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Zero-water exchange shrimp farming systems (extensive) in the periphery of Chilka lagoon, Orissa, India

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Abstract. The extensive zero-water exchange shrimp farming system in the periphery of Chilka lagoon (Orissa, India) was studied. The study aimed to describe this unique farming system with special reference to dynamics of macrozoobenthos, production characteristics and economics. The study conducted was based on a general survey as well as monitoring of five individual farms over a complete production cycle. The farming practice in this area is characterized by complete absence of water exchange during rearing. Ponds in this area are generally shallow (mean 72 cm). Most of the water and soil quality characteristics of these farms are within acceptable levels. Macrozoobenthos belonging to 12 taxa were collected, amphipods (81%) and polychaetes (13%) being most numerous. Overall macrobenthic density of farms studied varied from 968 to 11,470 individuals/m^2 with a gross mean of 5644 individuals/m^2. There was no general pattern to the variation in abundance of various taxa in different phases of the rearing cycle, suggesting a low predatory pressure by shrimp in the farms studied. Shrimp production was highly variable (91–250 kg/ha), but generally low with a mean of 145 kg/ha. The net income of these farms was estimated to be Rs. 63,250 per crop per ha. Compared with shrimp farming system with regular water exchange in the same area, Chilka farms generated high benefit-cost ratio indicating high profitability and sustainability.

Key words: Chilka lagoon, Macrozoobenthos, Shrimp farming, Zero-water exchange

Introduction

Shrimp farming has undergone an extraordinary expansion since 1980. Culture operations have progressed from extensive mixed species to intensive monospecies culture of tiger shrimp (*Penaeus monodon*). Annual global production has increased significantly during the last decade, from 50,000 mt (1990) to 642,750 mt (1999) (Rosenberry 1990

2000). This growth in production is impressive, but there have been several problems and impediments that have yet to be resolved. In most shrimp culture systems, pond water is frequently exchanged with new external water to maintain a desirable water supply for shrimp growth (Wang 1990). The nutrient laden effluent discharged from shrimp farming can cause eutrophication of coastal water and its impacts have been a major concern (Shang et al. 1998). Furthermore, shrimp pathogens appear to be transmitted horizontally through the influent water (Flegel et al. 1996). Innovative grow-out systems based on the concept of pathogen exclusion, and with little or zero water exchange are being developed (Menasveta 2002). However, most new knowledge is being generated to benefit corporate strategies rather than sustain local livelihoods (Lebel et al. 2002). It is almost certain that if shrimp farming continues to evolve as a corporate regulatory undertaking, it will never reach its potential (Costa-Pierce 2002). In order to increase its social acceptance, shrimp aquaculture needs family and community roots, in addition to corporate ones. Whilst several authors have judged shrimp farming to be unsustainable (Baird and Quarto 1994; Primavera 1998), there are farms and farming systems that have grown shrimp over many years, without apparent adverse social conflicts or environmental impacts (Phillips and Barg 1999). A low-level and low-input zero-water exchange farming system has been in existence in the periphery of Chilka lagoon (Orissa, India) since 1980 (Rajyalakshmi et al. 1988). It is estimated that 41% of total shrimp culture area in the state of Orissa is conducted under this type of farming making up 30% of total production (Anonymous 2000). Here culture technology is simple and less expensive. Most farmers are landless fishers or other marginalized members of society who have low occupational mobility and relatively little capital. Despite the socio-economic importance, few previous investigations (Mohanty and Mitra 1987; Rajyalakshmi et al. 1988; Dash and Patnaik 1994) have addressed various issues associated with this culture system. This paper addresses this general lack of information.

The present study was undertaken to characterize the extensive system of shrimp farming in the periphery of Chilka lagoon. The production characteristics and economics are described in comparison with other shrimp farms in this part of the Indian subcontinent. The examination of natural biota can give a more rapid indication of water quality and are often better and more rapid indicators of long-term water quality characteristics (Stirling 1985). This study therefore focused on gross features of development of macrozoobenthos during the rearing cycle to understand the ecology of this farming system. The results are directly applicable to the farms of Chilka lagoon, but information of potential relevance to other extensive shrimp cultivation is also given.

Materials and methods

Study site

The study was conducted in the shrimp farms at the periphery of Chilka lagoon (19° 28′ to 19° 54′ N and 85° 06′ to 85° 35′ E), India, Orissa (Figure 1). Chilka lagoon is the largest lagoon on the eastern seaboard of India, and it is one of two wetlands in India identified under the Ramsar Convention (IUCN 1987) as wetlands of international importance. On the periphery of the lake, ~5000 ha were demarcated for the development of shrimp aquaculture (Biswas 1995), and shrimp farms were constructed under various central and

