	$<1.00 \times 10^2$	4.60×10^4	$<1.00 \times 10^2$	$<1.00 \times 10^2$	6.35×10^4	1.60×10^2	$<1.00 \times 10^2$
90 – 97	7.40×10^5	2.70×10^2	$<1.00 \times 10^2$	1.09×10^5	3.40×10^2	$<1.00 \times 10^2$	4.70×10^5	6.00×10^1	$<1.00 \times 10^2$
114 – 120	2.10×10^5	3.00×10^2	$<1.00 \times 10^2$	3.20×10^5	2.70×10^2	$<1.00 \times 10^2$	5.20×10^5	1.70×10^2	$<1.00 \times 10^2$
Pond sediment	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g
0 – 7	1.63×10^6	2.00×10^3	$<1.00 \times 10^3$	1.56×10^6	$<1.00 \times 10^3$	$<1.00 \times 10^3$	1.96×10^6	2.00×10^3	$<1.00 \times 10^3$
30 – 37	1.27×10^7	2.00×10^3	$<1.00 \times 10^3$	2.93×10^6	2.30×10^3	$<1.00 \times 10^3$	4.15×10^6	2.40×10^3	$<1.00 \times 10^3$
60 – 67	4.60×10^6	$<1.00 \times 10^3$	$<1.00 \times 10^3$	2.67×10^6	$<1.00 \times 10^3$	$<1.00 \times 10^3$	1.94×10^7	$<1.00 \times 10^3$	$<1.00 \times 10^3$
90 – 97	1.06×10^6	1.10×10^3	$<1.00 \times 10^3$	1.99×10^6	7.30×10^3	$<1.00 \times 10^3$	2.18×10^6	6.20×10^3	$<1.00 \times 10^3$
114 – 120	8.00×10^6	1.60×10^3	$<1.00 \times 10^3$	4.10×10^6	6.00×10^3	$<1.00 \times 10^3$	1.80×10^7	7.50×10^3	$<1.00 \times 10^3$

THC: Total heterotrophic counts; PVC: Presumptive vibrio counts; LBC: Luminous bacterial counts

Table 4. Changes in the bacterial counts of medium saline (9-15 ppt) brackishwater modified extensive shrimp grow-out ponds

Days of culture	Pond 1 (0.0992 ha)			Pond 2 (0.1285 ha)			Pond 3 (0.11 ha)		
	THC	PVC	LBC	THC	PVC	LBC	THC	PVC	LBC
Pond water	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml
0 – 15	1.50×10^5	1.00×10^3	$<1.00 \times 10^2$	3.68×10^5	$<1.00 \times 10^2$	$<1.00 \times 10^2$	2.60×10^5	1.00×10^4	$<1.00 \times 10^2$
30 – 45	3.00×10^5	5.00×10^3	$<1.00 \times 10^2$	4.35×10^5	$<1.00 \times 10^2$	$<1.00 \times 10^2$	3.85×10^5	1.00×10^4	$<1.00 \times 10^2$
60 – 75	1.20×10^5	1.00×10^4	$<1.00 \times 10^2$	5.70×10^5	2.00×10^3	$<1.00 \times 10^2$	1.63×10^5	3.54×10^4	$<1.00 \times 10^2$
90 – 105	1.90×10^5	3.20×10^3	$<1.00 \times 10^2$	5.00×10^5	4.80×10^4	$<1.00 \times 10^2$	1.26×10^6	1.00×10^5	$<1.00 \times 10^2$
122 – 132	3.90×10^5	2.03×10^3	$<1.00 \times 10^2$	9.85×10^5	5.50×10^3	$<1.00 \times 10^2$	1.10×10^6	1.00×10^5	$<1.00 \times 10^2$
Pond sediment	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g
0 – 15	3.20×10^6	$<1.00 \times 10^4$	$<1.00 \times 10^3$	1.72×10^6	7.50×10^3	$<1.00 \times 10^3$	1.75×10^6	1.00×10^3	$<1.00 \times 10^3$
30 – 45	2.10×10^6	$<1.00 \times 10^4$	$<1.00 \times 10^3$	3.20×10^6	1.00×10^4	$<1.00 \times 10^3$	2.00×10^6	5.00×10^3	$<1.00 \times 10^3$
60 – 75	2.90×10^6	$<1.00 \times 10^4$	$<1.00 \times 10^3$	4.40×10^6	1.00×10^4	$<1.00 \times 10^3$	2.80×10^6	1.00×10^4	$<1.00 \times 10^3$
90 – 105	1.60×10^6	1.80×10^4	$<1.00 \times 10^3$	1.10×10^6	1.10×10^4	$<1.00 \times 10^3$	1.13×10^6	1.00×10^4	$<1.00 \times 10^3$
122 – 132	6.80×10^5	7.50×10^3	$<1.00 \times 10^3$	1.75×10^6	1.20×10^4	$<1.00 \times 10^3$	2.03×10^6	1.10×10^4	$<1.00 \times 10^3$

