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Small Scale Cage Aquaculture in River Ecosystem: Species Suitability, Production and Environmental Carrying Capacity

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University of Rajshahi

SMALL SCALE CAGE AQUACULTURE IN RIVER ECOSYSTEM: SPECIES SUITABILITY, PRODUCTION AND ENVIRONMENTAL CARRYING CAPACITY

A
THESIS SUBMITTED TO
THE UNIVERSITY OF RAJSHAHI, RAJSHAHI, BANGLADESH
FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY (Ph. D.)

By
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B. Sc. Fisheries (Hons.), BAU; M. S. in Fisheries Biology and Genetics, BAU

DEPARTMENT OF FISHERIES
FACULTY OF AGRICULTURE
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DEDICATION

In Memory of My Parents

My Wife

&

Daughters

whose love and inspiration encouraged me to
complete the research work

CERTIFICATE

Certifying that, the thesis entitled "SMALL SCALE CAGE AQUACULTURE IN RIVER ECOSYSTEM: SPECIES SUITABILITY, PRODUCTION AND ENVIRONMENTAL CARRYING CAPACITY" is a *bona fide* research work of Mr. Md. Shaheb Ali Pk., Ph. D. fellow, Roll no. 08913, Registration no. 0487 and Session: 2008-2009, Department of Fisheries, University of Rajshahi, Rajshahi, Bangladesh.

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DECLARATION

I do hereby declare that, the research work submitted as a thesis entitled "SMALL SCALE CAGE AQUACULTURE IN RIVER ECOSYSTEM: SPECIES SUITABILITY, PRODUCTION AND ENVIRONMENTAL CARRYING CAPACITY" in the Department of Fisheries, University of Rajshahi, Bangladesh for the Degree of Doctor of Philosophy is the result of my own investigation. The thesis or part of it has not been submitted to any other University or institution for any degree.

Dated: May, 2014

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The Author

ABSTRACT

A three years research protocol was set for the study on "Small scale cage aquaculture in river ecosystem: species suitability, production and environmental carrying capacity" involving three separate experiments like experiment-1 conducted in September to December, 2008 with a view to determine the suitable species, experiment-2 conducted in September to December, 2009 with a view to optimize the stocking density and experiment-3 conducted in September to December, 2010 with a view to optimize the dietary protein level for cage aquaculture in river. The experiments were conducted in $1\times1\times1m^3$ cages in Mahananda river under Chapainawabganj district, Bangladesh. Experiment-1 was designed with 3 treatments of aquaculture species like T_1 (*Macrobrachium rosenbergii* 200/m^3 cage), T_2 (*Oreochromis niloticus* 200/m^3 cage) and T_3 (*Barbodes gonionotus* 200/m^3 cage). Experiment-2 was designed with 3 treatments of stocking densities like T_1 (*O. niloticus* 200/m^3 cage), T_2 (*O. niloticus* 150/m^3 cage) and T_3 (*O. niloticus* 100/m^3 cage). Experiment-3 was also designed with 3 treatments of dietary protein level like T_1 (25% dietary protein feed), T_2 (30% dietary protein feed) and T_3 (35% dietary protein feed). Each treatment had three replications for all the experiments. The stocking weight of aquaculture species was 5.5 g in experiment-1, 41g in experiment-2 and 15g in experiment-3. Water quality parameters (Water temperature, transparency, dissolved oxygen, CO_2, pH, hardness, alkalinity and NH_3-N) were monitored fortnightly and the growth parameters were monitored monthly. Pellet feed was supplied twice daily at the rate of 10% of fish/prawn body weight at start and 5% at the end of the experiments. In case of experiment-1, mean values of water quality parameters were found with no significant difference with the treatments and were found within the suitable range. Treatment T_2 varied more significantly ($P<0.05$) than that of others for the mean values of growth parameters (final weight, weight gain, SGR, survival rate and yield) and CBR. In case of experiment-2, only dissolved oxygen and NH_3-N varied significantly ($P<0.05$) with the treatments. Growth parameters and CBR varied significantly ($P<0.05$) with the treatments. In spite of having highest yield, CBR was found lowest with treatment T_1 (i.e. highest stocking density). Both moderate yield and CBR were found with treatment T_2. In case of experiment-3, mean values of water quality parameters were found with no significant difference with the treatments and were found within the suitable range. Treatment T_3 (35% dietary protein feed) varied more significantly ($P<0.05$) than that of others for the mean values of growth parameters (final weight, weight gain, SGR, survival rate and yield) and CBR. Findings indicated that tilapia with a stocking density of 150/m^3 cage fed with 35% protein feed was the suitable technique for small scale cage farming in river. Further research is also recommended to explore the production and economics of tilapia farming in large scale in river ecosystem.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

Chapter One

GENERAL INTRODUCTION

1.1 Overview of the fisheries sector in Bangladesh

Fisheries resources of Bangladesh are considered to be one of the richest in the world which are in the form of rivers, beels, floodplains, ponds, haors, baors, Kaptai lake, brackish-water shrimp farms and vast fishing grounds of the Bay of Bengal. There are about 47,03,658 ha of inland and 68,480 sq. nautical miles of marine water in Bangladesh. Of the inland waters, 40,24,934 ha are open waters, 3,71,309 ha are ponds, 5,488 ha are baors and 2,76,492 ha are coastal shrimp farms. About 800 rivers including tributaries flow through the country constituting a waterway of total length around 24,140 km (DoF, 2013).

Fisheries sector plays an important role in providing income, employment, nutrition and foreign exchange earning in Bangladesh. It also plays a great role in the improvement of the socioeconomic condition of poor fishermen. The fisheries sector contributes 4.43% of the gross domestic product (GDP), 22.21% of agricultural resources and 2.73% of foreign exchange earning of Bangladesh. Fish alone contributes about 60% of total animal protein intake. More than 10% of total population of Bangladesh are directly or indirectly dependent on fisheries sector for their livelihoods. It provides full time employment to 12.8 million in fishing and other activities related to fisheries (DoF, 2013).

Total fish production in our country during the year 2011-2012 was about 3.26 million metric tons (Fig. 1.1) of which 2.68 million metric tons was produced from freshwater including culture fishes and 0.57 million metric tons from marine water (DoF, 2013). The need of annual per capita fish is 20.44 kg while the amount produced is only 18.94 kg (DoF, 2013). This quantity is even lower among the poor people, who live in the rural areas, which has resulted a tremendous negative impact on health condition of the people.

It indicates that the production from capture fisheries decreased recently which increased pressure on aquaculture to fill up the gap. Causes for decreasing capture fisheries production include habitat destruction, unplanned construction of flood control barrages, water abstraction for irrigation, over-fishing and reclamation of land for agriculture. Concurrently, aquaculture production increased due to the development and implementation of improved culture techniques and expansion of the pond culture area (Gupta *et al.*, 1999; Alam and Thomson, 2001).

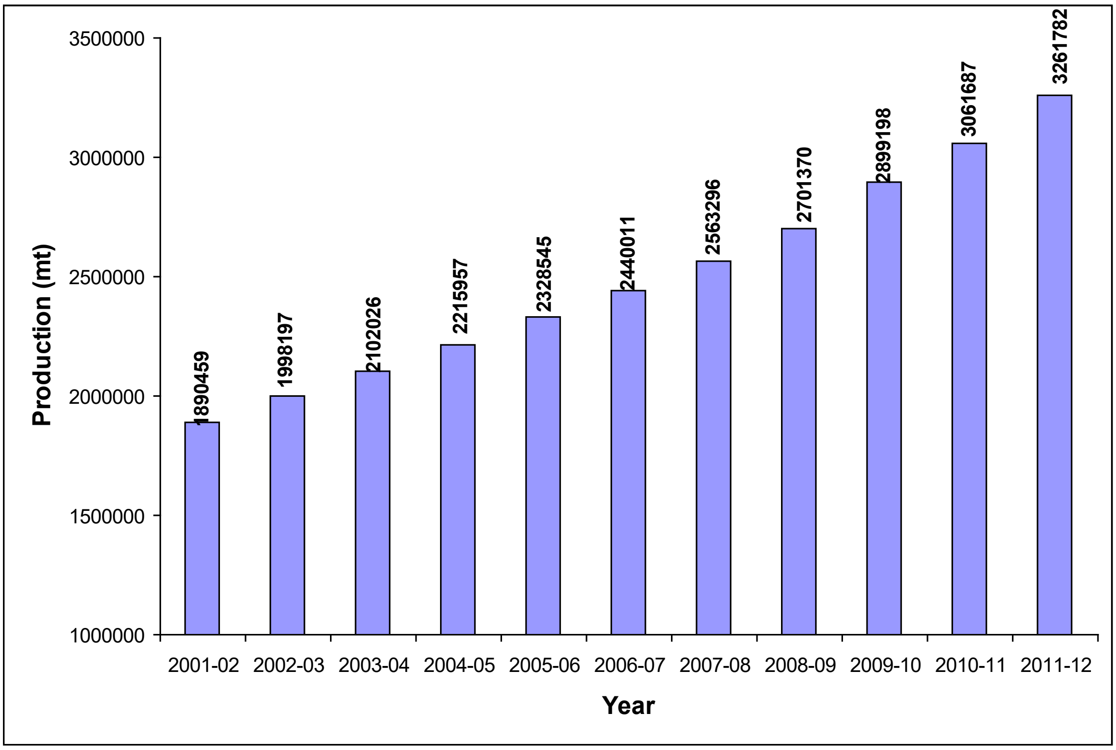


Fig. 1.1: Fish production trends from 2001-02 to 2011-12 (Source: DoF, 2013)

Due to the advancement of aquaculture technologies including the extension approaches, peoples are found to depend more on aquaculture than that of capture fisheries. Recently almost 50% of the total fish production comes from aquaculture sector in Bangladesh. Aquaculture is already found to be diversified in terms of both species and ecosystem. Major group of culturable fish species includes carps, tilapia, silver barb and catfish. Aquaculture of different species are found to be operated in ponds, rice fields, floodplains and rivers. Carp policulture in pond is found one of the popular technologies in the country (DoF, 2013). Actually almost all sorts of aquaculture have potentialities in Bangladesh. However priority should be given on the promotion of aquaculture specially by the resource poor those have no access to ponds. Fish culture in cage can be a suitable technology to solve such problems in the country. It is clear that cage culture is particularly suited to poverty alleviation, fulfillment of protein in Bangladesh (Hambrey *et al.*, 2001a). Cage aquaculture has certain advantages over other aquaculture systems that are potentially important in terms of uptake by rural poor and landless people. Cage aquaculture allows an easy observation of rearing populations and better predation control (Coche, 1978). Due to its apparent practicability, this rearing technology may be a viable alternative to traditional rearing techniques (Beveridge, 1996). By integrating the cage culture system into the aquatic ecosystem the carrying capacity per unit area is optimized because the free flow of current brings in water and removes metabolic wastes, excess feed and faecal matter (Beveridge, 1983). Cage culture is developing globally day by day for its benefits.

1.2. Global history of fish farming in cage

Now a day's cage aquaculture has gained popularity throughout the world. Cages were probably first used by fishermen as a convenient holding facility for fish until ready for sale (Beveridge and Little, 2002). The production of farmed aquatic organisms in caged enclosures has been a relatively recent aquaculture innovation. Although the origins of the use of cages for holding and transporting fish for short periods can be traced back almost two centuries ago to the Asian region (Pillay and Kutty, 2005), and may originate even earlier as part of indigenous practices of fisherfolk living on boats on the Mekong (De Silva and Phillips, 2007), marine commercial cage culture was pioneered in Norway in the seventies with the rise and development of salmon farming

(Beveridge, 2004). According to Pantulu (1979), the oldest records of cage culture come from Kampuchea where fishermen in and around the Great Lake region would keep *Clarias* spp. catfishes and other commercial fishes in bamboo or rattan cages and baskets until ready to transport to market. A similar type of cage culture, using floating bamboo cages to grow *Leptobarbus heoveni* fry captured from the wild, has been practiced in Mundung Lake, Jambi, Indonesia since 1922 (Reksalegora, 1979), and has since been extended to other parts of southern Sumatra. Yet another form of cage culture seems to have begun independently in Java, where Vas and Sachlan (1957) reported that the capture and enclosure of carps in submerged bamboo or 'bulian' cages has been practiced since the early 1940s. However, this method of culture is still almost solely restricted to west Java and Sumatra (Sodikin, 1977), and has had little influence on cage culture practices in other countries in Asia. In the last 15 years or so, the practice of cage culture in inland waters has spread throughout the world to more than 35 countries in Europe, Asia, Africa and America, and by 1978 more than 70 species of freshwater fish had been experimentally grown in cages (Coche, 1978). This traditional method of cage culture has been practiced since the end of the last century, and is now widespread throughout the lower Mekong area of the country (Ling, 1977). From here it has spread in recent year to Viet Nam, Thailand and other Indo-Chinese countries. Like most other types of aquaculture, cage culture began in Southeast Asia, although it is thought to be of comparatively recent origin (Ling, 1977). Modem cage aquaculture was introduced in china more than two decades ago. The techniques have spread wide by across the country with varying degrees of adaptation to local condition. Gradually cage aquaculture became one of the major aquaculture systems in china. It has contributed remarkably to the improvement of living standards, ensuring food security, generating higher income and creating additional jobs in china. Its contribution to improve the livelihoods in Asia is well documented (IIRR, IDRC, FAO, NACA and ICLARM, 2001). Cage fish culture is considered to be an old tradition that has developed into a major sector in aquaculture only in the recent past (De Silva and Phillips, 2007; Tacon and Halwart, 2007). The cage aquaculture sector has grown very rapidly during the past 20 years and is presently undergoing rapid changes in response to pressures from globalization and growing demand for aquatic products in both developing and developed countries. From the available report and literature, it is said that cage aquaculture is practiced very much in marine water than freshwater in some countries of the world (Fig. 1.2).

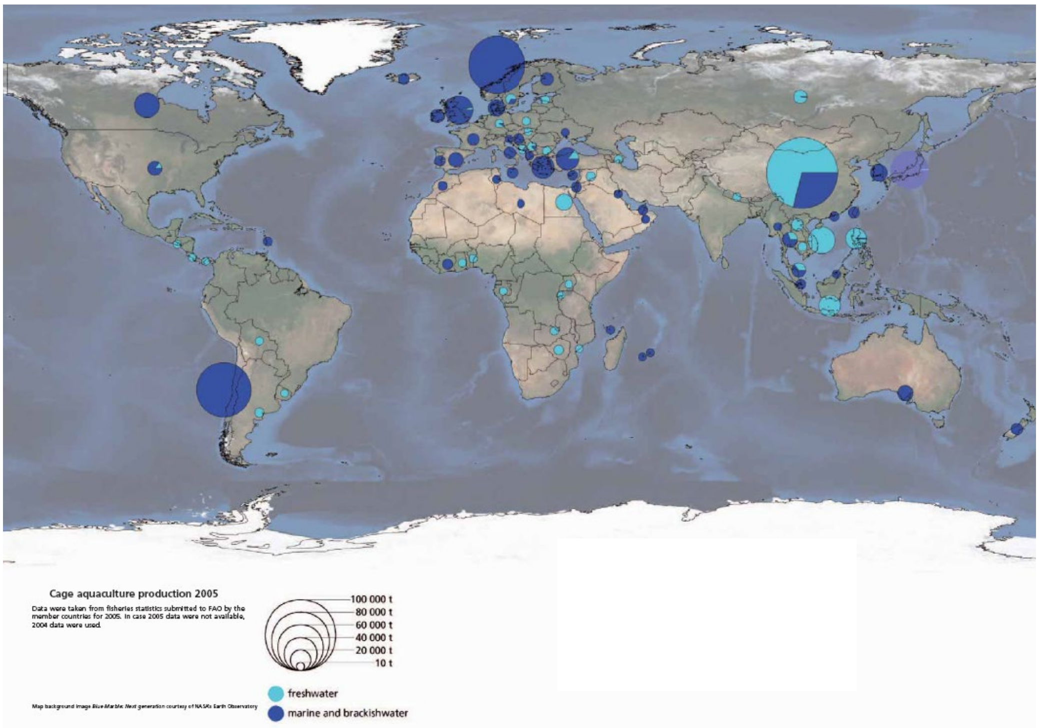


Fig. 1.2: A global review of cage aquaculture (adapted from FAO, 2007).