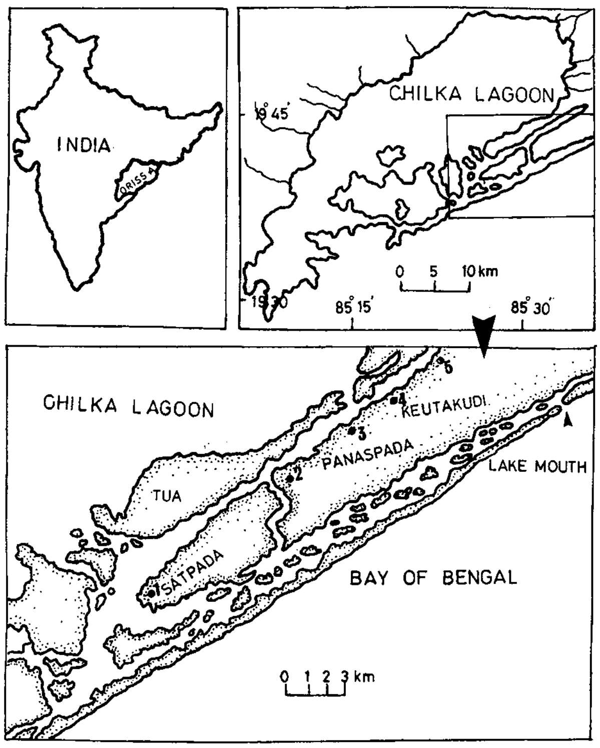

Figure 1. Location map of shrimp farms around Chilka lagoon.

state Government schemes. A total of five farms were selected as part of a general survey in this region, and morphometric and management characteristics of these farms are summarized in Table 1. All farms except farm no. 3 have a single pond, whereas farm no. 3 has 4 ponds. Ponds were treated with lime (75–400 kg/ha) before water rose in the pond. Fertilization was carried out after a few days. Among the five farms studied, farms 3 and 5 were not subjected to any type of fertilizer treatment, while in other farms either organic manure or inorganic fertilizers were used (Table 1). Wild or hatchery reared *P. monodon* seeds were stocked after one or two weeks (stocking density: 15,000–25,000 animals/ha). Shrimps were fed with snail meat or commercially available shrimp feed. Frequency and rate of feeding is given in Table 1. Selective and continuous harvest of bigger shrimps was started after 80–90 days of culture using a pound trap locally known as a 'disco-net'.

Analysis of water and soil

Water and soil samples were collected biweekly and analyzed using the following methods: temperature by mercury thermometer; salinity by potassium chromate method (Stirling 1985); transparency by Secchi disc; pH by laboratory pH meter; dissolved oxygen (DO) by Winkler method (Stirling 1985); soil organic carbon by chromic acid method of Walkey and Black (1934); soil texture by the pipette method of Krumbein and Petti John (1938) and soil conductivity by desk top conductivity meter.

Table 1. Morphometry and management practices of shrimp farms around Chilka lagoon, Orissa (India)

Farm no.	Area (ha)	Stocking density (no./ha)	Liming rate (kg/ha)	Organic manure (kg/ha)	Urea (kg/ha)	Super phosphate (kg/ha)	Feeding (kg/day)
1	0.41	25,000	25(weekly)	375	Nil	Nil	Formulated feed (0.5)
2	0.41	15,000	75	Nil	35	30	Snail meat (10)
3	5.00	15,000	150	Nil	Nil	Nil	Snail meat (10)
4	0.60	20,000	250	Nil	25	Nil	Snail meat (10)
5	0.25	25,000	185	Nil	Nil	Nil	Snail meat (10)

Analysis of macrozoobenthos

Benthic sampling was carried out biweekly throughout the rearing cycle. Macrozoobenthic fauna were collected from the upper 15 cm sediment layer using an Ekman dredge, which sampled 0.09 m^2 of the pond bottom. At each sampling period, 2–5 samples were taken from individual ponds. Samples were transferred to polyethylene bags containing pond water and brought to the laboratory for further analysis. The samples were elutriated and passed through 1.83 mm and 500 μm sieves. Animals retrieved in the 500 μm sieve were counted individually and stored in 4% formaldehyde for subsequent analysis. Later, the samples were examined for taxonomic identification.

General survey

A total of 89 shrimp farmers in the periphery of Chilka lagoon were interviewed to obtain general information on the farm management practices.

Statistical analysis

Influence of water and soil quality characteristics on the macrozoobenthos were analyzed using one-way ANOVA and Duncan's multiple range test was used to isolate differences. Data were transformed to a $\log(x+1)$ scale in order to normalize and homogenize the variance. Overall relationships between macrozoobenthic production and various water quality parameters were analyzed using linear regression analysis.

Results

Description of system and farming practices

The shrimp farming system in the periphery of Chilka lagoon is a form of extensive aquaculture. The earthen ponds, without inlet and outlet sluices, are constructed on the flat expanses of the lagoon. The ponds are filled with percolation water when the water level in the lagoon rises during the rainy season. The water turns brackish due to the highly saline nature of the soil. Once a pond is filled, one or two crops are taken from this static system. Farm area varied from 0.2 to 5 ha (mean of 0.85 ha). All farms were used exclusively for

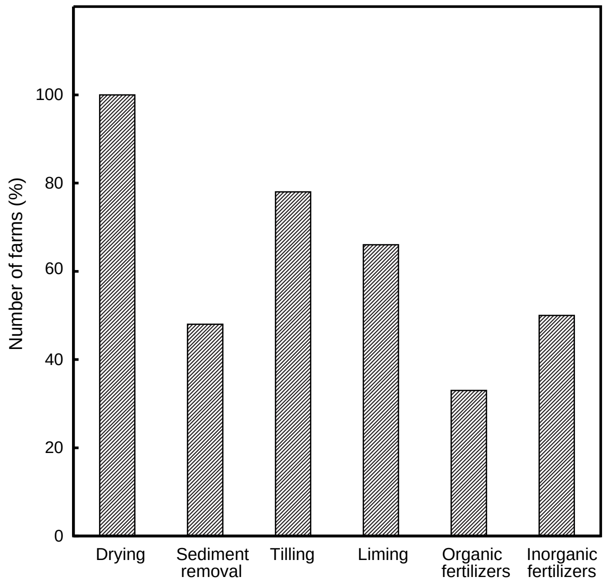

Figure 2. Common management practices in the shrimp farms in the periphery of Chilka lagoon (Orissa, India).

