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# Rice to shrimp: Land use/land cover changes and soil degradation in Southwestern Bangladesh

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**Abstract**

This paper examines the impact of shrimp farming on rice ecosystem in a village in Southwestern Bangladesh. The village Damarpota has experienced transformation of 274 ha (79%) of its prime quality rice fields into shrimp farms during the period between 1985 and 2003. Prolonged shrimp farming for 5-, 10-, and 15-year period has increased soil salinity, acidity, and depleted soil Ca, K, Mg, and organic C content of all three types of soils in the villages to a variable degree and caused soil degradation that significantly affected the rice yield. Declined yield and acreage of rice jointly reduced the total production of rice and animal fodder. Soil degradation and loss of acreage under rice have threatened the sustainability of the village rice ecosystem.


*Keywords:* Bangladesh; Soil degradation; Sustainability of agriculture

## Introduction

Transformation of rice fields into shrimp farms has changed the land use/land coverage of the densely populated coastal areas in tropical Asia and Latin America (Gujja and Finger-Stitch, 1996, p. 14; Dewalt et al., 1996, p. 1193; Flaherty et al., 1999, p. 2047). In Bangladesh, a country of 133 million people, farmers are engaged in smallholder subsistence rice farming. Its saline coastal landscape that was once dominated by rice fields is now occupied by shrimp ponds or *gheres* as the nation emerged as a major shrimp producing and exporting country in South Asia. During 1975–2000, the country's shrimp pond area has increased from <20,000 to 141,000 ha; and shrimp export revenue has grown from US$4.0 million to US$360 million (BBS, 1975, p. 205, 2002, p. 163). While its cost of production (US$4/kg) in Bangladesh is one of the highest in Asia, the net profit from shrimp is 12 times higher than that of high yielding variety (HYV) rice (Shang et al., 1998). Because of its high profit, shrimp farming has emerged as the most attractive land use practice that contributes to the economic development of the coastal districts of the country (Hossain et al., 2004).

Shrimp farming, either extensive or semi-intensive and intensive types, thrives well in saline wet rice ecosystem where it exerts wide range of adverse impacts on rice cultivation. Extensive shrimp farming, e.g., rapidly depletes the soil organic matter content (Shang et al., 1998). Intensive and semi-intensive shrimp farming, on the other hand, delivers high volume of organic and inorganic effluents and toxic chemicals to the ecosystem that result in hyper-nutrification and eutrophication and high soil toxicity (Beverage and Phillips, 1993; Deb, 1998; Flaherty et al., 1999). Prolonged saline water logging in shrimp ponds accelerates leaching of base minerals, and increases salinity and acidity of soil (Douglas, 1994; Flaherty et al., 1999; Landon, 1991). Rice plants cannot tolerate excessive salinity (EC > 7 dS/m) and acidity (pH < 4) as they reduce its vegetative

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growth and yield (Mass and Hoffman, 1977; Kyuma, 2004; Ponnamperuma et al., 1973). Highly saline and acidic soil and water also adversely affect the aquatic species living in rice ecosystem (Flaherty et al., 1999; Greenland, 1997; Khatun and Flowers, 1995; Welfare et al., 1996).

Several studies on shrimp farming in Bangladesh have recognized that this highly profitable land use practice, in turn, destroys the mangrove forest, increases soil acidity, salinity, and water pollution, affects rice cultivation, and increases rural unemployment, inequality, and social violence; and that there is a great need for multi-disciplinary empirical research to explore its further impacts and development prospects (Deb, 1998; Guimaraes and de Campos, 1989; Hossain et al., 2004; Rahman, 1994). The existing studies on shrimp farming, however, have not examined its impacts on soil properties, rice production, and aquatic and non-aquatic species inherent in rice ecosystem although such investigation is very important to ensure the nation's future food security in the face of rapid population growth.

The present study stems from the author's long standing research to understand the role of population pressure, market forces, and technology on agricultural growth in drought prone, saline wet rice ecosystems in Southwestern Bangladesh (Ali, 1987, 1995, 2004). These studies have revealed that the regional agriculture has intensified due to dry season cultivation of HYV *boro* (*Oryza sativa* L. var.) rice using low-lift pump irrigation; that most rice fields were transformed and used as shrimp ponds for 10–15 years, and are currently being cultivated in rice–shrimp rotations; and that their yields of rice have declined over time. While the impacts of population growth and technological change on soil qualities were explored in another study (Ali, 2004), understanding the impacts of market-oriented shrimp farming on soil qualities, rice production, and aquatic habitat formed the basis of this study.

Precisely, this study examines the impacts of shrimp farming on soil properties, rice production, and aquatic habitat in the village Damarpota in Satkhira district in Southwestern Bangladesh over an 18-year period between 1985 and 2003. The study measures the temporal changes in nine properties of soil samples taken from four types of rice and shrimp farms; computes and compares their composite soil degradation indices (SDIs); and investigates how soil degradation due to shrimp farming has affected the yield and production of rice and other aquatic species inherent in rice fields. The study results will provide an empirical basis of understanding the impacts of shrimp farming on coastal soils and rice ecosystem and thus they will contribute to better agricultural development planning in the country.

## Materials and methods

### *Study area and its ecological setting for rice and shrimp farming*

The village Damarpota is a medium sized village of 388 ha that had 1324 people living in 19 large holders (>3 ha), 21 medium-holders (1–3 ha), 44 smallholders (0.2–1 ha), and 55 near-landless (<0.2 ha) households. It is located at 4 km east of Satkhira town and 65 km north of the Sundarban forest in Southwestern Bangladesh (Fig. 1). Situated at the tidal floodplain of the Betravati River, a distributary of the Ganges River, the village typifies a saline wet rice and shrimp farming ecosystem. Before its establishment in the early 19th century, the village land formed the northernmost flank of the Sundarban forest and was covered by mangrove vegetation grown on dark gray tidal alluvium sediments deposited by the river. Over time, both sedimentation and human modification gave rise to four land elevation and floodibility levels; each is suitable for specific use and cultivation practices (Fig. 1). The highest land, *bhita*, is flood free and occupied by homesteads and gardens. Medium high land, *danga*, is flash flooded in high monsoon rain, and is suitable for rice, jute, legumes, oilseeds, and vegetable cultivation. Low and very low fields, *jhora and beel*, are tidally inundated regularly and are suitable for rice and shrimp farming. The ox-bow lakes and man-made ditches serve as water reservoirs and natural habitats for fish and other aquatic species.

Both non-calcareous gray floodplain and acid sulfate soils are identified in the village (Fig. 1). According to the USDA Soil Taxonomy, the non-calcareous gray floodplain soils are Typic Haplaquept (18%) and Thapto Histic (17%); and the acid sulfate soil (65%) is Thapto Histic Haplaquept type (Brammer, 1996, p. 154; Soil Resource Development Institute (SRDI), 1993; USDA, 1975). The Typic Haplaquept soil is non-saline and non-acidic; and both the Thapto Histic and Thapto Histic Haplaquept soils are extremely saline (EC>11 dS/m), rich in sulfur (>225 μg/l) and highly acidic (pH<4, SRDI, 1993, p. 45).[1] The river water changes from extremely saline (EC>15 dS/m) in dry months of April and May to moderately saline (EC = 8–10 dS/m) in monsoon months of July and

[1]Regular tidal inundation by saline, sulfur rich seawater from the Betravati River is responsible for high salinity and acidity of soils in the village. Both Kyuma (2004) and Brammer (1996) suggested that in mangrove forest areas, sulfur from the seawater precipitates in the sediment in the form of ferrous sulfide. During clearing of forest, cultivation, construction of river embankments and dykes around rice fields and shrimp ponds, as well as during low-lift pump irrigation, the sulfide materials were exposed to air, oxidized, and released sulfuric acid to soils and increased its acidity (Ali, 2004; Brammer, 1996, p. 39, 94; Hossain et al., 2004, p. 42; Kyuma 2004, p. 222).