It has been predicted that fish consumption in developing countries will increase by 57 percent, from 62.7 million metric tons in 1997 to 98.6 million in 2020 (Delgado *et al*., 2003). By comparison, fish consumption in developed countries will increase by only about 4 percent, from 28.1 million metric tons in 1997 to 29.2 million in 2020. Rapid population growth, increasing affluence, and urbanization in developing countries are leading to major changes in supply and demand for animal protein, from both livestock and fish (Delgado *et al*., 2003). As in terrestrial agriculture, the move within aquaculture towards the development and use of intensive cage farming system was driven by a combination of factors, including the increasing competition faced by the sector for available resources (Foley *et al*., 2005; Tilman *et al*., 2002), the need for economies of scale and the drive for increased productivity per unit area. Particularly the need for suitable sites resulted in the sector accessing and expanding into new untapped open water culture areas such as lakes, reservoirs, rivers, and coastal brackish and marine offshore waters. Although no official statistical information exists concerning the total global production of farmed aquatic species within cage culture systems or concerning the overall growth of the sector (FAO, 2007), there is some information on the number of cage rearing units and production statistics being reported to FAO by some member countries. In total, 62 countries provided data on cage aquaculture for the year 2005: 25 countries directly reported cage culture production figures; another 37 countries reported production from which cage culture production figures could be derived (Table 1.1). Of these 62 countries and provinces/regions, 31 countries provided relevant data to FAO both in 2004 and 2005 (Tacon and Halwart, 2007). Total reported cage aquaculture production from these 62 countries and provinces/regions amounted to 2412167 tonnes or 3403722 tonnes if reviewers' data particularly from (Chen *et al*., 2007) for China are included. On the basis of the above partial reported information, the major cage culture producers in 2005 included: Norway (652306 tonnes), Chile (588060 tonnes), Japan (272821 tonnes), United Kingdom (135253 tonnes), Viet Nam (126000 tonnes), Canada (98441 tonnes), Turkey (78924 tonnes), Greece (76577 tonnes), Indonesia (67672 tonnes) and the Philippines (66249 tonnes). However, it should be noted that, as stated above, meaningful interpretation of above data is constrained by the fact that for more than half of the countries (37 out of the 62) the method of culture had to be extrapolated based on other existing information. Missing information can seriously distort the overall picture, and China is the most important case in point. According to the review paper by Chen *et al*. (2007) total cage aquaculture production in mainland people republic of China in 2005 was reported as 991555 tonnes (704254 tonnes from inland cages and 287301 tonnes from coastal cages). In terms of national or regional importance, total cage culture production from China amounted to just 2.3 percent of total reported aquaculture production in 2005 (Chen *et al*., 2007; FAO, 2007). By contrast, Masser and Bridger (2007) reported that cage aquaculture production accounted for about 70 percent of total aquaculture production in Canada in 2004, and De Silva and Phillips (2007) have estimated that cage culture currently accounts for 80 to 90 percent of the total marine finfish production in Asia. To date, commercial cage culture has been mainly restricted to the culture of higher-value (in marketing terms) compound-feed-fed finfish species, including salmon (Atlantic salmon, Coho salmon and Chinook salmon), most major marine and freshwater carnivorous fish species (including Japanese amberjack, red seabream, yellow croaker, European seabass, gilthead seabream, cobia, searaised rainbow trout, Mandarin fish and snakehead) and an ever increasing proportion of omnivorous freshwater fish species (including Chinese carps, tilapia, *Colossoma*, and catfish). However, cage culture systems employed by farmers are currently as diverse as the number of species currently being raised, varying from traditional family-owned and operated cage farming operations (typical of most Asian countries) (De Silva and Phillips, 2007; Pillay and Kutty, 2005) to commercial cages used in Europe and the America (Grottum and Beveridge, 2007; Masser and Bridger, 2007). In terms of diversity, altogether an estimated 40 families of fish are cultured in cages, but only five families (Salmonidae, Sparidae, Carangidae, Pangasiidae and Cichlidae) make up 90 percent of the total production and one family (Salmonidae) is responsible for 66 percent of the total production (Tacon and Halwart, 2007). At the species level, there are around 80 species presently cultured in cages. Of those, one species (*Salmo salar*) accounts for about half (51 percent) of all cage culture production and another four species (*Oncorhynchus mykiss*, *Seriola quinqueradiata*, *Pangasius* spp. and *Oncorhynchus kisutch*) account for about another one fourth (27 percent). Ninety percent of total production is from only eight species (in addition to the ones mentioned above: *Oreochromis niloticus*, *Sparus aurata*, *Pagrus auratus* and *Dicentrarchus labrax*); the remaining10 percent are from the other 70+ species (Tacon and Halwart, 2007). In freshwater, China dominates with a production exceeding 700000 tonnes equivalent to 68.4 percent of total reported freshwater cage aquaculture, followed by Viet Nam (126000 tonnes or 12.2 percent) and Indonesia (67700 tonnes or 6.6 percent) (Table 1.2 and Fig. 1.3). While the production in peoples republic of China is composed of around 30 aquatic species for which no specific production figures are available (Chen *et al*., 2007), the production in the other countries is composed mostly of catfish and cichlids (Table 1.3 and Fig. 1.4).

Table 1.1: FAO member countries either reporting cage aquaculture production to FAO or otherwise known to be actively engaged in commercial cage aquaculture production, but not currently reporting data on cage aquaculture production to FAO (adapted from Tacon and Halwart, 2007)

Countries reporting cage aquaculture to FAO	Countries otherwise known to be actively engaged in commercial cage aquaculture
Latin America and the Caribbean region	
Argentina, Bolivia, Chile, Costa Rica, El Salvador, Martinique (France), Panama, Uruguay ***North American region***	Brazil, Colombia, Guatemala, Honduras, Mexico, Nicaragua
Canada, United States of America) ***Northern European region***	
Bulgaria, Denmark, Estonia, Finland, Germany, Iceland, Ireland, Norway, Poland, Russian Federation, Slovakia, Sweden, United Kingdom ***Mediterranean region***	
Albania, Bosnia and Herzogovina, Croatia, Cyprus, Egypt, France, Greece, Israel, Italy, Libyan Arab Jamahiriya, Malta, Morocco, Portugal, Slovenia, Syrian Arab Republic, Tunisia, Turkey ***Sub-Saharan African region***	Spain
Benin, Gabon, Ghana, Mauritius, Mayotte (France), Mozambique, Réunion (France), Zambia, Zimbabwe ***Asia and Oceania***	Côte d'Ivoire, Kenya, Madagascar, Nigeria, Rwanda, South Africa, Uganda
Azerbaijan, Brunei Darussalam, Cambodia, Hong Kong SAR, Taiwan Province of China, Indonesia, Japan, Republic of Korea, Kuwait, Lao People's Democratic Republic, Malaysia, Nepal, Oman, Philippines, Singapore, Thailand, Viet Nam	Australia, Bangladesh, China, India, Iran (Islamic Republic of), Democratic People's Republic of Korea, New Zealand

Table 1.2: Production of top ten of freshwater cage aquaculture by country (adapted from Tacon and Halwart, 2007

Country	Quantity (tonnes)	in percent of total
China	704254	68.4
Viet Nam	126000	12.2
Indonesia	67672	6.6
Philippines	61043	5.9
Russian Federation	14036	1.4
Turkey	10751	1.0
Lao People's Democratic Republic	9900	1.0
Thailand	7000	0.7
Malaysia	6204	0.6
Japan	3900	0.4

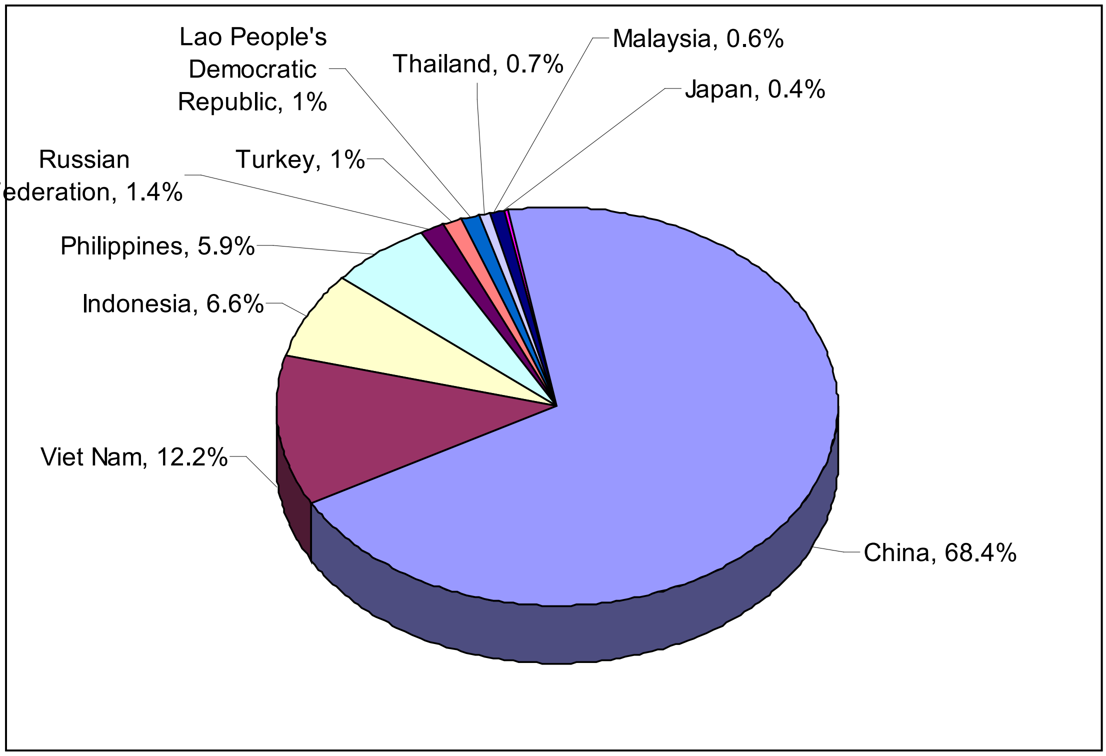


Fig. 1.3: Top ten freshwater cage aquaculture by country (adapted from Tacon and Halwart, 2007)

Table 1.3: Production of the top ten species/taxa in freshwater cage aquaculture (adapted from Tacon and Halwart, 2007)

Species	**Quantity (tonnes)**	**in percent of total**
Pangasius spp	133594	41.1
Oreochromis niloticus	87003	26.7
Cyprinus carpio	21580	6.6
Oreochromis (=Tilapia) spp	16714	5.1
Oncorhynchus mykiss	14625	4.5
Salmo spp	12071	3.7
Channa micropeltes	11525	3.5
Salmo trutta	8551	2.6
Freshwater fishes nei	6914	2.1
Acipenseridae	2368	0.7

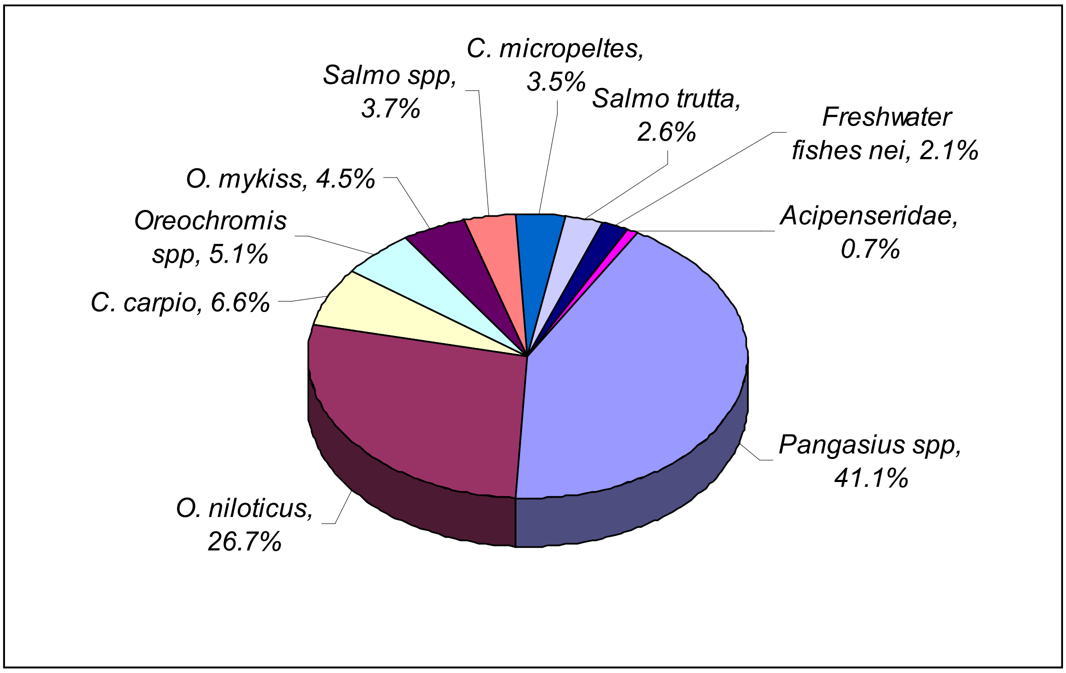


Fig. 1.4: Production of the top ten species/taxa in freshwater cage aquaculture (adapted from Tacon and Halwart, 2007)

1.3 Development potential of cage aquaculture

Cage culture has great development potential. For example, intermediate family-scale cage culture is highly successful in many parts of Asia (Phillips and De Silva, 2006) and one of the key issues for its continued growth and further development will not be how to promote but rather how to manage it (Hambrey, 2006). However, there is also an urgent need to reduce the current dependence of some forms of cage culture farming systems in Asia upon the use of low value/trash fish as feed inputs, including those for Pangasid catfish and high value species such as Mandarin fish, snakehead, crabs and marine finfish (Tacon *et al*., 2006). Other forms of cage aquaculture at various levels of intensity are emerging in Africa and challenges there mainly relate to the presence of an enabling economic, political and regulatory environment (Rana and Telfer, 2006).

However, the intensive cage culture of high value finfish is growing fastest and there are important social and environmental consequences of this growth and transformation of the sub-sector. Similar to global trends in livestock production, there is a risk that the fast growth of intensive operations can marginalize small-scale producers and high production at different levels of intensity can lead to environmental degradation if not properly planned and managed. Considering that most of the cage aquaculture takes place in the fragile yet already much pressured coastal environments, there is increasing agreement that particular emphasis has to be given to the environmental sustainability of the sub-sector. Despite the lack of reliable statistical information concerning the precise size and status of cage aquaculture production globally, it is evident from the various regional cage culture reviews (with the possible exception of the Sub-Saharan African region) that cage culture is currently one of the fastest growing segments of global aquaculture production. Expansion is likely to continue though with considerable regional differences: While the Asian region is likely to experience a further clustering of smaller-scale activities as a result of limited site availability in coastal waters (De Silva and Phillips, 2007), Cardia and Lovatelli (2007) report a wide choice of farming sites for the more capital intensive near and offshore cages along the Mediterranean shoreline, as do Blow and Leonard (2007) particularly for the Sub-Saharan African freshwaters. However, although cage culture allows the farmer access to new untapped aquatic resources and potential sites (including lakes, reservoirs, rivers, estuaries and the vast offshore marine environment), intensification of aquaculture production also brings increased environmental and economic risks which in turn necessitate the use of new farm management skills and in-country regulatory controls and environmental monitoring systems for the sustainable development of the sector (FAO, 2006). Of particular concern is the need to minimize the potential environmental and ecosystem impacts of most existing cage farms, which for the most part are operated as single species (*i.e.* monoculture) open farming systems (Tacon and Forster, 2003), with little or no regard usually given to the utilization of the waste outputs from these open farming systems as valuable nutrient inputs for the co-culture of other complementary aquatic species.

1.4 History of caged fish farming in Bangladesh

Though Bangladesh has a history of pond aquaculture of about 1000 years, cage culture is a very recent introduction and started from early 80's only on trial basis. Owing to the recent decline in capture fisheries, a prominent livelihood of the rural resource poor (Toufique, 1997), and an increase in the demand for fish protein there is considerable potential in Bangladesh for aquaculture expansion (Lewis and Gregory, 1991). Traditional aquaculture has focused on pond systems, which necessitates the ownership or lease of a pond or water body, thereby excluding the landless and rural resource poor. Previous attempts at introducing the technology of cage aquaculture in Bangladesh have failed primarily due to the inappropriate transfer of technology from other regions (Ireland, 1999) (Table 1.4). A consideration of the technical, economic, social and institutional context of the rural poor is required if cage aquaculture is to be successfully promoted. It is also important to recognize the presence of competing demands upon labour and capital as farmers and households manage a portfolio of interests (Ireland, 1999; Lewis *et al*., 1996). The uptake of a new activity such as cage aquaculture by rural households is therefore considered carefully prior to implementation, as it may necessitate a reallocation of resources and time within the household.

Cage culture was introduced into Bangladesh in the late 1970s on an experimental basis, a series of experiments were conducted at the Bangladesh Agricultural University (BAU) (Hasan *et al*., 1982 and Ahmed *et al*., 1997) which demonstrated the potential of cage aquaculture. The Department of Fisheries conducted a cage culture project in Kaptai lake during 1985–86 achieving a production of 6 900 tonnes of fish (Hasan, 1990). CARE, an international NGO, initiated a project at the end of 1995 until 2000, supported by the Department for International Development (DFID) named Cage Aquaculture for Greater Economic Security (CAGES). Due to the high initial cost of inputs and the comparatively complex management technology required cage culture is yet to become popular among the farmers.

Table 1.4: Main factors affecting the successful rearing of fish by cage operators in the Dhaka, Sylhet, Comilla, Barishal and Jessore areas, ranked by decreasing order of frequency of mention (adapted from DFID AQUACULTURE News, April 2000)

Dhaka area	Sylhet area (*)	Comilla area	Barishal area	Jessore area
Escapes	Lack of co-operation	Poaching and poisoning	Initial mortality	Jute retting
Floods (1998)	Unequal share of workload	Net cutting by crabs	Theft of cage and poaching	Poor net quality (nets cut by crabs)
Small fingerlings	Poor feed quality and feeding techniques	Fish mortality	Escapes during the 1998 flood	Aquatic weed concentration
Poaching	Stocking water	Escapes	Problem with getting feed	Parasites (fish death)
Fish mortality	Lack of care and time	Poor weather and storm	Small cages	Boat theft
Lack of interest and therefore lack of care	Floods (1998)	Lack of co-operation		High feed cost
Distance from the water body	Feeding	Lease of pond		Low quality seed
		Water retention		Poisoning
		Family problem		

(*) Cages are managed co-operatively by a group of cage operators.

