On-farm feed management practices for giant river prawn (*Macrobrachium rosenbergii*) farming in southwest Bangladesh

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Ahmed, N. 2013. On-farm feed management practices for giant river prawn (*Macrobrachium rosenbergii*) farming in southwest Bangladesh. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture.* FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 269–301.

ABSTRACT

This paper examines feed management practices for giant river prawn (*Macrobrachium rosenbergii*) farming in three production systems in southwest Bangladesh. Based on the production technology, prawn farming is classified either as extensive, improved-extensive or semi-intensive. Most farmers farm prawns in rice fields, and are primarily dependent on prawn, fish, rice and dike crops. Prawn farmers using extensive feeding practices depend solely on snail meat. The improved-extensive farming systems use farm-made aquafeeds comprising mixtures of locally available feed ingredients (e.g. rice bran, mustard oil cake, fishmeal, oyster shell, salt and vitamins). Prawn farms based on semi-intensive feeding practices use industrially manufactured pelleted feeds. The average annual prawn production using semi-intensive farming systems was 718 kg/ha, representing higher yields than the improved-extensive (489 kg/ha) and extensive (351 kg/ha) farming systems. The improved yields were mainly attributed to higher levels of inputs, including seed, feed, fertilizer and labour. On semi-intensive farms, the average annual production cost was estimated at US$2 875/ha. In improved-extensive systems, production costs were US$2 088/ha, and in extensive systems they were US$1 457/ha. Feeds constitute the second highest operational cost in extensive (15 percent) and improved-extensive (25 percent) farming, and the highest operational cost in semi-intensive farming (33 percent). Despite the higher production costs per hectare, the average annual net return was higher in semi-intensive farming (US$2 162), compared with improved-extensive (US$1 445) and extensive (US$1 092) farming.

The low production costs associated with the use of snail meat in extensive farming makes it a suitable feed source for resource-poor farmers. However, relatively low levels of production and net returns are attained. Moreover, in the long term, supply issues and the environmental costs associated with snail harvesting may make the practice unsustainable. Higher net returns per hectare were obtained using semi-intensive farming systems. In these systems, producers appear to be able to afford more inputs, including industrially manufactured pelleted feeds. The high level of investment required to develop

semi-intensive farming systems suggests that this type of farming would not be possible for resource-poor, small-scale farmers. The quality of industrially manufactured pelleted feeds that are available is of concern, and in particular, the presence of banned antibiotics. It is therefore recommended that farm-made aquafeeds provide the best feed choice for resource-poor farmers in terms of availability, quality and price. This article concludes that farm productivity as well as profitability can be increased through increasing the feeding rates of farm-made aquafeeds and improving feed management practices.

1. INTRODUCTION

The giant river prawn (*Macrobrachium rosenbergii* De Man 1879)[1] is the most widely cultured and distributed freshwater prawn. It is widely distributed throughout the tropics, the sub-tropics and temperate zones. It is indigenous to South and Southeast Asia, as well as in northern Oceania and the western Pacific Islands. *M. rosenbergii* is the species most commonly used for commercial prawn production[2], and it is now farmed in many countries, including Australia, Bangladesh, Brazil, China, Ecuador, Honduras, India, Indonesia, Israel, Malaysia, Mauritius, Mexico, the Philippines, Thailand, Viet Nam and the United States of America (New, 2002). In spite of its widespread distribution, freshwater prawn culture has been less important in terms of volume and value than marine shrimp[3] culture. In 2010, global farmed production of all species of river prawns (*Macrobrachium* spp.) was 450 158 tonnes, of which giant river prawn production was 215 029 tonnes (FAO, 2012) In Asia, farmed giant river prawns are primarily cultured in Taiwan Province of China, Thailand and Viet Nam (New, 2005). In 2010, China was the largest producer of *M. rosenbergii*, producing 125 203 tonnes equating to 58 percent of global production. Bangladesh was the third largest global producer, producing 30 636 tonnes equating to 14 percent of global production (FAO, 2012).

Due to its favourable climate and water resources, Bangladesh is considered one of the most suitable countries in the world for giant river prawn (*Macrobrachium rosenbergii*) farming. The sub-tropical climate and vast areas of shallow water provide a unique opportunity for the growth of many species of freshwater prawns. Twenty four species of freshwater prawn including 10 species of *Macrobrachium* are found in Bangladesh. However, only *M. rosenbergii* has significant aquaculture potential and is commercially cultured (Ahmed, Demaine and Muir, 2008). Within the overall agro-economy in Bangladesh, *M. rosenbergii* farming is currently one of the most important sectors and, during the last three decades, its development has attracted considerable attention in terms of its export potential. The freshwater prawn is a highly valued product in international markets, and almost all cultured prawns reared in Bangladesh are exported. Major export markets include the United States of America, Europe and Japan. In 2010/11[4], Bangladesh exported 54 891 tonnes of prawn and shrimp valued at US$446 million, of which 30 percent was attributed to prawns (DoF, 2012). The sector represents the largest agro-export sector, and after the garments sector, the second largest export earner. Approximately 1.2 million people are directly involved in prawn and shrimp production, processing and marketing, and a further 4.8 million household members are associated with the sector. In addition, the livelihoods of around 400 000 people, many of them women and children, are associated with prawn and shrimp

[1] The term 'freshwater prawn' generally refers to the genus *Macrobrachium*, a large genus of crustaceans comprising over 200 species. *M. rosenbergii* is the largest *Macrobrachium species*, and is officially known as the giant river prawn. The maximum recorded size for males and females of this species is 33 cm and 29 cm, respectively (New, 2002).

[2] The oriental river prawn (*Macrobrachium nipponense*) had a production level greater than the production of giant river prawns in 2010 (FAO, 2012) but is only reared in China.

[3] The term 'prawn' is used for freshwater species and 'shrimp' for marine and brackishwater organisms.

[4] Bangladesh fiscal year: 1 July – 30 June.

fry fishing in coastal Bangladesh (USAID, 2006). Unfortunately the number of people involved in prawn farming is not precisely known as the national statistics have not, until very recently (M. New, personal communication, 2012), distinguished between the prawn and shrimp sub-sectors. From a variety of published sources and personal communications with relevant government departments, it is estimated that around 600 000 people are directly involved in prawn farming, marketing and associated activities; this includes 120 000 farmers and 200 000 on-farm labourers (Ahmed, 2009). Prawn processing and marketing also provides economic returns, social benefits and livelihood opportunities to thousands of the rural poor (Islam, 2008; Ahmed *et al.,* 2009).

The total area under prawn cultivation in Bangladesh is estimated to be around 62 875 ha – about a fourth of the 276 492 ha that are available for shrimp farming (DoF, 2012). The majority of prawn farms (>75 percent) are located in southwest Bangladesh, mainly in Bagerhat, Khulna and Satkhira districts, with the remainder in the southeast region. Small-scale prawn farming in rice fields is widespread in southwest Bangladesh, where wild postlarvae (PL)[5] are available, and there are favourable resources, including low-lying rice fields and a warm climate (Ahmed, Demaine and Muir, 2008). In Bangladesh, freshwater prawn farming first started in the southwest region in the early 1970s (Mazid, 1994). The most significant developments have taken place in Bagerhat district, where thousands of farmers have converted their rice fields to prawn farms, locally known as '*gher*' (Kendrick, 1994; Rutherford, 1994). In Bengali, the term '*gher*' means an enclosure that is designed for prawn cultivation. This is achieved by modifying existing rice fields, building higher dikes, and excavating a canal several feet deep inside the periphery to retain water during the dry season. *Gher* farming is a 'quiet, indigenous technological revolution' suitable for the cultivation of prawns, fish and rice.

Innovative prawn farming in rice fields, combined with high prawn prices in the international markets, and rice and fish for household consumption, has led to increasing numbers of farmers converting their rice fields to prawn farms. The early innovators tended to be large and medium size farmers, but increasingly small and marginal farmers have also started farming prawns with fish in their rice fields (Rutherford, 1994). Since 1990, the prawn sector has grown rapidly and has spread to other southwest districts, such as Khulna and Satkhira, where prawn farming has now become one of the most attractive investment opportunities (Ahmed, Demaine and Muir, 2008). As a result of social, economic and technological constraints, including an inadequate supply of prawn fry, high seed and feed costs, prawn farming is marginal in the rest of the country. Feed management is also of grave concern for the expansion of the sector.

This paper examines various feeding practices used in prawn farming in Bangladesh. Prawn production comprises different feeding systems which are dependent upon the level of farming technology. The use of industrially manufactured aquafeeds in prawn culture elicits higher production levels, increases production costs, and improves financial returns (Ahmed, Demaine and Muir, 2008). Typically, resource-poor farmers are constrained by a lack of capital or inadequate technical knowledge, and thus they adopt lower cost input systems that are based on farm-made aquafeeds (mixtures of rice bran, oil cake and fishmeal) and snail meat. The present case study provides a comparative analysis of using three different feed types, namely: (1) snail meat, (2) farm-made aquafeeds[6] and (3) industrially manufactured pelleted feeds.

[5] The term 'postlarvae' usually applies to animals from the time of metamorphosis up to about 60 days later. The terms postlarvae and fry are used interchangeably in this paper.

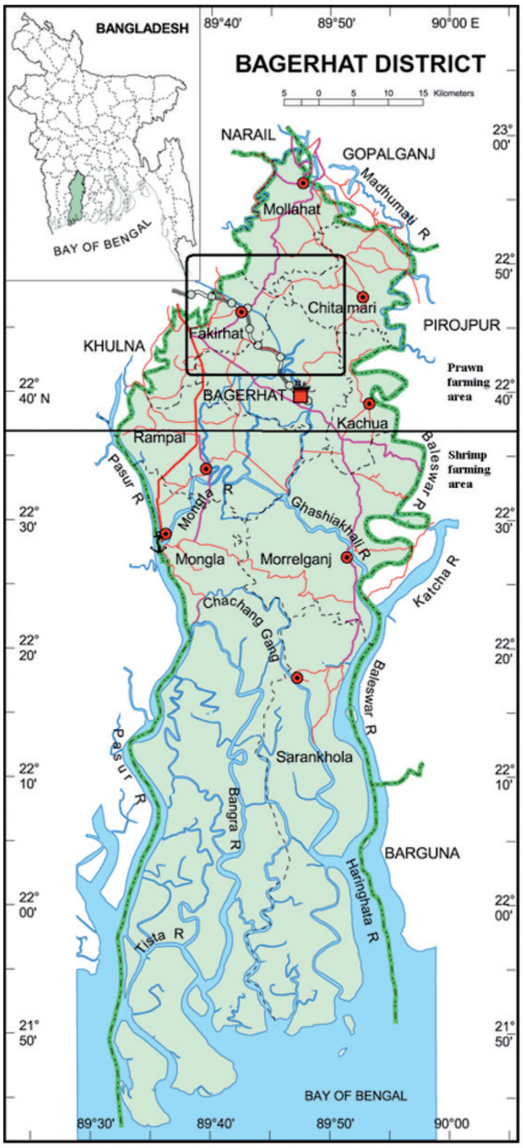
[6] The local abundance of certain raw materials is naturally reflected in their use for aquafeed production.

