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Farming Adaptation to Environmental Change in Coastal Bangladesh: Shrimp Culture versus Crop Diversification

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Abstract

Farming in coastal Bangladesh includes rice/shrimp and rice/non-rice cropping systems. The former has been highly profitable but has exacerbated salinization of soil and water. We evaluate the relative profitability, riskiness, and sustainability of the two cropping systems, using data from two coastal villages in Khulna District. Shrimp cultivation was initially very rewarding. However, over 12-15 years the cropping system experienced declining profitability, increased salinity, and adverse impacts on rice cropping and the local environment. From 2009, farmers adapted the system by changing the pond (*gher*) infrastructure, adopting delayed planting of a saline-tolerant rice cultivar, flushing out accumulated salt with freshwater during rice cropping, and allowing the soil to dry out after harvesting rice. The budgeting results show that, with current management practices, the rice/shrimp system is economically more viable (higher returns to land and labour and less risky) than the rice/non-rice system. Soil analyses showed that, while salinity was higher in the *gher* during the dry season, it was significantly reduced in the wet season and was very similar between the two systems (1-2 dS/m). Hence, as well as being more profitable and less risky, the rice/shrimp system may well be more sustainable than previously observed.

Keywords: coastal zone, salinity, rice, shrimp, farm budgeting, risk analysis, sustainability

1. Introduction

The coastal region of Bangladesh (Fig. 1) is ecologically and economically very important because of its agricultural, energy, and marine resources (CDS, 2006). It covers nearly 32% of the total area (BBS, 2010a) and 30% of net cultivable area (SRDI, 2012) and contributes about 25% of total rice output (BBS, 2010a). The region suffers from a range of problems, the most notable of which is soil and water salinity. The topsoil of nearly 223,000 ha of coastal arable land (27% of total cultivable land in the region) has been affected by various degrees of salinity during 1973-2009 due to decreasing freshwater flows of upstream rivers, an erratic rainfall pattern, the rise of brackish-water shrimp culture, tidal flooding, and capillary rise of dissolved salt (SRDI, 2012).

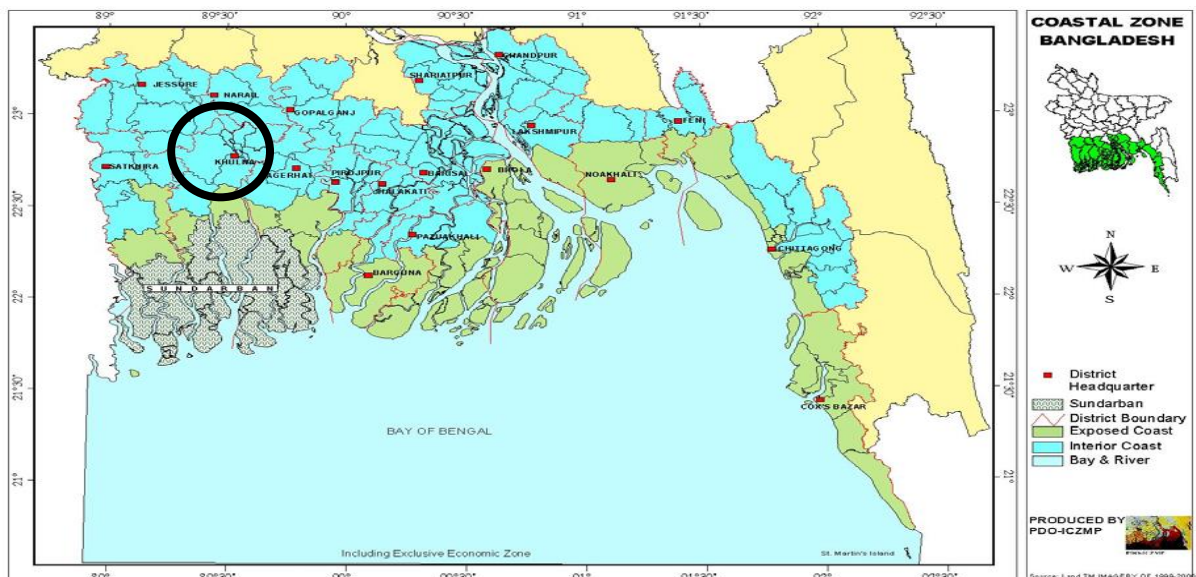


Figure 1 Coastal zone of Bangladesh (study area circled)

Source: http://unearthnews.org/wp-content/uploads/2013/07/coastal_bangladesh.gif

The land-use pattern in the coastal region has been substantially influenced by the level of salinity and the availability of irrigation water for dry-season crops. The proportion of fallowed areas has been increasing because of soil salinization and scarcity of freshwater irrigation (SRDI, 2012). Although most arable areas are used for crops (mainly rice), a good proportion is also used for shrimp farming, as seen in data for Khulna District in the south-west of the coastal zone (Table 1; Fig. 1). Rice fields that are subsequently used for shrimp culture in the dry season are locally known as *gher*; these involve some modification through constructing a trough inside the earthen enclosures to increase water depth over a portion of the field. Strong international demand for shrimp and high prices encouraged farmers to rapidly expand the shrimp farming areas, with encouragement from national leaders,

international development agencies, and private sector entrepreneurs (M. J. Alam, Islam, Saha, Tuong, & Joffre, 2010; Neiland, Soley, Varley, & Whitmarsh, 2001). The area under shrimp farming jumped from 64,000 ha in 1983 to 275,000 ha in 2012 (FRSS, 2013).

Table 1 Salinity level and land use in Khulna District

Salinity (dS/m)	Cropping patterns	% of total cropped area
2.0-8.0	Boro-fallow-T. Aman	55
	Pulses/oilseeds/vegetables/wheat-jute/Aus-T. Aman	28
	Boro-fallow/Shrimp-T. Aman	17
8.1-12.0	Boro-fallow-T. Aman	20
	Fallow-fallow-T. Aman	40
	Shrimp-Shrimp-T. Aman	20
	Boro-Shrimp-Shrimp	10
	Fallow-Sesame-T. Aman	10
>12.0	Boro-fallow-T. Aman	5
	Shrimp-Shrimp-T. Aman	17
	Fallow-fallow-T. Aman	38
	Boro-Shrimp-Shrimp	12
	Shrimp-Shrimp-Fallow	28

Source: Adapted from SRDI (2012, pp.16-18).

Notes: dS/m = deciSiemen per metre = 1,000 EC units; T. Aman refers to the transplanted wet-season rice crop; Boro refers to the irrigated dry-season rice crop.

Shrimp farming has contributed significantly to the national economy through foreign exchange earnings (averaging BDT 32 billion from 2006/07 to 2010/11) (BBS, 2011) and generating income, employment, and food for coastal dwellers (Ahamed, Hossain, Fulanda, Ahmed, & Ohtomi, 2012; Paul & Vogl, 2011). However, there have been severe environmental impacts in the form of sedimentation, salinization, pollution, disease outbreaks, and loss of biodiversity (Ali, 2006; Hossain, Uddin, & Fakhruddin, 2013). This was mainly because of poorly planned and unscientific practices (S. M. N. Alam, Kwei Lin, Yakupitiyage, Demaine, & Phillips, 2005; Paul & Vogl, 2011). Shrimp farming involved the introduction of exotic species and pathogens, and the ponds (*gher*) regularly discharged polluted water and sludge containing particulate matter, unused fish feed, fertilizer and other chemicals, microorganisms, and faeces (Azad, Jensen, & Lin, 2009; Datta, Roy, & Hassan, 2010). Consequently, the land and water resources of the coastal ecosystem were being degraded (WB, 2000), resulting in decreased production of rice (Ali, 2006), vegetables and other crops (S. Rahman, Barmon, & Ahmed, 2011), livestock, and freshwater species (Karim, 2006), exacerbating food insecurity and livelihood vulnerability (Swapan & Gavin, 2011).

The government faced a challenge to safeguard the livelihoods of coastal dwellers (WB, 2000). In this context, brackish-water shrimp cultivation was stopped in most areas of Dacope Upazila (sub-district) in Khulna District in 2008. The area under the rice/shrimp cropping system in Dacope decreased from 13,395 ha in 2008 to 2,464 ha in 2012 (DoF, 2013).

The key bottlenecks affecting the sustainability of cropping systems in the coastal region are twofold: (1) the existing geophysical setting, that is, the scarcity of freshwater for irrigation, soil salinization and erosion, siltation of drainage canals, and waterlogging (Rawlani & Sovacool, 2011); (2) the socioeconomic conditions, namely, that most farmers (84%) are semi-subsistence smallholders and resource-poor, with an average farm size of 0.6 ha (BBS, 2010b), a low rate of adoption of modern technologies (Bala & Hossain, 2010), and high dependence on seasonal weather conditions for cropping due to low access to irrigation (MoEF, 2009). The broader issue of shrimp farming in the coastal environment needs to be seen in this context. Despite the evidence that shrimp farming entails adverse environmental impacts and exacerbates the salinity problem, two alternative pathways have been pursued. One is to persist with brackish-water shrimp cultivation for short-term financial gains at the cost of possible long-term environmental impacts. The other is to protect the soil and water from salinity intrusion to enable freshwater irrigation and dry-season cropping. Managing this trade-off is a matter for collective choice faced by villages and districts in the coastal region.