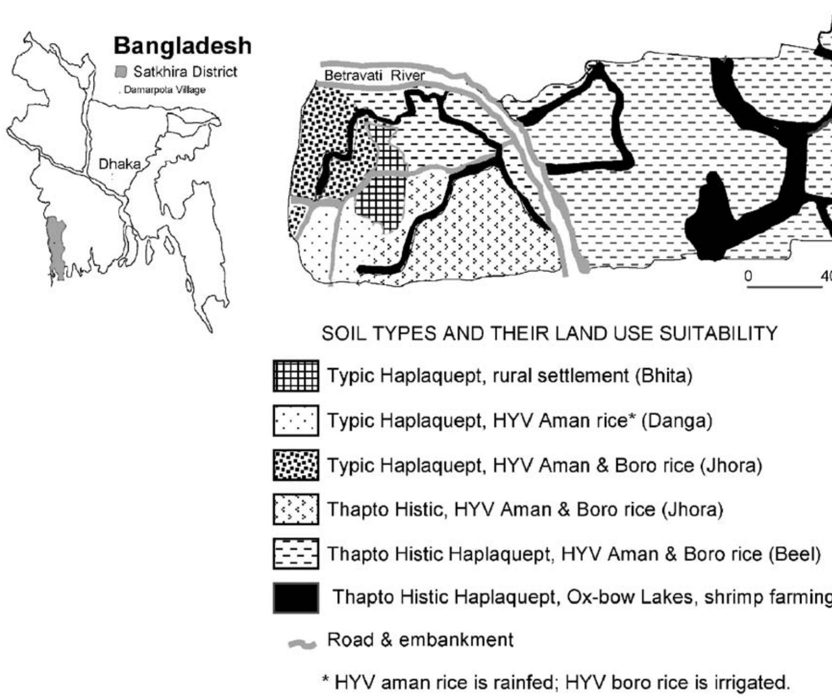


Fig. 1. Location, soil types, and land use suitability of the village Damarpota.

August when increased fresh water off-take from the Ganges River reduces the salinity (SRDI, 1993, pp. 53–54; BWDB, 2003, unpublished data).

The village agriculture is markedly influenced by the tropical monsoon climate. Its underlying three distinct temperature and rainfall regimes control the cropping schedules and cultigens grown. The Nor'wester summer (March–May) or *kalbaishaki*, dominated by very hot weather (>39 °C) with violent thunderstorms, cyclones, low rainfall (±250 mm), and extreme dryness restricts the Aus rice (*O. sativa* L. var.) cultivation during the *Kharif* cropping season (March–June) typical elsewhere in Bangladesh. The monsoon summer (July–October), characterized by hot weather (34 °C) and high rainfall (1400 mm) sponsors the *Haimantic* (July–December), the most important cropping season of the year when rain-fed transplanted local (27 ha) and HYV (287 ha) aman rice (*O. sativa* L. var.) crops are cultivated. These cultigens are sown in late June, transplanted in July–August, and harvested in November–December. The dry winter (November–February) is marked by foggy cold (<16 °C), and dry (rainfall <30 mm) weather that supports the *Rabi* (December–April) cropping season dominated by irrigated HYV boro rice (*O. sativa* L. var.) sown in December, transplanted in January and harvested in April–May. Non-irrigated fields are given to vegetables, tobacco, legumes, and oilseeds. Labor inputs in rice farming vary from 200 man-days/ha for HYV aman to 250 man-days for irrigated HYV boro rice depending upon the need for weeding and irrigation (Ali, 2004). Rice yields vary from 800 to 2500 kg/ha of HYV aman, and 1100 to 3500 kg/ha of HYV boro rice.

Unlike other coastal areas of Bangladesh, the village environment allows cultivation of both monsoon rain-fed HYV aman and dry season irrigated HYV boro rice crops in the same field. In addition, the Betravati River embankment with concrete sluice gates allows pumping in and out of saline tidal river water to rice fields which further enhances the village's potential for rice, fish, and shrimp farming. In the 1970s, only the ox-bow lakes (36.5 ha) were used as traditional extensive shrimp ponds. Formal shrimp farming began in 1986 with two extensive shrimp ponds occupying 75 ha of land. In 2003, there were five extensive (>40 ha), 24 semi-intensive (1–10 ha), and 10 intensive (<1 ha) shrimp ponds in the village. Until the late 1990s, the village shrimp ponds had operated year-round consecutively for 10–15 years without rice cultivation. Over the last 5–6 years, growing household population demand for rice and world market demand for shrimp production have induced farmers to cultivate both rice and shrimp following one or more of the three common rice–shrimp rotation systems. In type I (one-cycle shrimp) system, the land is inter-cultured in July with rain-fed HYV aman rice and fresh water fish viz., Nilotica, Tilapia, Silver Carp, and shrimp (*Macrobrachium rosenbergii*) those are harvested in November; after that shrimp and saline water fish are produced during December and June. In type II (one-cycle shrimp) system, rice fields are transformed into shrimp ponds in June and shrimp and saline water fish are produced till November; the land is dried out in December and cultivated to irrigated HYV boro rice to be harvested in May. In type III (two-cycle shrimp) system, rice fields are transformed into shrimp ponds to produce shrimp and saline water fish year-round (December–October) leaving no room for rice cultivation (Table 1).

*Village land use/land cover change data*

Land use/land coverage, crop area, and yield data for all plots in the village were collected in four phases during November 1984 and July 1985, June and December 1990, July and December 1995, and January and December 2003. Field data were mapped, and area under each land use and crop category was carefully measured with maximum accuracy, although some human error is always possible to remain undetected. In this study, the 1985, 1990, 1995, and 2003 data were compared to examine the land use/land cover changes, expansion of shrimp farming, and its impact on rice cultivation and production.

*Ecological data*

In 1985, based upon the proportional distribution of three types of soils in the village, 15 sample plots from each of Typic Haplaquept and Thapto Histic, and 30 plots from Thapto Histic Haplaquept soils (a total of 60 plots) were randomly selected as experimental plots then used as rice fields, and soil samples were collected from each of them. Since the beginning of shrimp farming in 1986, major land use/land cover changes occurred in the village. In 2003, four land use types were identified on three soil types: type I, rice fields in Typic Haplaquept soil those were never used for shrimp farming; type II, rice fields in Thapto Histic soil used as shrimp pond for 5 years (1995–2000) and now under rice–shrimp rotation; type III, rice fields in Thapto Histic Haplaquept soil used as shrimp pond for 10 years (1990–2000) and now under rice–shrimp rotation; and type IV, rice fields in Thapto Histic Haplaquept soil used as shrimp ponds for 15 years (1986–2001) and now under rice–shrimp rotation. From each land use type, those sample plots selected in 1985 were selected again in 2003 to collect soil samples and ecological data to perform comparative analysis.