2. METHODOLOGY

2.1 Study area

The study was conducted in the Bagerhat district, a coastal area of the Bay of Bengal, situated in the southwest part of Bangladesh (Figure 1). Geographically, Bagerhat has been identified as the most important and promising area for prawn culture. This is due to the availability of wild PL, the climatic conditions and favourable resources, including low-lying rice fields, fertile soils, and cheap and abundant labour (Ahmed, Demaine and Muir, 2008). The district is divided into nine sub-districts[7]; among them Bagerhat Sadar, Fakirhat, Mollahat and Chitalmari primarily culture *M. rosenbergii*. As a result of salt-water intrusion, the remaining sub-districts primarily culture tiger shrimp (*Penaeus monodon*). Among the four prawn farming sub-districts, Fakirhat is the most important – prawn farming was first started in this area in the early 1970s (Mazid, 1994). Though the sector has developed well in other areas, the number of prawn farms and farmers is still the highest in the Fakirhat area. For the people of Fakirhat, prawn production in rice fields was reported to have increased the incomes of subsistence farmers considerably (Ahmed, Allison and Muir, 2010). Fakirhat was therefore selected as the focus area for the study.

FIGURE 1
Map of Bangladesh showing the study area



Source: Banglapedia [http://banglapedia.com/].

2.2 Data collection

The field research was conducted between December 2009 and March 2010. Combinations of participatory, qualitative and quantitative methods were used to collect the primary data.

2.2.1 Questionnaire interviews

Questionnaire interviews with the prawn farmers were preceded by the preparation and testing of the questionnaire, and enumerator training. Pilot testing of the questionnaire was carried out with ten prawn farmers. The aim of the pilot survey was to ensure that the questions were clear of ambiguities, and that the respondents could answer the questions easily. Based on the results of the pilot survey, the questionnaire was modified and improved.

Farmers were selected through a stratified random sampling process that was based on the feeding strategies that they used. The farmers were classified into three groups according to the type of feed they used, *viz.* (1) snail meat, (2) farm-made aquafeeds and (3) industrially manufactured pelleted feeds

[7] Bagerhat district is divided into nine sub-districts, namely: (1) Bagerhat Sadar, (2) Fakirhat, (3) Mollahat, (4) Chitalmari, (5) Kachua, (6) Rampal, (7) Morelganj, (8) Mongla and (9) Sarankhola.

(Table 1). A simple random sampling technique was used to identify the famers that were included in the survey. A total of 90 prawn farmers, 30 in each stratum, were interviewed at their houses and/or farm sites. A more focused comparative examination of the three different feeding strategies was performed. Several visits were made to selected farmers to observe feeding practices. These visits were also useful for building up a rapport with the farmers; this assisted with the questionnaire interviews. The interviews focused on prawn farming systems, feeding strategies, feed management, feed marketing, feeding constraints, productivity, production costs and returns, and the socio-economic status of the farmers.

TABLE 1
Stratification of prawn farmers based on feeding systems

Feeding category	Sample size	Farming system	Characteristics
Snail meat	30	Extensive	Small farms (less than 50 decimals or 0.20 ha), resource-poor, using lower inputs (seed, feed, fertilizer and labour), typically subjected to financial constraints
Farm-made aquafeed	30	Improved-extensive	Medium farms (51–100 decimals or 0.21–0.40ha), intermediate inputs, typically requiring production loans
Industrially manufactured pelleted feed	30	Semi-intensive	Large farms (above 100 decimals or 0.41 ha), using higher inputs, typically using their own financial capital

Source: Field survey (2010).
Note: Land area in Bangladesh is commonly expressed as decimals; 1 ha of land = 247 decimals.

2.2.2 Participatory rural appraisal

In the current study, the PRA (Participatory Rural Appraisal) tool Focus Group Discussion (FGD) was conducted with prawn farmers and associated groups, including women, children and day labourers. FGD is a group meeting where people from the target communities discuss selected topics (Conroy, 2002). A total of 15 FGD sessions were conducted for this study with each group comprising between 6 and 12 persons (total: 131 people). FGD was used to provide an overview of prawn farming practices, on-farm feed management, feeding systems, feed procurement, feed quality and feeding issues. The method was also used to verify the information provided from the questionnaire interviews.

2.2.3 Rapid market appraisal

Rapid Market Appraisal (RMA) is an efficient way to obtain policy-relevant and intervention-focused information about commodity sub-sectors (Holtzman, 2003). RMA techniques primarily rely on interviews with knowledgeable sub-sector observers/actors. In this study, RMA techniques were used to: (1) identify prawn feed marketing channels, (2) visit physical facilities such as feed markets, and (3) directly observe feed processing, transporting and market systems. A total of 24 market operators were interviewed, including feed traders, intermediaries and suppliers.

2.2.4 Key informant interviews

A key informant is someone with special knowledge on a particular topic. Key informants are expected to be able to answer questions about the knowledge and behaviour of others, and the operations of the broader systems (Elmendorf and Luloff, 2006). In this study, key informant interviews were conducted with school teachers, local leaders, government fisheries officers, researchers, policymakers, relevant non-government organizations (NGO) workers and project staff (e.g. Bangladesh Shrimp and Fish Foundation, Danida, Katalyst, WorldFish Center, Winrock International). During the study, 20 key informants were interviewed.

2.3 Data analysis

Data from questionnaire interviews were coded and entered into a Microsoft Excel database. A statistical package (SPSS – Statistical Package for Social Science, SPSS Inc., Chicago, IL, United States of America) was used to analyse the data. The results from the data analyses, in combination with qualitative information collected through different data collection methods were used to describe feed management practices for prawn farming in rice fields. An economic analysis was conducted to determine net returns. The analysis was based on farm-gate prices, and current local market prices for farm inputs. Values were expressed in US dollars (US$1 = BDT 68 in February 2010). Table 2 presents the assumptions and calculations that were used for calculating the various costs and returns.

TABLE 2
Assumptions and calculations used to determine production costs and returns

Total costs	= variable costs + fixed costs
Variable costs	= cost of seed, feed, fertilizer, labour (family and hired), harvesting and marketing, and miscellaneous
Fixed costs	= cost of depreciation + interest + land use cost
Depreciation costs	= [(purchase price – salvage value)/economic life]
Interest	= 15 percent annual interest rate on operating capital (seed, feed, fertilizer and labour)
Land use cost	= valuation of land at its rental price or lease
Gross revenue	= total production x farm-gate price
Net return	= gross revenue – total costs

3. RESULTS AND DISCUSSION

3.1 Prawn farming systems

3.1.1 Prawn-fish-rice farming

Freshwater prawn farming in rice fields was widespread throughout the study area (Figure 2). The majority of farmers produce prawns, fish, rice and dike crops. Prawns are produced for export markets while fish, rice and vegetables are produced for the local markets and household consumption (Figure 3). A variety of vegetables are grown on the dikes; these include potatoes, tomatoes, onions, mustard, yard long beans, spinach, peas, ladies fingers (okras) and sweet gourds. A range of short production cycle fruits such as banana, guava and papaya are also grown on the dikes. Although integrated prawn-fish-rice farming is an extensive[8] farming practice, many farmers use improved farming methods where the prawns are cultivated in improved-extensive[9] (30 percent) and semi-intensive[10] (20 percent) systems. In general, extensive farmers mainly use snail meat as a feed source for the prawns. In contrast, farm-made aquafeeds and industrially manufactured pelleted feeds are used by improved-extensive and semi-intensive farmers respectively. Due to a lack of resources, technical knowledge, and inadequate technical support, none of farmers use intensive farming techniques.

[8] Extensive production systems typically use slightly modified versions of traditional methods and are called low-density and low-input systems (Shang, Leung and Ling, 1998). Inputs can be classified as material inputs (seed, feed and fertilizer) and management inputs (labour).

[9] An improved-extensive method is a modification of the traditional extensive farming systems where farmers apply higher stocking rates, and increase feed and other inputs (fertilizer and labour). Inputs remain lower than those used in semi-intensive farming systems. This method is suitable for prawn and shrimp aquaculture in Bangladesh.

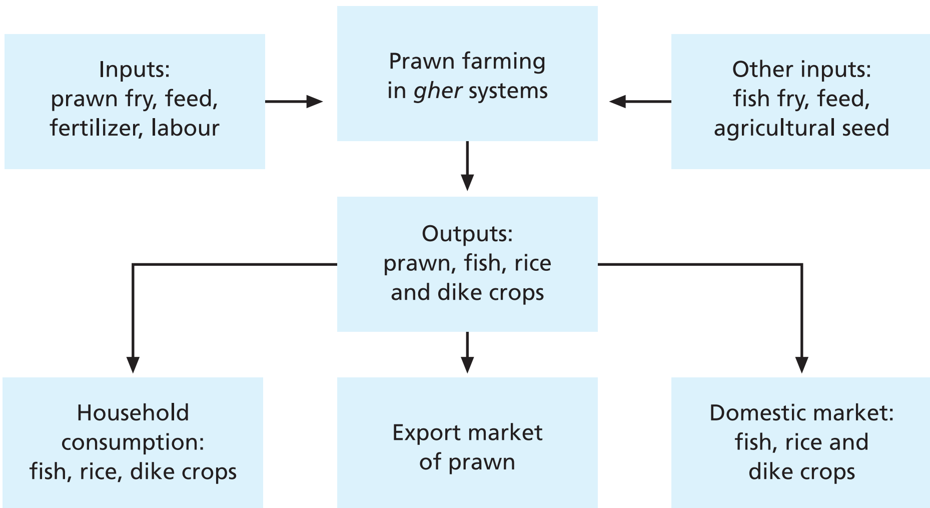
[10] Semi-intensive operations apply intermediate stocking levels and inputs. Feeding and pond fertilization is carried out on a regular basis (Shang, Leung and Ling, 1998).

FIGURE 2
A typical prawn-fish-rice farm in southwest Bangladesh

COURTESY OF FAO/NESAR AHMED.

There are two prawn farming systems that can be used in rice fields, *viz.* integrated and alternate systems (Table 3). The choice of farming system is dependent on the ecology of the area as well as biophysical resources (i.e. pond size, water depth, and financial ability of the farmers to buy seed, feed and fertilizer). While most farmers (>80 percent) practice integrated farming and cultivate the monsoon season *aman*[11] rice with prawns during June to October, a few alternate farmers avoid cultivating monsoon rice – this is due to the negative effects that rice cultivation can have on prawn growth. During the dry season between January and April, all farmers cultivate *boro*[12] rice on the central plateau of their rice fields. The alternate farmers suggested that the *aman* rice competed with the prawns for living space. Many Asian countries (e.g. China, Thailand and Viet Nam) promote prawn culture in rice fields as a form of Integrated Pest Management (IPM), and it has proved an effective way to increase the productivity of rice and prawns (Giap, Yi and Liu, 2005). Prawn culture with rice farming is ecologically sound with rice production improving as the prawns predate upon insects and improve soil fertility (Matteson, 2000). In addition, the rice fields provide planktonic, periphytic and benthic food sources to the fish (Mustow, 2002). Finally, shade from the rice plants helps to maintain favourable water temperatures for fish culture during the summer (Kunda *et al.*, 2008).