monoculture of *P. monodon*. The major type of land converted for farming was unutilized land bordering the lagoon (60%). Rice paddy area was the second major type of land converted to shrimp ponds. The average pond age (= the number of years since the pond was constructed) was 12 years, and more than 50% of ponds surveyed had a pond age of 10–12 years. The pond water was neither refreshed during the rearing cycle nor drained during the harvest time. Most common management practices are given in Figure 2. Stocking density averaged 2.6 animals/m^2 (range: 1.5–5 animals/m^2). Almost all farms used live feeds (snail meat) and 20% of farms used formulated feed in addition to the live feed.

Physico-chemical characteristics

Results of water and soil quality of five farms are summarized in Table 2. Shrimp farms studied here were generally shallow, averaging 72 cm (range 42–99); there was a significant variation among farms, and farm 1 had the greatest mean depth (83.6 ± 11.0 cm). Generally all the farms showed a lower level of water depth towards the end of the culture period (42–70 cm) (Figure 3). Salinity was low at the beginning

Table 2. Average concentrations, standard deviation and range of concentration for different chemical variables in the shrimp farms of Chilka during the rearing cycle (December–March). Transparency (cm) = depth of disappearance of Secchi disc

Variable	Mean	S.D.	Range
Water quality			
Temperature (°C)	24.7	1.5	20.5–26.0
Salinity (‰)	12.8	6.2	2.8–23.0
Dissolved oxygen (ppm)	6.1	0.6	4.5–7.8
pH	8.2	0.3	7.6–8.4
Alkalinity (ppm)	78.0	32.1	42.0–140.0
Transparency (cm)	42.9	12.6	16.0–64.0
Soil quality			
Organic carbon (%)	1.1	0.1	0.9–1.2
pH	7.6	0.4	0.7–8.2
Soil conductivity (ds/m)	5.9	0.4	5.4–6.4
Clay (%)	13.5	2.5	10.0–17.5
Silt (%)	16.5	17.6	0–50.0
Sand (%)	70.0	17.8	37.5–87.5

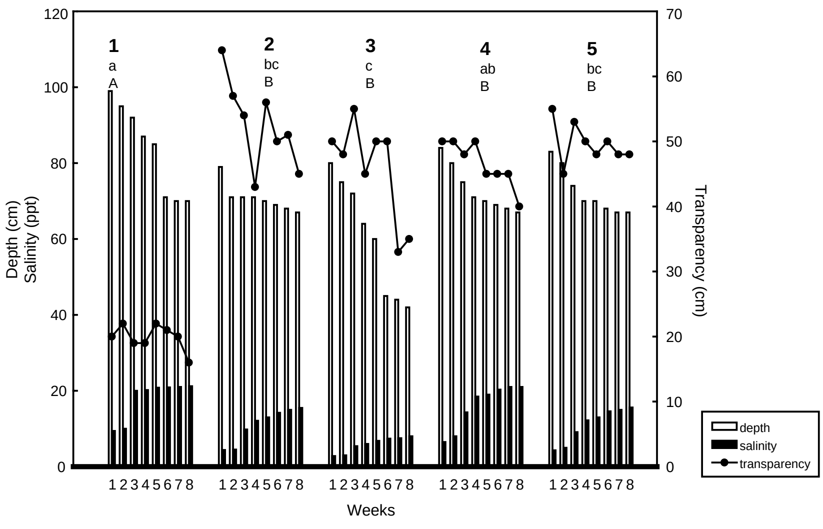

Figure 3. Plots of variation in depth, salinity and Secchi disc transparency in shrimp farms in the periphery of Chilka lagoon during the rearing cycle. Arabic numerals indicate the farm identification numbers. Common letter denote (lower case letters refer to salinity and upper case letters for Secchi disc transparency) no significant difference at the 5% level by Duncan's multiple range test.

of the rearing cycle (2.8–9.4 ppt), and subsequently increased steadily in all the ponds (Figure 3). Except farms 1 and 4, all the farms had an average salinity below 12 ppt (6.2–11.3 ppt). There was a significant difference in the salinity among farms, and farm 1 had highest mean salinity (18.2; S.D. = ± 4.9). All the farms except farm 1 showed a high Secchi disc transparency, whereas farm 1 had significantly low transparency (19.8 ± 1.8 cm) (Figure 3). Average alkalinity in all the farms were above 50 ppm (Table 2), and with a significantly higher alkalinity in farm 1 (110.6 ± 27.6). Water temperature (20.5–26.0°C), pH (4.6–7.8) and Dissolved Oxygen (D.O.) (4.5–7.8) remained relatively uniform during the rearing cycle. The average pond bottom soil texture was sandy silt with low clay content (13.5 ± 2.5%) and high proportion of sand (70 ± 17.8%). Overall average concentrations of carbon of soil were 1.1% and there was no significant variation over the rearing cycle or between farms. Generally the bottom soil was found to be alkaline and saline (5.9 ± 0.4 ds/m).