*(i) Soil properties*: During 1985 and 2003 fieldworks, from each of 60 sample plots, about 250 g of soil sample was collected and sealed in plastic bags to protect soils from moisture and salt loss. Soil samples were collected both in July and March to observe the effect of rainfall on soil salinity and acidity. Each bag was labeled with plot number and land use/land cover type to maintain distinct identification. Soil samples were taken to the SRDI, Dhaka, where they were air dried for 2 weeks,

Table 1
Expansion of shrimp farming and land use/land cover changes in Damarpota: 1985–2003

| Year | Land use/land cover types area in ha (%) | | Observed median frequency of rice cultivation | Potential rice area in ha[a] (%) | Month and area under rice and shrimp rotation in ha (% of crop land) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Settlement | Cropland | | | Rice–shrimp rotation type I 1 rice and 1 shrimp | | OR rice–shrimp rotation type II 1 rice and 1 shrimp | | Rice–shrimp rotation type III 0 rice and 2 shrimp | |
| | | | | | HYV aman rice inter-cultured with shrimp July–Nov. | One-cycle shrimp Dec.–June | One-cycle shrimp June–Nov.[b] | HYV boro rice Dec.–May | 1st shrimp cycle June–Nov.[c] | 2nd shrimp cycle Dec.–May[c] |
| 1985 | 13.9 (3.6) | 345.5 (88.9) | 1.68 | 582.0 (168.0) | 345.5 (100.0) | 0 | 36.5 (10.6) | 200.4 (58.0) | 0 | 0 |
| 1990 | 14.8 (3.8) | 344.6 (88.7) | 2.0 | 689.1 (200.0) | 344.6 (100.0) | 0 | 75.0 (21.8) | 269.6 (78.2) | 0 | 0 |
| 1995 | 16.7 (4.3) | 342.7 (88.2) | 2.0 | 685.4 (200.0) | 332.4 (97.0) | 0 | 210.0 (67.2) | 122.4 (32.8) | 10.3 (1.5) | 10.3 (1.5) |
| 2003 | 17.9 (4.6) | 341.5 (87.9) | 2.0 | 683.0 (200.0) | 314.0 (91.9) | 314.0 (91.9) | 255.8 (91.0) | 58.2 (17.0) | 27.5 (4.0) | 27.5 (4.0) |

[a]Potential rice area was estimated by multiplying the net cropland by the frequency of rice cultivation.
[b]One-shrimp cycle during the months of December–June affects the cultivation of HYV boro rice. During each cycle, shrimp is harvested several times.
[c]Two-shrimp harvests during the months of December–November affect the cultivation of both HYV aman and boro rice crops.

finely ground, sieved through 2 mm sieve to remove large stones and plant roots, and prepared for saturated extracts. Standard laboratory analytical procedures were followed to determine soil pH, salinity, Ca, Mg, K, S, N, P, and OC content.

*(ii) Rice cultivation data*: During 1985 and 2003 fieldwork, field size, labor inputs, and total production of HYV aman and boro rice in each type of land use were directly and carefully observed and recorded from each sample plot. The total rice production was divided by the plot size to obtain per hectare yield.

*(iii) Shrimp farming data*: During the 2003 fieldwork, each shrimp farm was visited twice and the owner was interviewed to obtain data on pond (*gehere*) size and uses of inputs including feed, chemical fertilizers, and antibiotics for shrimp disease. At the time of harvest, each shrimp pond was also visited to record the production of headless shrimp.

*(iv) Aquatic and non-aquatic species data*: During both 1985 and 2003 fieldworks, data on the number of aquatic, non-aquatic species present in rice fields, and the number of livestock animals owned by the farmers were collected. In this study, changes in the number of aquatic species and livestock population were computed to assess the impacts of shrimp farming on those species.

*Analytical methods*

*Computation of SDIs*

The term 'soil degradation' refers to temporal changes in a group of soil properties as they deteriorate the soil capability to sustain higher yields (Dumanski and Pieri, 1997). Soil degradation is generally measured by comparing of the present state of certain soil properties with their earlier state (Riquier, 1978). It is also measured by comparing variations in certain physical, chemical, and biological properties under different land use/land covers at a single point in time (Adejuwon and Ekande, 1988; Islam and Weil, 2000). In this study, the degree of soil degradation caused by shrimp farming was measured in the following manner. First, for each land use type, the median values of each of nine soil chemical properties were separately computed for both 1985 and 2003 samples (15 plots). Second, percent change in median value of each soil property during 1985–2003 was computed; and percent change values of all nine soil properties were added and averaged to obtain the mean soil quality change indicators (MSQI) for land use types I–IV. The MSQI for land use type I that never used as shrimp pond was taken as the baseline value to compare and compute the degree of effect of shrimp farming on land. It was assumed that larger negative values of MSQI of land use type II, III, and IV compared to that of land use type I would indicate higher degrees of degradation in soil qualities due to shrimp farming for 5-, 10-, and 15-year period, respectively. Finally, the composite SDIs for land use types I–IV were computed by calculating the percentage difference in their respective values of MSQI from the baseline value of MSQI of land use type I. Higher negative difference would indicate severe degradation. Thus, the present study has merged the two conventional methods to assess soil degradation among four land use types during the period between 1985 and 2003.

*Assessment of impact of shrimp farming on rice ecosystem*

*(i) Impacts on rice production*: Expansion of shrimp farming has reduced the area under rice cultivation; it has changed the soil properties causing their degradation that has reduced the rice yield.[2] The impact of shrimp farming on total rice production was estimated for 1985, 1990, 1995, and 2003 in the following manner. First, for each year, the net cropland was multiplied by the village's normal frequency of rice cultivation to obtain the potential rice area, which was again multiplied by the base year (1985) lowest, median, and highest yields of HYV aman and boro crops to estimate the expected total productions. The observed total rice area was multiplied by the observed lowest, median, and highest yields to estimate the observed total rice productions in a year. The increasing gap between the potential and observed total production estimates indicated the effect of transformation of rice fields into shrimp farm on rice production. Second, the observed area under each rice crop was multiplied by the difference between the observed base year (1985) and terminal year (2003) lowest, median, and highest yields to estimate the total possible loss of rice production due to yield decline. When added, the acreage and yield impacts indicated the total impacts of shrimp farming on rice production save any remaining minor undetected human error in measuring areas and recording the crop yields.

Among the four land use types, the fields in land use type I was never given to shrimp farming, therefore, any observed decline in median rice yield in these fields was assumed to be due to variations in rainfall and farm management practices including frequent cultivation of land using power tillers and low-lift pump irrigation that may have increased soil erosion, salinity, and acidity. Since all fields in land use types II–IV also experience similar rainfall variability and cultivation practices as those in land use type I, it was assumed that the initial decline in rice yield in land use types II–IV was equivalent to that observed in land use type I; and that

[2]Rice plants can withstand extremely adverse rainfall variation between 700 and 2000 mm; however, late onset of monsoon rain, prolong flooding, frequent cultivation, and soil erosion, excessively high soil salinity ($>8$ dS/m) and acidity (pH $<4.0$), and lack of irrigation water supply can also affect rice yield (Bray, 1989, p. 12; Grist, 1975, p. 20; Kyuma, 2004, p. 240).

any additional yield loss in land use types II–IV was due to shrimp farming for prolong time.