FIGURE 3
Prawn production processes in rice fields in gher systems



[11] *Aman* is the main rice crop in Bangladesh. It is planted during the monsoon season that begins in June. The crop is harvested in October-November.

[12] *Boro* rice is grown in the dry season from January to May. The crop is generally transplanted in January-February and harvested in April-May.

TABLE 3
Prawn farming systems in rice fields

Farming method	Extensive n = 30	Improved extensive n = 30	Semi intensive n = 30
Integrated farming (prawn-fish-aman rice in monsoon and boro rice in dry season)	27 (90%)	25 (83%)	24 (80%)
Alternate farming (prawn-fish in monsoon and boro rice in dry season)	3 (10%)	5 (17%)	6 (20%)

Note: n = sample size of prawn farmers.
Source: Field survey (2010).

3.1.2 Farm size

Management practices are important factors affecting productivity and profitability. Farm size appears to have an influence on productivity – an increase in farm size is generally associated with an increase in farming intensity, and hence productivity. In addition, farmers operating larger farms tend to have greater access to capital, managerial support, and the potential to operate and use resources efficiently. The survey revealed that the largest average farm size was 0.45 ha for semi-intensive farming systems, 0.28 ha for improved-extensive systems, and 0.19 ha for extensive farming systems. A significant difference ($p<0.05$, F-test) was found between the size of a farm and the farming system that was used. The principal water sources that supply prawn farms are rainfall, groundwater, and sometimes canal and river water.

According to Fan and Chan-Kang (2005), Asian farming is characterized by small farms, and small-scale farmers play an important role in providing food security and poverty alleviation. There is a positive relationship between farm size and labour productivity, and therefore income. In the study area, prawn farms average 0.31 ha compared with 0.60 ha for rice-only farms (Muir, 2003). Due to population increases, the average size of rice farms declined from 1.43 ha in 1961 to 0.87 ha in 1994, and is now just 0.60 ha (Rahman and Parkinson, 2007). In the past, prawn farms were also larger, and about two decades ago, they averaged 0.35 ha in Bagerhat district (Rutherford, 1994).

Farm size is also associated with cropping intensity (i.e. the total cropped area). The survey revealed that farmers using semi-intensive farming techniques attained higher cropping intensities of 191 percent, compared with 183 percent in improved-extensive, and 175 percent in extensive farming (the cropping intensities exceed 100 percent as the calculation takes into account those areas that are harvested more than once a year). In response to a growing population and demand for food, Bangladesh agriculture has generally increased cropping densities. In the study area, cropping intensity was found to be higher in the larger farms. This was attributed to farmer wealth, which was positively related to farm size and the ability to invest in farm inputs.

Saline water intrusion in coastal areas as a result of climate change is of serious concern to the farmers. However, it is likely that the issue can be resolved by adopting appropriate soil and water management practices, and introducing of salt tolerant rice varieties (Haque, 2006).

3.1.3 Postlarvae (PL) stocking and feeding

The peak season for prawn farming is between May to January. Prawn PL are stocked when they become available in May to June, and are primarily harvested between November and January; a culture period of around six to nine months. As hatchery produced PL are in limited supply, prawn culture remains dependent on the collection of wild PL. Farmers consider hatchery reared PL to be of a lower quality. The survival of wild-caught PL are reported to be much higher than that those of hatchery produced PL. Although there are 81 freshwater prawn hatcheries in Bangladesh, only 38 (47 percent) are operational. These hatcheries produce around 100 million PL per annum, equating to 20 percent of the total demand (Ahmed and Troell, 2010). A paucity of technical knowledge, inadequate skilled manpower and insufficient supplies of wild broodstock are important factors that account for the low levels of hatchery production. Farmers estimate that around 15 to 20 percent of PL stocked are hatchery produced.

As opposed to stocking juveniles, farmers prefer to stock PL. This is due to their low price and availability in the local markets. The average stocking densities (average weight 0.02 g) were found to be 2.5 PL/m^2 in semi-intensive farming, 2.0 PL/m^2 in improved-extensive and 1.5 PL/m^2 in extensive systems. There was a significant difference ($p<0.05$, F-test) between the stocking rates applied to the different farming systems. Until recently, most farmers stocked PL directly into their grow-out ponds, and did not use nursery systems. However, to improve survival rates, most farmers have started to use net cages (*hapas*) as nurseries. In general, farmers rear PL for a period of four to six weeks at stocking rates of 50 to 100 PL/m^2.

Between the farming systems, there are differences in the management of the PL nursery production phase. With respect to the pre-stocking in semi-intensive farming systems, nursery cages are limed (200–250 kg/ha) and fertilized with cow dung (100–150 kg/ha), urea (20–35 kg/ha) and triple super phosphate (TSP: 25–50 kg/ha). Farmers use fertilizers to enhance natural productivity in the nursery cages[13]. However, due to the cost and the availability of capital, most improved-extensive farmers use lower levels of inorganic fertilizer and cow dung. Nevertheless, most nursery operators using the extensive farming systems apply cow dung and mustard oil cake a few days before stocking their PL.

All semi-intensive, and the majority of improved-extensive farmers, use formulated commercial feeds for PL rearing. The use of these feed results in higher survival and growth rates. In general, farmers apply feeds at four to six percent of body weight per day. Formulated prawn nursery feeds contain 35–42 percent protein. However, formulated commercial feeds are expensive, and many improved-extensive and most extensive farmers are unable to afford these feeds. Wheat flour is commonly used as an alternative by resource-poor farmers for PL rearing. In the first week of PL stocking, 50 g of wheat flour is applied per 1 000 PL; double this quantity is fed in the second week.

3.1.4 Fish stocking

Almost all farmers surveyed rear fish with their prawns. Fish are stocked at the same time as the prawns, but are harvested throughout the year. Farmers stocked Indian major carps, such as catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus cirrhosus*), and exotic carps such as silver carp (*Hypophthalmichthys molitrix*), grass carp (*Ctenopharyngodon idella*) and the common carp (*Cyprinus carpio*). In general, farmers do not stock specific ratios of the different carp species. The average size of fingerlings stocked varied from 5 to 7 cm (5–7 g). The highest average annual stocking density was found to be 5 112 fingerlings/ha in semi-intensive farming systems, followed by 4 365/ha in improved-extensive systems, and 3 571/ha in extensive systems. There was a significant difference ($p<0.05$) in the fish stocking rates between the different farming systems.

In addition to the carps, a number of small indigenous fish species (SIS) are cultured with the prawns. There are 260 species of freshwater fish in Bangladesh. Of these, 143 species (55 percent) have been classified as SIS (Mazid and Kohinoor,

[13] PL are omnivorous, feeding mainly on zooplankton. It is necessary to maintain adequate zooplankton densities in nursery cages.

2003). The most common SIS cultured with prawns are mola (*Amblypharyngodon mola*), dhela (*Osteobrama cotio*), kholisha (*Colisa fasciatus*), puti (*Puntius* sp.), tengra (*Mystus vittatus*), shing (*Heteropneustes fossilis*) and koi (*Anabas testudineus*). Among the SIS, mola contains more available vitamin A than any other edible freshwater fish in Bangladesh (Roos, Islam and Thilsted, 2003). SIS are also regarded as self-recruiting species that enter the rice fields from adjacent floodplains during the monsoon and reproduce in the inundated rice fields. The natural aggregation of SIS in rice fields has inspired prawn farmers to increase productivity. As SIS are not deliberately stocked in the prawn farms, the number of SIS cultured remains unknown. Nevertheless, it was suggested by the respondents that the average number of SIS varied from 500 to 1 000/ha.

3.1.5 Prawn feeding

Prawn farming is primarily dependent upon an adequate supply of quality feeds. In terms of increasing production, feed is one of the most important inputs. A major limiting factor to growth is feed intake, and as prawns are generally slow feeders, pellet stability is of primary importance to ensure adequate feed intake.

There is great potential to increase farm productivity through increased feed supply. Supplemental feeds are used for prawn farming in rice fields. A variety are used, including freshwater snails, farm-made aquafeeds and industrially manufactured pelleted feeds. In general, semi-intensive prawn farming is dependent on reliable sources of pelleted feeds, while extensive and improved-extensive farming primarily rely on snail meat and farm-made aquafeeds respectively. The highest average annual feeding rate was estimated at 1 627 kg/ha in semi-intensive farming systems, followed by improved-extensive (1 506 kg/ha) and extensive farming systems (1 454 kg/ha; Table 4). There was a significant difference ($p<0.05$) between the feeding rates applied to the different production systems.

3.1.6 Fertilization

All the farmers reported using fertilizers for grow-out production. Fertilizers stimulate the growth of natural feeds (e.g. phytoplankton, zooplankton, benthos and periphyton), thereby increasing prawn and fish yields. Prawn farmers use organic and inorganic fertilizers. The most widely used organic fertilizer is cow dung, which is relatively cheap and readily available in rural Bangladesh. The use of inorganic fertilizer is not widespread, and only a few of the more prosperous farmers can afford them. They use a mixture of chemical fertilizers including urea and TSP, which are usually used in combination with cow dung.

Semi-intensive farmers using pelleted feeds applied more fertilizers than the improved-extensive or extensive farmers (Table 4). Extensive farmers using snail meat as a feed source only applied organic fertilizer – mainly cow dung. The use of cow dung was attributed to a lack of technical expertise in terms of fertilizer application, and an inability to afford most expensive, alternative fertilizers. Farmers employing improved-extensive farming techniques using farm-made aquafeeds relied on both organic and inorganic fertilizers but, due to financial constraints, applied their fertilizers at lower rates than the semi-intensive farmers. There was a significant difference ($p<0.05$) between the fertilization rates used in the different farming systems.

TABLE 4
Inputs of integrated prawn-fish-rice farming in different production systems

Input	Extensive Mean ± SD	Improved-extensive Mean ± SD	Semi-intensive Mean ± SD
Farm size (ha)	0.19 ± 0.07	0.28 ± 0.11	0.45 ± 0.13
Stocking (number/ha/year)			
Prawn PL	15 431 ± 2 560	20 369 ± 3 632	24 752 ± 4 597
Fish fingerlings	3 571 ± 681	4 365 ± 729	5 112 ± 905
Feeding (kg/ha/year)	1 454 ± 517	1 506 ± 719	1 627 ± 931
Fertilization (kg/ha/year)			
Cow dung	1 447 ± 223	1 228 ± 207	1 196 ± 189
Urea	-	119 ± 33	286 ± 47
TSP	-	57 ± 19	172 ± 35
Labour* (man-days/ha/year)	121 ± 29	139 ± 41	152 ± 38

Notes: SD = standard deviation.
*A man-day was defined as 8 hours of work.
Source: Field survey (2010).