However, the major considerations, potential and guidelines for cage fish culture need to be addressed. Culture based fisheries as well as different mode of aquaculture has given tremendous importance at the stagnant situation of world capture. In this aspect, cage aquaculture is coming up as a promising venture for optimum use of water resource without disturbing much the surrounding ecosystem.

Fish farming in low cost small scale cages was piloted and introduced in Bangladesh primarily to landless poor with access to lakes, rivers, water canals and seasonal water bodies. However, Bangladesh has a great opportunity for cage aquaculture. Open waters (49,20,316 ha) are almost out side of culture system. It can be easily used by cage aquaculture with focus on small scale fish farming.

1.5 Importance of small scale cage aquaculture in Bangladesh

Small-scale cage aquaculture is not a single technology but rather a suite or continuum of different activities targeting different stages of different species, and using different inputs. It ranges from activities which require little investment in seed and feed, with short cycles between crops, and modest returns to those which require significant investment in seed and feed, have longer cycles between crops, but generate higher returns. Other activities fall between these extremes. Therefore, different aquaculture activities can be adapted to the specific needs and conditions of particular households. Small-scale cage aquaculture must be a low input technology with low economic and opportunity costs (Hambrey *et al*., 2001a). Availability and ease of access to resources is therefore crucial in governing the type of production system. Key factors include consideration of the most appropriate type and source of cage materials and especially the lack of access to quality sources of seed and feed that are thought to be major constraints to cage aquaculture development. The role of cage culture in poverty alleviation for the fringe populations in developing countries have been discussed (Hambrey *et al*. 2001a, 2001b). In Bangladesh, cage aquaculture is relatively recent and introduced by a few Non-Government Organizatons (NGOs) as a poverty alleviation and income generation tool for the marginal or landless farmers (Brugere *et al*., 2001; Huchette *et al*., 2000; Hambrey *et al*., 2001a, 2001b) and for empowering rural women (Chowdhury and Rahman, 1998; Brugere *et al*., 2001). Cage culture is being introduced in lakes (Chowdhury and Yakupitiage, 2000; Kibria, 2004), rivers

(Huchette and Beveridge, 2002), and other water bodies (Hambrey *et al*., 2001a) of Bangladesh. However, to sustain and expand current practices, Edwards and Allan (2004) stressed the need for improved feed and feeding practices for pond and cage aquaculture, and suggested further intensification and introduction of commercially manufactured feed. In countries like Bangladesh, where the practice is relatively new and just taking off, cost of commercially produced formulated feed infringe the ability of the target group consists of marginal and landless farmers to adopt such production practices (Chowdhury, 1997; Brugere *et al*., 2001).

It is clear that small-scale cage culture is particularly suited to poverty alleviation in Bangladesh (Hambrey *et al*., 2001b). Perhaps the greatest strength is the lack of requirement for land. In Bangladesh many of the rural poor are landless. A second major strength is the flexibility of cage culture-especially in terms of investment requirements. Cage aquaculture can be started using a small cage and/or low stocking densities, with correspondingly low start-up costs. In case of Bangladesh, a range of species and systems is available from low investment/modest return to high investment/high return, which allows steady low-risk progression out of poverty. In Bangladesh the fish is produced for both food and income, and fish can be harvested in small or large packets as and when required. This is important as a strategy to deal with the seasonal nature of poverty in the country. Investment can be made when cash is available, and income can be realized during periods of hardship.

These various strengths are significant, especially given the very limited options alleviation; there remain some questions related to sustainability. Disease is a common problem of cage aquaculture throughout the world, and while this has not been a problem in Bangladesh. After the successful tenure of CARE-CAGES project in some districts of Bangladesh, It was evident that many farmers took off their cages from the water bodies and left their commitment. Many cages after abundant were either damaged or lost. First it seemed to be a disaster like others and some bureaucrats commented that there was no prospect in cage culture in the country. However, they forgot the reality of the farming system technology transfer. Where, any new technology could survive for some years or even for the tenure of the project. In hence research efforts are necessary for both upscaling and outscaling of cage aquaculture in Bangladesh.

1.6 Efforts made for the promotion of cage aquaculture in Bangladesh

Some efforts are already taken to promote the cage fish farming in Bangladesh (Table 1.5).

Table 1.5: Efforts made for the promotion of cage aquaculture in Bangladesh.

Efforts taken by	Study type	Ecosystem	Cage size	Species	Major thrust	Operation
Naser and Barman (2010)	Experiment	Ponds and reservoirs (Rangpur)	1 m^3	Silver carp (*Hypophthalmichthys molitrix*)	Fingerling production	Small scale
DoF (2008)	Report	River (Meghna, Laxmipur)	20×10×6	Tilapia (*O. niloticus*)	Table fish production	Large scale
Khatun *et al.* (2008)	Experiment	Ponds (Chandpur)	1 m^3	Tilapia (*O. niloticus*)	Adoption and impact study	Small scale
Begum *et al.* (2006)	Experiment	Ponds (Mymensingh)	1 m^3	Koi (*Anabas testudineus*)	Stocking density study	Small scale
Khatun *et al.* (2006)	Experiment	Ponds (Chandpur)	1 m^3	Tilapia (*O. niloticus*)	Impact on livelihood	Small scale
Rahman *et al.* (2006)	Experiment	Channel	1 m^3	Sutchi catfish (*Pangasius sutchi*)	Stocking density study	Small scale
Hambrey *et al.* (2001b)	Report	Ponds (North-west Bangladesh)	1 m^3	Tilapia (*O. niloticus*), carp (*Cyprinus carpio*), catfish (*Pangasius* sp.), silver carp (*H. molitrix*) and prawn *(Macrobrachium rosenbergii)*	Impact on livelihood	Small scale
Rahmatullah *et al.* (1997)	Experiment	River (Bhramaputra)	1 m^3	Prawn *(M. rosenbergii)*	Stocking density study	Small scale

1.7 Indications from the earlier efforts

Efforts made indicates that-

i) pond is more emphasized than that of river ecosystem;

ii) tilapia (*O. niloticus*) is used for commercial farming in river ecosystem;

iii) only prawn *(M. rosenbergii)* is used in small scale cage farming under river ecosystem in Bhramaputra river, Mymensingh;

iv) more diversification regarding species use is found in pond than that of river;

v) short cycle aquaculture species like silver barb (*Barbodes gonionotus*) in not included both in pond and river; and

vi) cage farming in river ecosystem is not found for different geographical locations.

1.8 Research questions

Based on the indications, some questions are also raised-

i) What about cage farming by the poor those have no access to ponds?

ii) Is tilapia suitable for small scale cage farming in river?

iii) Can species other than prawn and tilapia be suitable for cage culture in river or not?

iv) How the ecosystem affects the production and economics for a feed based system like the cage culture? (i.e. environmental carrying capacity should be considered or not?)

v) What about the performance of cage farming in river at other geographical location?

1.9 Research need for region and or ecosystem specific small scale cage aquaculture development

Earlier efforts made are found very much localized and not sufficient for wider adoption by one of the most vulnerable poor communities residing just beside the river embankments in Bangladesh. A technology has little or no value without its adoption and a similar technology can not be suitable for all most all the geographical locations. Based on those arguments, the present study emphasized the species suitability, production and environmental carrying capacity for the development of small scale cage farming in Mahananda river under Chapainawabganj district, Bangladesh.

1.10 Objectives

The general objectives of the present study were as follows:

- to evaluate the growth performance of fishes and prawn under cage system in river;
- to monitor the water quality parameters;
- to evaluate the economics for farming different species under cage system;
- to find out suitable species for cage farming in river;
- to optimize the suitable stocking density for cage fish farming in river;
- to estimate optimum protein level in feed for cage farming in river; and
- to recommend suitable strategy for small scale cage farming in river ecosystem.

Chapter Two

REVIEW OF LITERATURE

2.1 Cage culture potentials

Naser and Barman (2010) studied the technical and institutional issues on cage culture in ponds and reservoirs for fish fingerling production by ultra-poor Adivasi households. They reported that stocking 2 kg of silver carp in each cage could produce 8 kg of fingerling in 40 days.

Ofori *et al.* (2010) studied to calculate the potential for cage aquaculture to create economic opportunities for small-scale investors on the Volta Lake, Ghana. Cages were built locally from available materials at a cost of approximately US$1000 per 48 m^3 cage. An indigenous line of Nile tilapia, *Oreochromis niloticus*, was stocked either as mixed sex (first trial) or all-males (second trial) at an average rate of 103 fish/m^3 and grown on locally available pelleted feeds for approximately six months.

Khatun *et al.* (2008) studied on impact of tilapia cage culture technology at Matlab Upazila, Bangladesh. To introduce such new aquaculture technology of cage culture at Matlab Upazila, technological package was developed and disseminated to twenty women beneficiaries in 2005. They were provided with training and inputs like feed, fry and cage materials in the first cage culture technology from May to December 2006. The level of acceptance showed that out of twenty women beneficiaries from the first cycle, six dropped but created opportunities for social interactions that enhanced harmony among the communities.

Pantulu (1979) worked on floating cage culture of fish in the lower Mekong Basin and stated that the productivity through intensive culture (like cage culture) was much higher than that of pond culture.

Coche (1978) stated that intensive culture system like cage culture might offer immense scope and potential to increase fish production.

2.2 Species used

Chakraborty and Banerjee (2010) conducted study on comparison of growth performance between mixed-sex and androgen-treated, monosex tilapia in confined environment of cages. Control and hormone treated fish were stocked separately in mesh cages at a density of 50 fry / m3 and it was found that the androgen treated monosex fish grew significantly larger than their control mixed-sex counterparts. The monosex population showed a significantly higher weight, length, specific growth rate, daily weight gain, protein efficiency ratio and body protein content than the mixed-sex tilapia population. Thus, culture of hormone treated monosex tilapia in cages can be considered ideal for augmented production of the fish under Indian context.

Mondal, *et al.* (2010) conducted an experiment to compare production and economic performance of Thai Climbing Perch (*Anabas testudineus*) and Tilapia (*Oreochromis niloticus*) under three management systems in cages. Tilapia (*Oreochromis niloticus*) was focused as the potential candidate.

Reynaldo *et al.* (2009) reported two species like tilapia and milkfish for cage culture in Taal lake, Talisay, Batangas, Philippines.

Coulibaly *et al*. (2007) used the African catfish, *heterobranchus longifilis* to know the effect of stocking density on survival and growth rates in cage.

Yadav *et al.* (2007) used *Tor putit*ora in cage-cum-pond integration system of mixed-sex Nile tilapia **(***Oreochromis niloticus***)**.

Rahman *et al.* (2006) used sutchi catfish (*Pangasius sitchi*) in cages suspended in a river-fed channel.

Begum *et al.* (2006) worked on koi (*Anabas testudineus*) in cage for small scale farming. 12 ponds were used for farming of Koi in cage and carp outside cages where another 6 ponds were used for carp polyculture. The ratio of stocking density of Koi (initial stocking weight of 2-3 g/fingerling) and carps (initial stocking weight of 8-15 g/fingerling) in 6 experimental ponds was 1:1 (40nos./decimal: 40 nos./decimal) and other 6 experimental ponds followed the ratio of 2:1 (80:40). On the contrary 6 control ponds maintained stocking ratio as 40 pieces of carps per decimal water body. Koi production at ratio of 1:1 was found slightly better than the ratio of 2:1. In the same period production performance of carps in experimental ponds was also found better than control ponds.

Waidbacher *et al.* (2006) used tilapia, *Oreochromis niloticus* to develop a low-cost cage-cum-pond integrated system.

Beveridge(2004) reported that tilapia, carp, catfish, and a number of other species were found to be used for production in cages.

Hambrey *et al.* (2001b) studied aquaculture and poverty alleviation involving cage culture in freshwater in Bangladesh. Species included in their study were tilapia, Chinese carps, catfish (*Pangasius* sps.), silver barb (*Barbodes gonionotus*) and the freshwater prawn *Macrobrachium rosenbergii*.

Rahmatullah *et al.* (1997) conducted an experiment in the river old Brahmaputra with a view to investigate the feasibility of fresh water giant prawn *Macrobrachium rosenbergii* culture in floating cages.

Swar and Pradhan (1992) used planktivorous fishes, *Aristichthys nobilis* and *Hypophthalmicthys molitrix* for raising in floating cages, without supplemental feeding.

2.3 Stocking density used

Chakraborty and Banerjee (2012) conducted a study on comparative growth performance of mixed-sex and monosex Nile tilapia at various stocking densities during cage culture. Different stocking densities were 1, 5, 10, 15, 25, 50, 75 and 100 fish/m^3 in standing surface cages.

Baliao and Dosado (2011) studied on tilapia cage farming in freshwater reservoir using artificial diets during dry and wet seasons and stated that all net cages were stocked with tilapia fingerlings at 15 fish/m^3 with mean initial weight of 1.2 g and 1.3 g during the dry and wet seasons, respectively.

Rahman *et al.* (2006) used sutchi catfish *(Pangasius sutchi)* in cages suspended in a river-fed channel at densities of 60, 70, 80, 90, 100, 110, 120, 130, 140 and 150 fish/m^3 cages. A density of 150fish/m^3 produced the best production and farm economics.

Leboute *et al.* (1994) conducted a trial with all male Nile tilapia fry, *O. niloticus* to evaluate their performance in cages with different stocking densities and after 5 months, mean body weight gains were 140.50, 84.10, 79.80 and 71.00g at densities of 40, 60, 80 and 100 fish/m^3, respectively.

Swar and Pradhan (1992) worked on cage farming in lakes and stated that the stocking density varied with the trophic state of the lake: in Lake Phawa, 6 fish/m^3 and in Lake Begnas and Rupa, 10 fish/m^3 and annual production rates per m^3 were 3.4 kg in Lake Phawa, 4.7 kg in Lake begnas and 5.0 kg in Lake Rupa.

2.4 Cage size

DOF (2008) reported that the cage size was 20 feet ×10 feet × 6 feet and 10 feet ×10 feet × 6 feet for tilapia farming in Meghna river of Laxmipur.

Khatun *et al.* (2006) studied the growth of tilapia in cage at Chengar Char union of Matlab thana, Chandpur district and repoted that 1 cubic meter cage was used for culture of tilapia.

Rustadi *et al.* (2002) reported two units of floating net cages as 6×6 m^2 and 3×3 m^2 for farming of red tilapia (*Oreochromis* sp.) in Sermo reservoir of Indonesia.

Hambrey *et al.* (2001b) reported the cage size as 1m^3 for small scale cage farming in Bangladesh.

2.5 Diet used

Freato *et al.* (2012) conducted a study on the evaluation of Nile tilapia strains cultivated in cages under different feeding programme and stated the feeding programme with diets containing 36%, 32% and 28% CP, consecutively, promoted the highest weight gain and highest final biomass. Crude protein levels below 36% for tilapias between 60 and 170g and below 32% for tilapias between 170 and 700 g worsen fish performance.

Mondal, *et al.* (2010) used 35% protein feed while compare for production and economic performance of Thai Climbing Perch (*Anabas testudineus*) and Tilapia (*Oreochromis niloticus*).

Tavares *et al.* (2008) conducted a study on Nile tilapia in cage using three diets as commercial feed (40% crude protein), dried duckweed, a combination of commercial feed and dried duckweed were fed to triplicate groups of 20 tilapia (*Oreochromis niloticus*) fingerlings. The final average weights of fingerlings fed commercial feed (21.67g) and 50% feed + 50% dried duckweed (19.53g) were not significantly different ($p<0.05$).

Chowdhury *et al.* (2007) worked on Nile tilapia aquaculture in Bangladesh with three diets of 35%, 30%, and 25% crude protein and reported that 35% protein yielded the highest productivity and profitability over the 150-day culture period in cage.

Beveridge and Muir (1999) stated that sustainable production per cycle in cage aquaculture systems was typically in the range of 10–50 kg per cubic meter, depending on the natural productivity of the water. The fish in these systems must be fed more or less complete diets, meaning that substantial inputs of nutrients to natural waters are sometimes unavoidable, which can increase the risk of surface water pollution and eutrophication.

Rahmatullah *et al.* (1997) conducted a study on *Macrobrachium rosenbergii* farming in cage and reported the total production as 415.30g, 361.40g and 430.15g per cubic meter cage with 32% protein feed, frest mussel, and Saudi Bangla prawn feed, respectively.

2.6 Production and economics

Rahman *et al.* (2006) studied on cage culture of sutchi catfish and stated that the mean gross yield ranged from 15.6 ± 0.27 to 34.5 ± 0.44 kg/m^3 and the net yield ranged from

15.2 ± 0.22 to 33.5 ± 0.36 kg/m^3. Higher stocking density resulted in higher yield per unit of production cost and lower cost per unit of yield.

Khatun *et al.* (2006) worked on tilapia culture at Chengar Char union of Matlab thana, Chandpur district. Cages were operated by women who had pond very near to their house. The women used 1 cubic meter cages and 250 fries were stocked in each cage. Feed costs for tilapia were very low because women used kitchen wastes and spinaches around the pond as tilapia's feed. After three months tilapia grown up 150-200g and mortality rate was 5%. It was evident that tilapia culture in cage was a suitable fish culture technology for rural women to improve their livelihoods.