Macrozoobenthos

Twelve taxa of macrozoobenthos were identified in the farms around Chilka lagoon through the rearing cycle (Table 3). The dominant taxa were amphipods (81%) and polychaetes (13%). Whilst amphipods were dominant in the farms 1, 4 and 5, constituting 76–95% of the total count, the remaining farms were dominated by polychaetes (Figure 4). There was no general pattern to the variation in abundance of various taxa in different phases of the rearing cycle. In farms 4 and 5, amphipods were the major component throughout the rearing cycle whereas farms 1 and 2 amphipods dominated in the first two months of culture period only (Figure 5). Gastropods were the minor component in all the samples through out the rearing cycle.

Mean macrozoobenthic density of farms varied from 968 to 11,470 individuals/m^2 (with an overall mean of 5644 individuals/m^2) over the study period, and a significant variation was recorded among farms (Figure 6). Highest mean density was recorded in farm 1 (mean 11,470; S.D. ± 8517) followed by farm 4 (10,323 S.D. ± 7719). Almost all farms except farm 3 showed a decline in density during the mid-rearing cycle, but thereafter there was an increase until the end of the culture period. Analysis of correlation between macrobenthic density and salinity of pond water indicated a significant, but poor relationship at 5% level ($r = 0.33$, $P < 0.05$) (Figure 7a). Macrobenthic density was negatively related to Secchi disc transparency ($r = -0.038$, $P < 0.05$) (Figure 7b).

Table 3. List of macrobenthos recorded in shrimp farms around Chilka lagoon during 120-day rearing cycle. Taxa are reported as percentage of occurrence within the taxonomic group. % by numbers = contribution of taxa to the total numbers of macrozoobenthos recorded through out the rearing period. % Frequency of occurrence = percentage of Ekman dredge sample in which taxa was recorded

Taxa	% by number	Frequency(%)
Polychaeta		
Capitellidae	7.1	35.4
Sabellidae	4.1	12.9
Glyceridae	0.7	3.2
Spionidae	0.8	6.5
Terebellidae	0.8	12.9
Eunicidae	< 0.1	3.2
Oligochaeta	< 0.1	2.6
Amphipoda		
Gammaridae	80.6	80
Caprellidae	0.8	10.5
Decapod larvae	0.8	8.6
Gastropoda		
Cyclostrematidae	2.1	22.8
Epitoniidae	1.4	2.3
Atyidae	< 0.1	2.5

Production

Shrimp production was highly variable among farms, and generally low with a mean of 145 kg/ha (Table 4). Farm 1 was particularly successful with a yield of 250 kg/ha, 1.7 times greater than the average. The survival rate was comparatively low (22.2–32.9%) in all farms, whereas body weight was moderately high in all farms (25.0–30.4 g). Economic analysis of the zero-water exchange system of Chilka lagoon and a modified extensive farming system in the same state are given in Table 5. The systems yielded different levels of production, and Chilka farms generated lower total revenue. Nevertheless, they had lower total operating costs, thereby generating a higher benefit-cost ratio (3.7), almost twice that of conventional systems (Table 5).

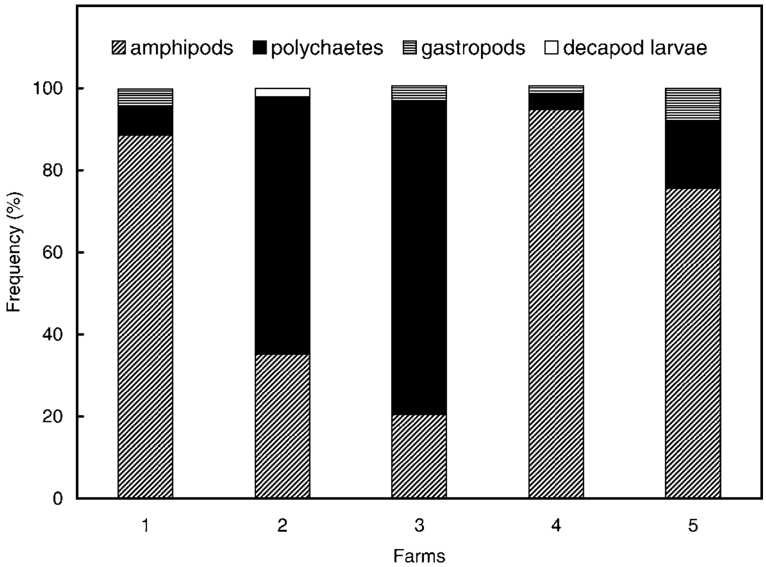

Figure 4. Percentage distribution of major taxa of macrozoobenthos in the farms around Chilka lagoon during the entire culture period.