3.1.7 Labour input

Labour is required for farm construction, stocking, feeding, fertilization, harvesting and marketing. The sources of labour that were reported in the survey included family labour[14], for which no payment was made, and hired labour, for which farmers had to pay in cash. The hired labour can be further classified into casual labour and labour hired on an annual basis. To determine the value of unpaid family labour, the opportunity cost[15] was calculated. It was difficult to estimate the amount of family labour involved in prawn farming, but respondents indicated that it contributed 60 – 70 percent of the total labour requirement of the farms. According to the survey, the highest labour requirements accrued to semi-intensive farming systems, followed by improved-extensive and extensive farming systems (Table 4). There was a significant difference ($p<0.05$) between the labour inputs between different farming systems.

3.2 Snail meat as a feed source in prawn culture

3.2.1 Snail harvesting

The use of snail meat as a prawn feed is widespread in southwest Bangladesh. There are about 450 species of snails in Bangladesh of which 300 inhabit the coastal belt (Gain, 1998). However, only the freshwater snail (*Pila globosa*) is traditionally used as a prawn feed. The snail is a valuable aquatic resource whose preferred habitat is low-lying marshland. This snail is widely distributed throughout the wetlands and rivers of Bangladesh. They can be found gliding upside down beneath the surface film of the water body in which they live (Baby *et al.,* 2010). They primarily feed on the leaves of aquatic plants, and their removal can result in increased growth of aquatic macrophytes, possibly reducing light penetration and photosynthesis, and ultimately leading to the eutrophication of water bodies (Gain, 1998).

[14] Family labour was difficult to quantify as the farmers were often unable to differentiate the use of family labour for different purposes.

[15] Opportunity costs refer to the costs associated with giving up an opportunity. The opportunity cost creates an implicit price relationship between competing alternatives. The opportunity cost of a human labour is its value as its best alternative use.

Snail populations are reported to have declined significantly in Bagerhat district. This is attributed to excessive harvesting during the monsoon period, which coincides with the peak reproductive season of the species. Snails are also harvested from wetlands and rivers in neighbouring districts including Gopalgonj, Faridpur and Madaripur. A large number of impoverished rural people live in the wetland areas of these districts where fishing and snail harvesting are the main economic activities. A wide variety of people including women and children are involved in snail harvesting, and the supply of snails has generated many employment opportunities in harvesting, processing, transport and marketing.

The practice of collecting snails to supply the prawn culture industry was initiated in 1992 (Ahmed, 2001). The peak season for snail harvesting is from June to October. On average, snail collectors are engaged for five hours (range: three to seven hours) a day. During the morning (06.00–10.00 hours) and late afternoon (14.00–17.00 hours), the snails float on submerged vegetation as well as on the surface of the water. During hot weather when there is strong sunshine, and during rainfall, the snails will drop from the surface and fall to the bottom of the water column. The snails are collected using a triangular concave mesh net attached to a short pole which is used to scoop the snails off the surface. Hundreds of small boats are involved in snail harvesting. Each boat is operated by a single harvester. A snail collector harvests an average of 20 kg of snails a day (range: 10–30 kg per day). The collected snails are stored in the boats, and transported to collection points.

3.2.2 Transporting snails

A large number of impoverished rural people are involved in transporting snails from the wetland areas to the prawn farming areas in Bagerhat district. Local suppliers carry them to Bagerhat district using trawlers, trucks or boats; these journeys, depending on the distance and the mode of transport, take between two and four hours. The snails are sold to traders. A number of people are employed by the suppliers as day labourers for loading and unloading. Rickshaws and vans are also commonly used to transport the snails to the prawn farms. To take advantage of the cooler temperatures, the snails are transported to the prawn farms at night or in the early morning hours. Nevertheless, due to hot temperatures and rough handling, some snails are spoiled during transit.

3.2.3 Processing snail meat

Prior to feeding to the prawns, the snails are shucked and the meat is removed from the shells. The snail traders employ adults and children as day labourers for this purpose (Figure 4). Processing involves breaking the operculum and removing the meat from the shells with a small curved knife. A woman can process five to six baskets of snails a day. Each basket contains 20 kg of snails and provides 8–10 kg of snail meat. To maintain meat quality, the snails must be processed within 24 hours of harvesting. Temperatures in excess of 30 °C increase the potential for spoilage.

FIGURE 4
Shucking the snails and removing the meat

COURTESY OF FAO/NESAR AHMED.

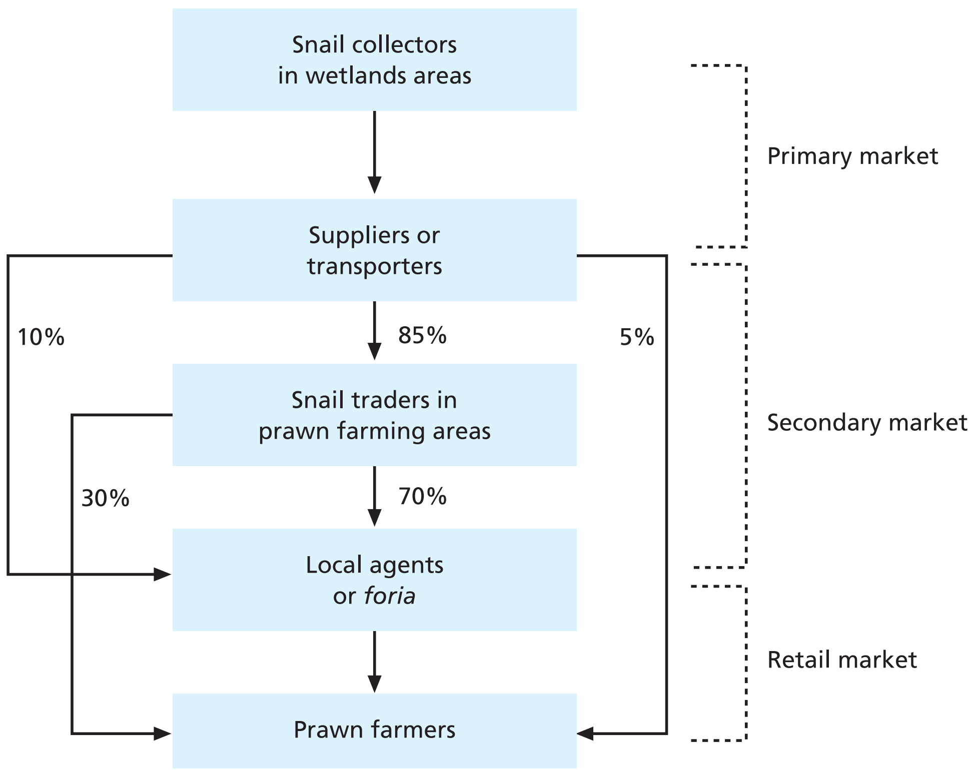
3.2.4 Use of snail shells

The use of snail meat as an agricultural feed generates large volumes of shells. The shells are generally discarded by the roadside, in canals, and other places away from the processing locations. In recent years, people have begun to collect and process the shells to produce lime, and the shells are now increasingly used in the local lime factories. In Bagerhat district, they are processed as poultry and/or fish feed supplements, and as a fertilizer for homestead gardening. They are also used as a duck feed. According to White *et al.* (2007), snail shells provide a rich source of calcium carbonate, which can be used to enrich the soil, and as a supplement in bird feeds.

3.2.5 Snail trading

The traditional snail marketing system plays a vital role in connecting the farmers and harvesters, and significantly contributes to the value adding process. The value chain from harvesters to farmers encompasses primary, secondary and retail markets, and involves suppliers, traders and local agents (Figure 5). The peak season for snail trading is between June and October, and corresponds to the period when the farmers cultivate prawns. During this period, the snail traders make their primary living by buying and selling snails. Snail trading is a seasonal business and traders engage in trading for six to ten hours a day. The rest of the time they are involved in prawn farming, PL trading and prawn marketing. In the study area, 15–20 snail traders were found to be operating in a single market. During the season, the traders sell an average of 90 kg snail meat per day (range: 45 to 130 kg). Traders sell their snails or snail meat either directly or *via* local agents to the prawn farmers. According to the snail traders, the average price of snail meat in 2010 was US$0.15/kg.

FIGURE 5
The freshwater snail supply chain from harvesters to prawn farmers



3.2.6 Feeding snail meat

Snail meat is mainly used by resource-poor farmers using extensive farming techniques. The survey revealed that an average 1 454 kg/ha/year of snail meat is used in these extensive systems. Almost all the farmers reported using broadcast feeding. It was evident that farmers had little understanding of how to improve their feed management practices. In general, chopped snail meat is fed in the morning and/or the evening (Figure 6). According to the survey, the vast majority of respondents (70 percent) fed the meat once a day; only 10 percent fed twice a day (Table 5). Twenty percent of respondents used feeds at irregular intervals – two to three times per week. Irregular feeding was attributed to inadequate supplies. The supply of snail meat is often irregular, and therefore farmers often supplement their use with farm-made feeds that are prepared by mixing cooked rice, rice bran and wheat flour. The farmers reported that the production of prawns is higher and production costs lower when snails are used as opposed to farm-made feeds.

FIGURE 6
Prepared snail meat

COURTESY OF FAO/NESAR AHMED.

TABLE 5
Feeding frequencies applied to different feed types

Feeding frequency	Snail meat n = 30	Farm-made feed n = 30	Manufactured aquafeed n = 30
Once daily	21 (70%)	18 (60%)	16 (53%)
More than once daily	3 (10%)	7 (23%)	14 (47%)
Irregular (2–3 times/week)	6 (20%)	5 (17%)	-

Note: n = sample size of farmers.
Source: Field survey (2010).

3.3 Farm-made aquafeeds

3.3.1 Feed ingredients

A variety of ingredients are used in the production of farm-made aquafeeds. In general, farmers use a mixture of rice bran, mustard oil cake, fishmeal, oyster shell, salt and vitamins. The feed is usually formulated to contain 40 percent rice bran, 30 percent mustard oil cake, 25 percent fishmeal, and 5 percent minerals and vitamins (oyster shell, salt and vitamins). Although many ingredients (i.e. rice bran, mustard oil cake, oyster shell) are on-farm agricultural by-products, it was estimated that about 60 to 70 percent of the feed ingredients used in the production of farm-made aquafeeds had to be purchased. Farmers mainly use rickshaws, vans and motorized vehicles to transport the feed ingredients from the local markets. Despite the importance of maintaining the quality of feed ingredients during transportation, storage and processing, it was evident that farmers have little knowledge on how best to store and handle their feed ingredients. Most farmers using farm-made aquafeeds prefer to purchase small amounts of ingredients and not store their feeds – this purchasing behaviour was attributed to a lack of financial means to purchase in bulk, and inadequate storage facilities.

The majority of farmers (65 percent) irregularly use machines to mix their feed ingredients (Figure 7). The remaining farmers (35 percent) do so manually (Figure 8). Farmers produce the pellets using their own machines, or have the local feed mills produce the pellets for them (Figure 9). The feed manufactures produce feeds using hauler machines (22 horsepower). Farmers transport their feed ingredients to the feed mills to manufacture the pellets, and pay for the manufacturing process. However, many farmers also reported mixing their own feed ingredients manually, and thereby reducing their feed manufacturing costs.