*(ii) Statistical assessment of the impacts of shrimp farming on soil and rice ecosystem*: The study involved two separate statistical approaches: first, to examine the impacts of shrimp farming on nine soil properties; and second, to assess the impact of soil degradation on rice yields. For the first approach, it was assumed that given all else being equal, any variation in soil chemical properties within 15 samples from each land use type would be the same as their variation between the samples taken from four different land use types; that any significant difference in within and between variations for 1985 (base year) soil properties would be due to variation in three soil types; and that any significantly higher variance in 2003 (terminal year) soil properties would be due to shrimp farming for different length of time. These assumptions involved two separate comparisons of means of nine chemical properties for 1985 and 2003 soil samples. One-way analysis of variance (ANOVA) statistic with LSD procedure was used to separate the means of soil properties at $p \leqslant 0.05$.

Second statistical approach involved the assessment of impacts of nine soil properties on rice yields after they were degraded due to shrimp farming. For the purpose, simple bi-variate correlation coefficients were computed using nine soil properties of 2003 samples as independent variables, affecting the 2003 yields of HYV aman and HYV boro rice crops. Soil properties with significant negative correlation coefficients have affected the rice yields.

## Results

### *Rice and shrimp: economic basis of competition for the land*

Given the fact that the village ecosystem is suitable for year-round cultivation of both HYV aman and boro rice crops and shrimp on the same field, shrimp and rice compete with each other for the land. For most village farmers, household consumption demand for rice and economic return from shrimp formed the basis of their land allocation decisions. In this village, the cost of production of shrimp was US$4.6/kg; its farm gate price of US$7.7 yielded a net profit return of US$3.1/kg; and its median production of 330 kg/ha/yr (headless) yielded a net profit of US$1000/ha/yr. When compared with rice farming, both HYV aman and boro rice crops jointly produced a median yield of 2.5 mt/ha/yr of paddy which would cost US$310 to produce and sold at farm gate price of US$415 yielding a net profit of US$105/ha/yr. Shrimp farming thus appeared to be nine times more profitable than rice. Higher profit has induced both village farmers and investors to transform rice fields into shrimp ponds.

### *Rice to shrimp: land use/land cover changes, 1985–2003*

In 1985, the village had 346 ha of farmland which was once cultivated to HYV aman rice during the monsoon rainy season; 200 ha (58%) of it was cultivated for the second time in dry season to irrigated HYV boro rice; and another 36 ha (11%) was transformed into shrimp ponds. This land use practice had produced a cropping frequency of 1.65; and thus the village had a potential rice area of 582 ha. In 2003, the village farmland declined to 342 ha; with the help of irrigation in dry season, it could be cultivated twice a year; thus, the potential rice area increased to 683 ha. However, as shrimp farming expanded, 314 ha was cultivated to HYV aman rice and fresh water fish (type I rotation) during July–November; 58 ha given to irrigated HYV boro rice, and 256 ha transformed into one-cycle (type II rotation) shrimp ponds during December–June; and 55 ha transformed into two-cycle (type III) shrimp ponds (December–November). Thus, during 1985–2003, 27.5 ha of HYV aman and 246.5 ha of potential HYV boro rice, or a total 274 ha of rice fields were transformed into shrimp ponds (Table 1).

## Shrimp farming and rice ecosystem change

Shrimp farming has affected the village rice ecosystem in several ways. It has brought major changes in soil properties and caused soil degradation that affects rice yields. Transformation of rice fields into shrimp ponds has reduced the total area under rice and fodder production and has created food shortage for both human and livestock population. Toxic chemicals and effluents in shrimp ponds have disrupted the habitat for fresh water fish and aquatic species inherent in rice ecosystem.

### *Changes in soil properties and soil degradation*

Analysis of the properties of 1985 soil samples indicated that the Typic Haplaquept soil was neutral in acidity, non-saline, rich in Ca, Mg, and K, but poor in N, P, and S contents (Table 2). It occupied the high flood free land and was cultivated to rain-fed HYV aman rice, legumes, vegetables, and oilseeds. The Thapto Histic soil occupying the medium highland was neutral in acidity, moderately saline (EC < 11 dS/m), rich in Ca, K and S, and poor in Mg, N, and P. During high tides, much of the land under this soil was inundated by saline river water. Both HYV aman and boro rice were grown on this soil. The Thapto Histic Haplaquept soil of the lowland was moderately acidic

Table 2
Soil properties under various land use/land cover types in Damarpota village: 1985–2003

| Soil type: USDA taxonomy land use/land cover type | Year | Selected soil properties | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | PH | EC (dS/m) | OC (%) | Ca (me/100 g) | Mg (me/100 g) | K (me/100 g) | N (μg/g) | P (μg/g) | S (μg/g) |
| Typic Haplaquept type I: rice and legumes | 1985 | 7.3 | 1.50 | 2.90 | 18.9 | 15.4 | 0.26 | 16.0 | 10.0 | 14 |
| | 2003 | 7.5 | 1.60 | 3.20 | 18.7 | 15.9 | 0.34 | 21 | 11 | 16 |
| Thapto Histic type II: rice and shrimp for 5 years | 1985 | 7.3 | 12.0 | 3.01 | 19.0 | 10.0 | 0.31 | 10 | 10 | 210 |
| | 2003 | 5.2 | 15.9 | 2.98 | 10.5 | 9.8 | 0.31 | 19 | 11 | 267 |
| Thapto Histic Haplaquept type III: rice and shrimp for 10 years | 1985 | 6.0 | 12.4 | 3.20 | 14.0 | 20.1 | 0.36 | 15 | 9 | 171 |
| | 2003 | 4.1 | 16.9 | 3.05 | 9.7 | 20.0 | 0.34 | 21 | 11 | 240 |
| Thapto Histic Haplaquept type IV: rice and shrimp for 15 years | 1985 | 5.80 | 13.5 | 3.20 | 11.9 | 19.8 | 0.40 | 10 | 10 | 200 |
| | 2003 | 3.70 | 18.7 | 2.60 | 7.2 | 18.5 | 0.37 | 13 | 12 | 346 |

(pH $<$ 6), saline (EC $>$ 12 dS/m), rich in Mg, K, and S, and poor in Ca, N, and P. This soil was regularly inundated by saline tidal water and was given to HYV aman rice. During the monsoon months, both salinity and acidity of all three types of soils would decline by 45%.

One-way ANOVA of 1985 soil data suggests that soil acidity, salinity, Ca, Mg, K, N, and S content varied significantly between land use types, which in the absence of major shrimp farming in the village was attributed to the difference in soil types (Table 3). Over time, properties of all three soil series have changed due to various land use practices. ANOVA of 2003 soil property data showed significant variation in all soil properties except P content; and much larger values of estimated between group variance indicated that soil properties have significantly changed over time due to continuous prolonged shrimp farming as well as high intensive rice cultivation using power tillers and low-lift pump irrigation (Table 3).