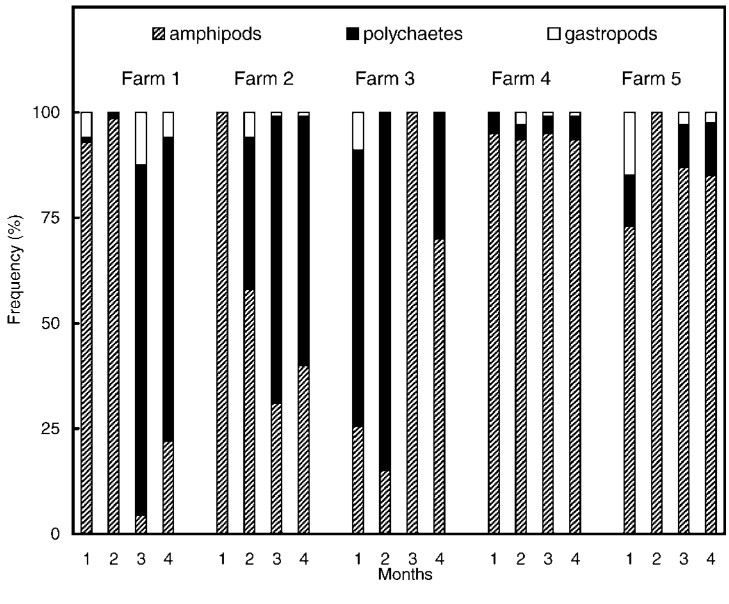

Figure 5. Variation in major taxonomic groups of macrozoobenthos in shrimp farms at the periphery of Chilka lagoon at 30-day interval of stocking.

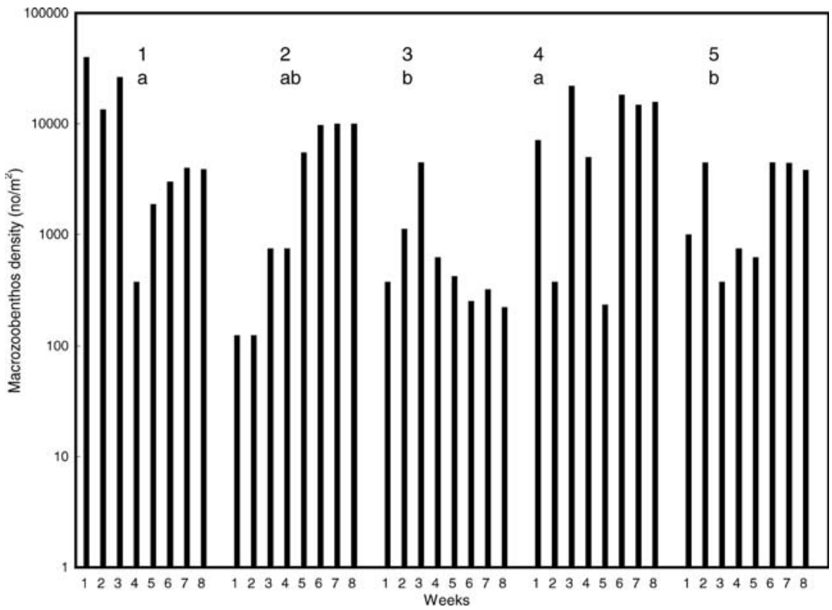

Figure 6. Changes in the density of macrozoobenthos in shrimp farms around Chilka lagoon during the entire culture period. Arabic numerals indicate the farm identification numbers. Common letters denote no significant difference at the 5% level by Duncan's multiple range tests. Note that density scale is logarithmic.

Discussion

Few studies have focused on macrozoobenthos in shrimp culture ponds, particularly in tropical areas. A moderately high density of zoobenthos (mean 5644 individuals/m^2) was recorded in shrimp ponds in Chilka periphery, and it is comparable to other shrimp farms in India (8560 individuals/m^2, Aravindakshan et al. 1992) and elsewhere (5938 individuals/m^2, Nunes and Parsons 2000). Studies in the tropical shrimp farms show that the population of zoobenthos successively declines as the culture period progresses (Nunes and Parsons 1998; Shishehchian and Yusoff 1999). *Penaeus monodon* acquires a more pronounced carnivorous habit as large body sizes are attained (Marte 1980). Such behavior combined with high shrimp population biomass usually results in an increased grazing pressure on naturally occurring pond prey species (Nunes and Parsons 1999). Our data did not indicate any meaningful reduction in the zoobenthos density at the end of the rearing cycle. In agreement with the present study, the data of Nunes and