FIGURE 7
A machine for preparing farm-made aquafeeds

COURTESY OF FAO/NESAR AHMED.

FIGURE 8
Manually mixing farm-made aquafeeds

COURTESY OF FAO/NESAR AHMED.

FIGURE 9
Drying of farm-made aquafeeds

COURTESY OF FAO/NESAR AHMED.

3.3.2 Rice bran

In Bangladesh, the most commonly used aquaculture feed is rice bran, a by-product of rice – the main crop of the country. There are three types of rice crops in Bangladesh: *aman*, *aus* and *boro*. While *aman* rice accounts for 50 percent of the total rice crop area, *aus* and *boro* account for 27 percent and 23 percent respectively. In 2008/09, over 29 million tonnes of rice was produced from about 10.8 million ha of rice fields (BRKB, 2010). The three types of rice provide a year round supply of rice bran which accounts for five percent (1.45 million tonnes) of the total rice yield (Barman and Karim, 2007). The average annual requirement for rice bran used in farm-made aquafeeds is estimated at 602 kg/ha. About 30–40 percent of rice bran supply is normally derived from on-farm rice production, and the remainder is purchased. The average price of rice bran was estimated to be US$0.15/kg. Considering the importance of rice bran in prawn feeds, it is necessary to maintain its quality during production, storage and transportation. The quality of rice bran depends on nutrient value, freshness, fineness, storage conditions and the duration of storage. In general, rice bran produced in automated rice mills has a higher nutrient value than that produced in the rural husking mills (Barman and Karim, 2007). The proximate composition of rice bran varies greatly, and is presented in Table 6.

TABLE 6
Proximate composition of farm-made aquafeed ingredients used in prawn farming (percent dry weight basis)

Feed composition	Rice bran	Mustard oil cake	Fishmeal
Crude protein	9.8–17	35–40	40–56
Crude lipid	7.7–22.4	19.8	16–20
Crude fibre	5.7–20.9	14.9	2–6
Ash	7.1–20.6	6.6	21.3
Nitrogen-free extract (NFE)	40–41	29.0	0.7

Source: Barman and Karim (2007).

3.3.3 Mustard oil cake

Mustard oil cake is widely used as a aquafeed ingredient in Bangladesh, and is one of the most important ingredients in prawn feeds. It is a by-product of the production of mustard seed oil. Annual oilseed production in Bangladesh is 267 000 tonnes, of which 72 percent (192 240 tonnes) accrues to mustard oilseed (Basak, Pandit and Khurram, 2007). Approximately 48 060 tonnes of mustard oil cake is produced per annum. The overall demand for mustard oil cake has increased as the national aquaculture sector has expanded. The survey revealed that an average of 452 kg/ha/year of mustard oil cake was used to prepare farm-made prawn aquafeeds. The vast majority of farmers (90 percent) reported purchasing this ingredient. The average price of mustard oil cake was estimated to be US$0.21/kg. Its quality depends on oil production systems, freshness, fineness, storage conditions and the storage duration. Mustard oil cake is rich in protein (35–40 percent). The proximate composition is presented in Table 6.

3.3.4 Fishmeal

Fishmeal is widely used as a protein source in aquafeeds, and is recognized by the prawn farmers as a high-quality, highly digestible feed ingredient. In Bangladesh fishmeal is generally produced from trash fish/low-value fish. Fishmeal can be manufactured from small pelagic marine fish that are not used for human consumption. It can also be made from fisheries by-catch, and seafood processing plant waste. Fishmeal quality varies according to the quality and composition of the source fish that are used in the manufacturing process. The Bangladesh Fisheries Development Cooperation has four fishmeal production plants with a combined production capacity of eight tonnes per day. Around four to five tonnes of fish are required to produce one tonne of dry fishmeal (Miles and Chapman, 2006). The survey revealed that on average, 377 kg/ha/year of fishmeal was used by farmers in their farm-made aquafeeds. Almost all respondents reported buying fishmeal from the local market. The average price of fishmeal was reported to be US$0.32/kg. Typical composition is shown in Table 6.

3.3.5 Other ingredients

In addition to rice bran, mustard oil cake and fishmeal, other ingredients, including oyster shell, vitamin premix and salt, are used by prawn farmers to prepare farm-made aquafeeds. The survey revealed that all these ingredients were purchased from the local market. Oyster shell contains a high proportion of calcium carbonate, and is used as a supplement in prawn feeds. A number of vitamin premixes are used – all include vitamins A, B, C, D, E and K. Vitamin premixes have beneficial effects on prawn growth, disease resistance, immune system functioning, and their use reduces stress (Mitra, Mukhopadhyay and Chattopadhyay, 2005). Iodized salt is also added to farm-made aquafeeds. The average price of iodized salt was reported to be US$0.29/kg, which is significantly higher than oyster shell (US$0.07/kg). The price of vitamin premixes range from US$0.65–1.2/g.

3.3.6 Feeding practices

Sixty percent of respondents fed farm-made feeds once a day, 23 percent fed twice a day, and 17 percent fed two to three times a week (Table 5). Based on these feeding frequencies, there was considerable variation in the quantity of feed used by the different farms surveyed. On average, the annual feeding rate of farm-made aquafeeds was estimated to be 1 506 kg per hectare. As the feed that is used is a slow sinking pelleted feed, it is applied by broadcast methods. Overall, the use of feed has increased in recent years, and as such, there has been a concomitant increase in the productivity of the systems. However, it was evident that there was considerable variation between the farmers in terms of the quantity of feed that they used. This variation was attributed to the availability of feed ingredients and farmer's ability to purchase feeds. Although most farmers indicated that they would like to use more feeds and increase productivity, many are unable to invest in additional feeds. The average price of farm-made aquafeeds was calculated as US$0.35/kg.

3.4 Commercially manufactured aquafeeds

3.4.1 The feed industry

The survey revealed that there are 44 registered commercial feed manufacturers in Bangladesh that produce poultry and aquaculture feeds, including those for prawns and shrimps. In reality this figure is likely to be larger as there are many unregistered feed manufacturers. While almost all the feed production facilities produce poultry and fish feed, only 25–30 percent produce prawn and shrimp feeds (Chisty, 2009). There are many commercial prawn feed manufacturers in Bangladesh, which use machinery imported from China, Germany, India, Thailand and the United States of America. They are located throughout the country and, *inter alia*, can be found in Chittagong, Dhaka, Gazipur and Khulna regions. Feed production rates vary between 5 and 25 tonnes/hour, depending on capacity and the available manpower. Bismillah Feed Mills have the major market share for prawn feeds, followed by Quality Feed Ltd, Sunny Feed Ltd and Niribili Feeds Ltd (Table 7). Farmers select their feeds according to a number of factors including quality, price, availability and the technical support supplied by the feed companies.

TABLE 7
Commercial prawn feed production capacity (2009)

Feed company	Production (tonnes/year)
Bismillah Feed Mill	20 000
CP Feed	1 200
Niribili Feed Ltd.	3 000
Quality Feed Ltd.	7 000
Saudi Bangla Fish Feed Ltd.	500
Spectra Hexa Feeds Ltd.	500
Sunny Feed Ltd.	5 000

Source: Field Survey (2010).

3.4.2 Feed ingredients

In general, feed manufacturers use similar ingredients to produce prawn feeds. These include fishmeal, mustard oil cake, de-fatted rice bran, rice polish, wheat flour, maize, meat and bone meal, soybean oil, calcium phosphate, sesame oil cake, salt and vitamin premixes. Although similar ingredients are used by the various aquafeed manufacturers, their formulations differ. The majority of feed ingredients are sourced locally; however some, including meat and bone meal and defatted soybean meal are imported.

The use of food additives, including anti-fungal, mould inhibitors and antibiotics, is commonplace. Nitrofurans and chloramphenicol are two types of antibiotic that are used to treat bacterial infections. Due to public health concerns, these antibiotics have been banned for use in animal production systems in many countries e.g. Australia, the European Union (EU), Canada and the United States of America. Almost all feed manufacturers in the survey denied using banned antibiotics. However, banned antibiotics have been found in many prawn feeds in the country (Islam, Khan and Reza, 2009). It is possible that these banned chemicals may be being introduced into the feeds by incorporating adulterated feed ingredients that contain the banned substances, possibly from imported ingredients such as meat, bone meal and fishmeal (Chisty, 2009). Carry-over contamination from batches of other animal feeds manufactured in the same equipment may also be responsible (M. New, personal communication, 2012).

3.4.3 Types of feed produced

The majority of prawn feed manufacturers produce three types of prawn feeds, *viz.* starter feeds for use in the nursery; grower feeds for juveniles and adult prawns; and finisher feeds for adult prawns. Most feed manufacturers use different trade names, and they usually use two or more brand names as a component of their marketing strategies. The nursery feeds are usually sold in 1 kg, 5 kg and 20 kg bags. Starter, grower and finisher feeds are sold in 25 kg bags. The average feed price was US$0.59/kg and, depending on the type and quality, varied between US$0.44 and US$1.03/kg. The quality of feed depends on the proximate composition and feed manufacturing process. The proximate composition of the different prawn feeds that are available in the market varies considerably; the composition of a selected example of each feed type is shown in Table 8. Nutritional information including the moisture, protein, lipid, fibre and energy contents is provided on the feed bags.

TABLE 8

The proximate composition of selected manufactured prawn feeds (percent dry matter basis)

Proximate composition	Starter*	Grower**	Finisher***
Crude protein	38	36	35
Crude lipid	6	4	4
Crude fibre	4	5	6
Ash	13	16	16
Moisture	10	11	12
Nitrogen-free extract	29	28	27

Notes: Feed brands - * Mega feed, ** Saudi-Bangla Fish Feed, *** Mega feed.

Source: Field survey (2010).

3.4.4 Transport of feed

The majority of feed manufacturers do not have their own vehicles, and depend on hired vehicles for feed transportation, but a few of the foreign feed manufacturing companies have a limited number of vehicles for this purpose. In general, trucks and pickups are used to transport feed from the manufacturers to the dealers. As dealers directly supply the feed to the sub-dealers, they operate storage facilities and have supply contracts with the latter. Pickups and vans are commonly used to transport feed from the dealers to the sub-dealers. Finally, the farmers transport the feed from the sub-dealers using vans, rickshaws, or by foot. Usually the cost of transporting the feed from the manufacturers to dealers is borne by the dealers. Similarly, the cost of feed transportation from the dealers to sub-dealers is borne by the sub-dealers. Ultimately, the farmers bear the cost of transporting the feed to the farm.

3.4.5 Feed marketing

Almost all prawn feeds manufactured in Bangladesh are produced for domestic prawn farming. A considerable number of people are employed in the feed market chain as suppliers, transporters, traders, intermediaries and day labourers. The feed market system is less competitive but plays a vital role in connecting the manufacturers to the farmers. In order to improve feed sales, some feed companies employ technical personnel to assist and advise both dealers and farmers.

The feed value chain from manufacturers to farmers involves primary, secondary and retail markets, suppliers, dealers and sub-dealers (Figure 10). With a few exceptions, manufacturers do not directly communicate with farmers.