Rustadi *et al.* (2002) reported that fish cage culture provided 1082 and 486 kg production on the average from each cage as 6×6 m^2 and 3×3 m^2, a survival rate of 93 to 97% in case of Red Tilapia (*Oreochromis* sp.)

Hambrey *et al.* (2001b) reported that growth was rapid in the warm climate of Bangladesh and the fish attained marketable size within 3-9 months, providing farmers with a rapid return on their investment and labour. Depending on species and grow-out period, the annual gross income per cage was between 20–100 $.

2.7 Water quality

Sattar *et al.* (2007) reported that in most cases water quality parameters of exceeded the standard range. During summer, the observed average values of TDS (Total dissolve solid), pH, DO (Dissolved Oxygen), NO_3 and hardness of the water of the river were 47.55mg/l, 7.66, 3.718mg/l, 9.68mg/l and 55.10 mg/l, respectively. During winter, the observed average values of TDS (Total Dissolve Solid), pH, DO (Dissolved Oxygen), NO_3 and hardness of the water of the river were 347.77mg/l, 7.64, 1.04 mg/l, 27.66mg/l and 121.77mg/l, respectively.

Nyananyo *et al.* (2006) studied the physico-chemical conditions of Brass River, Nigeria and reported the water pH, transparency (cm) and temperature (°c) values as 5.58 - 7.86, 17-63 and 28-35, respectively.

Ahmed *et al.* (2005) recorded the mean values of water temperature (°c), transparency (cm), pH, DO (mg/l), free CO_2 (mg/l), alkalinity (mg/l), total hardness (mg/l) and ammonia (mg/l) as 27.6±0.68, 34.2±18.08, 7.8±0.18, 6.7±0.81, 4.8±.81, 76.3±8.91, 72.5±6.21 and 0.35±0.08, respectively in Meghna river, Bangladesh.

Ahmed (2004) studied physico-chemical properties of Padma river and found the values of pH, DO, free CO_2, alkalinity and total hardness as 6.2-7.5, 5.1-10.3 mg/l, 2.3-13.4 mg/l, 57.7-110.0 and 2.9- 6.5 mg/l, respectively.

Champasri (2003) studied the water properties of the Phrom river in Thailand and recorded the water pH, temperature (°c), total alkalinity (mg /l), total hardness (mg/l), and the dissolved oxygen (mg/l) values as 7.02-7.54, 29.62-30.27, 25.78-30.35, 30.85-31.51, and 6.87-7.41, respectively.

Chowdhury and Yakupitiyage (2000) studied the efficiency of oxbow lake management systems in Bangladesh to introduce cage culture and reported > 100 cm transparency indicating the suitability of a lake for cage culture.

Chapter Three

SPECIES SUITABILTY FOR SMALL SCALE CAGE AQUACULTURE IN RIVER ECOSYSTEM

3.1 Introduction

Cage aquaculture has gained popularity throughout the world and its contribution to improve the livelihoods in Asia is well documented (IIRR, IDRC, FAO, NACA and ICLARM, 2001). Fish farming in low cost small scale cages was piloted and introduced in Bangladesh primarily to landless poor (ADB, 2005) and later on commercial aquaculture operation was also made in large cages (DoF, 2008). It is clear that small-scale cage culture is particularly suited to poverty alleviation in Bangladesh. Perhaps the greatest strength is the lack of requirement for land. In Bangladesh many of the rural poor are landless who can get easy access to lakes, rivers, water canals and seasonal water bodies for their livelihood improvement through cage aquaculture. A second major strength is the flexibility of cage culture-especially in terms of investment requirements. Cage aquaculture can be started using a small cage and/or low stocking densities, with correspondingly low start-up costs. Based on these benefits, cage aquaculture is already found to be considered as one of the important techniques to improve the livelihood of the resource poor fishers in Bangladesh (Chowdhury and Yakupitiyage, 2000). Research efforts for the promotion of cage aquaculture in Bangladesh are also made with emphasis on aquaculture species like tilapia, Chinese carps, catfish (*Pangasius* sp.), silver barb (*Barbodes gonionotus*), and the freshwater prawn (*Macrobrachium rosenbergii)* including the socio-economic aspects (Rahmatullah *et al*., 1997; Hambrey *et al*., 2001b; Rahman *et al.,* 2006). Unfortunately, due to less benefit obtained from small scale cage aquaculture, its extension is not found at desired level and recommendations for increase in number of cages or improve in feed ingredients of aquaculture species are also made for further development of this system (DoF, 2003). This situation clearly indicates the necessity of selecting appropriate aquaculture species under proper management to explore the benefits of small scale cage aquaculture especially in river ecosystem. Therefore, the present study evaluated the production and economics of prawn and fish farming in small cages at Mahananda river under Chapainawabganj district, Bangladesh. The specific objectives of this study were as follows:

i. to monitor the water quality parameters under different treatments of aquaculture species in cage farming in river;

ii. to evaluate the production and economics of different treatments of aquaculture species under cage system; and

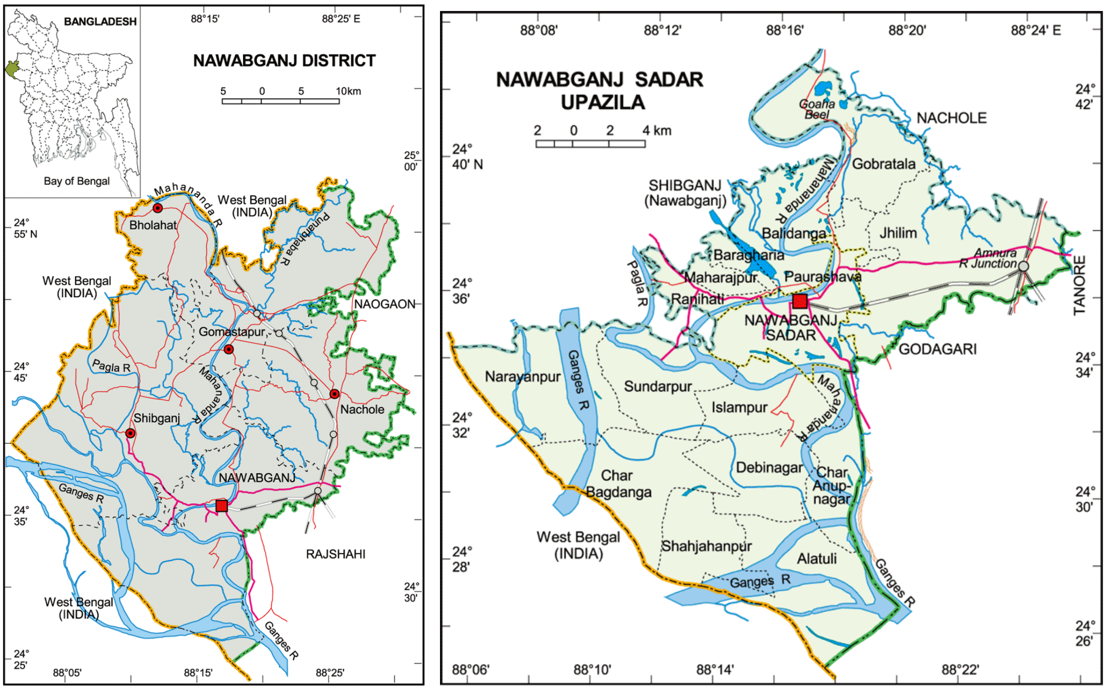
iii. to recommend suitable species for small scale cage farming in river ecosystem.

3.2 Materials and methods

3.2.1 Duration and location of the study

The experiment was conducted for the period of four months one cycle/culture from September 2008 to December 2008.

The study site was located at Nachipur fisherman Pallai adjacent to Mahananda River in Chapainawabganj district, Bangladesh. The Mahananda River flows through two Indian states- West Bengal and Bihar, and then Bangladesh. The Mahananda originates from the Himalayas Mahaldiram hill near Chimli, east of Kurseong in Darjeeling district of India at an elevation of 2,100 meters. It enters into Bangladesh near Tetulia in Panchagarh District, flows for 3 kilometres after Tetulia and returns back to India. After flowing through Uttar Dinajpur district in West Bengal and Kishanganj district in Bihar, it enters into Maldah district in West Bengal. Finally, it joins the Ganges/Padma in Chapainawabganj district in Bangladesh (Map 3.1).



Map 3.1: Shows the study area

3.2.2 Experimental design

Three species were evaluated under three treatments namely T_1, T_2 and T_3 each having three replications.

T_1: Prawn, *Macrobrachium rosenbergii* (200/1m^3 cage)

T_2: Tilapia, *Oreochromis niloticus* (200/1m^3 cage)

T_3: Sarpunti, *Barbodes gonionotus* (200/1m^3 cage)

3.2.3 Cage description

The study was carried out in a river using cages (1m x 1m x 1m) made of knotless, high-density polyethylene netting of 0.5mm mesh size. The submerged volume of each cage was 1m^3. Cage frames were made of bamboo bars. The cages were suspended from a bamboo structure fixed by cotton nylon cords to a walkway from the shore. Plastic bottles were attached along the four corners of each cage to keep them floating (Plate 1).

Plate 1: Shows the cage experiment in Mahananda river

3.2.4 Stocking of fish and prawn

Juveniles of *M. rosenbergii* were collected from Natore Govt. fish farm and the seeds of *O. niloticus* and *P. gonionotus* were collected from a hatchery located at Chapainawabganj district. Both prawn and fish seeds (initial weight of 5.5 g) were brought to the experimental site through oxygenated polythene bag.

Prawn and fish seeds were acclimatized by letting the transport bags float in the fish cage for about 30 minutes, after which letting them get out freely from the bags. The prawns/fishes were randomly released into different replicates of three treatments. They were stocked early in the morning when the water was cool**.** The prawn and fish seeds stocking rate was 200 individuals/m^3 cage in each treatment (T_1, T_2 and T_3).

3.2.5 Feeding

A commercial pellet feed (ACI, Dhaka, Bangladesh) with 28% crude protein content was used for this experiment (Plate 2). Fish were hand-fed using feeding trays at10% of body weight at the start of the feeding trial. Feeding level was reduced to 5% of body weight by the end of the trial. Fish were fed twice a day at 09:00-10:00 hours and at 05:00-06:00 hours with 50% of the ration allocated at each time. Feed quantity was adjusted every month according to prawn/fish biomass determined by sub sampling. The cage nets and feeding trays were cleaned in each week.

Plate 2: Shows the feed used in cage experiment

3.2.6 Water quality monitoring

3.2.6.1. Monitoring of physico-chemical parameters

Water quality parameters viz. water temperature, transparency, dissolved oxygen (DO), hydrogen ion concentration (pH), free carbon dioxide (CO_2), alkalinity, total hardness and ammonia-nitrogen (NH_3-N) were studied fortnightly between 10 am to 11 am for the present study.

- **Physical parameters**

3.2.6.2 Water temperature

Water temperature (Plate 3) was recorded by the help of a Celsius thermometer at 20 to 30 cm water depth. The temperature was expressed as °C.

Plate 3: Shows the measurement of physical parameters of water

3.2.6.3 Water transparency

Transparency of water was measured by a secchi disc (Plate 3). The secchi disc was slowly lowered into the water on a graduated line and the depth at which it became invisible was noted. The sinking of the disc was always viewed under a sunshade for considerable accuracy in result. The data, thus obtained were expressed as secchi disc depth in cm.

➢ Chemical parameters

3.2.6.4 Dissolved Oxygen (DO)

The dissolved oxygen concentration of water was determined by the aid of a water quality test kit (HACH kit FF-2, USA) (Plate 4). Alkaline Iodide-Azide powder pillows, Manganous sulfate powder pillows, Sodium thiosulfate titration cartridge (0.2000 N), Starch indicator solution and Sulfamic acid powder pillows were used for determination of dissolved oxygen. The concentration of dissolved oxygen thus estimated was expressed in milligram per litter (mg/l) of water.

Plate 4: Shows the measurement of chemical parameters of water

3.2.6.5 Hydrogen Ion concentration (pH)

Water pH of river was measured by using HACH kit (FF-2, USA) (Plate 4). A colour disc, wide range pH (1919-00) and wide range 4 pH indicator solution were used for determination of water pH. A colour comparator disc ranging from 1-14 were also used for this purpose.

3.2.6.6 Free carbon dioxide (CO_2)

Free carbon dioxide was determined through digital titration by the help of a HACH kit (FF-2, USA) (Plate 4). Phenolphthalein powder pillows and Sodium hydroxide titration cartridge (0.3636 N) were used for determination of free carbon dioxide. It was also expressed as mg/l of water.

3.2.6.7 Alkalinity

Alkalinity was determined through digital titration by the help of a HACH kit (FF-2, USA) (Plate 4). Bromcresol Green-Methyl Red Powder Pillows, Phenolphthalein powder pillows and Sulfuric acid titration cartridge (0.1600 N) were used for total alkalinity determination. It was also expressed as mg/l of water.

3.2.6.8 Total hardness

Total hardness was measured by using a HACH kit (FF-2, USA) (Plate 4). Man Ver Powder Pillow and 0.800 M EDTA titration cartridge were used for determination of total hardness. It was also expressed as mg/l of water.

3.2.6.9 Ammonia-nitrogen (NH_3-N)

Ammonia-nitrogen was measured by using a HACH kit (FF-2, USA) (Plate 4). Rochelle salt solution and Nessler reagent were used to measure the NH_3-N. A colour comparator (value ranging from 0 to 3.0 mg/l) was also used for the same. The concentration of ammonia-nitrogen thus estimated was expressed in milligram per litter (mg/l) of water.

3.2.7 Growth monitoring

At least 10% (by number) of the fish in each cage were randomly sampled on a monthly basis by partially lifting the cage and removing fish with a dip net. On each sampling day, individual fish from each cage were weighed and measured (Plate 5). The purpose was to determine fish growth in weight and to adjust the ration. The following parameters were used to monitor the growth-


Plate 5: Shows the growth monitoring of fish/prawn

1. Weight gain (g/)

Weight gain (g) = Mean final weight (g) – Mean initial weight (g).

2. Specific growth rate (SGR, % bwd⁻¹)

$$SGR = \frac{L_n \text{ (final weight) - } L_n \text{ (initial weight)}}{\text{Culture period}} \times 100$$

(Brown, 1957)

3. Survival rate (%)

$$\text{Survival rate(\%)} = \frac{\text{No. of fish harvested}}{\text{No. of fish stocked}} \times 100$$

4. Production/ yield of fishes

Yield (Kg /cage/cycle) = Fish biomass at harvest –fish biomass at the stock

5. Economics

In order to assess the financial viability of cage culture, economic data were collected and a simple economic analysis was conducted to determine economic returns of different treatments based on market prices in Bangladesh for harvested fishes/prawn. The total cost (variable cost and fixed cost) was calculated and total return was determined from the current market prices of harvested fish/prawn. CBR was also calculated by the following equation:

CBR= Total return / Total cost

3.2.8 Statistical analysis

All the data collected during experiment were recorded and preserved on a computer spreadsheet. Data of water quality, growth and economics were analyzed statistically by one-way analysis of variance (ANOVA) using the SPSS (Statistical Package for Social Science, version-15.0). Significance was assigned at the 0.05% level. The mean values were also compared to see the significant difference through DMRT (Duncan Multiple Range Test) after Zar (1984).

3.3 Results

3.3.1 Water quality parameters

A number of water quality parameters such as, water temperature, transparency, dissolved oxygen, pH, free CO_2, alkalinity, hardness and ammonia-nitrogen were measured fortnightly during the study period.

3.3.2 Fortnightly variation

The variations in the mean values of water quality parameters in different treatments at different fortnights are presented in Table 3.1 to Table 3.8.

Water temperature varied from 19.10±0.06 (with treatment T_1 at 8^{th} fortnight) to 35.23±0.03°c (With treatments T_2 and T_3 at 1^{st} fortnight). Water transparency was found to range from 14.07±0.03 (with treatment T_3 at 1^{st} fortnight) to 72.67±0.03 cm. (with treatment T_3 at 8^{th} fortnight). Dissolved Oxygen of water varied from 4.97±0.07 (with treatment T_2 at 8^{th} forthright) to 5.60±0.10mg/l (with treatment T_1 at 2^{nd} forthright). pH of river water varied from 6.77±0.03 (with treatment T_1 at 8^{th} forthright) to 7.67±0.09 (with treatment T_2 at 1^{st} forthright). Free carbon dioxide was found to range from 2.73±0.03 (with treatment T_3 at 8^{th} forthright) to 4.10±0.06mg/l (with treatments T_1 and T_3 at 1^{st} forthright). Total alkalinity was found to range from 70.07±0.03 (with treatment T_2 at 1^{st} forthright) to 81.43±0.07mg/l (with treatment T_2 at 8^{th} forthright). Water hardness was found to range from 70.00±0.58 (with treatment T_1 at 1^{st} forthright) to 95.00±0.58 mg/l (with treatment T_2 and T_3 at 8^{th} forthright). Ammonia-nitrogen in river water was found to range from 0.10± 0.00 (with treatment T_2 at 1^{st} forthright) to 0.77± 0.03mg/l (with treatment T_1 at 8^{th} forthright).