The key questions that need answering in making this choice are: Just how profitable, risky, and sustainable is the rice-shrimp system compared with cropping-only systems? Can brackish-water shrimp culture be made sustainable in a region where salinity poses an increasing threat to overall sustainability? The existing literature has not addressed these issues adequately, particularly for coastal Bangladesh. Thus the present study analyses the profitability, riskiness, and sustainability of a rice/shrimp cropping system relative to rice/non-rice cropping systems in south-western coastal Bangladesh. The specific objective of the study was to assess the economic viability and sustainability of two contrasting land-use pathways in the south-west. We draw on case studies of two villages in Khulna District, in one of which farmer adaptations have enabled a rice-shrimp system to be sustained, based on access to tidal, saline water during the dry season and freshwater during the wet season. This village's situation is not representative of the whole coastal zone but is an important case where rice-shrimp farming may be considered sustainable, at least for the time being. The second village represents a context where access to freshwater for irrigation enables dry-

season cropping to be sustained, providing a reference point for comparison with the shrimp farming village.

2. Methodology

2.1 Study location, data collection, and validation

Two villages in Dacope Upazila in Khulna District with contrasting farming systems were selected for study (Fig. 1). In the first village – Shaheberabad – arable land was intensively used for rice and non-rice cropping because of low levels of salinity, the availability of freshwater irrigation for dry-season cropping, and better access to extension services and markets. The second village – Uttar Kaminibasia – practised rice-fish farming in the wet season and brackish-water shrimp farming in the dry season. This village had better access to tidal water throughout the year but poorer access to markets and extension services.

Fieldwork was conducted during February and March 2013 and from May to early December 2014. A census was first carried out in each village using a structured checklist to collect basic socio-demographic data and develop a sampling frame. Thereafter, farm-level data to address the research objectives were collected through group interviews and nine case studies of farmers in different farm-size classes. The group interview was conducted with 3-5 knowledgeable farmers in each village. The case studies involved face-to-face interviews with each farmer.

Representative enterprise budgets for the major cropping systems were developed using input and output data obtained from these sources. These budgets were subjected to risk analysis. During May 2014 the results were presented to the key informants in the case-study villages and to an expert panel consisting of researchers and extension personnel working in the study area. The key informants and expert panel confirmed that the approach of estimating costs and returns on an enterprise basis was practical for selecting between enterprises, and the budgets were mostly consistent with reality. Some modifications were suggested to estimated input use (labour, fertilizers, and pesticides) and harvested yield.

In addition, soil samples were collected from eight plots in March 2013 – two plots where the rice/shrimp cropping system was practised and six plots where rice/non-rice cropping systems were practised (watermelon, pumpkin, or fallow). Samples were collected following standard procedures and analysed in the Soil Resources Development Institute (SRDI)

laboratory in Khulna to estimate key chemical properties. Soil and water samples were also taken from six plots in the first and third weeks of each month during mid-August to early-December 2014 and the level of salinity measured using a conductivity meter.

2.2 Estimating costs and returns for farm enterprises

The farm enterprise budget is a planning device not only for choosing better (economically viable) farming options (crops, livestock and aquaculture) but also for allocating inputs (land, labour and capital) within the enterprises (Debertin, 1986). It corresponds well to the way farmers view their activities and decisions, even in low-income rural economies such as that of coastal Bangladesh. There are various ways to specify costs and returns in a farm enterprise. We follow Herdt (1978), who makes the important distinction between “paid-out costs” for purchased inputs and “unpaid costs” for family-supplied inputs, including labour. Herdt (1978) specifies enterprise returns as “gross income” (gross benefit less paid-out costs) and “net income” (gross income less the imputed value of unpaid costs). These measures focus on the return to the family’s resources used in farming as well as indicating the welfare of the farm family.

The farm operators in the study locations used purchased and home-supplied inputs, hired and family labour, own and rented land, and different types of machinery. Following Herdt’s (1978) distinction, total paid-out costs (TPC) were defined to include the actual payments (cash and in-kind) for purchased inputs (seeds, fertilizers, farmyard manure (FYM), pesticides, fuel), hired-in labour, machinery services (power tiller, pump, and thresher), and rented-in land. Total imputed costs (TIC) were defined to include home-supplied inputs of family labour, land, FYM, machinery, and seed. The cost of these inputs was estimated according to the opportunity-cost principle. It was assumed that the imputed cost was equal to the income the farmers could earn by hiring out family resources (family labour, land, and machinery) for an equivalent time and/or selling the resources (home-supplied seed and FYM) to other farmers. It is well known that the market wage rate may overstate the opportunity cost of family labour, especially for women and teenagers helping out part-time, but also for full-time male labour, as there is not always an alternative opportunity to the specific use of labour in question. However, in this study, prevailing market rates were used for labour and other inputs, giving an upper-bound estimate of TIC. The total cost of an enterprise (TC) was the sum of TPC and TIC.

The gross benefit (GB) of an enterprise was defined as the value of produced output (including by-products) at the actual selling prices at the farm gate, regardless of whether the products were sold, used for consumption, retained as seed or livestock feed (rice straw), paid in kind, given to others, or stored (Dillon & Hardaker, 1993). Following Herdt (1978), the gross income (GI) of an enterprise was estimated as the GB less TPC. The net income (NI) of an enterprise was estimated by subtracting TIC from GI. Hence $NI = GB - TC$. (Flinn, Jayasuriya, & Maranan (1991) define the return to family labour as net income plus the opportunity cost of family labour divided by the number of days of family labour used. For convenience, we used a proxy measure, namely the GI per work-day of family labour, that is, the ratio of GI per ha to the number of days of family labour per ha for each enterprise. Given the high proportion of family labour in TIC, this measure gave a reasonable indicator of the return to family labour relative to a benchmark wage.

2.3 Allowing for risk

Farming operates under various degrees of external risk arising from variability in weather, pests and diseases, and prices of farm inputs and outputs (Chavas, Chambers, & Pope, 2010; McConnell & Dillon, 1997). Enterprise budgeting gives a fixed-point estimate of economic performance, without incorporating the influence of uncertain factors (Lien, 2003). Hence stochastic budgeting was used to incorporate the risk associated with the major cropping systems. Farmers were asked to estimate the typical, best-case, and worst-case yields and prices for each enterprise. The best-case yield was that obtained under favourable weather conditions and the worst-case yield under unfavourable weather conditions, but extreme events such as cyclones and storm surges causing productivity decreases of over 60% were not included. The @RISK Program Version 6.2 was used with Microsoft Excel to construct stochastic budgets via Monte Carlo simulation. Triangular probability distributions were assumed because the variables were continuous in nature (Hardaker, Huirne, Anderson, & Lien, 2004), with the lower limit as the estimated worst case, the mode as the perceived most likely outcome, and the upper limit as the best case. The highest number of iterations (10,000) was used for simulating each farm budget as the stability of the distribution increases with the number of iterations (Lien, 2003). Stochastic dominance or efficiency analysis was carried out to evaluate risk-return trade-offs by comparing cumulative probability distributions of the alternative enterprise and cropping system choices (Anderson, Dillon, & Hardaker, 1977; Dillon & Hardaker, 1993). The concept of first degree stochastic dominance (FSD) assumes merely that, in choosing between income-earning options, farmers

prefer more income to less, whereas the concept of second degree stochastic dominance (SSD) assumes that, for a given expected income, farmers prefer less variability to more variability.

2.4 Assessing sustainability

Agricultural sustainability implies the capacity of an agro-ecosystem to maintain its productivity over time, that is, to display a non-negative trend in productivity over a reasonable planning horizon of say several decades (Lynam & Herdt, 1989). However, assessment of sustainability is not a straightforward matter. Cropping system sustainability in this study has been assessed from two perspectives. On the one hand, the study focused on how farmers have adapted over time to the changing environment, the trends in crop yields, changes in the quantity and quality of material inputs, reported changes in land use and the local ecology, and changes in livelihoods. On the other hand, soil chemical properties and salinity in both the dry and wet seasons were analysed (as noted above) to indicate trends in the underlying resource base of the systems.

3. Village Profiles

3.1 Socio-demographic features

Shahebrabad had 180 households with an average family size of 5.5. About 80% of households were farming families, of which the majority (77%) were in the small farm category (<1.0 ha). The remaining 20% of total households were landless. Uttar Kaminibasias consisted of 210 households with an average family size of 5.3. About 79% of households were farming families, of which 61% were small farmers. The remaining 21% of total households were landless (Table 2). Table 3 shows that a higher proportion of households had more than one occupation in Shaheberabad (74%) than in Uttar Kaminibasias (60%). Most households (> 90%) in the two villages were directly (through own-account farming) or indirectly (through off-farm employment) dependent on agriculture for their principal source of livelihood. Because of the generally small farm size, not only landless labourers but also most farming families engaged in off-farm wage employment for cash income. Thus the two villages were very similar in socio-demographic terms.

Table 2 Classification of farming households

Farm type	Shaheberabad				Uttar Kaminibasias			
	Households		Farm size (ha)		Households		Farm size (ha)	
	No.	%	Mean (SD)	Range	Number	% of total	Mean (SD)	Range
Small	111	77	0.4 (0.25)	0.1-0.9	102	61	0.5 (0.27)	0.1-1.0
Medium	22	15	1.4 (0.33)	1.0-2.0	42	25	1.6 (0.54)	1.1-2.9
Large	11	8	3.0 (0.79)	2.0-4.7	22	13	4.9 (1.6)	3.1-9.1
Total	144	100			166	100		

Source: Village census. Farmers' definitions of medium and large farms differed between the two villages.