*(i) Increased soil acidity*: The soil samples collected in 2003 showed that soil pH in the Thapto Haplaquept soil under land use type I still remained neutral. In contrast, pH value of the Thapto Histic soil under 5-year shrimp farms has declined by 29%; and that of Thapto Histic Haplaquept soils under 10- and 15-year shrimp farms declined, respectively, by 32% and 36% than their 1985 values (Table 4). This increment can be attributed to construction of dykes around rice fields and shrimp ponds by digging out 0.5–1 m of top soil, and low-lift pump irrigation for HYV boro rice cultivation as they both expose the underlying iron sulfide (pyrite) materials to air. In addition, long-term trapping of tidal water in shrimp ponds allows sulfur from the seawater to precipitate at the pond bottom. As the land dries out after shrimp harvest and is tilled for rice cultivation, the exposed sulfide deposits are oxidized and release sulfuric acid to soil and increase its acidity.

*(ii) Increased soil salinity*: Over the period, salinity of the Typic Haplaquept soil under rice field (land use type I) increased slightly by 7% owing to low-lift pump irrigation for HYV boro rice cultivation. In contrast, salinity of the Thapto Histic soil under 5-year shrimp farms increased by 33%; and that of the Thapto Histic Haplaquept soil under 10- and 15-year shrimp farms has increased, respectively, by 36% and 39% (Table 4). Since these fields are only recently being cultivated to HYV boro rice, a minor increase in salinity may be attributed to low-lift pump irrigation; and its large percentage increase was attributed to prolong trapping of saline tidal river water in shrimp ponds.

*(iii) Decreased organic C*: During the period in question, soil under land use type I rice fields has experienced 10% increase in organic C content due to application of cow manure, kitchen refuse, and vegetable mulch; while those under land use types II, III, and

Table 3
Analysis of variance of 1985 and 2003 soil properties under four land use/land cover types in Damarpota

| Year | Groups | Selected soil properties | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | pH | EC (dS/m) | OC (%) | Ca (me/100 g) | Mg (me/100 g) | K (me/100 g) | N (μg/g) | P (μg/g) | S (μg/g) |
| ANOVA 1985 estimated variance | Between groups | 13.0[a] | 402.0[a] | 0.38 | 204.5 | 340.7 | 0.055 | 153.4 | 3.27 | 156083 |
| | Within groups | 0.7 | 6.0 | 0.16 | 0.99 | 1.55 | 0.001 | 1.5 | 1.30 | 5586 |
| | *F*-value | 18.6 | 67.0 | 2.4* | 204.9 | 219.1 | 55.0 | 105.0 | 2.5* | 27.9 |
| ANOVA 2003 estimated variance | Between | 35.0[a] | 914.0 | 0.9 | 340.8 | 307.9 | 0.009 | 228.2 | 5.7 | 291805 |
| | Within | 0.27 | 1.9 | 0.07 | 1.32 | 1.22 | 0.001 | 2.8 | 1.1 | 1060 |
| | *F*-value | 129.6 | 481.0 | 12.1 | 256.8 | 252.9 | 7.66 | 80.8 | 5.2* | 275.1 |

*Not significant at 0.05 level. $V_1 = 3$, $V_2 = 56$, $N = 60$.
[a]Wet season pH and EC did not vary significantly between land use and soil types.

Table 4
Effects of shrimp farming on soil properties and soil degradation index in Damarpota village: 1985–2003

| Soil type: land use type | Percent change in selected soil properties during 1985–2003 | | | | | | | | | Mean soil quality change index (MSQI) % | Soil degradation index (SDI) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | EC | OC | Ca | Mg | K | N | P | S | | |
| Typic Haplaquept type I: rice and legumes | 1.03 | 6.7 | 10.3 | −1.1 | 3.2 | 30.8 | 31.2 | 10 | 14.3 | 11.8 | 1.0 |
| Thapto Histic type II: rice and shrimp for 5 years | −28.8 | 32.5 | −1.0 | −44.7 | −1.0 | 0.0 | 90 | 10 | 27.1 | 9.3 | −21.2 |
| Thapto Histic Haplaquept type III: rice and shrimp for 10 years | −31.7 | 36.3 | −4.7 | −30.7 | −0.0 | −5.5 | 40 | 22.2 | 40.4 | 7.4 | −37.5 |
| Thapto Histic Haplaquept type IV: rice and shrimp for 15 years | −36.2 | 38.5 | −18.8 | −39.5 | −6.6 | −7.5 | 30 | 20.0 | 73.0 | 5.9 | −49.8 |

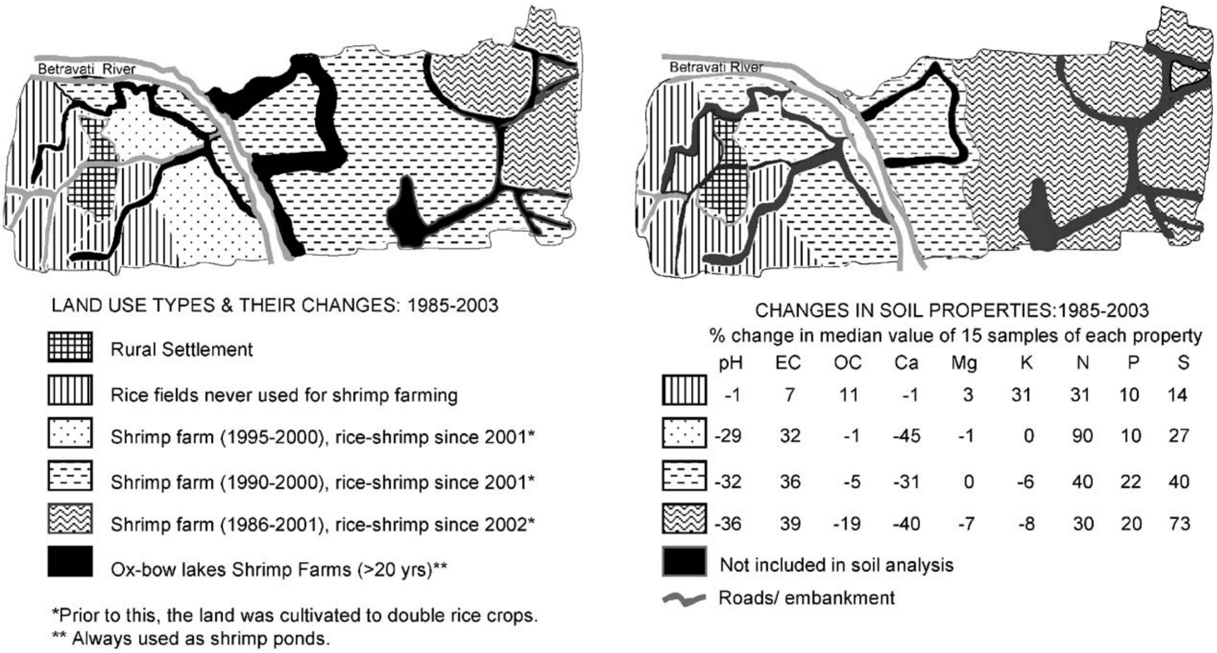


Fig. 2. Land use changes and soil degradation in Damarpota village: 1985–2003.

IV, i.e., 5-, 10-, and 15-year shrimp farms have experienced its decline, respectively, by 1%, 5% and 19% (Table 4). Long-term water logging during rice and extensive type shrimp farming had increased soil acidity (pH $<$ 5.5), and reduced bacterial activity and nitrification of organic C to cause its rapid depletion as they occurred in land use types II–IV (for details, see Douglas, 1994; Landon, 1991).