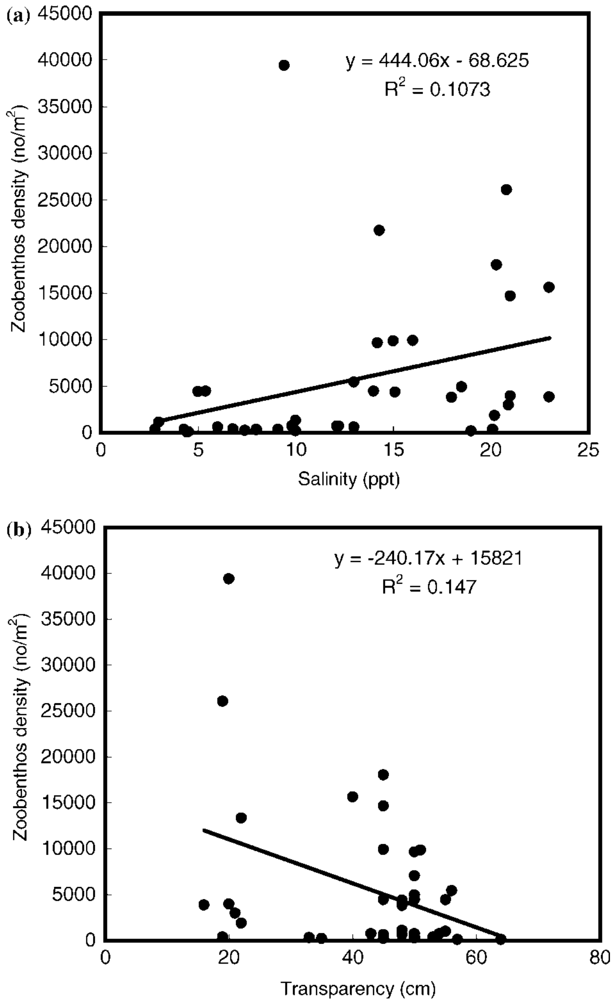

Figure 7. Correlation between density of macrozoobenthos and water quality characteristics in farms in the periphery of Chilka lagoon (a) macrobenthic density and (b) Secchi disc transparency.

Parsons (2000) provided no indication of reduction in the polychaete density in the shrimp farms of Brazil at the end of the rearing cycle. The number of benthic organisms usually decreases when predatory pressure increases above carrying capacity of the ecosystem (Virnstein 1977). Stocking densities of Chilka farms were very low (1.5–2.5 individuals/ m^2), and therefore there is little possibility of increasing grazing pressure beyond the carrying capacity. These results suggest that present benthic productivity is sufficient to support the current stocking densities.

Table 4. Harvest results of shrimp farms around Chilka Lagoon, Orissa, India

Farm identification No.	Mean shrimp size(g)	Daily wt. gain (g)	Survival (%)	Production (kg/ha)
1	30.4 ± 2.4	0.25	36.5	250
2	27.4 ± 1.4	0.23	30.2	91
3	26.0 ± 1.2	0.22	34.5	105
4	29.4 ± 2.0	0.24	28.6	168
5	25.0 ± 1.8	0.21	24.4	111
Total	27.6 ± 2.0	0.23 ± 0.01	26.5 ± 4.1	145 ± 58.6

Table 5. Comparison of economics of zero-water exchange shrimp farming system in the periphery of Chilka lagoon (a representative farm) and a typical modified extensive farm in the same area. Cost and profit calculated as Rs./ha/Crop (1US $ = Rs. 46.00)

	Zero-water exchange farming system around Chilka lagoon	Modified extensive farming system (Balasubramanian unpublished data)
Fixed cost	5000	30,000
Total operating cost		
Shrimp PL	2500	35,000
Feed	10,000	100,000
Lime	800	40,000
Fertilizer/manure	500	300
Human labor	1950	18,000
Diesel	Nil	13,650
Others	1000	30,000
Total	16,750	200,950
Gross return	80,000	480,000
Net profit	63,250	249,050
Benefit–Cost ratio	3.7	1.2

In most tropical shrimp farms, polychaetes are reported to be the predominant benthic macrofauna (Rubright et al. 1981; Aravindakshan et al. 1992; Shishehchian and Yusoff 1999; Nunes and Parsons 2000). In contrast, our observation showed that amphipods were the major component (81%) in the shrimp farms around Chilka lagoon. In the northern sector of Chilka lagoon, where the present study was conducted, amphipods form the major component of zoobenthos (Rajan

1971). Shishehchian and Yusoff (1999) studied the benthic infaunal community of a tropical intensive *P. monodon* farm and found that gastropods were the only taxa at the end of the rearing cycle. They concluded that this might be due to an increase of organic matter input in the culture system in the form of feed, fecal matter and dead organisms. In the present study, however, dominance of gastropods could not be found at the end of culture period in any of the ponds (Figure 6). These results suggest that organic inputs into the Chilka farms were too low to degrade the pond ecosystem.

Although average pond production was generally low (145 kg/ha), some farmers in this region are highly successful in terms of the benefit–cost ratio (Table 5). For example, farm 1 had a production of 250 kg/ha. Examination of differences between farm 1 and other farms revealed that better management techniques were primarily responsible for the better yield. In particular, in farm 1 maximum Secchi disc transparency was only 20 cm, whereas other farms showed a higher transparency (> 40 cm). Furthermore, farm 1 was deep with a stable water level. Decreased water transparency is generally related to increased pond production (Hariati et al. 1996). Similarly, pond depth is positively correlated with shrimp yields (Johnson et al. 2000). Survival rate of shrimps in Chilka farms was found to be low (22.1–32.9%). Hopkins et al. (1993) reported low survival rates associated with an absence of water exchange. In Chilka farms the input costs were very low, so survival rate does not need to be very high to have an economically feasible shrimp farming system as suggested by Brennan et al. (1999) for the rice shrimp system in Vietnam.

Shrimp production reported in the present study (average: 145 kg/ha) is similar to earlier studies conducted in this area (100 kg/ha, Reyntjens, 1987; 135–203 kg/ha, Rajyalakshmi et al. 1988). The studies conducted in the 1980s in the same type of farms in the same area recorded a growth rate similar to the present data (Mohanty and Mitra 1987). Further, growth rate of shrimps in Chilka farms are almost similar to the adjacent conventional shrimp farms with regular water exchange (Figure 8). A decline in pond production and growth rate has often been observed in many shrimp farming areas (e.g., Cha et al., 1997 in Hong Kong). The results presented here, however, show that pond production and growth rate of *P. monodon* have not declined over time, indicating the sustainable nature of this system.