Table 3 Occupational classification of the village households

Occupations		% of households	
Primary	Secondary	Shaheberabad, (n=182)	Uttar Kaminibasias (n=208)
Farming	Wage-employment	43	39
Wage-employment	Farming	18	12
Wage-employment	Nil	17	20
Farming	Nil	6	19
Self-employment	Farming	5	1
Farming	Self-employment	4	5
Self-employment	Nil	3	1
Farming	Service	3	1
Service	Farming	1	1
Total		100	100

Source: Village census

3.2 Physical features

Shaheberabad and Uttar Kaminibasias are villages of Dacope Upazila in Khulna District. Shaheberabad is located on Polder 30 on the bank of the Bhadra River, 5 km from the upazila headquarters and hence with relatively better access to markets for both inputs and outputs and to government services (agricultural extension, education, and health). Uttar Kaminibasias is located on Polder 31 on the bank of the Shibsha and Dhaki Rivers, about 15 km from the upazila headquarters and 10-12 km from the World Heritage Sundarbans mangrove forest. Its

location gives it better access to tidal water but poorer access to basic services (markets, extension, education, and health).

According to key informants, the village areas are flat. Most arable land (85%) in Shaheberabad is classed as “medium-high” (land flooded to about 90 cm) and the rest (15%) is “medium-low” (land flooded to 90-180cm). However, in Uttar Kaminibasias most arable land (85%) is medium-low and the rest (15%) is low (land flooded to 180-275 cm) (BBS, 2011).

Farmers in the discussion group in Shaheberabad stated that their sources of irrigation for dry-season cropping were reserved freshwater in the Chunkuri River (a branch of the tidal Bhadra River), a canal, homestead fish ponds, and in-field troughs. Conversely, in Uttar Kaminibasias the main sources of water for farming (including rice-fish in the wet season and brackish water shrimp in the dry season) were tidal water from the Shibsha and Daki Rivers admitted through three sluice gates and a number of small man-made opening in the embankment.

These physical differences between the villages were influential in the choice of cropping systems, as discussed below.

4. Agricultural Change and Impacts

4.1 Evolution of farming systems

Despite the prospect of high economic returns, farm households in Shaheberabd collectively decided against adopting brackish-water shrimp farming in 1986. This was partly due to the unavailability of well-suited arable lands for shrimp culture and partly because of likely adverse environmental consequences. In contrast, despite strong protests from small and medium farmers, brackish-water shrimp culture commenced in Uttar Kaminibasias in 1985 because of support from large, influential farmers. The opportunity to exploit the abundant coastal resources, including favourable topography (medium-low to low land), the location of the village between two large rivers (the Shibsha and the Daki), and the availability of saline water and wild post-larvae of fish and shrimp underpinned this decision. Key informants in Uttar Kaminibasias reported that, before 1985, only a few paddy areas would be used for dry-season crops, including rice, vegetables, and sesame, and some areas would be used for

cultivating jute in the early-wet season, but these dry-season crops are no longer found in the village.

Table 4 shows changes in cropping systems in paddy lands and associated trends in rice yields in the two villages since 1985. The area of wet-season rice in Uttar Kaminibasias decreased to 70-75% of total arable area after a decade of shrimp farming, and plummeted to 25-35% after two decades, mainly because of a substantial decline in rice yield. In this respect, a member of the expert panel – a soil specialist¹ from the Bangladesh Rice Research Institute (BRRI) – suggested that the productivity of local varieties of wet-season rice might have decreased due to changes in the soil physical properties (increased salinity, decreased fertility, and trapped marsh gases underneath the muddy soil, e.g., CO₂ and CH₄), late transplanting, increased infestation of rice water-logging disease (in which the roots become black) due to prolonged inundation of arable land, and zero application of pesticides (because they are harmful to fish). Key informants in the village added that higher economic reward and less arduous cultural operations encouraged some farmers to continue shrimp culture year-round, as in an adjacent sub-district (Paikgachha). Decreased area and productivity of monsoon rice was identified as a major adverse consequence of brackish-water shrimp cultivation in previous studies (Chowdhury, Khairun, Salequzzaman, & Rahman, 2011; Hossain et al., 2013; M. M. Rahman, Giedraitis, Lieberman, & Akhtar, 2013). A significant change in shrimp culture in the village occurred in 2008-9. The local Member of Parliament (MP) used his political influence to declare Dacope Upazilla free from brackish-water shrimp culture from 2009 in response to the opposition to shrimp culture of most villagers in the upazilla. This opposition stemmed from the low rice yields, chronic severe viral infestation, the decline in the number of livestock, and loss of homeyard production of fruit and vegetables. Though most farmers in Uttar Kaminibasias were still reluctant to abandon shrimp farming, tidal water was not admitted to the *gher*. Most of the land was left fallow and dried out; some was used for transplanted dry-season rice but the seedlings wilted because of high soil and water salinity. Thereafter, a group of 15-18 farmers decided to violate the verbal order from the local MP and admitted tidal brackish water in early April 2009 to recommence shrimp culture by. They found that, after drying out the land, infestation of virus in the shrimp field and of algae in both the rice and shrimp field markedly decreased, and the yield of the modern saline-tolerant cultivar of rice increased in the following wet season. On this basis, the union council (the lowest tier of government) made a new provision that tidal water

¹ Dr Md. Abu Salaque, Chief Scientific Officer, Soil Science Division, BRRI, Gazipur-1701.

could be admitted to the shrimp *gher* a month after harvesting the wet-season rice so that the land would be adequately dried out. Moreover, land left fallow in the wet season would not be given access to tidal water in the dry season for shrimp culture; this was to increase the level of rice production and self-sufficiency in the village.

This, since 2009, the area of wet-season rice has been restored to 90-100%, as have the productivity of both the wet-season rice-fish and the dry-season shrimp components of the farming system (Table 4). The wet-season rice yield in both case-study villages (3.0-4.5 tonnes/ha) was higher than the national average yield of modern cultivars of 2.6 tonnes/ha (BBS, 2011). The key informants in Uttar Kaminibasia stated that the increase in productivity was due to the adoption of a saline-tolerant modern rice cultivar; changes in the time of crop establishment, with transplanting brought forward by about two weeks; delaying stocking of shrimp post-larvae by nearly a month; regular flushing-out of rice-fields from the final harvest of shrimp to the rice-maturity stage to reduce salinity; and new soil management practices (drying out fields after harvesting rice and pulverizing wet soil between the tillering and panicle-initiation stages of the rice crop to mix sediment, algae, and alluvium and release trapped gases and increase the ability of the rice plants to take up nutrients). In addition, the application of new pesticides (thiamethoxam and chloraniliprole) contributed markedly to increased productivity of both rice and fish as they are very effective against rice pests but do not affect the fish in the paddies, hence the fish can be grown for a longer period. Previously farmers harvested undersized fish to allow the application of pesticides or refrained from using pesticides so as not to harm the fish.

In contrast, there was no change in the area of wet-season rice in Shaheberabad and the yield of wet-season rice steadily increased, particularly after 2005, due to the large-scale adoption of modern cultivars. In addition, the area of dry-season crops markedly increased after 2005 as watermelon, pumpkin, and various vegetables were found to be profitable and substantially less irrigation-intensive than rice (Table 4). The activities of the local government to prevent the intrusion of saline water into the freshwater reserve, the deepening of the canals through NGO-sponsored projects, and the excavation and deepening of canal, troughs in crop fields and of homestead ponds by individual farmers have facilitated dry-season cropping.

However, the area of the major cash crop (watermelon) has recently decreased somewhat from 70% to 60% as the productivity of watermelon has been affected by inadequate irrigation, erratic rainfall, and soil salinity.

Table 4 Evolution of cropping systems in rice paddies and trends in rice yields in case-study villages

Period	Wet season	Dry season	Early wet season	Area (%)	Rice yield (ton/ha)
Uttar Kaminibasias					
1987-1995	Rice-fish	Shrimp		90-100	2.0-2.4
1996-2000	Rice-fish	Shrimp		70-75	1.5-2.0
	Fish	Shrimp		25-30	
2001-2008	Rice-fish	Shrimp		30-40	1.0-1.2
	Fish	Shrimp		60-70	
2009-	Rice-fish	Shrimp		95-100	3.0-4.0
Shaheberabad					
1980-1987	Rice	Fallow	Fallow	60	1.5-1.9
	Rice	Sesame-vegetables	Fallow	30	
	Rice	Rice	Fallow	10	
1990-2004	Rice	Fallow	Fallow	70	2.2-2.6
	Rice	Vegetables	Fallow-rice	55	
	Rice	Rice	Fallow	8	
2005-2010	Rice	Watermelon	Rice-fallow	70	3.0-4.5
	Rice	Pumpkin-vegetables	Rice-fallow	30	
2011	Rice	Watermelon	Fallow	60	3.0-4.5
	Rice	Fallow	Fallow	15	
	Rice	Pumpkin-watermelon	Rice	11	
	Rice	Vegetables	Fallow	4	

Source: Group interviews in villages.