*(iv) Leaching of base minerals*: During the period in question, all three types of soils in the village have experienced declines of Ca, Mg, and K base minerals through leaching. The rate of leaching of Ca varied from 1% in the rice fields to 45% in 5-year, 31% in 10-year, and 40% in 15-year shrimp farms (Table 4, Fig. 2). Leaching of Mg and K in soils ranged from $<$1% in 5-year to 7% in 15-year shrimp farms. High monsoon rain caused some leaching on all rice fields; however, year long water logging resulted in high rate of leaching of base minerals in soils under shrimp farms.

*(v) Accumulation of N, P, and S*: Soils under all four types of land uses have accumulated N, P, and S. Frequent application of Muriate of potash ($K_2O$), urea, triple super phosphate (TSP), gypsum, and zinc sulfate as chemical fertilizers in both rice fields and shrimp ponds, and various inorganic and organic fish meals added to shrimp farms have released N, P, and S to all soils in the village. Shrimp ponds, which use sulfide rich tidal water, have accumulated more S than rice fields.

*(vi) Composite soil degradation*: Prolonged shrimp and rice farming has brought significant changes in various soil properties and caused degradation of village soils observable among land use types. The MSQI computed accounting the percentage change in soil acidity (pH), salinity (EC), Ca, Mg, K, N, P, S, and organic C contents suggest that the soils under all land use types have experienced qualitative changes over the past 18-year period due to various land use practices. However, the MSQI values of 11.8, 9.3, 7.4, and 5.9, respectively, for land use types I, II, III, and IV suggest variable degree of soil quality change and degradation: lowest value indicates the most severe degradation and vice versa. It is observed that soil properties under rice fields (land use type I) has experienced higher positive change indicating lesser soil degradation compared to soils under 5-, 10-, and 15-year shrimp farms (Table 4, Fig. 2). This was due to frequent cultivation using power tillers, low-lift pump irrigation, and chemical fertilizers. The composite indices (SDI) suggest significant soil degradation in land use types II–IV due to prolonged shrimp farming (Table 4). The index values varied from 1 for rice fields, −21.2 for 5-year shrimp farms, −37.5 for 10-year shrimp farms, and −49.8 for 15-year shrimp farms indicating the fact that longer the period the land was under shrimp farming, the more severely its soil degraded (Table 4, Fig. 3). While depletion of organic C, Ca, Mg, and K, and enrichment of N and P can equally be attributed to prolonged water logging of fields under frequent rice cultivation, increasing S content, soil acidity, salinity are particularly attributed to shrimp farming. Both depletion of soil nutrients and increased soil salinity and acidity have affected the rice ecosystem.

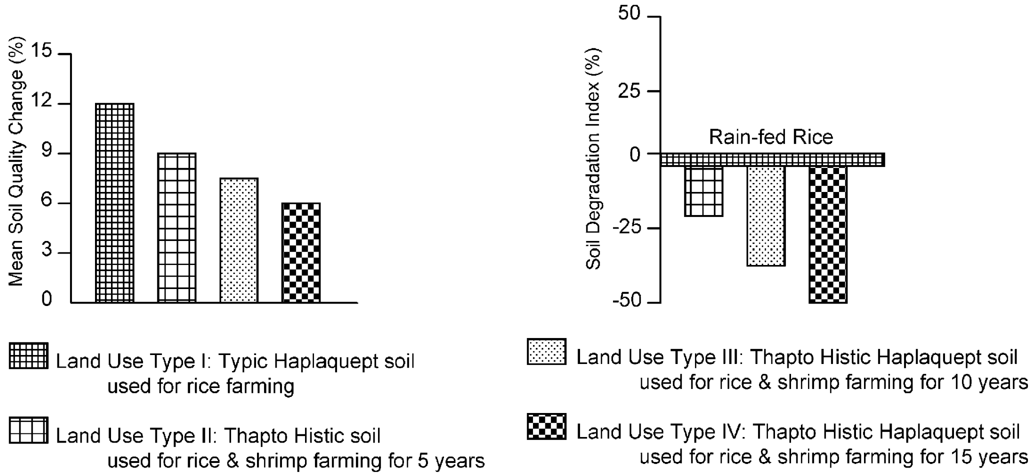


Fig. 3. Effects of shrimp farming on soil degradation in Damarpota village: 1985–2003.

*Impact of soil degradation on rice yield*

During 1985–2003 periods, yields of both HYV aman and boro rice have declined significantly. The median per hectare yield of HYV aman rice in land use types I, II, III, and IV has declined, respectively, by about 11%, 23%, 30%, and 35%; and that of HYV boro rice has declined, respectively, by 28%, 35%, 41%, and 51% (Table 5). Yield loss of HYV aman and boro rice in land use type I, which was never used for shrimp farming, was attributed to loss of soil fertility due to frequent cultivation using power tiller that promoted soil erosion, and untimely occurrence and fluctuations in the amount of monsoon rainfall at the time of rice planting. Lack of water supply and low-lift pump irrigation has increased soil salinity and acidity and affected the yield of HYV boro rice (Ali, 2004). Since all the village farmlands, regardless of their uses, have been frequently cultivated, power tilled, irrigated using the low-lift pumps, and experienced the variability of monsoon rainfall, these factors may be equally responsible for the initial 10% and 28% decline, respectively, in HYV aman and HYV boro in land use type II, III, and IV; and their higher percentage decline in yield of both crops would be due to 5, 10, and 15 years of continuous shrimp farming that had increasingly degraded the soil qualities in these fields prior to the beginning of present rice–shrimp rotation practices (Table 5).

Among the nine soil chemical properties considered in this study, soil acidity showed significant moderate positive (July pH, $r = 0.42$), and strong positive (March pH, $r = 0.76$) correlations, respectively, with the yields of HYV aman and boro rice crops. It indicates that high monsoon rainfall reduces the soil acidity in July when its impact on the yield of HYV aman rice would be lesser. In contrast, lack of rain and dryness increases the soil acidity in March and exerts greater impact on the yield of HYV boro rice (Table 6). Soil salinity also shows significant negative relationships with the rice yields. Again, the soil salinity shows relatively weak negative (July EC, $r = -0.35$) correlation with HYV aman rice yield, and very strong negative correlation (March EC, $r = -0.73$) with HYV boro rice yield indicating the fact that soil salinity significantly reduces the crop yield and such impact is lessened under high rainfall. Soil Ca, K, N, P, S, and organic C contents showed relatively strong positive correlations with the yields of both rice crops demonstrating that their depletion would also reduce the rice yield. It is to be noted here that depletion of soil Ca, Mg, K, N, P, and organic C content can also occur in any rice field due to long-term water logging for double rice cultivation; however, high increase in soil salinity, acidity, and S content are specially attributed to long-term shrimp farming. The depletion of soil nutrients can be recovered through application of chemical fertilizers; however, soil salinity and acidity are difficult to minimize and they are more detrimental to rice farming than the depleting nutrients considered here.