The present results show that in the farms around Chilka lagoon effluent discharge is completely excluded, and inputs into the pond were too small to have a deleterious effect on the pond ecosystem. In order to

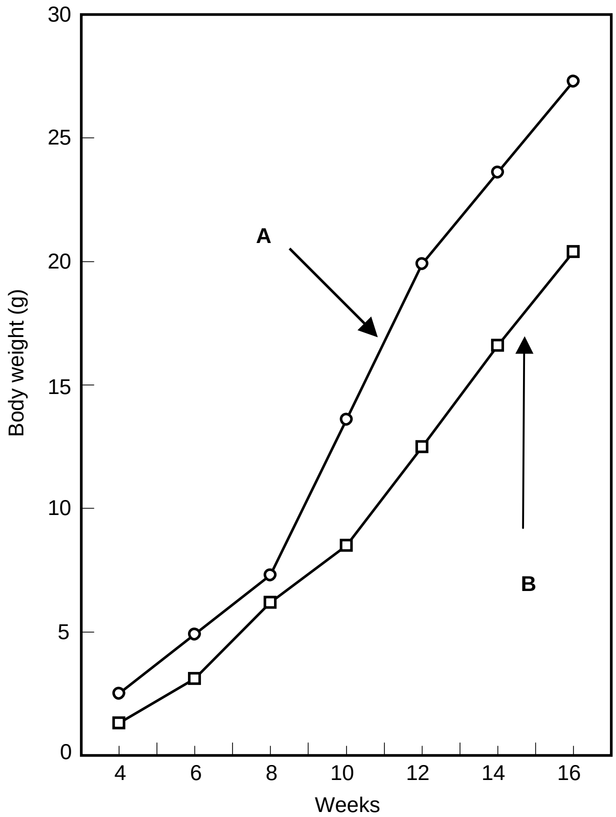

Figure 8. Mean sample weight of shrimp sampled biweekly from (A) the farm 1 (B) Semi-intensive farm at Balasore Orissa (Mohandas, N.N.C.P. Feeds, Andrapradesh, India, Personal communication).

reduce disease problems and increase sustainability of shrimp farming Kautsky et al. (2000) suggested two different strategies, i.e. a less intensive ecological approach and highly technical oriented biotechnical approach. As the biotechnological model involves great expenditure and specialized skills, the less intensive ecological approach will be the only viable alternative for resource-poor developing countries. The shrimp farming system at the periphery of Chilka lagoon is a typical representative of less intensive and sustainable farming systems. These provide better economic returns to the rural poor inhabiting around the lagoon, and they may represent a highly viable form of rural aquaculture. Further, the Chilka model shrimp farming system can be taken as a model for the development of vast stretches of saline wasteland into cost effective and sustainable shrimp production system in India and elsewhere.

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References

Anonymous 2000. Handbook on Fisheries Statistics, Orissa, 2001-01. Directorate of Fisheries, Orissa, India, pp. 117.

Aravindakshan, P.N., Balasubramanian, T., Lalithambikadevi, C.B., Nair, K.K.C., Gopalakrishnan, T.C., Jayalakshmi K.V. and Krishnankutty, M. 1992. Benthos and substratum characteristics of prawn culture fields in and around the Cochin Backwater. Journal of Marine Biological Association of India 34: 203–217.

Baird, I.G. and Quarto, A. 1994. The environmental social costs of developing coastal shrimp aquaculture in Asia. In: Trade and Environment in Asia-Pacific: Prospects for Regional Cooperation, Nautilus Institute for Security and Sustainable Development, California, USA, pp. 188–214.

Biswas, K.P. 1995. Ecological and Fisheries Development in Wetlands. Daya Publishing House, New Delhi, India, 192 pp.

Brennan, D., Clayton, H., Be, T.T. and Heip, T.T.N. 1999. Economic and social characteristics and farm management practices of farm in the brackish water of Soc Trang and Bac Lieu provinces, Mekong Delta, Vietnam. Results of a 1997 survey. http://www.reap.com.au/riceshrimpsurvey97.pdf.

Cha. M.W., Young, L. and Wong, K. 1997. The fate of traditional extensive (gei wai) shrimp farming at the Mai Po Marshes Nature Reserve, Hong Kong, Hydrobiologia 352: 295–303.

Costa-Pierce, B.A. 2002. Ecological Aquaculture. Blackwell Science, Oxford, UK.

Dash, M.C. and Patnaik. P.N. 1994. Brackish Water Prawn Culture. Palani Paramount Publications, Palani, India, 233 pp.

Flegel, T.W., Boonyaratpalin, S. and Withyachumnamkul, B. 1996. Current status of research on Yellow–head virus and white spot virus in Thailand. In: Book of Abstracts, The 1996 Annual Meeting of the World Aquaculture Society. Bangkok, Thailand, 126 pp.

Hariati, A.M., Wiadnya, D.G.R., Tanck, M.W., Boon, J.H. and Verdegem, M.C. 1996. *Penaeus monodon* (Fabricius) production related to water quality in East Java, Indonesia. Aquaculture Research 27: 255–260.