THC: Total heterotrophic counts; PVC: Presumptive vibrio counts; LBC: Luminous bacterial counts

Table 5. Changes in the bacterial counts of high saline (15-26 ppt) brackishwater modified extensive shrimp grow-out ponds

Days of culture	Pond 1 (0.28 ha)			Pond 2 (0.38 ha)			Pond 3 (0.35 ha)		
	THC	PVC	LBC	THC	PVC	LBC	THC	PVC	LBC
Pond water	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml	Cfu/ml
0 – 7	3.10×10^5	8.00×10^3	$<1.00 \times 10^2$	4.80×10^5	2.90×10^4	$<1.00 \times 10^2$	3.75×10^5	8.00×10^3	$<1.00 \times 10^2$
35 – 42	4.90×10^5	2.15×10^4	1.00×10^4	7.00×10^5	4.10×10^4	2.00×10^3	1.12×10^6	1.20×10^4	3.00×10^3
60 – 67	3.40×10^5	1.50×10^4	5.00×10^2	1.10×10^6	2.00×10^5	5.50×10^2	9.70×10^5	1.50×10^4	2.00×10^2
85 – 92	8.10×10^5	7.10×10^4	7.00×10^2	7.20×10^5	5.50×10^4	4.50×10^2	1.20×10^6	6.00×10^4	6.00×10^2
102 – 104	6.90×10^5	8.00×10^4	9.00×10^2	1.10×10^6	9.00×10^4	7.00×10^2	2.30×10^6	1.50×10^5	8.00×10^2
Pond sediment	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g	Cfu/g
0 – 7	5.90×10^5	3.00×10^4	$<1.00 \times 10^3$	9.20×10^5	5.00×10^4	$<1.00 \times 10^3$	3.50×10^5	1.00×10^4	$<1.00 \times 10^3$
35 – 42	9.30×10^5	4.00×10^4	$<1.00 \times 10^3$	6.45×10^5	9.00×10^4	3.50×10^4	3.80×10^6	5.00×10^4	$<1.00 \times 10^3$
60 – 67	1.60×10^6	3.50×10^4	1.00×10^3	2.00×10^6	4.50×10^5	1.50×10^4	4.30×10^6	6.00×10^4	1.00×10^4
85 – 92	7.10×10^6	1.40×10^5	4.00×10^4	4.30×10^6	8.00×10^5	3.00×10^4	7.60×10^6	1.25×10^5	7.00×10^4
102 – 104	6.70×10^6	3.10×10^5	6.50×10^4	5.80×10^6	1.00×10^6	9.00×10^4	2.80×10^7	3.10×10^6	1.00×10^5

THC: Total heterotrophic count; PVC: Presumptive vibrio counts; LBC: Luminous bacterial counts

pond sediment. The PVCs were observed to be in the range of $<1.00x10^2$-$4.00x10^2$/ml pond water and $<1.00 \times 10^3$-7.50×10^3/g pond sediment (Table 3).

In medium saline shrimp ponds, the THCs in the range of 1.20×10^5-1.26×10^6/ml pond water and 6.80×10^5-4.40×10^6/g pond sediment were recorded. The counts of presumptive vibrios were in the range of $<1.00 \times 10^2$-1.00×10^5/ml of pond water and 1.00×103-1.80×10^4/g of pond sediment (Table 4). The LBCs could not be detected in the lowest dilution tried in water and sediment samples of low (Table 3) and medium saline ponds (Table 4).

The high saline shrimp grow-out ponds had higher counts of presumptive vibrios (8.00×10^3 - 2.00×10^5/ ml and 1.00×10^4-3.10×10^6/g) and luminous vibrios ($<1.00 \times 10^2$-1.00×10^4/ml and $<1.00 \times 10^3$-1.00×10^5/g). The counts of luminous vibrios were observed to be high in all the high saline ponds at around 40 days of culture. The THCs were recorded in the range of 3.10×10^5-2.30×10^6/ml pond water and 3.50×10^5-2.80×10^7/g pond sediment (Table 5).