FIGURE10

Feed supply chain from feed manufactures to prawn farmers

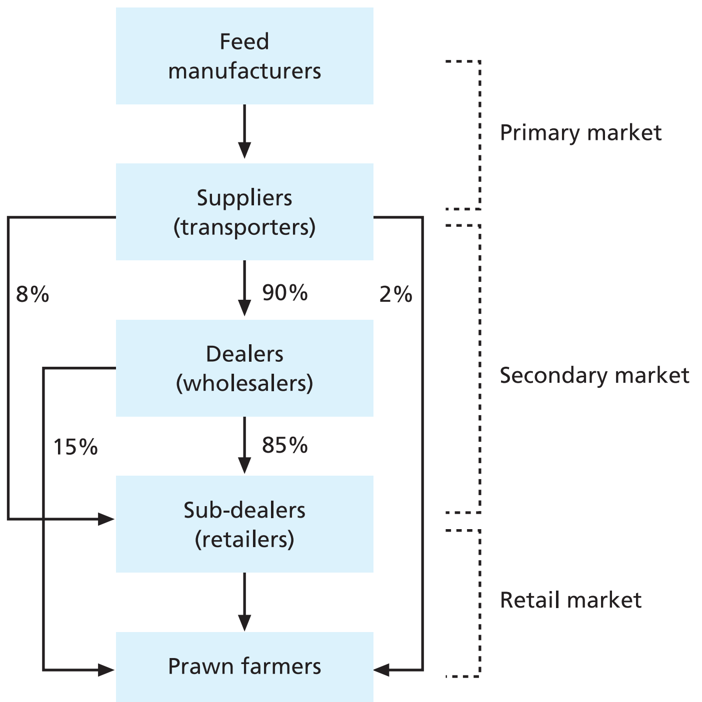


FIGURE 11
The store of a local dealer selling manufactured pelleted feeds

COURTESY OF FAO/NESAR AHMED.

The communication networks between the market actors is generally good and is assisted by the use of mobile phones. Suppliers include intermediary traders who supply feed from the manufacturers to the dealers (Figure 11). In general, the suppliers are tied to a limited number of dealers. Similarly, a limited number of sub-dealers are associated with the dealers. Finally, the sub-dealers sell feed to the farmers for cash or on credit. It was reported that most feed is sold on credit.

FIGURE 12
Commercially manufactured pelleted feeds

COURTESY OF FAO/NESAR AHMED.

3.4.6 Feeding practices

Almost all industrially manufactured prawn feeds (Figure 12) are slow sinking, and farmers feed using broadcast methods. The survey revealed that 53 percent of the farmers fed once a day, with the remaining 47 percent feeding twice a day. Typical feeding schedules for use with starter, grower and finisher feeds are presented in Table 9. When the PL become juveniles, farmers apply starter feeds at the rate seven to ten percent of body weight per day for a period of 4 weeks. Grower feeds are used five to six percent of body weight per day for 5–24 weeks. Finally, finisher feeds are used at the rate of three to four percent of body weight per day for the last four to six weeks of the production cycle. On average, annual feeding rates were estimated at 1 627 kg/ha across all feeding classes.

TABLE 9
Feeding schedules for commercially manufactured pelleted feeds

Feed type	Prawn size (g)	Feeding duration	Feeding rate (% body weight/day)
Starter	4–7	First 4 weeks	7–10
Grower	8–20	5–24 weeks	5–6
Finisher	>20	Last 4–6 weeks	3–4

Source: Field survey (2010).

3.5 Constraints to feed management

The farmers surveyed reported a number of feed and feed management issues. These included the high price of feed, an inadequate supply of feed and feed ingredients, poor feed quality, procurement problems, the decomposition of feed, water pollution due to excessive feed use, and a poor knowledge of feed management practices. The following section describes the constraints to feed management in the different culture systems that are currently in use.

3.5.1 Snail meat

Snail meat is a non-conventional but important feed source for prawn farming. Forty three percent of respondents using snail meat identified an inadequate supply as the key production constraint (Table 10). During the peak farming season (June to October) farmers reported that they required 30–40 kg/ha of snail meat per day. However, the supply of snails is irregular and farmers reported only having access to 10–20 kg/ha/day at some times. The high price of snail meat is also a key constraint for resource-poor farmers, and in recent years the price of snail meat has increased significantly. In 2010, the average price of snail meat paid to the harvesters was US$0.07/kg. In contrast, the prawn farmers paid an average price of US$0.15/kg. The majority of farmers reported that over a decade ago, snail meat was sold at an average of US$0.04/kg.

Thirteen percent of the farmers using snail meat indicated that procuring this commodity was their most important feed management constraint. Despite recent and substantial improvements to the road infrastructure, access to remote areas remains problematic, particularly in the monsoon season. Transport time can be considerable, resulting in the snails degrading during transit. Indeed, ten percent of respondents identified the decomposition of snail meat as a constraint. The use of decomposed snail meat results in poor water quality, and is believed to be a key factor causing disease. Only seven percent of farmers reported an inadequate knowledge on feed management practices to be the most important constraint.

TABLE 10
Key constraints to feed management

Key constraint	Snail meat n = 30	Farm-made feed n = 30	Commercial feed n = 30
High price	6 (20%)	14 (47%)	16 (53%)
Inadequate supply	13 (43%)	6 (20%)	2 (7%)
Procurement problem	4 (13%)	4 (13%)	4 (13%)
Poor quality	3 (10%)	3 (10%)	5 (17%)
Water pollution by feed	2 (7%)	2 (7%)	1 (3%)
Inadequate knowledge on feeding	2 (7%)	1 (3%)	2 (7%)

Note: n = sample size of farmers.

Source: Field survey (2010).

3.5.2 Farm-made aquafeeds

Forty seven percent of the farmers using farm-made feeds identified high feed prices as the most important issue affecting their feed use. The price of feed ingredients, including rice bran, mustard oil cake, fishmeal, oyster shell, vitamin and salt has increased significantly as prawn farming has become widespread throughout southwest Bangladesh. Moreover, the supply of feed ingredients is often inadequate, and in this regard, 20 percent of these farmers identified feed ingredient availability as a constraint. Due to salt water intrusion, the production of rice is insufficient in coastal Bangladesh, and the production of mustard oil seed is also limited in the coastal area. As such, the availability of rice bran and mustard oil cake in the local markets is dependant on supplies from other parts of the country. This results in high transport costs and increased prices. Due to the proximity to the coastal areas, the supply of fishmeal and oyster shell is adequate. Nevertheless, 13 percent of the farmers identified feed ingredient procurement as the major issue. This was due to the rural nature of many farms, and the concomitant long distances to markets.

Ten percent of the farmers using farm-made feeds identified poor quality of feed ingredients as the major constraint to their operations. To resolve the issue, these farmers reported applying more feed to obtain the desired levels of growth. Overfeeding often leads to water pollution, which can manifest itself in low levels of production. The number of respondents identifying feed related water quality issues and an inadequate knowledge of feeding practices as the key constraint was seven and three percent respectively.

3.5.3 Commercially manufactured pelleted feeds

The majority of the respondents (53 percent) reported that high feed prices was the single most important constraint regarding their use of commercially manufactured pelleted feeds. Although wealthier farmers use these feeds, a major issue for farmers is a shortage of operating capital to purchase them. There are many commercial feed producers in Bangladesh and they reported that the price of industrial feeds has increased significantly as a result of increased manufacturing costs.

Despite the high feed prices, many farmers reported that they were not satisfied with the quality of the feeds that were available. Indeed, 17 percent of the farmers identified poor feed quality as the major constraint to their use. The use of feed additives including fungicides, mould inhibitors and antibiotics are common (Islam, Khan and Reza, 2009). Banned antibiotics including nitrofuran have been found in prawns, the source of which is thought to come from contaminated feeds. During May to December 2009, the Bangladesh Frozen Foods Exporters Association (BFFEA) imposed a ban of prawn exports to remove the antibiotic nitrofuran, which had been detected by EU importers. The ban was lifted after the BFFEA confirmed that prawns produced in Bangladesh no longer contained nitrofuran (Financial Express, 2010). The EU team suggested that the feed industry and processing plants should be brought under governmental regulation, and that an awareness campaign on antibiotic use was initiated at farm level. With this mind, the government has recently passed new feed legislation to regulate fish and animal feed manufacturers.

Feed management and a poor understanding of the means of determining appropriate ration sizes was identified as the major constraint by seven percent of the farmers. Although many feed manufacturers employ technical personnel to provide technical assistance in terms of optimizing feed management practices, many farmers still had a poor understanding of these practices, resulting in overfeeding, and concomitant water quality issues. Three percent of farmers reported feed-derived water pollution as their most important production constraint.

3.6 Productivity

3.6.1 Prawn production

The highest average annual yields of prawns (Figure 13) were reported from semi-intensive farming systems (718 kg/ha), followed by improved-extensive (489 kg/ha) and extensive systems (351 kg/ha; Table 11). A number of factors affect on-farm growth rates and productivity. These include farm size, inputs (seed, feed and fertilizer), feed quality, water quality, and farm management. As a result of using higher inputs and using commercially manufactured pelleted feeds, prawn yields were highest under the semi-intensive culture conditions. The lower prawn yields attained in the extensive farming systems were attributed to lower inputs and the use of snail meat as a feed source. The highest average economic feed conversion ratio[16] (FCR) was recorded in the extensive farming system (FCR: 4.14:1), followed by the improved-extensive system (FCR: 3.08:1), and the semi-intensive farming system (FCR: 2.27:1; Table 11). There was a significant difference ($p<0.05$) between the FCR attained in the different farming systems.

FIGURE 13
Harvested prawns for the international market

COURTESY OF FAO/NESAR AHMED.

TABLE 11
Productivity of prawn, fish and rice in different farming categories

Productivity	Extensive Mean ± SD	Improved-extensive Mean ± SD	Semi-intensive Mean ± SD
Feeding (kg/ha/year)	1 454 ± 517	1 506 ± 719	1 627± 931
Productivity (kg/ha/year)			
Prawn	351 ± 56	489 ± 71	718 ± 93
Fish	526 ± 68	824 ± 95	1 173 ± 124
Rice	2 453 ± 529	2 527 ± 758	2 491 ± 629
Feed conversion ratio (FCR)*	4.14:1 ± 0.78	3.08:1 ± 0.62	2.27:1 ± 0.55

*FCR is only calculated for the prawns because farmers provided supplementary feed specifically for the prawns. However, as fish also consume both farm-made and commercially manufactured pelleted feeds, the FCR may not be accurate in improved-extensive and semi-intensive systems. Nevertheless, the FCR is more likely to be accurate in extensive farming as the fish species stocked do not eat snail meat.

Source: Field survey (2010).

Larger prawns were harvested in semi-intensive farming systems. This finding was probably due to the improved nutrition that these animals were receiving from the commercially manufactured feeds. Conversely, smaller prawns were harvested in extensive farming. Farmers using improved-extensive systems and farm-made aquafeeds obtained medium-sized prawns. The effect of feed type and the size of prawns at harvest is presented in Table 12. According to the survey, the average harvest size was found to be 70 g in the semi-intensive system, 60 g in the improved-extensive system and 45 g in the extensive system.