*Impact of shrimp farming on total rice production*

The transformation of potential HYV aman (27.5 ha) and HYV boro (283 ha) rice fields into shrimp ponds and declining yield of both cultivars has jointly reduced the total production of rice in the village. Holding the lowest, median, and highest yields of HYV aman and boro rice as constants, the village had a potential (expected) to produce between 1260, 1371, and 1562 mt of rice annually in 1985 (Table 7). That year, however, transformation of 36.5 ha of land into shrimp ponds caused the observed total production to be 125–184 mt less than its expected estimates. Over the next 5, 10, and 18 years, as the potential rice area declined, respectively, by 75, 231, and 311 ha due to their transformation into

Table 5
Land use types, soil degradation, and its impact on HYV rice yields in Damarpota village: 1985–2003

| Soil type: land use type | Year | Median yield of HYV rice crops | | % Decline 1985–2003 | | % Decline due to | | | | Soil degradation index |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Initial decline due to rainfall, farm mgmt., and low-lift pump irrigation practices | | Shrimp farming and soil degradation | | |
| | | Aman | Boro | Aman Col. 5 | Boro Col. 6 | Aman Col. 7 | Boro Col. 8 | Aman Cols. 5–7 | Boro Cols. 6–8 | |
| Typic Haplaquept type I: rice and legumes | 1985<br>2003 | 1.96<br>1.75 | 3.21<br>2.30 | −10.7 | −28.3 | −10.7 | −28.3 | 0 | 0 | 1.0 |
| Thapto Histic type II: rice and shrimp for 5 years | 1985<br>2003 | 2.0<br>1.55 | 3.0<br>1.95 | −22.5 | −35.0 | −10.7 | −28.3 | −11.8 | −6.7 | −21.2 |
| Thapto Histic Haplaquept type III: rice and shrimp for 10 years | 1985<br>2003 | 1.88<br>1.32 | 2.82<br>1.64 | −29.8 | −41.4 | −10.7 | −28.3 | −19.1 | −13.1 | −34.4 |
| Thapto Histic Haplaquept type IV: rice and shrimp for 15 years | 1985<br>2003 | 1.70<br>1.11 | 2.6<br>1.28 | −34.7 | −50.8 | −10.7 | −28.3 | −24.0 | −22.5 | 49.8 |

Table 6
Relationship between yield of HYV aman and boro rice and nine soil chemical properties

| Soil property | Yield of HYV rice | |
|---|---|---|
| | Aman rice | Boro rice |
| pH | 0.42 | 0.74 |
| EC | −0.35 | −0.73 |
| Organic C | 0.38 | 0.50 |
| Calcium | 0.73 | 0.71 |
| Magnesium | −0.35 | −0.38 |
| Potassium | 0.56 | 0.57 |
| Nitrogen | 0.56 | 0.70 |
| Phosphorus | 0.60 | 0.36 |
| Sulfur | 0.40 | 0.76 |

shrimp ponds, and the yield of both HYV aman and boro rice crops declined simultaneously, the differences between the expected and observed total rice production estimates increased steadily over time. In 2003, without any shrimp farming, the village had a potential to produce between 1393, 1673, and 1916 mt of rice based on the 1985 low, median, and high yield rates, respectively. Based on the median production estimate, the village produced only 522 mt of rice, and suffered a total loss of 1151 mt, 77% (890 mt) of which was attributed to loss of rice area to shrimp ponds, and the remaining 23% (261 mt) loss was due to declining yield (Table 7). Since about 39% (11% in aman, 28% in boro) decline in HYV rice yield is attributable to variation in rainfall and farm management practices, the actual total loss in median rice production due to expanded shrimp farming would be 1049 mt, i.e., 62% of the expected median total production. In the face of rapidly growing village population, which grew from 888 people in 1985 to 1324 people in 2003, such drastic reduction in rice production has increased food deficit among the smallholders.

## *Declining fodder and livestock population*

Like elsewhere in Bangladesh, there is no grazing land in Damarpota village. Grasses and weeds grown on rice fields, as well as rice straw, hays, bran, and husks are used as livestock feed. Expanded shrimp farming and declining rice area has reduced the fodder production that has led to a rapid decline in livestock population from 630 in 1985 to 168 in 2003.

## *Disruption of rice–fish aquatic habitat*

Farmers apply dolomite powder (>75 kg/ha) to clean up water, and use urea (40 kg/ha), TSP (75 kg/ha), Muriate of potash (40 kg/ha) mixed with composted cow manure, and purchased feed to maintain the nutrition

Table 7
Shrimp farming and declining rice production in Damarpota village: 1985–2003

| Year | Potential rice area in ha[a] (%) | Area and months under rice and shrimp farming in ha (% of crop land) | | | | Observed rice yield ($O_Y$) per ha in mt. | | | Exp. total rice production[d] | Obs. total rice production | Decline in total rice production due to loss of[e] | | Total loss of rice production due to reduced area and yield[f] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | HYV Aman July–Nov. | HYV Boro Dec.–May | One-shrimp cycle Dec.–Jun.[b] | Two-shrimp cycle Dec.–Nov.[c] | Yield category | Aman | Boro | | | Area | Yield | |
| 1985 | 582.0 (168) | 345.5 (1 0 0) | 200.4 (58) | 36.5 (10.6) | 0 | Lowest | 1.78 | 2.30 | 1260 | 1076 | 184 | — | 184 |
| | | | | | | Median | 1.95 | 2.95 | 1373 | 1265 | 108 | — | 108 |
| | | | | | | Highest | 2.16 | 3.45 | 1562 | 1437 | 125 | — | 125 |
| | | | | | | St. dev | 0.09 | 0.31 | | | | | |
| 1990 | 689.1 (200) | 344.6 (1 0 0) | 269.6 (78.2) | 75.0 (21.8) | 0 | Lowest | 1.50 | 1.73 | 1406 | 983 | 173 | 250 | 423 |
| | | | | | | Median | 1.70 | 2.50 | 1689 | 1260 | 221 | 208 | 429 |
| | | | | | | Highest | 1.86 | 3.33 | 1933 | 1539 | 259 | 135 | 394 |
| | | | | | | St. dev | 0.10 | 0.36 | | | | | |
| 1995 | 685.4 (200) | 332.4 (97.0) | 122.4 (32.8) | 210.0 (67.2) | 20.6 (3.0) | Lowest | 1.20 | 1.25 | 1398 | 552 | 525 | 322 | 846 |
| | | | | | | Median | 1.45 | 2.15 | 1679 | 745 | 670 | 264 | 934 |
| | | | | | | Highest | 1.78 | 3.55 | 1922 | 1027 | 780 | 115 | 895 |
| | | | | | | St. dev | 0.15 | 0.44 | | | | | |
| 2003 | 683.0 (200) | 314.0 (91.9) | 58.2 (17) | 255.8 (91.0) | 55.0 (8.0) | Low | 1.0 | 1.23 | 1393 | 386 | 701 | 306 | 1007 |
| | | | | | | Median | 1.31 | 1.90 | 1673 | 522 | 890 | 261 | 1151 |
| | | | | | | High | 1.78 | 2.17 | 1916 | 685 | 1036 | 195 | 1231 |
| | | | | | | St. dev | 0.24 | 0.34 | | | | | |

[a]Potential rice area was estimated by multiplying the net cropland by the frequency of rice cultivation.
[b]One-shrimp cycle during the months of December–June affects the cultivation of HYV boro rice.
[c]Two-shrimp cycle during the months of December–November affect the cultivation of both HYV aman and boro rice crops.
[d]Expected total rice production was computed as follows: $\sum(P_A \times P_Y)$, where $P_A$ and $P_Y$ represent potential cropland used for HYV aman and boro rice, potential baseline (1985 = 100) yield of HYV aman and boro rice, respectively.
[e]Decline in rice production due to loss of rice area to shrimp farms was computed as: Area under shrimp $\times P_Y$.
[f]Decline in rice production due to declining yield due to shrimp farming was computed as: Area under crop $\times (P_Y - O_Y)$. Lowest, median, and highest observed yield have been taken into account to calculate the total rice production.

level of the shrimp pond. Tea and tobacco dusts, rotenone, thiodan, and antibiotics, such as tetracycline, oxytetracycline, and streptomycine, are also used in shrimp ponds to control shrimp disease and unwanted snails, and improve production. Application of higher volume of chemicals increases both soil and water toxicity. In addition, Aflatoxin produced by *Aspergillus flavus* and *Aspergillus parasiticus* fungi developed in shrimp feed stored under excessive humidity also releases toxic elements to water and soil in rice–shrimp field (Deb, 1998).