There existed highly significant differences in the THCs of water samples among the grow-out ponds of different salinity regime ($P<0.000001$)) and among the days of culture ($P<0.0002$). Significant differences in the THCs also existed among the medium saline ($P<0.02$) and high saline ($P<0.01$) grow-out ponds. The differences among the THCs of pond sediment samples from different salinity regime were insignificant ($P>0.05$). However, the differences in the THCs of sediment with days of culture (DOC) were significant ($P<0.02$). Likewise, significant differences were observed in the PVCs of water samples among the ponds ($P<0.002$) and DOC ($P<0.000001$), and also of sediment samples among the ponds ($P<0.0001$) and DOC ($P<0.000001$). The levels of LBCs did not vary much ($P>0.05$) among the high saline ponds, but differences were noted with DOC ($P<0.0001$). The correlations between the salinity and THCs, and salinity and vibrios were statistically significant ($P<0.05$).

Shrimp Production

There were no abnormalities and diseases in low and high saline ponds and the overall health status of shrimp was good. A very few scattered presence of epicommensals with severity grade ranging from 0-0.5 was noticed on shrimps of all the ponds with increasing DOC. The shrimps of medium saline ponds, however, experienced stress due to lack of oxygen and mortalities. The FCR (1:1.08-1:1.10) and survival (87-91%) in high saline ponds were better than the low saline (1:1.26-1:1.46; 76-87%) ponds. On the other hand, the medium saline ponds, which were about 1.7-2.0 m deep, had no provision for water inlet and outlet for effective water exchange and also for aeration, recorded low survival (60-75%) and high FCR (1:1.36-1:1.49). The crops were successful and the production/ha achieved was in the range of 2067-2595 kg in low saline, 2273-2490 kg in medium saline and 2200-2650 kg in high saline ponds (Table 6). The differences in shrimp production among the three categories of ponds were insignificant ($P>0.05$).

Discussion

The intensification coupled with unscientific farming practices has led to serious environmental and shrimp health related problems in most of the farms. Successful shrimp farming depends on maintaining salinity, pH, DO and other water and soil quality parameters in appropriate ranges. Temperature is an important component, which greatly influences and directly affects the pond dynamics, controls the effect on the rates of both food consumption and metabolism and the growth (Wootton, 1996). The present study recorded temperature within the optimum level (26-32°C) recommended for *P. monodon* culture (Chiu, 1988) in the ponds of all categories (Table 2). Das and Saksena (2001) noted an inverse significant correlation of temperature with the growth and the low temperature negatively impacted shrimp metabolism. Although the DO values were always above 4 ppm, it was comparatively low in medium saline ponds as there was no provision for water exchange and aeration (Tables 1 and Table 2). Critical oxygen level can hamper the production and survivability of shrimp as was observed in medium saline ponds (Table 6). The DO content of water in shrimp ponds is influenced by quantity of flushing of freshwater, tidal flow, temperature, salinity, algal growth and organic matter decomposition. The balance between the autotrophic and heterotrophic productions in brackishwater

Table 6. Details of *Penaeus monodon* production from brackishwater modified extensive grow-out ponds

Particulars	Low saline ponds (4-9 ppt)			Medium saline ponds (9-15 ppt)			High saline ponds (15-26 ppt)		
	Pond 1	Pond 2	Pond 3	Pond 1	Pond 2	Pond 3	Pond 1	Pond 2	Pond 3
Total days of culture	114	114	120	132	122	127	104	104	102
Average body weight* (g)	29.50	28.25	27.20	30.00	30.00	29.50	29.50	29.00	29.00
Survival (%)	86.20	87.00	76.00	65.50	59.90	75.60	86.90	91.00	89.00
Total production/pond (kg)	519	983	827	230	320	250	615	950	930
Total production/ha (kg)	2595	2458	2067	2318	2490	2273	2200	2500	2650
Food conversion ratio	1:1.26	1:1.32	1:1.46	1: 1.44	1:1.49	1:1.36	1:1.10	1:1.08	1:1.09

*: At the time of harvest

shrimp culture ponds determines the oxygen dynamics (Chiu, 1988). Although the redox potential values of pond water fluctuated greatly possibly due to varying organic load and the demand for oxygen, it remained always on the positive side between 49 and 246 mV (Table 2) thus, indicating the overall health status of these ponds.

The water pH values recorded in all the ponds (Table 2) were, however, slightly deviating from the optimum range recommended (7.5-8.5) for ideal shrimp culture (Chiu, 1988). Das and Saksena (2001) observed a direct correlation ($P<0.01$) between pH and salinity, and growth of *P. monodon*. The transparency values were generally low during the monsoon months which might have been caused by the addition of surface run off through rainfall. Nevertheless, the mean values of different ponds were well within the recommended transparency values for shrimp culture (20-40 cm), except the pond 3 of Petuaghat. Das *et al*. (2001) in their studies in the coastal belt of Orissa, India observed that the growth of *P. monodon* was significantly related with dynamics of transparency because higher values of transparency caused more photosynthetic activities leading to the availability of more natural food. Although the optimum salinity suitable for shrimp culture is about 15-25 ppt (Boyd, 1995) which is vital for pond dynamics, the shrimps were grown in salinities between 4 and 26 ppt in West Bengal, India (Table 2). Likewise, in an earlier study also the salinity range of 6.5-25.5 ppt favoured the growth of *P. monodon* (Das *et al*., 2001). The higher levels of salinity recorded during the summer months were well within the optimum limit. But, during the monsoon months the values reduced to 4 ppt in Rasulpur region and the role of fall in salinity might bear close relationship with fall in THCs and PVCs (Tables 3-5).