Farmers also cultivated vegetable crops outside the paddy fields, mainly in the houseyards. Key informants in Uttar Kaminibasias said that cultivation of vegetables in the houseyard had stopped a decade after adopting shrimp farming due to soil and water salinity. However, after the changes to the main cropping system introduced from 2009, 65-70% of households had commenced to cultivate early-winter vegetables in the houseyard during November-February so that they could be harvested before commencing the shrimp season. Some households (55-60%) planted summer vegetables (taro and amaranth) in the wet season once salinity had declined. In contrast, in Shaheberabad, vegetables were intensively cultivated in houseyards and along the dikes of ponds due to the favourable environment (low salinity and access to the ponds for freshwater irrigation).

In Uttar Kaminibasias, herds of livestock (cattle, buffaloes, and goats) plunged from 10-12 per household to 0-1 per household within half a decade of adopting shrimp farming, due to the scarcity of feed. This was because the pasture areas were occupied by *gher* during January to August, and production of rice straw, the main cattle feed, had markedly decreased as the area of rice had declined and farmers shifted to harvesting only rice panicles, having no time for handling and drying rice straw. However, the number of livestock slightly increased after 2009 partly due to the increased area of wet-season rice, hence increased production of rice straw, and partly due to a reversion to harvesting paddy with the straw. Moreover, the availability of pasture areas in adjacent villages that had ceased shrimp farming facilitated livestock rearing.

In Shaheberabad, livestock numbers decreased from 12-20 per household in 1980-90 to 3-5 per household in 2008 because of the lack of pasture land for grazing, due mainly to the increase in the area cropped in the dry and pre-monsoon seasons. However, rearing livestock has become more popular in Shaheberabad again with the recent decrease in the area of dry-season and pre-monsoon crops (Table 4).

According to respondents, fish aquaculture in household ponds was not economic in Uttar Kaminibasias as the pond water was saline for six months but fresh for rest of the year, hence neither fresh-water fish nor the brackish-water fish had adequate time to grow to a marketable size. The indigenous freshwater fish died in the pond because of the intrusion of saline water during the shrimp season. Similarly, pond aquaculture was usually affected by dry-season crops in Shaheberabad as the ponds were an important source of freshwater irrigation for these crops. Consequently, fish were harvested before getting to the standard size for marketing.

4.2 Changes in the local environment

Changes in the environment were evaluated considering changes in local biodiversity (flora and fauna), soil quality, and hydrology. Key informants highlighted that in Uttar Kaminibasias these three elements were adversely affected by brackish-water shrimp cultivation. Although a relatively favourable environment for local flora and fauna was maintained in Shaheberabad by preventing shrimp cultivation, the process of soil salinization has prevailed.

(a) Biodiversity. Key informants reported that, in Kaminibasias, 27 indigenous fruit and timber trees² and even grasses and other weeds in the rice fields became rare within a decade of adopting shrimp cultivation due to rising salinity levels. Other indigenous fruit trees (coconut and sapodilla) survived but hardly bore any fruit. Karim (2006) also reported that, in a village in Bagerhat District in Khulna Division, about 60% of trees had died and some trees, aquatic plants, and weed species had completely disappeared due to shrimp culture. In contrast, the homesteads of Shaheberabad continued to be surrounded by an abundance of fruit and timber trees. A member of the expert panel – a rice farming systems specialist³ – further claimed that beneficial arthropods, amphibians, and birds have significantly decreased in numbers because of salinity, hence pest infestations in wet-season rice have increased. Moreover, about 16 species of freshwater fish have become scarce due to increased salinity after introducing shrimp farming.⁴ Swapan and Gavin (2011) also reported a marked decline in freshwater fish due to cultivation of brackish-water shrimp.

(b) Soil. Farmers in the group discussion in Kaminibasias highlighted that, after 12-15 years of continual admission of tidal water, soil fertility had decreased, leading to a decline in the productivity of wet-season rice. Other writers have reported that prolonged saline water inundation depletes soil organic matter, C, Ca, K and Mg (Ali, 2006), inhibits nitrogen fixation and mineralization (Islam, 2003), and generally degrades the land for cropping (Hossain et al., 2013). Moreover, farmers reported that the level of the shrimp *gher* has been raised and the depth of water in the *gher* reduced because of sedimentation. The productivity of shrimp has also markedly declined, in part due to virus infestation.

(c) Salinisation. Informants stated that soil and water salinity in the shrimp *gher*, rivers, canals, and household fish ponds increased in the dry season, largely because of brackish-water shrimp cultivation, but decreased to low levels in the wet season because of continual flushing-out by fresh tidal water during the rice-growing season. Conversely, despite being protected from brackish-water shrimp culture, soil salinity in the rice/non-rice cropping system in Shaheberabad has been steadily increasing over time in the dry season.

The perception of key informants was consistent with the results of the soil analyses (Table 5). These revealed that differences between the villages in the main soil properties (acidity,

² Including mango, jackfruit, banana, guava, black berry, star apple, tamarind, date palm, lemon, betel nuts, papaya, Indian lilac, red silk-cotton, bamboo, common-bur-flower, and teak.

³ Dr Harunur Rashid, Senior Scientific Officer, Rice Farming System Division, BRRI.

⁴ Including catfish, striped spin eel, tank goby, freshwater shark, climbing perch, giant snakehead, spotted snakehead, leaf fish, and Indian carplet.

organic matter, and primary macronutrients) were not pronounced, except for salinity. It was found that, despite not adopting brackish-water shrimp, soil salinity in the rice/non-rice crop fields was elevated (5.73 dS/m) in the dry season but substantially lower than in the rice-fish/shrimp fields (14.28 dS/m). However, mean soil and water salinity of the wet-season rice fields, canals, and rivers decreased to low (0.57 to 2.5 dS/m) in both the systems.

Table 5 Soil chemical properties and salinity in the rice/non-rice and rice-fish/shrimp systems

Properties	Rice/non-rice system			Rice-fish/shrimp system		
	Mean	Range	St. Dev.	Mean	Range	St. Dev.
pH	6.9	5.6-7.8	0.79	6.9	5.3-7.9	0.95
Soil salinity (dS/m) in DS	5.73	4.28-7.5	1.27	14.30	11.87-18.8	2.73
Soil salinity (dS/m) in WS	0.57	1.5-0.1	0.29	1.49	0.5-2.5	0.68
Water salinity (dS/m) in WS	1.19	0.6-3.0	0.61	2.50	0.8-4.3	2.50
Organic Matter (%)	2.22	1.82-3.41	0.52	2.00	2-2.48	0.36
Total Nitrogen (%)	0.13	0.11-0.18	0.02	0.12	0.12-0.14	0.02
Potassium (meq/100gm soil)	0.41	0.3-0.59	0.1	0.79	0.79-0.86	0.06
Phosphorus (µg/g soil)	12.7	9.6-18.9	2.9	7.8	7.8-11.8	2.6

Note: Dry-season soil samples collected in March 2013. Soil and water samples collected during wet-season rice cropping (mid-August to early-December) 2014.

4.3 Changes in livelihoods

The changes in livelihoods were assessed based on reported trends in rice self-sufficiency and cash income, access to employment, household assets, level of education, and the health of villagers over the last three decades.

Key informants in Uttar Kaminibasia reported that, during the first five years (1986-1991), shrimp farming was highly profitable but the beneficiaries were outside interests and large landowners who leased in the majority of the area for brackish-water shrimp culture in exchange for a lump-sum rental. Hossain et al. (2013) similarly report that nearly 75% of shrimp farming areas in the early 1990s was under the control of external businessmen and large farmers, and Swapan and Gavin (2011) found that the major share of profits went to these actors. Hence many small and marginal farmers were forced to migrate to other places for employment and a better living (Hossain et al., 2013). However, after three years of continuous campaigning by all landowners in the village, these external interests withdrew

one year before their lease agreements expired. S. M. N. Alam et al., (2005) likewise report that influential outsiders have mostly withdrawn and landowners are enjoying the operating rights for farming shrimp and other crops.

Landowners took back their land and commenced farming mostly under a common *gher* system. In this system, a group of farmers would use their adjacent land as a large shrimp *gher* (15-25 ha) in a cooperative system. The cultural operations for the common *gher* would be undertaken by daily wage-workers and a seasonally-employed manager and guard under the supervision of an executive body consisting of some of the landholders. Each participating landowner was a “shareholder” in the group but would cultivate monsoon rice individually. The landowners would pay the costs and receive the returns of the shrimp operation in proportion to their share of the land. Despite declining wet-season rice yield, shrimp followed by rice-fish farming was profitable at least for the next 3-4 years (1992-1995). The system created scope for additional non-farm work and petty trading but most family members just took it easy.

According to the informants, individual *gher* farming began to replace the common *gher* system after 1995 because it was considered more profitable, the common system had poor management and accounting, and conflicts had arisen over who would hold the executive positions. The individual system proved more efficient as most cultural operations were carried out by farm-family members who were motivated to reap the greatest benefit from their farm. However, during 1998-2008 shrimp culture faced decline; most farmers were in a dilemma as to whether they should continue shrimp culture as the system became less economically rewarding. This was mainly because of the changes in the *gher* environment discussed above, as well as virus infestation. Most small, medium, and even large landholders became rice-deficit households with high debts and declining interest in the existing farming system. Other researchers have reported that diseases meant that shrimp farmers received reduced benefits over time (S. M. N. Alam et al., 2005) and experienced decreased food security due to the associated decrease in rice production (Hossain et al., 2013).