[16] Biological FCR is the net amount of feed used to produce one kilogramme of fish. The economic FCR takes into consideration all the feed used and the effects of feed losses and mortalities (Tveteras, 2000). This study calculated the economic FCR.

TABLE 12
Grade, harvest size prawn and their production share in different farming practices

Grade*	No. of head-on prawns/kg	Average weight (g)	Product share (%) in farming category		
			Extensive	Improved-extensive	Semi-intensive
5	5 or less	200	1	3	5
10	6–10	125	4	7	10
20	11–20	70	30	35	40
30	21–30	40	40	35	30
50	31–50	25	25	20	15

*Bangladesh grading system.
Source: Field survey (2010).

3.6.2 Fish yields

Average annual fish yields varied from 526 kg/ha in the extensive systems to 824 kg/ha in the improved-extensive systems, and 1 173 kg/ha in the semi-intensive systems (Table 11). The size of fish at stocking, the culture period, and the size at which the fish were harvested influenced yields. Moreover, fish yields were also dependent on environmental and culture conditions. Amongst others, these included water quality, culture species, stocking density, and feed and fertilizer inputs. It was assumed that in terms of using farm-made aquafeeds and commercially manufactured pelleted feeds, the fish consume a portion of the feed that is provided. However, as carps are herbivorous, they were unlikely to eat the snail meat that was provided in the extensive farming systems. Nevertheless, fish farming in rice fields is primarily dependent on natural feeds (e.g. phytoplankton, zooplankton, periphyton and benthos). With respect to increasing fish productivity, farmers indicated that they required increased supplies of quality fry. Furthermore, production could be increased by increasing stocking densities and supplementary feeding and fertilization.

3.6.3 Rice yield

The highest average annual rice yields were achieved in the improved-extensive farming system (2 527 kg/ha), followed by the semi-intensive (2 491 kg/ha), and extensive (2 453 kg/ha) farming systems (Table 11). Measures of rice productivity included the area of canal and water devoted to aquaculture, and thus, actual yields per hectare are likely to be 25–30 percent higher than those reported. Nevertheless, rice productivity in these systems is significantly lower than in other parts of the country where an average of over 4 000 kg/ha per crop is the norm (BRKB, 2010). In the study area, total rice production has probably decreased as a result of the widespread conversion of rice fields into prawn farms. In addition, climate change, including floods and drought, is of grave concern in coastal Bangladesh. Many farmers reported that soil and water salinity have already increased substantially in prawn farms as a result of flooding. The farmers attribute these changes to climate change.

3.7 The economics of the farming systems

An economic analysis of the three production systems, comprising a comparison of production costs, cost structures and production efficiencies was undertaken.

3.7.1 Variable costs

Variable costs are those associated with the cost of seed, feed, fertilizer, labour, rice production and other miscellaneous items such as electricity, lime and marketing. The average annual variable costs of prawn farming (excluding dike cropping) varied from US$1 082/ha in the extensive farming systems to US$1 627/ha in the improved-extensive systems, and US$2 314/ha in the semi-intensive farming systems (Table 13). Variable costs varied from 74 percent of the total costs in the extensive farming systems, to 78 percent in the improved-extensive farming systems, and 81 percent in the semi-intensive farming systems. Seed and feed are the two highest variable costs in prawn production. The average annual cost of seed in extensive, improved-extensive and semi-intensive farming was calculated to be 35 percent, 32 percent and 28 percent of the total variable costs, respectively. Feed costs comprised the second highest operational cost in extensive (15 percent) and improved-extensive (25 percent) farming, and constituted the highest operational cost in semi-intensive farming (33 percent of total variable costs). Considerable variation was also observed among other variable costs.

TABLE 13
Average production costs and returns (US$/ha/year) of different prawn farming systems

Cost and return	Farming system		
	Extensive	Improved-extensive	Semi-intensive
Variable costs			
Seed (prawn and fish)	506 (35%)	663 (32%)	803 (28%)
Feed	218 (15%)	527 (25%)	959 (33%)
Fertilizer	29 (2%)	60 (3%)	128 (5%)
Labour (family and hired)	178 (12%)	204 (10%)	224 (8%)
Rice cultivation	127 (9%)	138 (6%)	153 (5%)
Miscellaneous	24 (1%)	35 (2%)	47 (2%)
Total variable costs (TVC)	1 082 (74%)	1 627 (78%)	2 314 (81%)
Fixed costs			
Depreciation[1]	101 (7%)	113 (5%)	125 (4%)
Interest[2]	116 (8%)	181 (9%)	262 (9%)
Land use cost[3]	158 (11%)	167 (8%)	174 (6%)
Total fixed costs (TFC)	375 (26%)	461 (22%)	561 (19%)
Total costs (TC = TVC + TFC)	1 457 (100%)	2 088 (100%)	2 875 (100%)
Gross revenue[4]			
Prawn	1 418 (56%)	2 078 (59%)	3 231 (64%)
Fish	542 (21%)	849 (24%)	1 208 (24%)
Rice (including rice straw)	589 (23%)	606 (17%)	598 (12%)
Total gross revenue (GR)	2 549 (100%)	3 533 (100%)	5 037 (100%)
Net return (NR = GR – TC)	1 092	1 445	2 162
Benefit-cost ratio (BCR) = GR/TC	1.74	1.69	1.75

Notes: Parentheses indicate the percentage of total costs
[1](purchase price - salvage value)/economic life
[2]Interest on operating capital or loan was charged at the rate of 15 percent per annum (this calculation was applied to the 9 months of culture period)
[3]Valuation of land at its rental or lease price
[4]Productivity (kg/ha/year) x farm gate price (US$/kg)
Source: Calculated based on information collected from field survey (2010).

3.7.2 Fixed costs

The fixed costs accruing to prawn farming in rice fields relate to the depreciation of equipment (water pump, net and feed machine), land use costs or leases, and interest on operating capital. According to the survey, the average annual fixed costs for prawn farming varied from US$375/ha in the extensive farming systems, to US$461/ha in the improved-extensive systems, and US$561/ha in the semi-intensive systems (Table 13). Fixed costs accounted for 26 percent, 22 percent, and 19 percent of total costs in extensive, improved-extensive and semi-intensive farms respectively.

3.7.3 Total costs

The average total annual cost of prawn farming per hectare varied from US$1 457 in the extensive farming systems, to US$2 088 in the improved-extensive systems, and US$2 875 in the semi-intensive systems (Table 13). Almost all the farmers that were interviewed indicated that the production costs had increased significantly over recent years as a result of increased input prices. As a result of high input costs, the production costs were highest for the semi-intensive farmers.

3.7.4 Gross revenue

Gross revenues are affected by the level of production and the market price attained. The market price of aquaculture products primarily depends on the size, weight, quality of the product, seasonality, and supply and demand issues (Ahmed *et al.*, 2009). The average farm-gate prices of prawns, fish and rice were calculated to be US$4.26, US$1.03 and US$0.22/kg, respectively. The average annual gross revenue per hectare varied from US$2 549 in the extensive farming systems, to US$3 533 in the improved-extensive systems, and US$5 037 in the semi-intensive systems (Table 13). Extensive farming is characterized by a relatively low level of production per hectare, and therefore gross revenues are low. In contrast, the semi-intensive farming systems attain a comparatively high level of production per hectare, and therefore gross revenues are correspondingly higher.

3.7.5 Net return

The highest average annual net return for prawn farming in rice fields was estimated at US$2 162/ha in the semi-intensive farming systems, followed by US$1 445/ha in the improved-extensive systems, and US$1 092/ha in the extensive systems (Table 13). Almost all the farmers in the survey indicated that their returns had decreased as the costs of prawn farming had increased, and furthermore that the price of prawns had not increased in line with increased production costs.

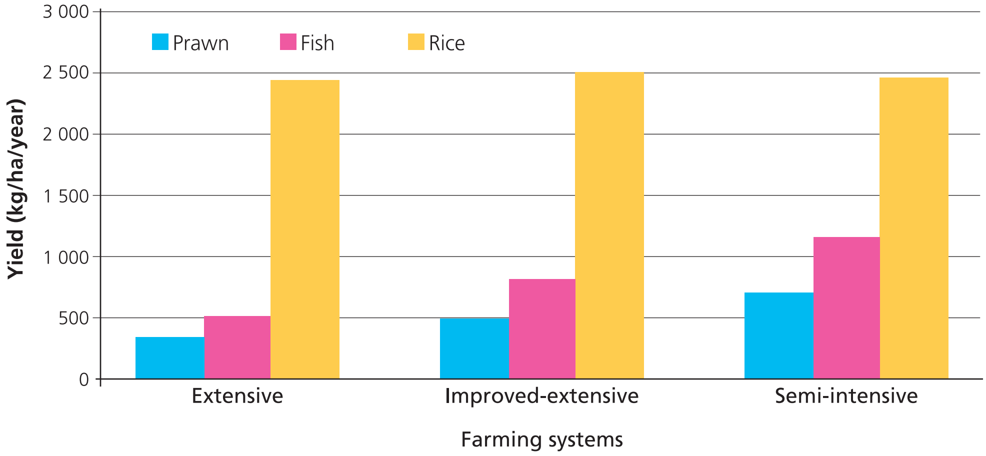
3.7.6 Benefit-cost ratios

The benefit-cost ratio (BCR), or profitability index, is defined as the gross revenue divided by the total costs. A ratio of 1 indicates that the operation is at a break-even point, i.e. costs and revenues are similar. A BCR greater than 1 indicates that the operation is producing positive net benefits. The BCR in the semi-intensive farming systems averaged 1.75. This indicates that the prawn farmers are able to recover US$1.75 for every US$1 of investment. The BCR in the extensive and the improved-extensive farming systems was calculated at 1.74 and 1.69, respectively (Table 13).

3.8 A comparison of the farming systems

Prawn, fish and rice production levels vary between the farming systems (Figure 14). Prawn productivity was the lowest in the extensive farming system. This was attributed to the use of snail meat as a prawn feed and to low farm inputs. In contrast, the highest level of productivity was observed in the semi-intensive farming system and attributed to the use of commercially manufactured pelleted feeds and the high level of farm inputs. Prawn production ranged from 351 kg/ha in the extensive farming systems, to 489 kg/ha in the improved-extensive systems, and 718 kg/ha in the semi-intensive systems (Table 11). Comparison with other prawn producing countries in Asia indicates that yields in Bangladesh are relatively low (Table 14).

FIGURE 14
Prawn, fish and rice productivity in different farming systems



Source: Field survey (2010).