Among the water quality parameters only the values of ammonia-nitrogen (at 4^{th}, 5^{th} and 8^{th} fortnights) differed significantly among the treatments.

3.3.3 Mean variation

The mean values of different water quality parameters in different treatments by the total of all fortnights are presented in Table 3.9 and Fig. 3.1.

The mean value of water temperature during the study period was found to be ranged from 26.90±2.32 to 27.04± 2.31°C. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_3. The mean value of water transparency varied from 33.63±8.72 to 33.71 ± 8.75 cm. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_3. The mean value of DO varied from 5.27±0.07 to 5.39± 0.08 mg/l. The minimum value was recorded in treatment T_2 whereas the maximum value was recorded in treatment T_1. The mean value of water pH varied from 7.10± 0.09 to 7.12± 0.10. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_2. The mean value of free carbon dioxide varied from 3.36±0.14 to 3.47±0.14 mg/l. The minimum value was recorded in treatment T_2 whereas the maximum value was recorded in treatment T_1. The mean value of total alkalinity varied from 74.07±1.43 to 74.09±1.44 mg/l. The minimum value was recorded in treatment T_2 whereas the maximum value was recorded in treatment T_3. The mean value of water hardness varied from 83.29±3.44 to 84.13±3.47 mg/l. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_2. The mean value of ammonia-nitrogen varied from 0.29±0.07 to 0.38±0.07 mg/l. The minimum value was recorded in treatment T_2 whereas the maximum value was recorded in treatment T_1. No significant difference was found among the treatments for the mean values of all the water quality parameters.

3.3.4 Growth of prawn and fishes

3.3.5 Monthly variation

Monthly variation in the mean values of growth parameters are presented in Table 3.10 to Table 3.13.

3.3.5.1 Weight gain (g/month)

The monthly weight gain (g/month) of prawn varied from 4.33±0.67 (with treatment T_1 at 4^{th} month) to 7.17±0.93g (with treatment T_1 at 2^{nd} month). The weight gain (g/month) of tilapia varied from 12.67±1.33 (with treatment T_2 at 4^{th} month) to 20.67±0.44g (with treatment T_2 at 2^{nd} month). The weight gain (g/month) of sarpunti varied from 4.67±0.67 (with treatment T_3 at 4^{th} month) to 10.93±0.74g (with treatment T_3 at 2^{nd} month). Among the different species, the lowest monthly weight gain was found with prawn (treatment T_1) whereas the highest weight gain was found with tilapia (treatment T_2). Weight gain varied significantly under the different treatments in all the months.

3.3.5.2 Specific growth rate (%, bwd^{-1})

Specific growth rate (%, bwd^{-1}) of prawn varied from 0.58±0.11 to 2.31±0.15. The minimum SGR of prawn was recorded with treatment T_1 at 4^{th} month whereas the maximum SGR recorded with treatment T_1 at 1^{st} month. Specific growth rate (%, bwd^{-1}) of tilapia varied from 0.72±0.02 to 4.49±0.07. The minimum SGR of tilapia was recorded with treatment T_2 at 4^{th} month whereas the maximum SGR recorded with treatment T_2 at 1^{st} month. Specific growth rate (%bwd^{-1}) of sarpunti varied from 0.45±0.01 to 2.58±0.03. The minimum SGR of sarpunti was recorded with treatment T_3 at 4^{th} month whereas the maximum SGR recorded with treatment T_3 at 1^{st} month. Among the different species, the lowest monthly SGR was found with prawn (treatment T_1) whereas the highest SGR was found with tilapia (treatment T_2). SGR varied significantly under the different treatments in all the months.

3.3.6 Mean variation

The variations in the mean values of different growth parameters under the different treatments during the study period are presented in Table 3.14 and Fig 3.2.

Weight gain (g/month)

The mean weight gain (g/month) of prawn, tilapia and sarpunti were found as 5.82±0.61g, 15.84±1.70g and 7.28±1.34g, respectively. All the treatments varied significantly for the mean values of weight gain.

Specific growth rate (%, bwd^{-1})

The mean specific growth rate (%, bwd^{-1}) of prawn, tilapia and sarpunti were found as 1.38±0.39, 2.16±0.85 and 1.57±0.51, respectively. All the treatments varied significantly for the mean values of specific growth rate (%, bwd^{-1}).

Final weight (g)

The mean final weight of prawn, tilapia and sarpunti were found as 28.67±2.19g, 68.67±1.86g and 34.33±1.86g, respectively. All the treatments varied significantly for the mean values of final weight.

Survival rate (%)

The survival rate (%) of prawn, tilapia and sarpunti were found as 85.67±4.84%, 95.67±0.33% and 82.50±3.82%, respectively. All the treatments varied significantly for the mean values of survival rate (%).

Yield (kg/cage/cycle)

The mean yield (kg/cage/cycle) of prawn, tilapia and sarpunti were found as 4.87±0.08kg, 13.14±0.33kg and 5.64±0.03kg, respectively. All the treatments varied significantly for the mean values of yield (kg/cage/cycle).

3.3.7 Economics

The economics of different treatments are presented in Table 3.15 and Fig. 3.3.

The total cost (Tk/cage/cycle) of prawn, tilapia and sarpunti were found as Tk. 1213.67±2.33, Tk. 608.67±6.33 and Tk. 332.67±0.67, respectively. Among the different species, the highest cost (Tk/cage/cycle) was found with prawn (treatment T_1) whereas the lowest cost (Tk/cage/cycle) was found with sarpunti (treatment T_3). Total cost (Tk/cage/cycle) varied significantly under the different treatments.

The total return (Tk/cage/cycle) of prawn, tilapia and sarpunti were found as Tk. 1091.33±79.33, Tk. 1583.33±41.67 and Tk. 550.00±0.00, respectively. Among the different species, the highest return (Tk/cage/cycle) was found with tilapia (treatment T_2) whereas the lowest return (Tk/cage/cycle) was found with sarpunti (treatment T_3). Total return (Tk/cage/cycle) varied significantly under the different treatments.

The CBR of prawn, tilapia and sarpunti were found as 0.90±0.07, 2.60±0.04 and 1.66±0.003, respectively. Among the different species, the highest CBR was found with tilapia (treatment T_2) whereas the lowest was found with prawn (treatment T_1). CBR varied significantly under the different treatments.

Table 3.1: Variations in the mean values of water quality parameters under different treatments at 1st fortnight

Treatments / Parameters	T_1	T_2	T_3
Water temperature(°C)	35.17±0.09[a]	35.23±0.03[a]	35.23±0.03[a]
Transparency (cm)	14.10±0.06[a]	14.20±0.06[a]	14.07±0.03[a]
DO (mg/l)	5.60±0.06[a]	5.53±0.09[a]	5.60±0.06[a]
pH	7.53±0.09[a]	7.67±0.09[a]	7.60±0.06[a]
CO_2 (mg/l)	4.10±0.06[a]	4.00±0.06[a]	4.10±0.06[a]
Alkalinity (mg/l)	70.20±0.06[a]	70.07±0.03[a]	70.17±0.03[a]
Hardness (mg/l)	70.00±0.58[a]	71.00±0.58[a]	70.67±0.88[a]
NH_3-N (mg/l)	0.17±0.03[a]	0.10±0.00[a]	0.13±0.03[a]

Figures bearing common letter(s) in a row as superscript do not differ significantly (P<0.05)

Table 3.2: Variations in the mean values of water quality parameters under different treatments at 2nd fortnight

Treatments / Parameters	T_1	T_2	T_3
Water temperature(°C)	34.20±0.12[a]	34.23±0.03[a]	34.23±0.03[a]
Transparency (cm)	14.30±0.06[a]	14.27±0.03[a]	14.30±0.06[a]
DO (mg/l)	5.60±0.10[a]	5.43±0.09[a]	5.53±0.09[a]
pH	7.30±0.06[a]	7.30±0.06[a]	7.30±0.06[a]
CO_2 (mg/l)	3.77±0.03[a]	3.67±0.03[a]	3.67±0.03[a]
Alkalinity (mg/l)	70.10±10.06[a]	70.13±0.03[a]	a70.10±0.06[a]
Hardness (mg/l)	71.00±0.58[a]	72.00±0.58[a]	71.67±0.88[a]
NH_3-N (mg/l)	0.17±0.03[a]	0.13±0.03[a]	0.13±0.03[a]

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 3.3: Variations in the mean values of water quality parameters under different treatments at 3rd fortnight

Treatments / Parameters	T_1	T_2	T_3
Water temperature(°C)	32.13±0.09[a]	32.23±0.03[a]	32.33±0.03[a]
Transparency (cm)	17.40±0.06[a]	17.40±0.06[a]	17.40±0.06[a]
DO (mg/l)	5.60±0.06[a]	5.40±0.06[a]	5.50±0.06[a]
pH	7.20±0.06[a]	7.20±0.06[a]	7.20±0.06[a]
CO_2 (mg/l)	3.70±0.06[a]	3.53±0.03[a]	3.60±0.06[a]
Alkalinity (mg/l)	71.83±0.06[a]	71.80±0.06[a]	71.70±0.06[a]
Hardness (mg/l)	76.00±0.58[a]	76.00±0.58[a]	76.67±0.88[a]
NH_3-N (mg/l)	0.27±0.03[a]	0.17±0.03[a]	0.23±0.03[a]

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 3.4: Variations in the mean values of water quality parameters under different treatments at 4th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	29.17 ± 0.09^{a}	29.20 ± 0.06^{a}	29.30 ± 0.06^{a}
Transparency (cm)	19.10 ± 0.06^{a}	19.10 ± 0.06^{a}	19.20 ± 0.06^{a}
DO (mg/l)	5.40 ± 0.06^{a}	5.37 ± 0.03^{a}	5.40 ± 0.06^{a}
pH	7.03 ± 0.03^{a}	7.10 ± 0.06^{a}	7.10 ± 0.06^{a}
CO_2 (mg/l)	3.43 ± 0.03^{a}	3.30 ± 0.06^{a}	3.33 ± 0.09^{a}
Alkalinity (mg/l)	72.10 ± 0.06^{a}	72.13 ± 0.09^{a}	72.17 ± 0.09^{a}
Hardness (mg/l)	86.00 ± 0.58^{a}	87.00 ± 0.58^{a}	86.00 ± 0.58^{a}
NH_3-N (mg/l)	0.27 ± 0.03^{a}	0.13 ± 0.03^{b}	0.23 ± 0.03^{ab}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 3.5: Variations in the mean values of water quality parameters under different treatments at 5th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	24.17 ± 0.09^{a}	24.27 ± 0.03^{a}	24.33 ± 0.03^{a}
Transparency (cm)	21.40 ± 0.06^{a}	21.40 ± 0.06^{a}	21.40 ± 0.06^{a}
DO (mg/l)	5.47 ± 0.12^{a}	5.30 ± 0.06^{a}	5.30 ± 0.06^{a}
pH	7.10 ± 0.06^{a}	7.10 ± 0.06^{a}	7.13 ± 0.03^{a}
CO_2 (mg/l)	3.23 ± 0.09^{a}	3.17 ± 0.03^{a}	3.23 ± 0.03^{a}
Alkalinity (mg/l)	73.30 ± 0.06^{a}	73.17 ± 0.03^{a}	73.20 ± 0.06^{a}
Hardness (mg/l)	85.00 ± 0.58^{a}	86.00 ± 0.58^{a}	87.33 ± 0.88^{a}
NH_3-N (mg/l)	0.37 ± 0.03^{a}	0.23 ± 0.03^{b}	0.33 ± 0.03^{ab}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 3.6: Variations in the mean values of water quality parameters under different treatments at 6th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	21.13 ± 0.03^{a}	21.10 ± 0.06^{a}	21.10 ± 0.06^{a}
Transparency (cm)	40.17 ± 0.09^{a}	40.20 ± 0.06^{a}	40.30 ± 0.06^{a}
DO (mg/l)	5.30 ± 0.06^{a}	5.10 ± 0.06^{a}	5.20 ± 0.06^{a}
pH	6.97 ± 0.03^{a}	6.93 ± 0.03^{a}	6.97 ± 0.03^{a}
CO_2 (mg/l)	3.50 ± 0.06^{a}	3.40 ± 0.06^{a}	3.37 ± 0.03^{a}
Alkalinity (mg/l)	75.40 ± 0.06^{a}	75.40 ± 0.06^{a}	75.47 ± 0.03^{a}
Hardness (mg/l)	91.67 ± 0.88^{a}	93.00 ± 0.58^{a}	92.67 ± 0.88^{a}
NH_3-N (mg/l)	0.47 ± 0.03^{a}	0.37 ± 0.03^{a}	0.43 ± 0.03^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 3.7: Variations in the mean values of water quality parameters under different treatments at 7th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	$20.10±0.06^a$	$20.20±0.06^a$	$20.30±0.06^a$
Transparency (cm)	$70.17±0.09^a$	$70.20±0.06^a$	$70.30±0.06^a$
DO (mg/l)	$5.10±0.06^a$	$5.03±0.03^a$	$5.08±0.04^a$
pH	$6.87±0.03^a$	$6.83±0.03^a$	$6.87±0.03^a$
CO_2 (mg/l)	$3.20±0.06^a$	$3.07±0.03^a$	$3.07±0.09^a$
Alkalinity (mg/l)	$78.43±0.03^a$	$78.40±0.06^a$	$78.40±0.06^a$
Hardness (mg/l)	$92.67±0.67^a$	$93.00±0.58^a$	$92.67±0.88^a$
NH_3-N (mg/l)	$0.57±0.03^a$	$0.53±0.03^a$	$0.53±0.03^a$

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 3.8: Variations in the mean values of water quality parameters under different treatments at 8th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	$19.10±0.06^a$	$19.20±0.06^a$	$19.30±0.06^a$
Transparency (cm)	$72.37±0.19^a$	$72.53±0.12^a$	$72.67±0.03^a$
DO (mg/l)	$5.07±0.12^a$	$4.97±0.07^a$	$5.03±0.03^a$
pH	$6.77±0.03^a$	$6.80±0.00^a$	$6.80±0.00^a$
CO_2 (mg/l)	$2.80±0.06^a$	$2.73±0.09^a$	$2.73±0.03^a$
Alkalinity (mg/l)	$81.37±0.03^a$	$81.43±0.07^a$	$81.40±0.06^a$
Hardness (mg/l)	$94.00±0.58^a$	$95.00±0.58^a$	$95.00±0.58^a$
NH_3-N (mg/l)	$0.77±0.03^a$	$0.63±0.03^b$	$0.73±0.03^{ab}$

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 3.9: Variations in the mean values of water quality parameters under different treatments during study period

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	$26.90±2.32^a$	$26.96±2.32^a$	$27.02±2.31^a$
Transparency (cm)	$33.63±8.72^a$	$33.66±8.73^a$	$33.71±8.75^a$
DO (mg/l)	$5.39±0.08^a$	$5.27±0.07^a$	$5.33±0.08^a$
pH	$7.10±0.09^a$	$7.12±0.10^a$	$7.12±0.09^a$
CO_2 (mg/l)	$3.47±0.14^a$	$3.36±0.14^a$	$3.39±0.15^a$
Alkalinity (mg/l)	$74.09±1.43^a$	$74.07±1.44^a$	$74.08±1.44^a$
Hardness (mg/l)	$83.29±3.44^a$	$84.13±3.47^a$	$84.09±3.46^a$
NH_3-N (mg/l)	$0.38±0.07^a$	$0.29±0.07^a$	$0.34±0.07^a$

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 3.10: Variations in the mean values of weight gain and SGR under different treatments at 1st month

Treatments / Parameters	T_1	T_2	T_3
Weight gain (g)	5.43±0.55^b	15.03±0.03^a	6.10±0.06^b
SGR (%, bwd^{-1})	2.31±0.15^b	4.49±0.07^a	2.58±0.03^b

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 3.11: Variations in the mean values of weight gain and SGR under different treatments at 2nd month

Treatments / Parameters	T_1	T_2	T_3
Weight gain (g)	7.17±0.93^c	20.67±0.44^a	10.93±0.74^b
SGR (%, bwd^{-1})	1.68±0.09^b	2.34±0.03^a	2.25±0.09^a

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 3.12: Variations in the mean values of weight gain and SGR under different treatments at 3rd month

Treatments / Parameters	T_1	T_2	T_3
Weight gain (g)	6.33±1.33^b	15.00±0.002^a	7.40±0.31^b
SGR (%, bwd^{-1})	0.92±0.04^b	1.10±0.05^a	1.00±0.03^b

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 3.13: Variations in the mean values of SGR and weight gain under different treatments at 4th month

Treatments / Parameters	T_1	T_2	T_3
Weight gain (g)	4.33±0.67^b	12.67±1.33^a	4.67±0.67^b
SGR (%, bwd^{-1})	0.58±0.11^b	0.72±0.02^a	0.45±0.01^b

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 3.14: Variations in the mean values of growth parameters under different treatments during the study period

Treatments / Parameters	T_1	T_2	T_3
Weight gain (g/month)	5.82±0.61[b]	15.84±1.70[a]	7.28±1.34[b]
SGR (%, bwd^{-1})	1.38±0.39[b]	2.16±0.85[a]	1.57±0.51[b]
Final weight (g)	28.67±2.19[b]	68.67±1.86[a]	34.33±1.86[b]
Survival rate (%)	85.67±4.84[ab]	95.67±0.33[a]	82.50±3.82[b]
Total yield (kg/cage/cycle)	4.87±0.08[c]	13.14±0.33[a]	5.64±0.03[b]