However, as discussed above, over the last 4-5 years the productivity of the rice-fish/shrimp system in Uttar Kaminibasia has recovered because of marked changes in cultural practices and in the physical structure of the *gher*. In addition, in Shaheberabad, the productivity of rice has increased and the area of dry-season cash crops (mainly watermelon and pumpkin) has increased. Thus households have experienced increased total rice production, a higher incidence of rice self-sufficiency, increased cash income, whether from shrimp (providing

cash flow for 5-6 months), fish, or dry-season crops (providing cash flow for 2-3 months), additional household assets (solar plants, motorbikes, and farm equipment), and an increased level of education. Key informants highlighted that despite such developments family members of small landholders and landless labourers suffer from malnutrition, perhaps due to the continuing lack of indigenous fruits, vegetables, and livestock products.

The scope for local employment for both men and women has significantly increased after the recent changes in shrimp farming and dry-season cropping in the case-study villages. Hence there has been no increase in temporary wage-migration among poorer households and a decreased incidence among medium and large landholders. Other researchers have also reported that shrimp farming has generated employment (Ahamed et al., 2012; Azad et al., 2009; Paul & Vogl, 2011) and increased farm income (AECOM, 2010; Ahmed, Bunting, Rahman, & Garforth, 2014; Paul & Vogl, 2011).

Finally, scarcity of fresh water for drinking and regular domestic activities is a common phenomenon in coastal Bangladesh. However, the situation has become very acute in Uttar Kaminibasias due to marked salinity increase during the dry season, even in household ponds. Increased scarcity of fresh water for drinking was reported as an adverse consequence of shrimp culture in the bulk of previous research (Hens, Vromant, Tho, & Hung, 2009; Hossain et al., 2013; S. Rahman et al., 2011; Tho, Vromant, Hung, & Hens, 2008). Moreover, key informants reported that the incidence of various waterborne diseases in this village was very high due mainly to carrying out cultural operations in saline water and using saline pond water for bathing and other domestic purposes, even for drinking.

5. Economic Viability of Current Farming Systems

5.1 Current farming systems

At present, the farming system in Shaheberabad is based mainly on rice/non-rice cropping systems on paddy land, as well as dryland cropping in homestead gardens and on pond dikes, livestock raising, and freshwater aquaculture. In Uttar Kaminibasias, rice-fish farming in the wet season and brackish-water shrimp in the dry season are the essential components of the farming system, while pond aquaculture, homestead gardening, and livestock are not very important.

For 2013, Table 6 shows that, in the wet season, transplanted rice (*T. Aman*) occupied all the available paddy lands in Shaheberabad. Despite the inadequacy of freshwater irrigation (i.e.,

some salinity), nearly three-fourths of paddy land was used for various dry-season crops and some land (11%) was used for broadcast, rainfed, early-wet-season rice (*B. Aus*). (Shaheberabad farmers used to cultivate nearly 50% of their land with *B. Aus* until 2010, when the planted area plunged due to price falls and erratic rainfall.) In contrast, in Uttar Kaminibasias, the only cropping system in 2013 was transplanted wet-season rice (*T. Aman*) and fish, followed by brackish-water shrimp during the dry and early-wet seasons (Table 6).

Table 6 Major rice-based cropping patterns in the case-study villages in 2013

Villages	Patterns	Wet season	Dry season	Early wet season	% of area
Shaheberabad	P ₁	<i>T. Aman</i> rice	Watermelon	Fallow	50
	P ₂	<i>T. Aman</i> rice	Fallow	Fallow	30
	P ₃	<i>T. Aman</i> rice	Watermelon	<i>B. Aus</i> rice	6
	P ₄	<i>T. Aman</i> rice	Pumpkin	Fallow	5
	P ₅	<i>T. Aman</i> rice	Pumpkin	<i>B. Aus</i> rice	5
	P ₆	<i>T. Aman</i> rice	Vegetables	Fallow	4
Uttar Kaminibasias	P ₇	<i>T. Aman</i> rice-fish	Shrimp	Shrimp	100

Source: Group discussions in villages.

The adoption of modern varieties of rice in the wet season in both villages was markedly higher (85% of paddy area) than in coastal Bangladesh more (25%) generally (BBS, 2010a). Taking each of the three seasons as a potential cropping period, the cropping intensity of Shaheberabad (180-190%) was close to the national average and markedly higher than the mean for the upazila (121%) (BBS, 2010b), while in Uttar Kaminibasias it was technically 300% as shrimp cultivation occupied the land for most of the dry and early-wet seasons.

5.2 Profitability analysis

Representative budgets were developed for the major cropping systems (P1, P2, P4 and P7 in Table 6) as practised in 2013, that is, after substantial changes had occurred in the cultural practices and infrastructure of the rice/shrimp system, as described above. Figure 2 shows that a single wet-season rice crop followed by fallow (P2) gave farmers much lower GI/ha and NI/ha than the other cropping patterns. Key informants in Shaheberabad explained that, despite the low return, around 30% of the area was left fallow in the dry season mainly due to insufficient fresh water for irrigation and the lack of working capital, but the fallowed areas were used for grazing cattle. Of the rice/non-rice cropping patterns, the rice/watermelon pattern (P1) returned higher GI/ha and NI/ha than the rice/pumpkin system (P4). These

income measures were 3-4 times the corresponding figures for P2. However, the rice/shrimp system (P7) gave 50-100% higher GI/ha and 35-88% higher NI/hectare than the rice/non-rice cropping systems (P1 and P4). The results are consistent with the findings of Ahmed et al. (2014) that the rice/shrimp system is currently the most economically rewarding.

Figure 2 shows that the rice/shrimp system (P7) incurred much higher costs per ha (both TPC and TIC) than the rice/non-rice and rice/fallow systems (P1, P2 and P4), but these high costs were offset by the high GB/ha, especially from shrimp. Figure 3 shows that the three rice/non-rice cropping systems had a higher proportion of paid-out costs than imputed costs (in the ratio of about 70:30), due to the use of hired labour, tractors, pumps, rice threshers, rented-in land, and the purchase of fertilisers, pesticides and seeds. By comparison, in the rice/shrimp system the ratio of paid-out costs to imputed costs was about 60:40. The shrimp system used a higher proportion of family labour and other imputed costs, i.e., the opportunity cost of the household's own land and interest on operating capital.

The rice/shrimp system also gave the highest GI per work-day of family labour, followed by the rice/watermelon system (Fig. 4). The most important feature of this finding is that all farming systems were more rewarding than off- and non-farm activities. The GI per work-day was not only 2-3 times higher than that of local off-farm wages (BDT 200-250 per work-day) but also significantly higher than urban wages for labouring work (BDT 300-400 per work-day).

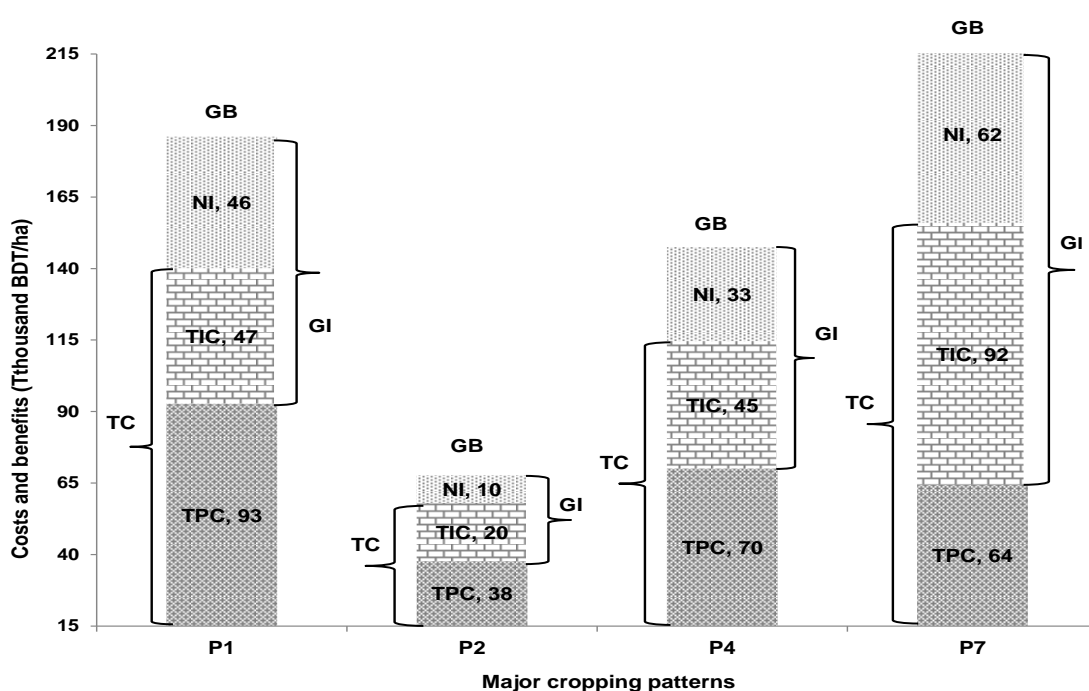


Figure 2 Comparative profitability of major cropping patterns in the case-study villages