TABLE 14
Comparison of prawn (*M. rosenbergii*) yields in Bangladesh and other Asian countries

Country	Yield (kg/ha/ year)	Reference
Bangladesh	351–718	Current study
China	1 500	Weimin and Xianping (2002)
India	600–1 000	Raizada *et al.* (2005)
Thailand	2 338	Vicki (2007)
Viet Nam	1 000–1 500	New (2005)

Prawn production is dependent on a number of factors including feed quality, farm size, stocking rates, fertilization and the management practices employed. The relative importance of production and feed conversion efficiencies depend upon the quality of the feed applied and management practices. Protein is the most important dietary component in fish diets and is of a primary concern in diet formulation (Bombeo-Tuburan *et al.*, 2001). The use of snail meat as prawn feed and cow dung as a fertilizer can in many respects be considered as organic farming. Snails are highly digestible and rich in protein, fat, vitamins and minerals. Freshwater snails contain between 37–68 percent protein, 6–11 percent fat and 3–6 percent glycogen, and provide a suitable feed for prawns. Moreover, on a dry weight basis, *P. globosa* contains between 4.74–5.59 kcal/g energy (Sing, 1991). The golden apple snail has a proximate composition of 54 percent crude protein, with an essential amino acid index of 0.84 (Bombeo-Tuburan, Fukumoto and Rodriguez, 1995).

Snail supplies are irregular and farmers often have to resort to using home-made feeds. Thus, using snail meat as a prawn feed cannot be considered a sustainable solution to the farmers' feed requirements. The snail population has become extinct in most areas where prawns are farmed. This is due to excessive harvesting during the monsoon which correlates with their reproductive season. Removal of the snails is also likely to result in an increase in the growth of some species of aquatic weeds which could reduce light penetration as well as photosynthesis, and could lead to eutrophication (Gain, 1998). The snail populations are important in maintaining a clean aquatic environment, and they serve an important function in terms of maintaining the balance between the aquatic weeds, other organisms, and the wetland soils. Over-harvesting the snails has also created problems in terms of the disposal of large quantities of snail shells. In some cases this has resulted in pollution and the blockage of canals and waterways.

The cost of commercially manufactured pelleted feeds is a concern. The average unit price of commercial pelleted feeds (US$0.59/kg) is significantly higher than farm-made aquafeeds (US$0.35/kg), and snail meat (US$0.15/kg). Although the improved-extensive farmers are aware of the positive effects of using manufactured pelleted feeds, a lack of access to finance prevents them from buying and upgrading their production systems.

At present, the supply of commercially manufactured pelleted feeds is not an issue; however, if the sector expands rapidly, supplies may become limited. At annual production level of 23 377 tonnes of prawns in 2008 (FAO, 2010), and at an average FCR of 2.5:1, the annual feed requirement would be in the region of 58 443 tonnes. Currently prawn feed production is in the country is limited to 38 000 tonnes per annum (Chisty, 2009), and it must therefore be assumed that the feed requirements of the industry have to be partially met by the production of farm-made aquafeeds.

The use of farm-made aquafeeds is the best option for resource-poor farmers in terms of availability, quality and price (Table 15). Due to supply and environmental issues, snail meat feed is not a sustainable feed source. Thus, farm-made aquafeeds represent an appropriate feed production technology for use in Bangladesh. However, in order to increase production using farm-made aquafeeds, feed formulation and feed management practices need to be improved.

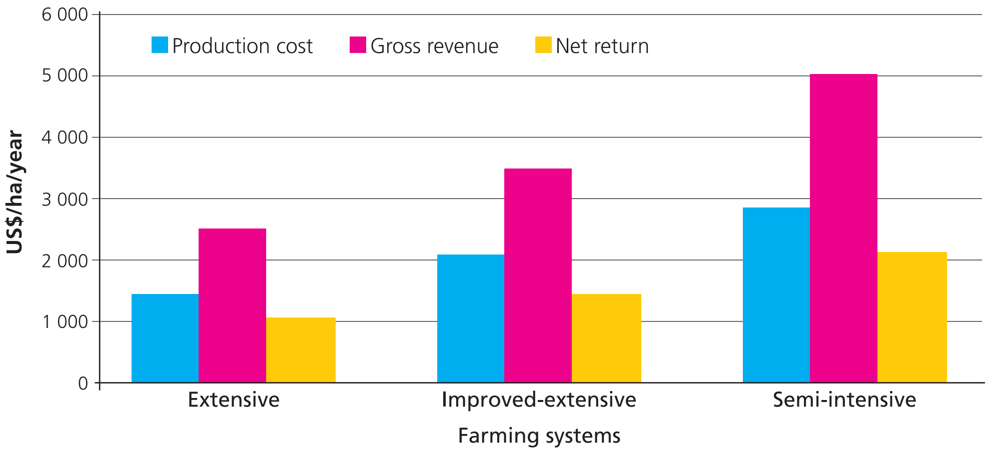
TABLE 15
A comparison of the aquafeeds that are currently available to the prawn farmers

Feeding system	Positive attribute	Negative attribute
Snail meat	• Low-cost feed • Suitable for poor farmers • Natural source (organic farming) • Good proximate composition that satisfies the prawn nutritional requirements	• Low productivity • Restricted supplies • Cannot be used as a fish feed • Environmental costs associated with snail harvesting
Farm-made aquafeeds	• Use locally available and on-farm agricultural by-products • Comparatively low-cost • Moderate nutritional value • Suitable for both prawn and fish farming	• Lower feeding rate • Low level of prawn production • Poor production techniques are often employed
Commercially manufactured aquafeeds	• High nutritional value • Suitable for both prawn and fish farming • High productivity • High growth of prawns (large size of harvested prawns)	• High cost • Unsuitable for resource-poor farmers • Presence of banned antibiotics and human health concerns (i.e. carcinogenesis from banned antibiotics)

Source: Field survey (2010).

The results of the study show that the three farming systems have different cost structures and profitability (Figure 15). The production costs per hectare accruing to semi-intensive farms was significantly higher than those accruing to the other two production systems. Feed costs represents the highest single operational costs in semi-intensive farming systems, accounting for 33 percent of the total costs. Feed costs constitute the second highest operational cost in extensive (15 percent) and improved-extensive (25 percent) farming systems. The survey results indicate that the benefit-cost ratio (Table 13) of using commercially manufactured pelleted feeds is only slightly higher than that attained by employing the two extensive systems. Reducing feed costs is an important consideration in terms of increasing profitability, and ensuring the long term sustainability of the industry. In terms of reducing feed costs, improving pond fertilization strategies can lead to a reduction in feed costs (Muir, 2003). Furthermore, the development of a feed based on low-cost locally produced ingredients could further help reduce feed costs and improve profit margins.

FIGURE 15
Production cost, gross revenues, and net returns in the three production systems



Source: Based on data from Table 13.

4. CONCLUSIONS

The sustainability of prawn farming among rural households with limited resources in southwest Bangladesh remains a challenge. Although using snail meat as a feed source is suitable for resource-poor farmers, relatively low levels of production are attained, and thus net returns are low. Moreover, feeding snail meat may not be environmentally sustainable in the long term. Higher net returns are obtained using semi-intensive culture techniques. Semi-intensive systems require more inputs than the extensive farming systems, and need the use of commercially produced pelleted feeds. However, the high costs associated with the use of pelleted feeds suggests that this type of farming would not be possible for a large number of small-scale and resource-poor farmers. The quality of these feeds is also of concern as some reportedly contain banned antibiotics. It is recommended that the feed manufacturers use quality raw materials to produce their feeds, and that imported feed ingredients such as meat and bone meal should be free from banned antibiotics.

Feed cost is one of the major constraints to the expansion of the sector. The development of a low-cost feed to replace or reduce the dependence on snail meat is required. Feed formulations based on low-cost, locally produced ingredients would help to improve profit margins, and reduce the negative environmental impacts associated with snail harvesting. According to Shang, Leung and Ling (1998), the unit cost of farm-made feeds can be lowered using locally available feed materials, thus negating the need to use commercially manufactured aquafeeds. This being the case, it is evident that farm-made aquafeeds provide the best prospects for developing cost effective feeds. Such feeds would be suitable for use by resource-poor farmers in terms of availability, quality and price. Farm productivity can also be improved by increasing feeding rates and improving feed management practices. Most prawn farms could become more efficient by adjusting inputs, and there is sufficient scope to increase production as well as profits by increasing inputs, including farm-made aquafeeds.

Although farm-made aquafeeds provide the best prospects for supplying cost effective feeds to the industry, technical support in terms of raw material selection, storage, processing, feed formulation and preparation needs to be improved. There is also a need for research programmes to focus on developing cost effective feed formulations, and improving feeding strategies. The knowledge base of extension workers needs to be enhanced so that farmers can be taught to improve their farming practices. Institutional support could also be used to improve farm-made aquafeed production and marketing.

While extensive and improved-extensive farmers are aware of the positive effects of increasing inputs, a lack of capital has prevented them from engaging in semi-intensive farming. Access to capital could be improved by providing low interest credit through government sources, NGOs and commercial banks. In addition, training would help to improve productivity, profitability and reduce risks. Improving management capacity requires the provision of adequate training (Jahan, Beveridge and Brooks, 2008), and in this regard, farmer training represents a relatively low cost method that could be used to improve production efficiencies.

4.1 Recommendations

The following recommendations are suggested to improve feed management practices:

- The use of farm-made aquafeeds can increase farm productivity and profitability. Farmers and associated groups often lack the basic technical knowledge to optimize feed management practices. Feed management training programmes should be provided. The Department of Fisheries and NGOs should be approached to assist in the provision of these services. Moreover, successful prawn farmers with this knowledge could be used as trainers for farmer-to-farmer training programmes.
- The use of farm-made aquafeeds can increase farm productivity and profitability. Farmers should be encouraged to use these feeds. Farm-made aquafeeds that use low-cost, locally produced ingredients should be developed.
- Technical support with respect to raw material selection, storage, processing, feed formulation and the preparation of farm-made aquafeeds should be improved. Technical support, training and extension services should be sought from the Department of Fisheries.
- Government support and the development of public-private partnerships could be used to improve the production capacity, the quality of feeds, and marketing systems.
- The quality of commercially produced pelleted feeds needs to be improved. It is recommended that the commercial feed industry should only use high quality raw materials in their feeds. Government control over the trade of commercially manufactured pelleted feeds should be improved in terms of quality control and the development of marketing systems.
- Access to finance remains a problem for resource-poor farmers. Assisting farmers to obtain cheaper credit would enable them to increase feed use and become more profitable. Access to finance at zero or very low interest rates could be provided by the government/national banks.

4.2 Further research

Applied research in areas such as quality feed production using low-cost locally available feed ingredients and on-farm by-products needs to be given particular attention. Research interventions should take into consideration existing technologies and the transfer, adaptation and development of new technologies. Issues of environmental sustainability in terms of feed use are poorly understood, and further research is required to determine the quantitative and qualitative environmental impacts that accrue to feed use. Considering the lack of information services among feed producers, distributors, marketing agencies, and development and research institutions, the establishment of an information network related to aquafeeds needs to be given special attention.

ACKNOWLEDGEMENTS

The study was funded by the Food and Agriculture Organization (FAO) of the United Nations. The author would like to thank Md. Ruhul Amin for assisting with the fieldwork, Md. Abdul Aziz and Md. Ershad Hossain for providing valuable information for this study. The author expresses his gratitude to all the prawn farmers and associated groups and those that have given valuable information without which the study could not have been realized.

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