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 3.15: Variations in the mean values of different parameters of economics under different treatments

Treatments / Parameters	T_1	T_2	T_3
Fixed/common cost (Tk.)			
Net	500±0.00[a]	500±0.00[a]	500±0.00[a]
Bamboo	30±0.00[a]	30±0.00[a]	30±0.00[a]
Rope	10±0.00[a]	10±0.00[a]	10±0.00[a]
Labour	60±0.00[a]	60±0.00[a]	60±0.00[a]
Sub total (Tk.)	600±0.00[a]	600±0.00[a]	600±0.00[a]
Cost/cycle (Tk.)	100±0.00[a]	100±0.00[a]	100±0.00[a]
Variable cost (Tk.)			
Fish/prawn seed	1000.00±0.00[a]	200.00±0.00[b]	100.00±0.00[c]
Feed	113.67±2.33[c]	308.67±6.33[a]	132.67±0.67[b]
Sub total (Tk.)	1113.67±2.33[a]	508.67±6.33[b]	232.67±0.67[c]
Total cost (Tk.)	1213.67±2.33[a]	608.67±6.33[b]	332.67±0.67[c]
Return/cage/cycle (Tk.)	1091.33±79.33[b]	1583.33±41.67[a]	550.00±0.00[c]
Return/cage/year (Tk.)	3274.00±238.00[b]	4750.00±125.00[a]	1650.00±0.00[c]
CBR	0.90±0.07[c]	2.60±0.04[a]	1.66±0.003[b]

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

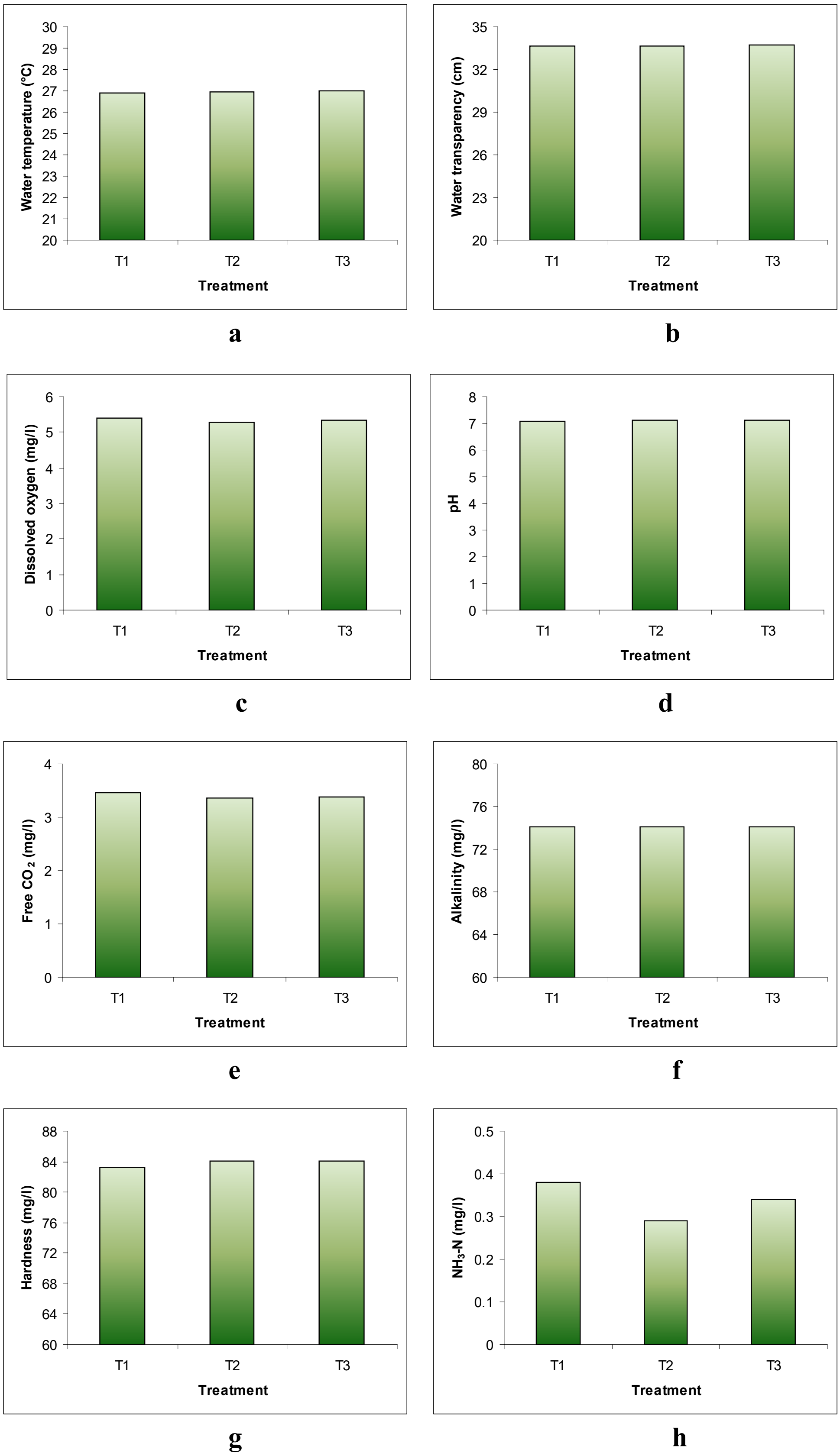
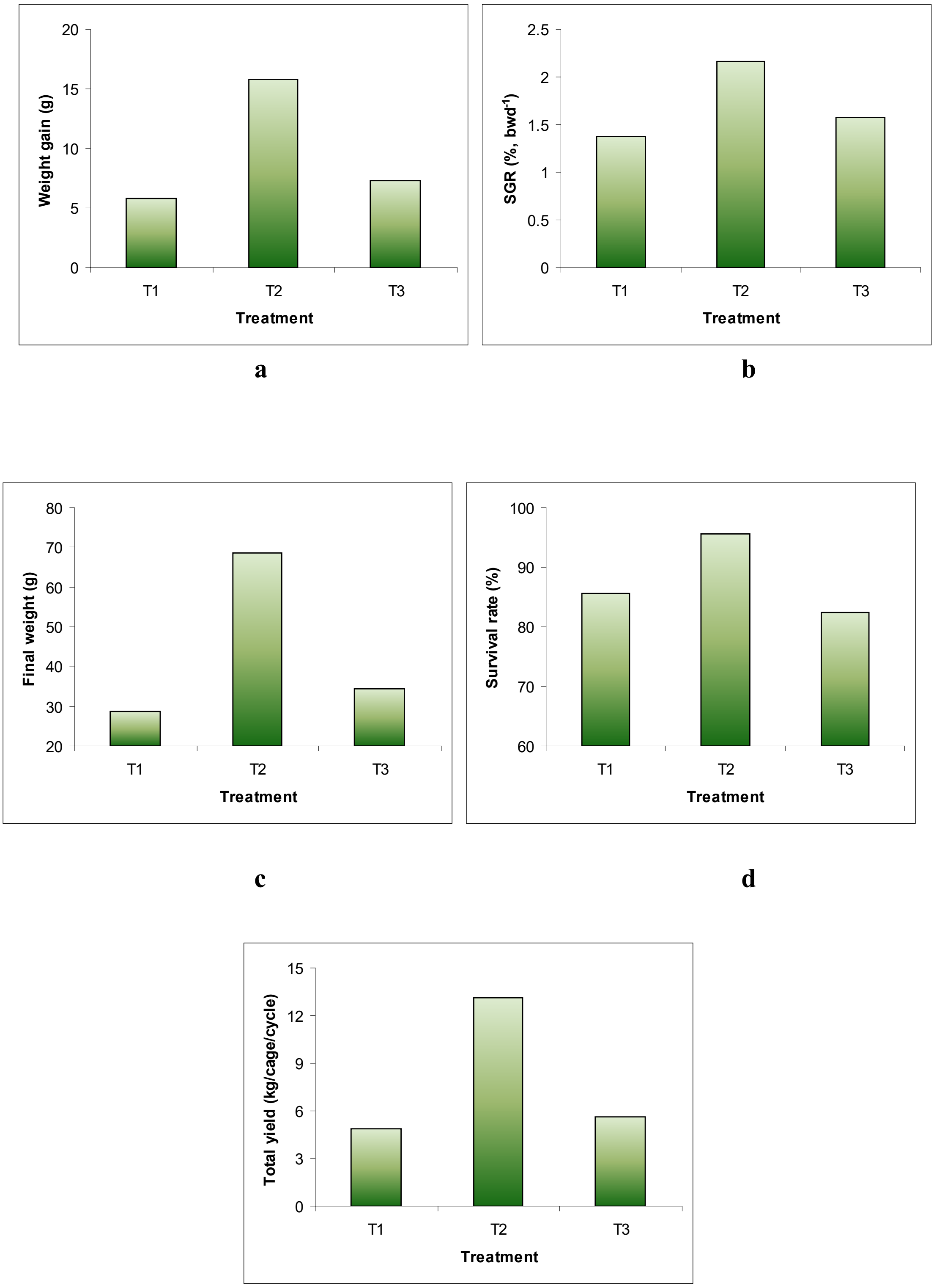


Fig. 3.1: Variations in the mean values of water quality parameters (a. water temperature; b. transparency; c. DO; d. pH; e. CO_2; f. alkalinity; g. hardness; h. NH_3-N) under different treatments during study period.



E

Fig. 3.2: Variations in the mean values of growth parameters (a. weight gain; b. SGR; c. final weight; d. survival rate; e. total yield) under different treatments during the study period

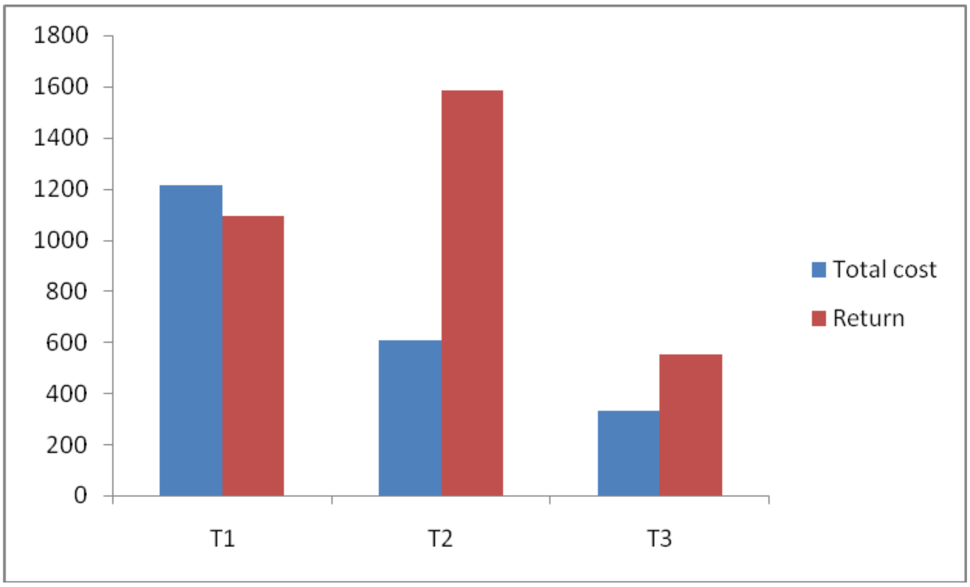


Fig. 3.3: Total cost and return of cage farming under different treatments

3.4 Discussion

3.4.1 Water quality parameters

Environmental parameters play an important role on the growth and production of fish and other aquatic organisms. The suitable water quality parameters are prerequisites for a healthy aquatic environment and for the production of sufficient fish food organisms. The primary productivity of a water body depends on the physical, chemical and other factors of the environment

3.4.2 Fortnightly variation

Temperature

Temperature is an ecological factor in aquatic ecosystem. All metabolic and physiological activities and life processes such as feeding, reproduction, movement and distribution of aquatic organisms are greatly influenced by water temperature (Jhingran, 1975). In the present study the water temperature was found to vary from 19.10±0.06 to 35.23±0.03 °C. Lower temperature (19.10±0.06°C) with treatment T_1 at 8^{th} fortnight (i.e. December 2008) might be due to shorter day length and cold wind (Appendix 1). Ahmed *et.al.* (2005) found water temperature varied from 24.1 to 30.5°C in Meghna river. Ashfaque (2004) recorded water temperature from 22.8 to 34.4°C in Padma river. Nyananyo *et al*. (2006) found water temperature as 28 to 35°C in Brass River, Nigeria.

Transparency

Water transparency acts as an index of productivity of a water body. Sometimes it indicates the turbidity of a water body. In the present study the water transparency varied from 14.07±0.03 to 72.67±0.03cm. The lowest value was recorded in 1^{st} fortnight (i.e. September) and highest in 8^{th} fortnight (i.e. December). Ahmed *et al.* (2005) found the water transparency ranged from 12 to 90cm in Meghna river.

Nyananyo *et al*. (2006) found water transparency as 17 to 72 cm in Brass River, Nigeria.

Dissolved oxygen

The DO concentrations of the river Mahananda varied from 4.97±0.07 (T_2 at 8th fortnight) to 5.60±0.10mg/l (T_1 at 2nd fortnight). Such low values might be due to high phytoplankton concentration, respiration, decomposition of bottom organic matter, inflow of oxygen deficient water, inorganic reductants such as NH_3, Fe+2 and other oxidizable substances. Also similar assumptions were made by Ahmed *et al*. (2005) in Meghna river and Ashfaque (2004) in Padma river. They observed DO range from 5.1 to 8.3 mg/l and 5.1±06 to 10.3±0.9mg/l, respectively. Shafi *et al*. (1978) found almost similar values (6.25 to 10.5 mg/l) in the river Meghna. Talukdar *et al.* (1974) reported DO varied within a normal range (5.4-8.7 mg/l). Islam *et al*. (1992) also reported similar ranges. Venkateswarlu (1969) observed range of DO concentration from 2.39 to 8.6 mg/l in the river Moosi, Hyderabad (India).

pH

There were no wide variations in pH values in the investigated river. The values of pH in the river water ranged from 6.77±0.03 to 7.67±0.09. The highest value was recorded in the month of September at 1st forthright and lowest in December at 8th fortnight. Ahmed *et al*. (2005) obtained the vales of pH in the river Meghna ranged from 7.00-8.00. Nyananyo *et al*. (2006) found pH as 5.58 to 7.86 in Brass River, Nigeria. Ashfaque (2004) found the pH of the river water slightly acidic to slightly alkaline and varied between 6.2 to 7.5. Roy (1955) observed the pH of the river Hoogly to be more or less stable within the range of recorded in summer might have been due to 8.3 to 8.4 which is another example of high buffering capacity. In the river Meghna, pH values obtained by Shafi *et al*. (1978) ranged from 6.79 to 8.41. Talukdar *et al*. (1994) found pH value of 8.1 in their study of the river Padma near North Western region of Bangladesh. Nile water in Egypt showed a pH range of 7.4-8.4 (Ahmed *et al*., 1986).

Free carbon dioxide

The mean values of free carbon dioxide varied from 2.73±0.03 mg/l at 8th fortnight to 4.10±0.06mg/l at 1st fortnight. The high free CO_2 content during summer was possibly due to the high temperature and heavy rainfall with heavy land drainage which speeded up the decomposition of organic matter, low photosynthetic activity which consumed free CO_2, low precipitation of free CO_2 (Islam and Bhuiyan, 2000). Higher values of free CO_2 accelerated the rate of decomposition of organic matter by microbes, decrease of photosynthetic activity and high rate of respiration by benthic biota and microorganisms (Chowdhury *et al*., 1992: Palharya *et al*., 1993).

Total alkalinity

Total alkalinity values obtained during the study period were found to vary from 70.03±0.06mg/l at 1st fortnight to 81.43±0.07mg/l at 8th fortnight. Lowest value was recorded in the month of September and highest was in December. The findings were strongly supported with results ranged from 48.0 to 88.7mg/l in Meghna river and 57.7±4.3 to 110.0±7.8mg/l in Padma river found by Ahmed *et al*. (2005) and Ahmed (2004), respectively.

Hardness

Hardness of river water ranged from 70.00±0.58mg/l at 1st fortnight to 95.00±0.58mg/l at 8th fortnight in 2008. High concentration was recorded in the month of December and low in September. Hossain *et al*. (1999) reported that high hardness values of (75-105mg/l) were found during winter in the Bhahmaputra river due to high deposition of calcium. Ahmed *et al*. (2005) found the range of concentration of hardness from 42.3 to 94.5mg/l in Meghna river. The water of the river showed higher hardness value during near winter but lower in wet season. Probably, high hardness value was occurred due to deposition of calcium components in the river.

Ammonia-nitrogen

Ammonia-nitrogen in river water was found to range from 0.10± 0.00mg/l (with treatment T_2 at 1^{st} forthright) to 0.77± 0.03mg/l (with treatment T_1 at 8^{th} forthright). Lowest value was recorded in the month of September and highest was in December. NH_3-N is an important parameter because very high value of it makes hazardous condition for fish. Chen (1988) found that lower than 1 mg/l of NH_3 gas content in pond was good for fish culture. Ahmed *et al*. (2005) found the range of concentration of ammonia-nitrogen from to 0.1 to 0.8mg/l in Meghna river. Nirod (1997) recorded total ammonia nitrogen between 0.10 to 0.49 mg/l. The range of ammonia-nitrogen mentioned above was more or less similar to the present finding.