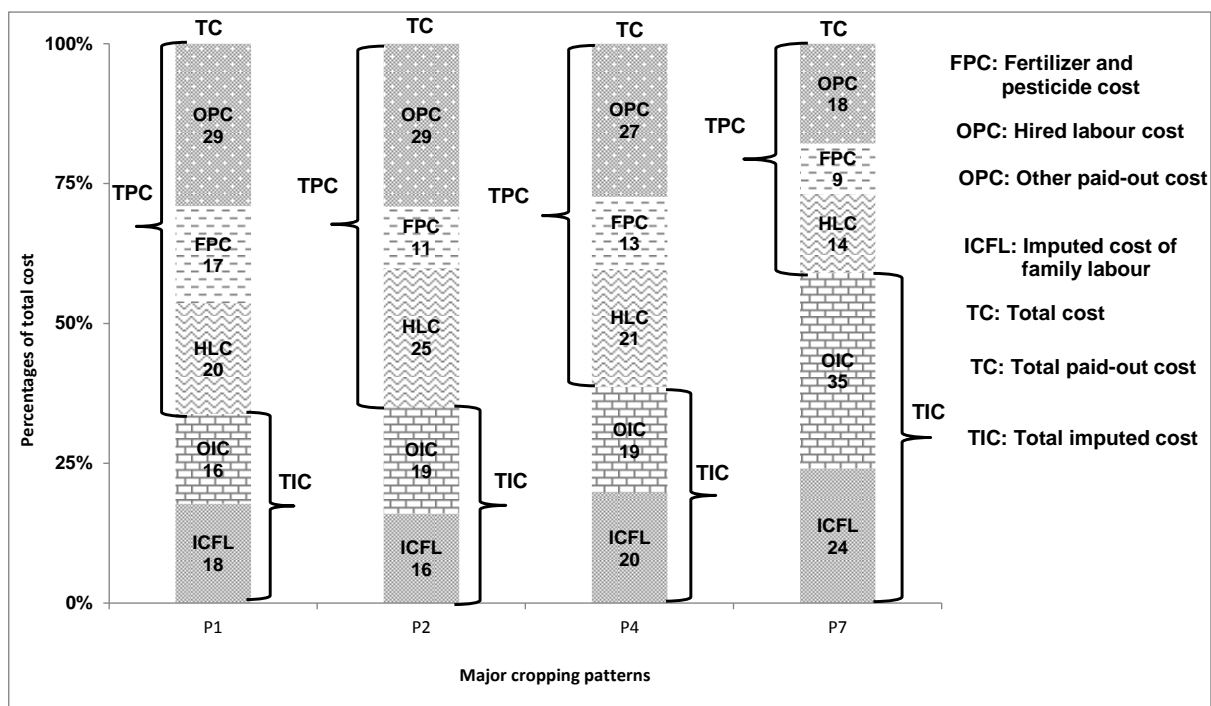


Figure 3 Relative importance of factor inputs in the total cost of major cropping patterns

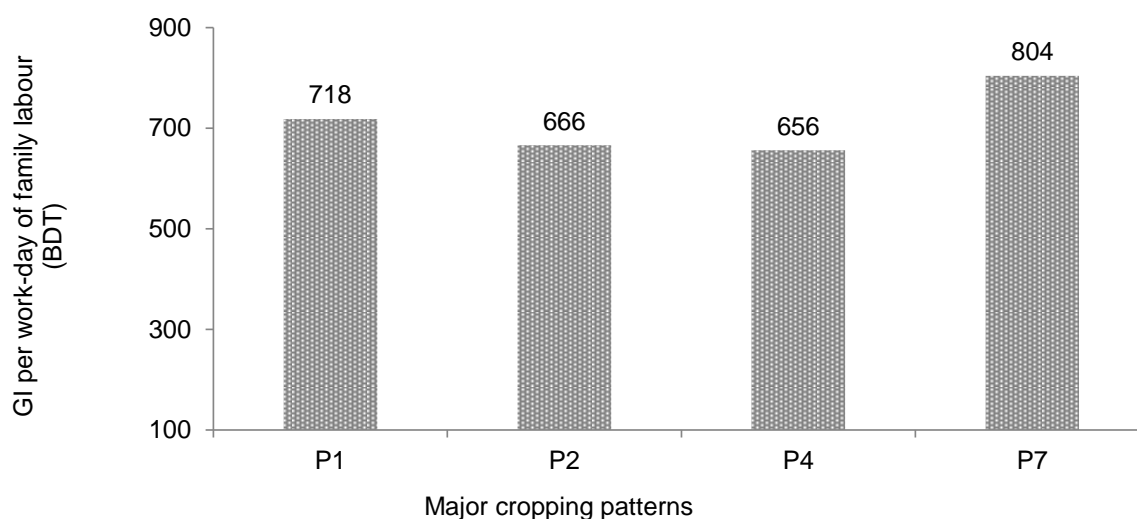


Figure 4 Gross income per work-day of family labour in study villages

5.3 Risk analysis

The findings of the enterprise budgeting presented in Figures 2 and 4 indicated that rice/shrimp farming was the most rewarding farming option in terms of the return to family-owned resources (GI), whether expressed on a per-hectare or a per-workday basis. However,

key informants highlighted that financial returns to the cropping systems are very volatile. In particular, the productivity and profitability of rainfed monsoon rice, partially-irrigated dry-season crops, and shrimp culture in the coastal setting are highly uncertain. The abiotic stresses (seasonal weather variation and salinity) and biotic stresses (pests and diseases) cause wide variability in yields, and poor access to markets due to the underdeveloped transportation system exacerbates fluctuations in farm-gate prices. Hence a risk analysis of the major cropping systems was undertaken, based on the farmers' perceived variability in yields and prices (Table 7).

Table 7 Farmers' perceived variability in yields and prices of major crops in case-study villages

Pattern	Crops	Yield (ton/ha)			Price (BDT/ton)		
		Typical	Best	Worst	Typical	Best	Worst
P1	T. Aman	3.6	4.6	2.2	17,500	19,000	16,500
	Watermelon	29.6	38.5	17.5	4,000	4,500	3,000
P2	T. Aman	3.6	4.6	2.2	17,500	19,000	16,500
P4	T. Aman	3.6	4.6	2.2	17,500	19,000	16,500
	Pumpkin	16.8	24.0	13.5	4,750	5,250	3,750
P7	T. Aman	3.7	4.2	2.4	17,500	19,000	16,500
	Fish	0.12	0.15	0.06	250,000	280,000	230,000
	Shrimp	0.214	0.265	0.09	475,000	650,000	400,000

Source: Key informants

Figure 5 presents cumulative probability distribution curves (CDF) for net income per ha of the four major cropping systems. It was found that the rice-fish/shrimp system showed first degree stochastic dominance (FSD) over the other systems – the CDF lies everywhere to the right of all the other CDFs. Not surprisingly, the rice/non-rice systems also showed FSD over the rice/fallow system. It was also the case that the rice/watermelon system showed second degree stochastic dominance (SSD) over the rice/pumpkin system.

Figure 6 presents the CDFs for GI per work-day of family labour. The lower benchmark (BDT 250) was the local off-farm wage rate and the upper benchmark (BDT 400) was the daily wage rate in urban centres. Again, the rice-fish/shrimp system showed FSD over the other systems and the rice/non-rice cropping systems showed FSD over the rice/fallow system. However, the rice/pumpkin system reversed its ranking, showing SSD over the rice/watermelon system. All systems had at least an 85% probability of generating a GI/day above the urban wage rate and at least a 97% probability of generating GI/day above the local farm wage rate.