Hopkins, J.S., Hamilton, R.D., Sandifer, P.A., Browdy, C.L. and Sokes, A.D. 1993. Effects of water exchange rate on production, water quality, effluent characteristics and nitrogen budgets of intensive shrimp ponds. Journal of World Aquaculture Society 24(3): 304–320.

IUCN, 1987. India, In: IUCN (ed.), A Directory of Asian Wetlands, IUCN, Gland, Switzerland, pp. 367–505.

Johnson, D., Trong, N.V., Tien, D.V. and Xuan, T.T. 2000. Shrimp yield and harvest characterizations of mixed shrimp farms in Southern Vietnam: factors affecting production. Aquaculture 88: 263–284.

Kautsky, N., Ronnback, P., Tedengren, M. and Troell, M. 2000. Ecosystem perspectives on management of disease in shrimp pond farming. Aquaculture 191: 145–161.

Krumbein, W.C. and Petti John, C.T. 1938. Manuel of Sedimentary Petrography. Appleton Century-crofts, New York.

Lebel, L., Tri, N.H., Saengnoree, A., Pasong, S., Buatama, U. and Thoa, L.K. 2002. Industrial transformation and shrimp aquaculture in Thailand and Vietnam: pathway to ecological, social and economic sustainability? Ambio 31(4): 311–323.

Marte, C.L. 1980. The food and feeding habits of *Penaeus monodon* Fabricius collected from Makato River, Aklan, Philippines (Decapoda, Natantia). Crustaceana 38: 225–236.

Menasveta, P. 2002. Improved shrimp grow-out system for disease prevention and environmental sustainability in Asia. Reviews in Fisheries Science 10(3, 4): 391–402.

Mohanty S.K. and Mitra, H.K. 1987. Case studies on the monoculture of tiger prawn *Penaeus monodon* (Fabricius) in confined brackish water ponds in Puri and Ganjam Districts, Orissa. Journal of Indian Society of Coastal and Agriculture Research 5(10): 223–230.

Nunes, A.J.P. and Parsons, G.J. 1998. Dynamics of tropical coastal aquaculture system and the consequence to waste production. World Aquaculture 29: 27–37.

Nunes, A.J.P. and Parsons, G.J. 1999. Feeding levels of the southern Brown shrimp *Penaeus subtilis* in response to food dispersal. Journal of World Aquaculture Society 30: 331–348.

Nunes, A.J.P. and Parsons, G.J. 2000. Effect of southern brown shrimp, *Penaeus subtilis* predation and artificial feeding on the population dynamics of benthic polychaetes in tropical pond enclosures. Aquaculture 183: 125–147.

Phillips, M. and Barg, U. 1999. Experiences and opportunities in shrimp farming. In: Sustainable Aquaculture, Balkema, Rotterdam, pp. 43–72.

Primavera, J.H. 1998. Tropical shrimp farming and sustainability. In: DeSilva, S.S. (ed.), Tropical Mariculture. Academic Press, San Diego, pp. 257–289.

Rajyalakshmi, T., Mohanty, A.N., Ravichandran, P. and Pillai, S.M. 1988. The soil and water quality characteristics of confined brackishwater ponds on Chilka Lake fringe area. In: Joseph, M. (ed.), The First Indian Fisheries Forum. Asian Fisheries Society, Indian Branch, Mangalore, pp. 125–128.

Rajan, S. 1971. Environmental studies of the Chilka Lake 2 benthic animal communities. Indian Journal of Fisheries 12(2): 492–499.

Reyntjens, D.J.R. 1987. Confined – pond Shrimp Farming near Chilka Lake. BOBP News issues 25: 8–12.

Rosenberry, R. 1990. World Shrimp Farming. Aquaculture Digest, San Diego, CA.

Rosenberry, R. 2000. World Shrimp Farming 1999, Annual report, Shrimp News International, San Diego, CA.

Rubright, J.S., Harrel, J.L., Holcomb, H.W. and Parker, J.C. 1981. Response of planktonic and benthic communities to fertilizers and feed applications in shrimp mariculture ponds. Journal of World Mariculture Society 12(1): 281–299.

Shang, Y.C., Leung, P. and Ling, B.H. 1998. Comparative economics of shrimp farming in Asia. Aquaculture 164: 183–200.

Shishehchian, F. and Yusoff, F.M. 1999. Composition and abundance of macrobenthos in intensive tropical marine shrimp culture ponds. Journal of the World Aquaculture Society 30(1): 128–133.

Stirling, H.P. 1985. Specific chemical analysis. In: Stirling, H.P. (ed.), Chemical and Biological Methods of Water Analysis for Aquaculturists. Institute of Aquaculture, University of Stirling, UK, pp. 33–85.

Vimstein, R.W. 1977. The importance of predation by crabs and fishes on benthic in fauna in Chesapeake Bay. Ecology 58: 1199–1217.

Walkey, A. and Black, I.A. 1934. An examination of the Degrjarelf method for determining soil organic matter and proposed modification of the chromic acid titration method. Soil Science 37: 29–38.

Wang, J.K. 1990. Managing shrimp pond water to discharge problems. Aquaculture Engineering 9: 61–73.