3.4.3 Mean variation

In the present study, the mean value of water temperature varied from 26.90±2.32 to 27.04±2.31°C. The average water temperature of 29.4°C was found in the Padma river by Ashfaque (2004), 27.52°C in Buriganga by Islam *et al*. (1974) and 27.6±6.68 °C in Meghna river by Ahmed *et. al.* (2005). Patra and Azadi (1987) found the average temperature of 25°C in Halda river. In the Karnafully estuary, the value of water temperature as 27.52°C was recorded by Mahmood *et al.* (1976). Warm water aquaculture species grow best at temperature between 25-32 °C (Boyd, 1998).

The mean value of water transparency in this study varied from 33.63±8.72 to 33.71±8.75cm. Present finding has similarity with the findings of Ahmed *et al*. (2005) who found the value of 34.2 ±1.18cm in Meghna river. Wahab *et al.* (1995) suggested that the transparency of productive water should be 40 cm or less. However, Boyd

(1998) reported the secchi disc reading between 30 to 45 cm as suitable for fish farming. Chowdhury and Yakupitiyage (2000) found mean transparency as 24.4cm in oxbow lake in Bangladesh.

The mean value of dissolved oxygen varied from 5.27±0.07 to 5.39±0.08mg/l, this value is more or less similar to the findings of Ahmed *et al*. (2005) who got the mean value of 6.7±0.8 mg/l in Meghna river. Chowdhury and Yakupitiyage (2000) found mean DO value as 6.29 mg/l in oxbow lake in Bangladesh. According to Boyd (1982), dissolved oxygen can be crucial in the tropics and sub tropics where fish growth and survival in aquatic environment is frequently oxygen limited.

The mean value of pH varied from 7.10 ±0.09 to 7.12±0.10 in 2008. Ahmed *et al*. (2005) recorded the mean pH value in Maghna river as 7.8±0.18. According to Swingle (1967), pH of 6.5 to 9 is suitable for fish culture. Chowdhury and Yakupitiyage (2000) found mean pH value as 7.1 in oxbow lake in Bangladesh. In the present study the alkaline pH range in all treatments indicate good pH condition for biological production and fish culture.

Free CO_2 varied from 3.36±0.14 to 3.47±0.14mg/l which was close to the findings of Ahmed *et al*. (2005) obtaining the value of 4.8±0.74 mg/l in Meghna river.

The recorded mean total alkalinity varied from 74.07±1.43 to 74.09±1.44mg/l which has similarity with Ahmed *et al*. (2005) who obtained the value of 76.3±8.94mg/l in Meghna river.

The recorded mean total hardness varied from 83.29±3.44 to 84.13±3.47mg/l. This value is more or less similar to the findings of Ahmed *et al*. (2005) who got the mean harness value of 72.5±6.21mg/l in Meghna river.

The recorded mean value of ammonia-nitrogen varied from 0.29±0.07 to 0.38±0.07mg/l. This value is more or less similar to the findings of Ahmed *et al*.

(2005) who got the mean value of 0.35±0.08mg/l in Meghna river. Chowdhury and Yakupitiyage (2000) found mean ammonia-nitrogen value as 0.12 mg/l in oxbow lake in Bangladesh.

3.4.5 Fish/prawn growth

3.4.6 Monthly variation

Weight gain (g/month)

Among fishes the highest monthly weight gain was observed in tilapia (12.67±1.33g to 20.67±0.44g) and lowest in sarpunti (4.67±10.67g to 10.93±0.74g). In case of prawn, the weight gain was 4.33±0.67g to 7.17±0.93g. The weight gain with treatment T_2 was highest in comparison to treatment T_1 and T_3. Significant difference among the weight gain of prawn and fishes in every month might be due to individual nature of the species. The highest weight gain of tilapia was found in the month of October and lowest weight gain in the month of December.

Specific growth rate (%, bwd^{-1})

Among the prawn and fishes the highest specific growth rate (%, bwd^{-1}) was observed in tilapia (0.68±0.06 to 4.49±0.07). In 1st and 2nd months significant difference was found in SGR. The SGR values for tilapia was highest in the month of October and lowest in the month of December.

Comparatively higher values of weight gain and SGR in the month of October might be due to higher temperature causing higher metabolic activity of prawn/fishes (Boyd, 1998).

3.4.7 Mean variation

Mean final weight (g), weight gain (g), SGR (%, bwd^{-1}), survival rate (%) and yield (kg/cage/cycle) significantly varied ($P<0.05$) from 28.67±2.19 (T_1) to 68.67±1.86 (T_2), 5.82±0.61 (T_1)to 15.84±1.70 (T_2), 1.38±0.39 (T_1) to 2.16±0.85 (T_2), 82.50±3.82 (T_3) to

95.67±0.33 (T_2) and 4.87±0.08 (T_1)to 13.14±0.33 (T_2), respectively. Results indicated that treatment T_2 varied more significantly than that of other treatments for the mean values of growth parameters. This might be due to the fast growing nature of tilapia over others. Mean final weight (28.67±2.19 g) was found lowest with treatment T_1 (prawn) during this study. Almost similar growth pattern was found with Rahmatullah *et al*. (1997) who reported a mean final weight of prawn as 26.52 g from cage farming in river provided with 28% protein feed. Chakraborty and Benerjee (2010) stated that significantly highest weight, length, specific growth rate, and daily weight gain were found in monosex tilapia.

3.4.8 Economics

The mean total cost (Tk/cage/cycle), return (Tk/cage/cycle) and CBR of prawn/fish significantly varied ($P<0.05$) from 332.67±0.67 (T_3) to 1213.67±2.33 (T_1), 550.00±0.00 (T_3) to 1583.33±41.67 (T_2) and 0.90±0.07 (T_1) to 2.60±0.04 (T_2), respectively. Among the different treatments, treatment T_2 (cage farming with tilapia) was found best in terms of economics. Small scale aquaculture requires very modest investment and is accessible to the extreme poor and landless in many situations. Highest return and moderate investment were found with tilapia during this study. Present findings almost agreed with (DoF, 2003) reporting better profit with tilapia in cage farming. Overall findings indicated that tilapia performed better than that of prawn and sarpunti under small scale cage farming in river ecosystem. Yield of tilapia was found as 13.14±0.33 kg/cage/cycle using a stocking density of 200 fishes/1m^{3}cage. DoF (2003) reported the yield of tilapia as 50-60 kg/1m^{3}cage/year. Such variation in yield might be due to the variation in stocking density. Almost similar assumption was found with Abo-El-Wafa (1996) who stated that tilapia cage culture was productive (~28.1 Kg/m^3/5 months) and economically feasible under scientific management while using optimum density of tilapia fed with suitable diet.

3.5 Conclusion

No significant difference was found for all the mean values of water quality parameters during study period. However, almost all the parameters were found within the suitable range. Treatment T_2 varied more significantly than that of others in case of almost all the growth parameters during study period. Treatment T_2 also varied more significantly for CBR. This was mainly due to comparatively less cost involvement with high return though high level of production in treatment T_2. Considering water quality, growth and economics, Treatment T_2 ie. tilapia is found suitable candidate for cage farming in the present study.

3.6 Recommendation

Based on the present findings it is recommended to conduct future research on the optimization of stocking density of tilapia for cage farming in river ecosystem.

Chapter Four

OPTIMIZATION OF STOCKING DENSITY FOR CAGE FARMING OF *OREOCHROMIS NILOTICUS* IN RIVER ECOSYSTEM

4.1 Introduction

Tilapia is the third most important aquaculture species in terms of production after salmon and carp (FAO, 2009). During the end of the 20th century, tilapia has the highest rate of annual growth among all finfish, exceeding that of salmonids and cyprinids (De Silva, 2001). Tilapia plays an important role in food security and poverty alleviation in the developing countries such as Indonesia, the Philippines, Thailand and Taiwan Province of China (De Silva *et al*., 2004). In particular, the *Oreochromis niloticus* species has impacted on aquaculture development since the 1970s, and has become the preferred tilapia species for aquaculture, especially in the developing countries in Asia and Africa (Smith and Pullin, 1984). In low income and protein deficient countries, *O. niloticus* is commonly cultured in backyard and/or home garden ponds of relatively poor water quality, such as sewage-fed ponds, to supplement the income of poor households as well as to make available a fresh source of animal protein to the family (Edwards, 1990; Edwards *et al.,* 1990; Khalil and Hussein, 1997). There have been no reported health effects after consumption of such tilapia (Nandeesha, 2002). Tilapia production from aquaculture accounted for about 2.5 times more than production from wild capture fisheries, although the reverse was the case before the 1980s (De Silva *et al*., 2004). Nile tilapia (*Oreochromis niloticus* L.) is one of the widely farmed tilapia species in tropical countries. This is because they feed low in the food chain and also consume a wide variety of materials (Csavas, 1993). Production in developing countries such as Kenya occurs mainly in semi-intensive ponds, where cheap feed supplements and fertilizers are applied to produce low cost fish. At low levels of production, fertilizers are applied to increase fish yields (Green *et al*., 1989; Knud-Hansen *et al*., 1991), while at high levels, fed-only or feed combined with fertilizers are applied to optimize fish yields (Diana *et al*., 1991; Diana *et al*., 1994). However, culture of this fish has been largely restricted to land-based pond aquaculture systems. Tilapia (*Oreochromis niloticus* L.) can also be raised in cage aquaculture because the fish grows well with diets, can tolerate high stocking densities and can be easily spawned (Edwards, 1990; Edwards *et al.,* 1990; Csavas 1993; Khalil and Hussein, 1997). However, the growth and yield characteristics of this fish in cages have not been studied in detail. Bangladesh is characterized by vast aquatic resources including natural depressions and wetlands, rivers and lakes, borrowpits, large impoundments canals and dugout ponds that are potential sites for commercial cage aquaculture. Cages are easy to manage, produce fish of high quality and utilize existing water bodies (Beveridge, 1996); therefore, cage aquaculture offers a viable alternative for the landless farmers in resource-poor areas like Bangladesh. Stocking density is a significant factor that determines production in cages. Understocking results in failure to make the maximum possible utilization of the space, and overstocking may result in stress that may lead to enhanced energy requirements causing reduced growth and feed utilization (Leatherland and Cho, 1985). Both under and overstocking affect farm economics and productivity. Identifying the optimum stocking density for a species is, therefore, a critical factor in designing an efficient cage aquaculture system. Therefore, the present study aimed at optimizing the stocking density of tilapia in cage in Mahananda river of Bangladesh. The specific objectives of this study were as follows:

i. to monitor the water quality parameters under different treatments of tilapia stocking densities in cage farming in river;

ii. to determine the effects of stocking density on the growth, survival and yield of the tilapia (*Oreochromis niloticus*) in cages;

iii. to evaluate the economics of tilapia farming in cage under different treatments of stocking densities; and

iv. to recommend suitable stocking density of tilapia for small scale cage farming in river ecosystem.

4.2 Materials and methods

4.2.1 Duration and location of the study

The experiment was conducted for the period of four months cycle from September 2009 to December 2009.

The experiment was conducted in Mahananda River adjacent to Nachipur Fishermen Pallai in Chapainawabganj district. The Mahananda River flows through the Indian states- West Bengal and Bihar and Bangladesh. It originates in the Himalayas Mahaldiram hill near Chimli, east of Kurseong in Darjeeling district at an elevation of 2,100 metres. It enters into Bangladesh near Tetulia in Panchagarh District, flows for 3 kilometres after Tetulia and returns back to India. Finally, it joins the Ganges/Padma in ChapaiNawabganj district through Uttar Dinajpur district in Bangladesh.

4.2.2 Experimental design

Three different stocking densities of all male tilapia were evaluated under three treatments namely T_1, T_2 and T_3 each having three replications.

T_1: *Oreochromis niloticus* (200/1m^3 cage)

T_2: *Oreochromis niloticus* (150/1m^3 cage)

T_3: *Oreochromis niloticus* (100/1m^3 cage)

4.2.3 Cage description

The study was carried out in a river using cages (1mx1mx1m) made of knotless, high-density polyethylene netting of 0.5mm mesh size. The submerged volume of each cage was 1m^3. Cage frames were made of bamboo bars. The cages were suspended from a bamboo structure fixed by cotton nylon cords to a walkway from the shore. Plastic bottles were attached along the four corners of each cage to keep them floating.

4.2.4 Stocking of fish fingerlings

The fingerlings of *O. niloticus* (initial stocking weight 41.0 g) were collected from a rearing pond located at Nachole. Fingerlings were brought to the experimental site through oxygenated polythene bag. Fingerlings were acclimatized by letting the transport bags float in the fish cage for about 30 minutes, after which letting the fingerlings get out freely from the bags. The fishes were randomly released into different replicates of three treatments. Fish were stocked early in the morning when the water was cool.

4.2.5 Feeding

A commercial pellet feed (ACI, Dhaka, Bangladesh) with 28% crude protein content was used. Fish were hand-fed using feeding trays at10% of body weight at the start of the feeding trial. Feeding level was reduced to 5% of body weight by the end of the trial. Fish were fed twice a day at 09:00-10:00 hours and at 05:00-06:00 hours with 50% of the ration allocated at each time. Feed quantity was adjusted every month according to fish biomass determined by sub sampling. The cage nets and feeding trays were cleaned in each week.

4.2.6 Water quality monitoring

4.2.6.1. Monitoring of physico-chemical parameters

Some important physico-chemical parameters such as water temperature, transparency, dissolved oxygen (DO), hydrogen ion concentration (pH), free carbon dioxide (CO_2), alkalinity, total hardness and ammonia-nitrogen (NH_3-N) were studied fortnightly between 10 am to 11 am for the present study

- **Physical parameters**

4.2.6.2 Water temperature

Water temperature was recorded by the help of a Celsius thermometer at 20 to 30 cm water depth. The temperature was expressed as °C.

4.2.6.3 Water transparency:

Transparency of water was measured by a secchi disc. The secchi disc was slowly lowered into the water on a graduated line and the depth at which it became invisible was noted. The sinking of the disc was always viewed under a sunshade for considerable accuracy in result. The data, thus obtained were expressed as secchi disc depth in cm.

- **Chemical parameters**

4.2.6.4 Dissolved Oxygen (DO)

The dissolved oxygen concentration of water was determined by the aid of a water quality test kit (HACH kit FF-2, USA). Alkaline Iodide-Azide powder pillows, Manganous sulfate powder pillows, Sodium thiosulfate titration cartridge (0.2000 N), Starch indicator solution and Sulfamic acid powder pillows were used for determination of dissolved oxygen. The concentration of dissolved oxygen thus estimated was expressed in milligram per litter (mg/l) of water.

4.2.6.5 Hydrogen Ion concentration (pH)

Water pH of river was measured by using HACH kit (FF-2, USA). A colour disc, wide range pH (1919-00) and wide range 4 pH indicator solution were used for determination of water pH. A colour comparator disc ranging from 1-14 were also used for this purpose.

4.2.6.6 Free carbon dioxide (CO_2)

Free carbon dioxide was determined through digital titration by the help of a HACH kit (FF-2, USA). Phenolphthalein powder pillows and Sodium hydroxide titration cartridge (0.3636 N) were used for determination of free carbon dioxide. It was also expressed as mg/l of water.

4.2.6.7 Alkalinity

Alkalinity was determined through digital titration by the help of a HACH kit (FF-2, USA). Bromcresol Green-Methyl Red Powder Pillows, Phenolphthalein powder pillows and Sulfuric acid titration cartridge (0.1600 N) were used for total alkalinity determination. It was also expressed as mg/l of water.

4.2.6.8 Total hardness

Total hardness was measured by using a HACH kit (FF-2, USA). Man Ver Powder Pillow and 0.800 M EDTA titration cartridge were used for determination of total hardness. It was also expressed as mg/l of water.

4.2.6.9 Ammonia-nitrogen (NH_3-N)

Ammonia-nitrogen was measured by using a HACH kit (FF-2, USA). Rochelle salt solution and Nessler reagent were used to measure the NH_3-N. A colour comparator (value ranging from 0 to 3.0 mg/l) was also used for the same. The concentration of ammonia-nitrogen thus estimated was expressed in milligram per litter (mg/l) of water.

4.2.7 Growth monitoring

At least 10% (by number) of the fish in each cage were randomly sampled on a monthly basis by partially lifting the cage and removing fish with a dip net. On each sampling day, individual fish from each cage were weighed and measured. The purpose was to determine fish growth in weight and to adjust the ration. The following parameters were used to monitor the growth-

1. Weight gain (g)

Weight gain (g) = Mean final weight (g) – Mean initial weight (g).