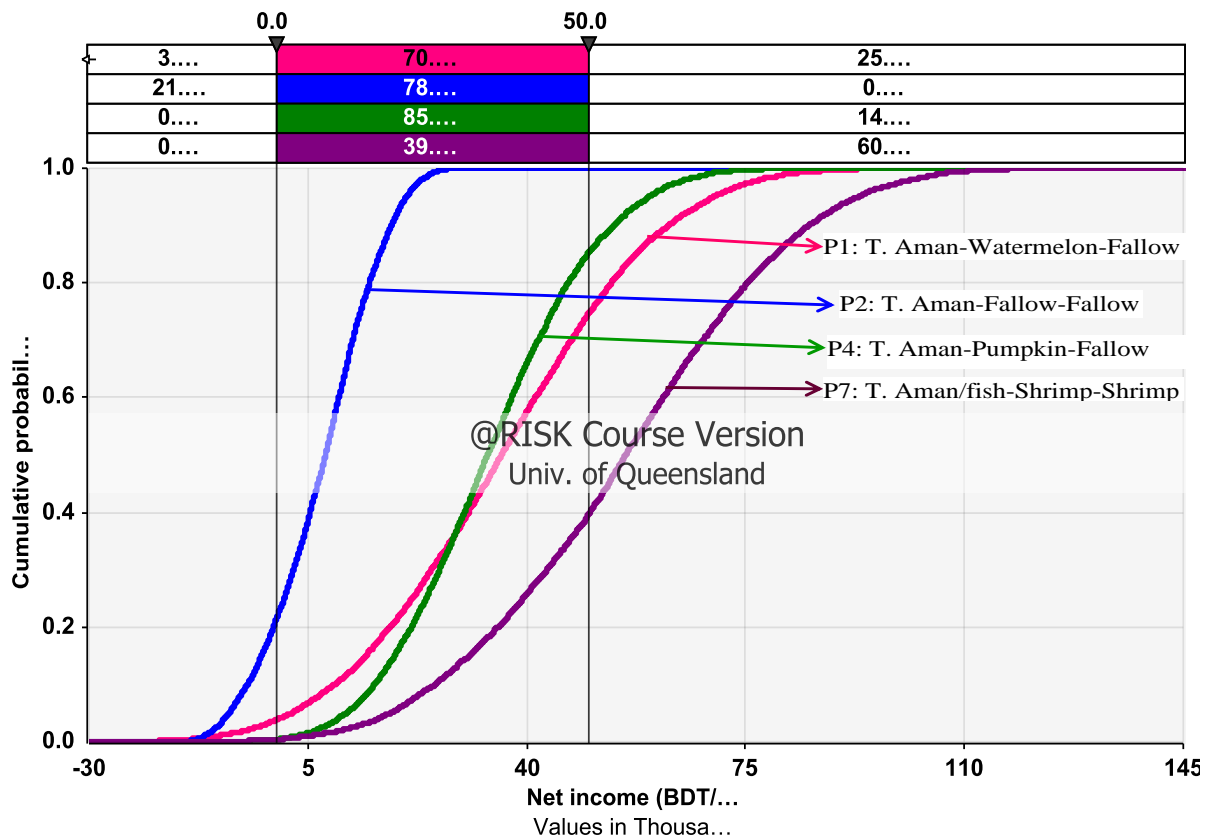


Figure 5 Probability distribution of net-income per ha for cropping systems in study villages

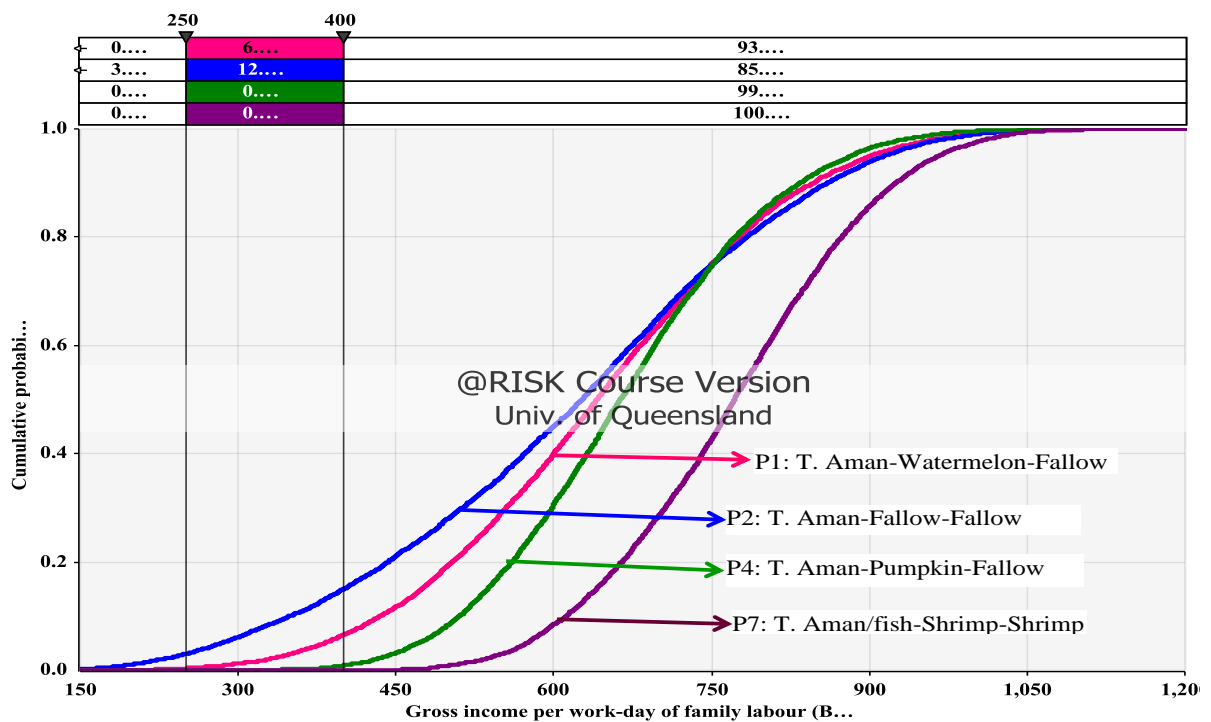


Figure 6 Probability distribution of GI per workday of family labour for cropping systems in study villages

Figure 7 shows the impact of yield and price variability on GI/ha of the four main cropping systems (leaving aside the rice-fallow system). In the rice/non-rice cropping systems, fluctuations in the yield of the non-rice crop contributed most to the variability in GI, especially in the case of watermelon. The price of watermelon was also a large contributor to variability in GI. Watermelon was thus more sensitive to both seasonal weather and market variability. In the rice/shrimp system, variability in GI/ha was mostly affected by fluctuation in shrimp yield and secondarily by fluctuation in the price of shrimp.

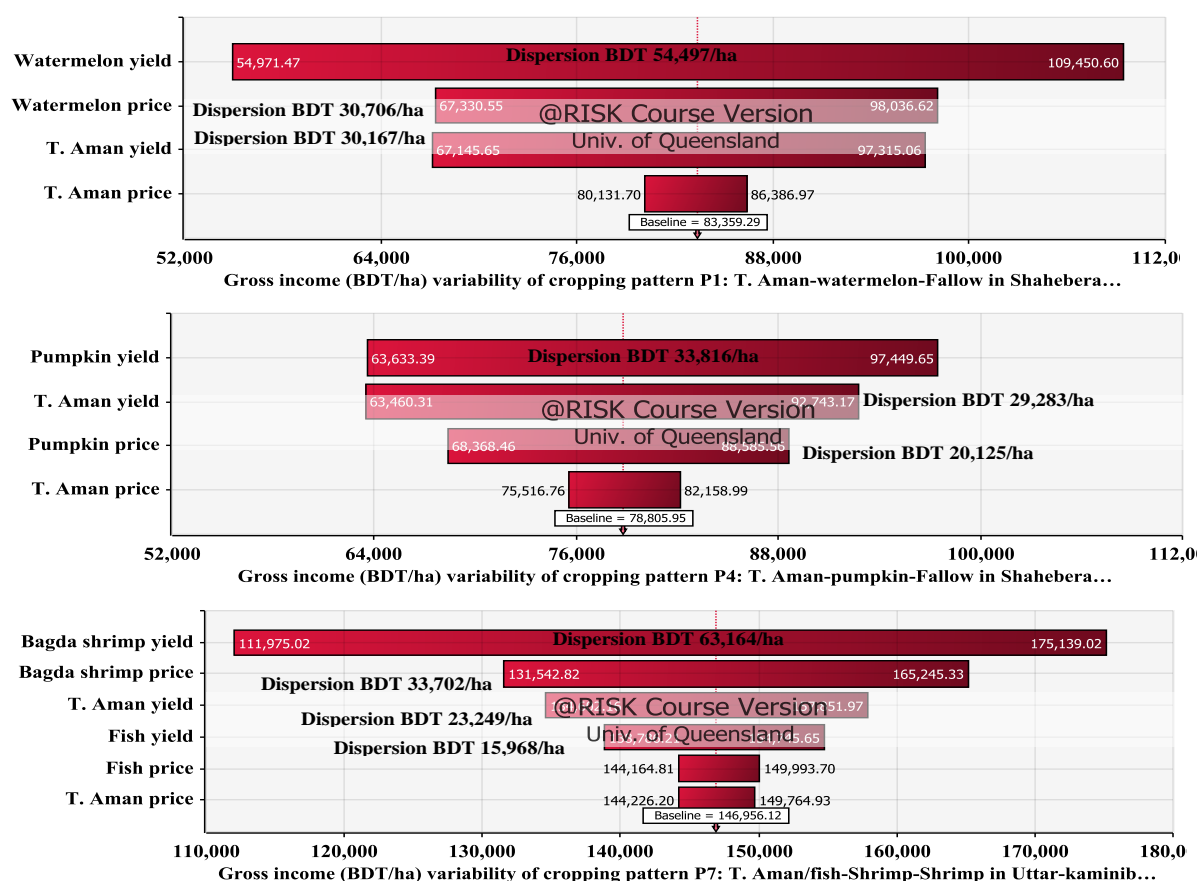


Figure 7 Yield and price variables ranked by effect on variability of GI/ha of major cropping systems

6. Discussion

Similar socio-demographic features notwithstanding, the two study villages typify two distinct farming systems due in part to contrasting environments: the suitability of arable land (degree of susceptibility to flooding in the wet season and soil salinity in the dry season), access to aquatic resources (freshwater irrigation and tidal water, along with wild fish fingerlings and shrimp post-larvae), and geo-physical setting (proximity to rivers and the Bay of Bengal). For these reasons, it was more feasible for farmers in Uttar Kaminibasias to

cultivate shrimp during the dry and early-wet seasons (February to mid-September) by using tidal brackish water and to cultivate rice and fish during the wet season (mid-September to December) when river water was fresh. At the same time, it was more feasible for farmers in Shaheberabad to cultivate wet-season rice (September to mid-December) followed by various non-rice crops using limited freshwater reserves in canals, ponds, and in field troughs. Hence the two types of farming system are not strictly comparable as it would not be a simple matter to switch between them in a given village setting. Nevertheless, a comparison between them sheds some light on the motivations for farmers to adopt what has been considered to be the environmentally unsustainable practice of brackish-water shrimp farming in the coastal zone.