The pond sediment pH values ranged from slightly acidic (6.80) to highly alkaline (9.30). These are probably the results of acidic nature of the soil and/or the practice of addition of lime or lime stone powder during the course of shrimp culture. The results of the present study are, more or less, in conformity with Chakraborti *et al*. (1986) and Chattopadhyay and Mondal (1986). The observed increase in TOC (Table 2) together with bacterial counts (Tables 3-5) with DOC may probably be the result of accumulation of organics on pond bottom. These results corroborate the findings of Sharmila *et al*. (1996) and defer with those of Boyd (1992) who reported 1.5 - 2.5% TOC in shrimp pond soil.

The ranges of THCs recorded in West Bengal modified extensive shrimp grow-out ponds (Tables 3-5) are within the levels reported earlier in India (Sharmila *et al*., 1996; Prabhu *et al*., 1999; Otta *et al*., 1999) and South-East Asia (Peranginangin *et al*., 1992; Sung *et al*., 2001). Relatively high THCs to the tune of 1.2×10^8/g and 2.23×10^8/g sediment of shrimp culture ponds were noticed in Tamil Nadu, India (Prabhu *et al*., 1999) and South-East Asia (Paranginangin *et al*., 1992), respectively. Otta *et al*. (1999) documented THCs ranging from 10^3 to 10^5/ml and PVCs from 10^1 to 10^4 /ml from *P. monodon* culture ponds of east and west coast of India. Further, the THCs recorded in shrimp pond sediment samples were higher than in water so also the PVCs, probably due to continuous availability of substrate and nutrients in the form of unconsumed feed, shrimp excreta, dead plankton and other organic and inorganic matter on the pond bottom. The fact is that the sediment gives shelter to both planktonic and biofilm forming bacteria, while water column contain only planktonic (free living) bacteria. The salinity levels showed significant positive correlation ($P<0.05$) with THCs and vibrios. The high saline modified extensive ponds had more vibrios including luminous vibrios. The results are in conformity with Abraham *et al*. (2003), who reported salinity dependant distribution of luminous vibrios in shrimp farms. The dominance of luminous bacteria within first 32-42 DOC possibly indicate shift in bacterial abundance within the high saline ponds and conform the observations of Lavilla-Pitogo *et al.* (1998). The results of the quantitative bacterial counts of three different salinity regime shrimp ponds (Table 3, Table 5) indicated that the THCs, PVCs and LBCs of water samples are influenced by salinity and their counts increased with increase in salinity. In the brackishwater environments, wide variations in THCs occur due to many factors. Colwell and Morita (1974) demonstrated values ranging between 10^2 and 10^5/ml for any given day and location and no predictable pattern of these fluctuations in marine near-shore environments. Similar results were recorded in the shrimp grow-out ponds of this study.

As shown in Table 6, the culture period decreased with increase in salinity and the shrimp production and FCR were affected by management practices. The stocks of *P. monodon* attained the size of about 29 g in 102–104 days in high saline grow-out ponds compared to 114-120 days in low saline and 122–132 days in medium saline ponds. The crops were successful and the production/ha achieved was 2373±223 kg in low saline, 2360±93 kg in medium saline and 2450±187 kg in high saline ponds. The results of shrimp production of the present study conform to the observations of Saha *et al*. (1999) recorded in Sunderbans regions of West Bengal. Although the production/ha among the three categories of ponds did not vary much ($P>0.05$), the farmers were to extend the culture period by about 12 –18 days in low saline and 20-30 days in medium saline ponds and to incur additional operational expenditure compared to high saline ponds to achieve a harvest size of 29-30 g. Despite the higher counts of heterotrophs, vibrios and luminous vibrios in pond water and pond sediment, the results clearly indicated the positive effect of optimum salinity on the growth and the overall health status of shrimp as has been observed earlier (Das *et al.*, 2001; Das and Saksena, 2001).

Acknowledgement

The Indian Council of Agricultural Research, Government of India, New Delhi under the National Agricultural Technology Project financed this study.

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