In Damarpota, wet rice fields, ponds, ditches, and ox-bow lakes have been important habitats for fish, snails, frogs, birds, and large number of aquatic micro-organisms. Over the past two decades, shrimp farming has increased water salinity; it may have caused some unknown degree of chemical toxicity of water that has severely damaged the aquatic habitat inherent in the rice fields. As evidenced during field research, 19 species of fresh water fish belonging to *Cichlidae*, *Saccobranchidae*, *Clariidae*, *Schilbidae*, *Cobitididae*, *Cyprinodontidae*, *Cyprinidae*, *Notopteridae*, *Osteoglossinae*, *Channidae*, *Mastacembelidae*, *Synbranchidae*, *Afronandus*, *Sheljukoi*, *Nandidae*, *Belonidae*, *Trypanchenidae*, *Samaris*, and *Tetraodon* families have become either totally extinct or removed by the shrimp farmers to protect shrimp and other saline water fish. While shrimp is very expensive for the poor villagers, declining fresh water fish has reduced their protein availability.

## Discussion

Over the recent decades, transformation of rice fields into shrimp farms has been a major land use/land cover change in coastal areas of Bangladesh. Apart from its negative impacts on soil and rice ecosystem, such transformation and its economic rationale has important theoretical implications toward understanding the complexities of smallholder production behavior. Traditional smallholders in the tropics respond to population growth by intensifying agricultural production via frequent cultivation employing more labor inputs, and using improved techno-managerial strategies and high yielding crops (Boserup, 1965; Turner et al., 1977; Turner and Ali, 1996). Increased population demand for consumption production is the central issue underlying this consumption demand thesis of agricultural change (Boserup, 1965). Smallholders also respond efficiently to increased market opportunities for commodity crops, change their land use/land cover strategies, and shift toward commodity production by allocating more cropland into commodity production to obtain the best monetary benefits from the market (Schultz, 1964). Agriculture intensifies in response to the growing market demand, be it more of one product or shift to another. Numerous empirical studies have also supported this commodity demand thesis of agricultural change (Hopper, 1965; Huang, 1976; Mellor, 1969; Wharton, 1969).

What is not recognized in either the consumption or the commodity demand thesis of agricultural growth is the fact that most traditional farmers produce both consumption and commodity crops and exhibit "dual" or mixed production behavior. They could not be true risk-takers and gamble wholly with the market (Lipton, 1968). Rather, they are "proficient" to first ensure the subsistence production, and then engage in commodity production (Schluter and Mount, 1976). Indeed, traditional farmers in the tropics are engaged in various mixes of consumption and commodity production and intensify agriculture in response to population, market, and social demands. Underlying this rationale, the modified demand thesis argues that the mixed production behavior does not lead to "optimization" in either the consumption or the commodity meanings of the terms (Brush and Turner, 1987). The consumption side is marked by the interplay of least cost (labor) and least risk objectives to achieve a bio-culturally determined satisfactory level of subsistence. Population pressure remains as the central force controlling the level of consumption production and cropping strategies involved (Boserup, 1965; Turner et al., 1977; Turner and Ali, 1996). The commodity production is characterized by optimizing toward material gain. Local, regional, and international demands for certain commodity(s) induce farmers to change their cropping strategies and allocate more lands for commodity production although they still maintain substantial production for direct consumption.

Yet what are not recognized in either the commodity or modified consumption–commodity demand themes of agricultural growth are the environmental consequences of mixed production behavior in cases where the ecology of consumption and commodity crops is not uniform and compatible, and a switch from one to the other requires major transformation of the ecosystem. A unique example to this situation is the transformation of rice fields into shrimp farms in densely populated tropical coastal areas of Asia and Latin America. On the one hand, high population pressure induced smallholders to intensify rice production by shifting from low yielding variety to HYVs of rice (Hossain, 1991; Ali, 1987; Turner and Ali, 1996). On the other hand, increased global market demand for cultured shrimp and its high profit has induced tropical farmers to transform part of their rice fields into shrimp ponds and thus transformed into dual farmers (Pingali et al., 1997). It is important to understand the environmental consequences of such land transformation: whether this would disrupt the ecological conditions and sustainability of rice production; and how that would affect the farmers mixed production behavior.

Findings of the present study provide an important empirical example verifying the negative consequences of transformation of land to increase commodity production. They show that over the 18-year period in question, a significant amount of prime quality rice fields have been transformed into shrimp ponds in the study area. The intent for such transformation is to increase commodity production to earn material gains. However, under growing population pressure, the village farmers could not totally give up the production of rice needed for consumption; therefore, they adapted to a rice–shrimp rotation system and gradually expanded shrimp farming onto rice fields. While they showed dual production behavior, intensive rice cultivation using chemicals, power tillers, and low-lift irrigation pump have already degraded soil qualities; and the expansion of shrimp farming has contributed to further degradation of soil that was once ideal for rice farming. Increased soil salinity and acidity, and depletion of basic nutrients need for optimum vegetative growth of rice plants have significantly lowered the yield and total production of rice in the village. Shrimp farming has also disrupted both aquatic and non-aquatic habitat inherent in rice ecosystem. The study results thus suggest that despite their higher economic returns, increased commodity production can exert significant negative impacts on the consumption production if the ecosystem for both consumption and commodity crops are not identical and uniform.

## Conclusion: rice or shrimp?

This study has examined both the environmental and economic rationales for shrimp farming in the village Damarpota in Southwestern Bangladesh. The results show that prolonged shrimp farming on rice fields has significantly degraded the village's soil qualities, drastically reduced its rice production, and destroyed the aquatic and non-aquatic habitat inherent in the rice ecosystem. While the economic benefit from shrimp is much higher than rice, its negative impacts on rice farming are also alarming given the fact that increased food production via intensive rice cultivation is highly demanded by the rapidly growing village population. Shrimp farming has reduced the total rice production; and by degrading soil qualities, it has lowered rice yields and threatened the sustainability of the rice ecosystem and thus pushed the smallholder village residents, whose land was transformed into shrimp ponds, toward a greater risk of food shortage and poverty. Since both rice and shrimp productions are important to ensure food security and economic well-being of the village, it is recommended that government and local community formulated strong rural land use planning regulations should be imposed to stop unplanned shrimp farming on prime quality rice fields. Efforts should be made to identify the agriculturally marginal lands that can be solely used for year-round intensive shrimp farming. This will save the rice fields and still allow the opportunities for highly profitable shrimp farming much needed for both food security and economic well-being of the village.

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