Initially shrimp farming was highly profitable but the beneficiaries were external merchants and large landowners who leased in lands for large-scale shrimp culture. Then small and medium landowners took back the cultivation rights to their land and continued production, first in common *gher* and then in individual *gher*, with high financial returns. The process of continual shrimp farming for 12-15 years resulted in decreased area and productivity of wet-season rice and declining returns to shrimp culture. The latter was due to changes in the *gher* environment (decreased depth of *gher* because of sedimentation, deterioration in soil quality, salinization, and severe infestation of algae). Therefore, most farm households became food insecure, incurred financial losses, and became indebted. Karim (2006) also claims that crop yields (of wheat, jute, sugarcane, as well as wet-season rice) declined after commencing shrimp farming. Moreover, local biodiversity (flora and fauna), homestead gardening, and livestock were also adversely affected.

As a consequence, most villages of Dacope Upazila except some in Tildanga Union and Sutarkhali Union (including Uttar Kaminibasias, the case-study village) stopped farming brackish-water shrimp. Fisheries specialists consulted⁵ suggested that the root cause of stopping shrimp cultivation in those areas was chronic severe viral infestation because of improper infrastructure (no troughs dug in the *gher*, hence inadequate water depth), inadequate access to tidal water, and improper soil and water management. However, most farmers in Uttar Kaminibasias preferred to continue with shrimp cultivation due to limited alternative livelihood options and better access to tidal water. To address the downward spiral of the rice-fish/shrimp system, significant changes were introduced from around 2009, leading to a reversal in the decline of both the rice and shrimp phases of the system.

⁵ Mr Ripon Roy, Senior Fisheries Officer, Dacope Upazila, Khulna; Dr Golam Faruque, Program Manager, Aquatic Agricultural Systems Program; and Quazi A. Z. M. Kudrat-E-Kabir, Project Manager, Feed the Future Aquaculture Project, Worldfish, Bangladesh.

These changes were the result of the combined efforts of farmers, the village community, local government (with respect to water management), and research and extension to develop and disseminate suitable technologies. While Karim (2006) reports that salinity is not a serious problem for wet-season rice because the accumulated salt in the soil is leached out by the monsoon rains, BRRI researchers expressed the opinion that the key innovations leading to increased rice yield have been adopting a saline-tolerant rice cultivar (BR23), advancing the date for planting, intermittent inundation, regular flushing-out of the rice paddy to reduce salinity, pulverising the soil during the rice season, and use of pesticides on rice that are not harmful to fish. Moreover, the fisheries specialists consulted suggested that changing the *gher* infrastructure (digging out a trough in part of the *gher* to provide a section with deeper water) was the root cause of decreasing viral infestation and increased shrimp and fish yield.

Wet-season rice is now a significant source of family subsistence, with increased levels of rice self-sufficiency in both communities. Currently dry-season crops (watermelon, pumpkin and vegetables) and shrimp are the main sources of cash income, with shrimp generating regular cash flows for 4-5 months and dry-season crops for 2-3 months, with benefits also to wage-workers (men and women) and traders. Furthermore, vegetables, pond fish, livestock, and tree crops are important sources of food and flexible assets for Shaheberabad households. However, in Uttar Kaminibasias, households still have limited access to these sources of food and income, except fish.

The soil chemical properties in both villages were very similar, except for salinity. Salinity in shrimp fields was higher than that of crops fields in the dry season, though soil and water salinity in the wet season were similar between the two systems due to the natural and deliberate flushing out of salinity described above. M. R. Rahman, Ando, & Takeda (2013) in a study of Shuktia Village in Satkhira District in Khulna Division, also found little variation in soil salinity in the wet season between shrimp-rice (2.80 dS/m) and rice-rice (2.18 dS/m) systems.⁶ Nevertheless, the salinity level in the dry season in both the rice/shrimp and rice/non-rice systems has been increasing over time. This indicates that, apart from the practice of brackish-water shrimp cultivation, there are other environmental factors contributing to the phenomenon of salinization in the coastal region – reduction of upstream freshwater flows, saline-water intrusion, more erratic rainfall patterns, and tidal flooding.

⁶ In contrast, Tho et al. (2008) found that, in the Mekong Delta, there was not much reduction in salinity from very high levels in the shrimp fields (mean 33.44 dS/m) to still high levels in monsoon rice fields (mean 24.65 dS/m).

These results indicate that, despite culturing shrimp for over three decades, salinity has not accumulated, even in the soil of the shrimp *gher*. Thus, farming brackish-water shrimp alone is not responsible for increasing overall salinity in the coastal lands, hence it may not be possible to protect against further intrusion of salinity by merely stopping shrimp culture.

Moreover, the comparative enterprise analysis revealed that the improved rice-fish/shrimp system was financially more attractive than the rice/non-rice cropping system. Free access to tidal water and wild post-larvae of fish, crab, and some shrimp kept down the paid-out costs of the rice-fish/shrimp system. In addition, this system had some beneficial symbiotic relations between the various components. Residual fertilizers used in the *gher* and fish faeces provided nutrients for the rice. The movement of fish around the paddy fields also helped to release gases (CO_2 and CH_4) trapped underneath the mud and this aeration helped rice plants to take up nutrients from the soil. At the same time, fish fed on phytoplankton that grew in the rice paddies due to the fertilizers applied for rice. Rotten roots, leaves, and rice flowers were also good sources of fish feed. The rice plants provided shade for the fish, minimising the impact of high temperature during October to mid-November when there was less water in the field.

Incorporating variability in prices and yields showed that the rice-fish/shrimp system was not only the most profitable farming option but was also less risky than the rice/non-rice cropping systems. The rice-fish/shrimp system was financially more resilient because of the increase in productivity due to the recent changes in the *gher* infrastructure and the management of soil, water, salinity, and crops. Due mainly to such changes, the survival rate of shrimp post-larvae had increased while the severity of virus infestation in the shrimp crop and pest infestation in the rice crop had decreased substantially. In addition, multiple (4-5) stockings of shrimp post-larvae have decreased the risk of receiving negative income. If shrimp post-larvae or juveniles died due to virus infestation or weather variation, farmers could make up for the loss by obtaining a return on additional stockings.

Among the rice/non-rice cropping systems, the rice/watermelon system provided somewhat higher returns to land and labour than the rice-pumpkin system. However, when subjected to risk analysis, there was little between them, with the rice/watermelon system displaying SSD in terms of NI/ha while the rice-pumpkin system displayed SSD in terms of GI/day. Moreover, the variability in returns to the rice/watermelon system was strongly influenced by variability in watermelon yield and price. Even so, the rice/watermelon system was the most widely adopted because of the larger market.

7. Conclusion

This study shows that there is a complex, discontinuous interaction between farming choices and environmental changes in coastal Bangladesh, involving what might be called a “struggle for sustainability”, particularly in the face of salinisation. Farmers have adapted their farming and livelihood systems in response to market incentives, the availability of land and water resources, trends in their local environment, and the flow of new technologies. In recent years, the adoption of dry-season crops by some farmers and aquaculture (shrimp and fish) by others has increased the production of food and income, permitted the acquisition of household assets, and generated employment in the coastal region, with positive signs for sustainability.

While brackish-water shrimp cultivation was financially rewarding, it was initially very harmful to the local environment, as well as to livelihoods through its impact on the wet-season rice crop and other crop and livestock activities. However, after the recent widespread adoption of a suite of technical changes in the entire rice-fish/shrimp farming system, the overall productivity of the system has increased and the negative environmental impacts have been reduced. Despite variability in shrimp yield and price, the rice-fish/shrimp system as a whole is more economically viable (higher returns to land and labour and less risky) than the rice/non-rice cropping systems examined (though it still lags behind in terms of fruit, vegetable, and livestock production).

Moreover, expert opinion and field data indicated that the build-up of salinity due to brackish-water shrimp farming is impermanent, as soil and water salinity fall to low levels in the wet season, comparable to levels in the rice/non-rice cropping system, despite the long-term practice of brackish-water shrimp in Uttar Kaminibasia. This was due to the natural and deliberate flushing out of salinity by rainfall and tidal freshwater during the wet season. Thus the rice-fish/shrimp system was both economically superior and appeared to be sustainable in its present form.

The rice/non-rice cropping systems studied were also sustainable, making no or minimal contribution to salinity in either the wet or dry seasons, and were economically viable, providing a clear gain in terms of mean returns and degree of risk over the benchmark rice/fallow system and compared to off-farm and non-farm wages. However, the farmers operating these systems faced constraints due to the inadequacy of freshwater irrigation,

seasonal weather variation, and poor access to markets, aggravating the variation in yield and price of the main dry-season crops (watermelon, pumpkin, and vegetables).

Although both systems reflect a broad path of farmer adaptation that is contributing to the wellbeing of coastal dwellers, they face on-going challenges, including seasonal weather variation, and poor access to irrigation, roads, and markets. More important, the salinization of the environment is continuing, independently of cropping choices, and is thus still a threat to the long-term sustainability of coastal farming systems. Addressing these issues is beyond the adaptive capacity of farm households and village communities in the region and requires continuing public investment in new technologies and infrastructure to help sustain the coastal ecosystem.

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