2. Specific growth rate (SGR, % bwd^{-1})

$$SGR = \frac{L_n\ (\text{final weight}) - L_n\ (\text{initial weight})}{\text{Culture period}} \times 100$$

(Brown, 1957)

3. Survival rate (%)

$$\text{Survival rate}(\%) = \frac{\text{No. of fish harvested}}{\text{No. of fish stocked}} \times 100$$

4. Production/ yield of fishes

Yield (Kg /cage/cycle) = Fish biomass at harvest –fish biomass at the stock

5. Economics

In order to assess the financial viability of cage culture, economic data were collected and a simple economic analysis was conducted to determine economic returns of different treatments based on market prices in Bangladesh for harvested fishes. The total cost (variable cost and fixed cost) was calculated and total return was determined from the current market prices of harvested fish. CBR was also calculated by the following equation:

CBR= Total return / Total cost

4.2.8 Statistical analysis

All the data collected during experiment were recorded and preserved on a computer spreadsheet. Data of water quality, growth and economics were analyzed statistically by one-way analysis of variance (ANOVA) using the SPSS (Statistical Package for Social Science, version-15.0). Significance was assigned at the 0.05% level. The mean values were also compared to see the significant difference through DMRT (Duncan Multiple Range Test) after Zar (1984).

4.3 Results

4.3.1 Water quality parameters

4.3.2 Fortnightly variation

The variations in the mean values of water quality parameters in different treatments at different fortnights are presented in Table 4.1 to Table 4.8.

Water temperature varied from 17.53±0.03°C with treatment T_3 at 8th fortnight to 34.53±0.03°C with treatments T_3 at 1st fortnight. Water transparency was found to range from 15.07±0.03cm with treatment T_1 at 1st fortnight to 72.20±0.05 cm with treatment T_3 at 8th fortnight. Dissolved Oxygen of water varied from 4.75±0.08 mg/l with treatment T_1 at 5th forthright to 6.47±0.03mg/l with treatment T_3 at 1st and 2nd forthrights. pH of river water varied from 7.10±0.06 with treatment T_1 at 8th forthright to 7.87±0.03 with treatments T_2 and T_3 at 1st forthright. Free carbon dioxide was found to range from 5.03±0.03 mg/l with treatment T_3 at 8th forthright to 6.67±0.03mg/l with treatment T_1 at 1st forthright. Total alkalinity was found to range from 73.37±0.03 mg/l with treatment T_2 at 3rd forthright 85.20±0.12mg/l with treatment T_3 at 8th forthright. Water hardness was found to range from 78.00±0.58 mg/l with treatment T_2 at 1st forthright to 99.33±0.88 mg/l with treatment T_3 at 8th forthright. Ammonia-nitrogen was found in river water to range from 0.10± 0.00 mg/l with treatment T_3 at 1st forthright to 0.77± 0.03mg/l with treatment T_1 at 8th forthright.

Among the water quality parameters the values of DO at all fortnights, free CO_2 at 1st, 2nd, 3rd, 4th, 6th, 7th and 8th fortnights, and ammonia-nitrogen at 4th, 5th, 6th and 7th fortnights differed significantly among the treatments.

4.3.3 Mean variation

The mean vales of different water quality parameters in different treatments by the total of all fortnights are presented in Table 4.9 and Fig. 4.1.

The mean value of water temperature during the study period was found to be ranged from 26.18±2.40 to 26.29±2.41°C. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_3. The mean value of water transparency varied from 33.91±8.59 to 33.96 ±8.58cm. The minimum value was recorded in treatment T_1 where as the maximum value was recorded in treatment T_3. The mean value of DO varied from 5.38±0.14 to 5.95± 0.16mg/l. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_3. The mean value of water pH varied from 7.43± 0.08 to 7.50± 0.08. The minimum value was recorded in treatment T_1 where as the maximum value was recorded in treatment T_2. The mean value of free carbon dioxide varied from 5.80±0.16 to 6.00±0.16mg/l. The minimum value was recorded in treatment T_3 whereas the maximum value was recorded in treatment T_1. The mean value of total alkalinity varied from 77.89±1.22 to 81.85±1.23mg/l. The minimum value was recorded in treatment T_2 whereas the maximum value was recorded in treatment T_3. The mean value of water hardness varied from 89.02±3.41 to 91.08±3.23mg/l. The minimum value was recorded in treatment T_2 whereas the maximum value was recorded in treatment T_3. The mean value of ammonia-nitrogen varied from 0.27±0.07 to 0.49±0.10mg/l. The minimum value was recorded in treatment T_3 whereas the maximum value was recorded in treatment T_1. The mean values of DO and ammonia-nitrogen varied significantly with the treatments.

4.3.4 Fish growth

4.3.4.1 Monthly variation

Monthly variation in the mean values of growth parameters are presented in Table 4.10 to Table 4.13.

4.3.4.2 Weight gain (g/month)

The monthly weight gain of tilapia at densities of $200/1m^3$ varied from 13.80±0.06g with treatment T_1 at 4^{th} month to 25.27±0.12g with treatment T_1 at 1^{st} month. The weight gain of tilapia at densities of $150/1m^3$ varied from 15.07±0.03g with treatment T_2 at 4^{th} month to 31.07±0.03g with treatment T_2 at 1^{st} month. The weight gain of tilapia at densities of $100/1m^3$ varied from 23.07±2.67g with treatment T_3 at 4^{th} month to 42.30±0.20g with treatment T_3 at 1^{st} month. Among the different densities, the lowest monthly weight gain was found with density of $200/1m^3$ (treatment T_1) whereas the highest weight gain was found with density of 100/1m^3 (treatment T_3). Weight gain varied significantly under the different treatments in all the months.

4.3.4.3 Specific growth rate(%, bwd^{-1})

The specific growth rate (%, bwd^{-1}) of tilapia at treatment T_1 varied from 0.42±0.06 to 1.27±0.01. The minimum SGR of tilapia at treatment T_1 was recorded at 4th month whereas the maximum SGR was recorded at 1st month. The specific growth rate (%, bwd^{-1}) of tilapia at treatment T_2 varied from 0.39±0.001 to 1.82±0.003. The minimum SGR of tilapia at treatment T_2 was recorded at 4th month whereas the maximum SGR recorded at 1st month. The specific growth rate (%, bwd^{-1}) of tilapia at treatment T_3 varied from 0.49±0.006 to 2.23±0.01. The minimum SGR of tilapia at treatment T_3 was recorded at 4th month whereas the maximum SGR was recorded at 1st month. Among the different densities, the lowest SGR was found with density 200/1m^3 (treatment T_1) whereas the highest SGR was found with density 100/1m^3 (treatment T_3). SGR varied significantly under the different treatments in 1st and 2nd months.

4.3.4.4 Mean variation

The variation in the mean values of different growth parameters under the different treatments during the study period are presented in Table 4.14 and Fig. 4.2.

Weight gain (g/month)

The mean weight gain (g/month) of tilapia at different treatments of stocking densities were found as 18.59±2.48 at treatment T_1, 23.63±4.06 at treatment T_2 and 31.97±5.11 at treatment T_3.

Specific growth rate (%, bwd^{-1})

The mean specific growth rate (%, bwd^{-1}) of tilapia at different treatments of stocking densities were found as 0.86±0.21 at treatment T_1, 0.99±0.33 at treatment T_2 and 1.18±0.41 at treatment T_3.

Final weight (g)

The mean final weight of tilapia at different treatments of stocking densities were found as 115.60±0.21g at treatment T_1, 135.70±0.06g at treatment T_2 and 169.07±0.22g at treatment T_3. All the treatments varied significantly for the mean values of final weight.

Survival rate (%)

The survival rate (%) of tilapia at different treatments of stocking densities were found as 94.67±0.33 at treatment T_1, 95.13±0.43 at treatment T_2 and 96.00±0.58 at treatment T_3. No significant difference was found among the treatments for the mean values of survival rate (%).

Yield (kg/cage/cycle)

The mean yield (kg/cage/cycle) of tilapia at different treatments of stocking densities were found as 21.96±0.0.67 at treatment T_1, 19.41±0.67 at treatment T_2 and 16.22±0.58 at treatment T_3. All the treatments varied significantly for the mean values of yield (kg/cage/cycle).

4.3.5 Economics

The economics of different treatments are presented in Table 4.15 and Fig. 4.3.

The total cost (Tk/cage/cycle) of tilapia at different treatments of stocking densities (i.e. 200, 150 and 100) were found as Tk. 1886.67±3.33 at treatment T_1, Tk. 1563.33±3.33 at treatment T_2 and Tk. 1176.67±3.3 at treatment T_3. Among the different treatments, the highest total cost (Tk/cage/cycle) was recorded at treatment T_1 whereas the lowest cost (Tk/cage/cycle) was obtained at treatment T_3. Total cost varied significantly under the different treatments.

The total return (Tk/cage/cycle) of tilapia at different treatments of stocking densities (i.e. 200, 150 and 100) were found as Tk. 2520.00±0.00 (at treatment T_1), Tk.

2470.00±0.00 (at treatment T_2) and Tk. 2080.00±0.00 (at treatment T_3). Among the different treatments, the highest return (Tk/cage/cycle) was found with treatment T_1 whereas the lowest return (Tk/cage/cycle) was found with treatment T_3. Total return (Tk/cage/cycle) varied significantly under the different treatments.

The CBR of tilapia at different treatments of stocking densities (i.e. 200, 150 and 100) were found as 1.33±0.003 at treatment T_1, 1.58±0.003 at treatment T_2 and 1.77±0.01 at treatment T_3. Among the different treatments, the highest CBR was found with treatment T_3 whereas the lowest was found with treatment T_1. CBR varied significantly under the different treatments.

Table 4.1: Variations in the mean values of water quality parameters under different treatments at 1st fortnight

Treatments / Parameters	T_1	T_2	T_3
Water temperature(°C)	34.40 ± 0.06^{a}	34.50 ± 0.06^{a}	34.53 ± 0.03^{a}
Transparency (cm)	15.07 ± 0.03^{a}	15.10 ± 0.06^{a}	15.20 ± 0.06^{a}
DO (mg/l)	6.07 ± 0.03^{c}	6.27 ± 0.03^{b}	6.47 ± 0.03^{a}
Ph	7.77 ± 0.03^{a}	7.87 ± 0.03^{a}	7.87 ± 0.03^{a}
CO_2 (mg/l)	6.67 ± 0.03^{a}	6.53 ± 0.03^{b}	6.33 ± 0.03^{c}
Alkalinity (mg/l)	78.03 ± 0.03^{a}	76.13 ± 0.03^{a}	74.10 ± 0.05^{a}
Hardness (mg/l)	81.00 ± 0.58^{a}	78.00 ± 0.58^{a}	82.67 ± 0.33^{a}
NH_3-N (mg/l)	0.17 ± 0.03^{a}	0.13 ± 0.03^{a}	0.10 ± 0.00^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.2: Variations in the mean values of water quality parameters under different treatments at 2nd fortnight

Treatments / Parameters	T_1	T_2	T_3
Water temperature(°C)	33.70 ± 0.06^{a}	33.80 ± 0.06^{a}	33.80 ± 0.06^{a}
Transparency (cm)	16.23 ± 0.03^{a}	16.27 ± 0.03^{a}	16.30 ± 0.06^{a}
DO (mg/l)	5.90 ± 0.06^{c}	6.20 ± 0.06^{b}	6.47 ± 0.03^{a}
pH	7.57 ± 0.03^{a}	7.60 ± 0.05^{a}	7.67 ± 0.08^{a}
CO_2 (mg/l)	6.33 ± 0.03^{a}	6.30 ± 0.06^{ab}	6.17 ± 0.03^{b}
Alkalinity (mg/l)	79.23 ± 0.03^{a}	80.23 ± 0.06^{a}	76.23 ± 0.08^{a}
Hardness (mg/l)	91.00 ± 0.58^{a}	92.00 ± 0.58^{a}	82.67 ± 0.33^{a}
NH_3-N (mg/l)	0.17 ± 0.03^{a}	0.13 ± 0.03^{a}	0.13 ± 0.03^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.3: Variations in the mean values of water quality parameters under different treatments at 3rd fortnight

Treatments / Parameters	T_1	T_2	T_3
Water temperature(°C)	32.20 ± 0.06^{a}	32.23 ± 0.03^{a}	32.33 ± 0.03^{a}
Transparency (cm)	17.33 ± 0.03^{a}	17.37 ± 0.03^{a}	17.40 ± 0.06^{a}
DO (mg/l)	5.83 ± 0.03^{c}	6.07 ± 0.03^{b}	6.23 ± 0.03^{a}
pH	7.57 ± 0.03^{a}	7.60 ± 0.05^{a}	7.63 ± 0.03^{a}
CO_2 (mg/l)	6.23 ± 0.03^{a}	6.13 ± 0.03^{ab}	6.03 ± 0.03^{b}
Alkalinity (mg/l)	75.27 ± 0.03^{a}	73.37 ± 0.03^{a}	77.27 ± 0.06^{a}
Hardness (mg/l)	86.00 ± 0.58^{a}	82.00 ± 0.58^{a}	91.00 ± 0.58^{a}
NH_3-N (mg/l)	0.27 ± 0.03^{a}	0.20 ± 0.06^{a}	0.13 ± 0.03^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.4: Variations in the mean values of water quality parameters under different treatments at 4th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature(°C)	29.17 ± 0.09^{a}	29.20 ± 0.06^{a}	29.30 ± 0.06^{a}
Transparency (cm)	19.03 ± 0.03^{a}	19.03 ± 0.03^{a}	19.10 ± 0.05^{a}
DO (mg/l)	5.67 ± 0.03^{c}	5.90 ± 0.06^{b}	6.20 ± 0.06^{a}
pH	7.53 ± 0.03^{a}	7.63 ± 0.03^{a}	7.63 ± 0.03^{a}
CO_2 (mg/l)	6.17 ± 0.03^{a}	6.03 ± 0.03^{b}	5.97 ± 0.03^{b}
Alkalinity (mg/l)	82.03 ± 0.03^{a}	76.17 ± 0.03^{a}	79.13 ± 0.08^{a}
Hardness (mg/l)	94.00 ± 0.58^{a}	91.00 ± 0.58^{a}	89.67 ± 0.88^{a}
NH_3-N (mg/l)	0.27 ± 0.03^{a}	0.23 ± 0.03^{ab}	0.13 ± 0.03^{b}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.5: Variations in the mean values of water quality parameters under different treatments at 5th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature(°C)	23.17 ± 0.09^{a}	23.27 ± 0.03^{a}	23.33 ± 0.03^{a}
Transparency (cm)	21.23 ± 0.03^{a}	21.20 ± 0.05^{a}	21.27 ± 0.08^{a}
DO (mg/l)	4.75 ± 0.08^{b}	5.60 ± 0.06^{a}	5.80 ± 0.06^{a}
pH	7.37 ± 0.03^{a}	7.40 ± 0.05^{a}	7.23 ± 0.08^{a}
CO_2 (mg/l)	5.90 ± 0.06^{a}	5.87 ± 0.03^{a}	5.87 ± 0.03^{a}
Alkalinity (mg/l)	79.53 ± 0.03^{a}	81.53 ± 0.08^{a}	83.40 ± 0.05^{a}
Hardness (mg/l)	88.00 ± 0.58^{a}	86.00 ± 0.58^{a}	91.00 ± 0.58^{a}
NH_3-N (mg/l)	0.72 ± 0.08^{a}	0.33 ± 0.03^{b}	0.23 ± 0.03^{c}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.6: Variations in the mean values of water quality parameters under different treatments at 6th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature(°C)	20.13 ± 0.07^{a}	20.23 ± 0.03^{a}	20.23 ± 0.07^{a}
Transparency (cm)	40.13 ± 0.03^{a}	40.17 ± 0.03^{a}	40.10 ± 0.05^{a}
DO (mg/l)	4.97 ± 0.12^{b}	5.63 ± 0.03^{a}	5.77 ± 0.03^{a}
pH	7.33 ± 0.03^{a}	7.50 ± 0.05^{a}	7.43 ± 0.06^{a}
CO_2 (mg/l)	5.87 ± 0.03^{a}	5.83 ± 0.03^{ab}	5.73 ± 0.03^{b}
Alkalinity (mg/l)	78.03 ± 0.03^{a}	79.23 ± 0.03^{a}	76.23 ± 0.08^{a}
Hardness (mg/l)	91.00 ± 0.58^{a}	92.33 ± 0.33^{a}	95.33 ± 0.88^{a}
NH_3-N (mg/l)	0.74 ± 0.006^{a}	0.40 ± 0.06^{b}	0.33 ± 0.03^{b}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.7: Variations in the mean values of water quality parameters under different treatments at 7th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	$18.10±0.06^a$	$18.20±0.06^a$	$18.30±0.06^a$
Transparency (cm)	$70.10±0.06^a$	$70.13±0.03^a$	$70.17±0.08^a$
DO (mg/l)	$4.87±0.09^b$	$5.23±0.03^a$	$5.33±0.03^a$
pH	$7.17±0.03^a$	$7.27±0.08^a$	$7.23±0.08^a$
CO_2 (mg/l)	$5.47±0.03^a$	$5.37±0.03^a$	$5.23±0.03^b$
Alkalinity (mg/l)	$81.23±0.03^a$	$76.24±0.08^a$	$76.20±0.05^a$
Hardness (mg/l)	$94.00±0.58^a$	$96.67±0.88^a$	$97.00±0.58^a$
NH_3-N (mg/l)	$0.76±0.007^a$	$0.53±0.03^b$	$0.50±0.06^b$

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P <0.05$)

Table 4.8: Variations in the mean values of water quality parameters under different treatments at 8th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	$17.57±0.03^a$	$17.60±0.06^a$	$17.53±0.03^a$
Transparency (cm)	$72.13±0.03^a$	$72.20±0.05^a$	$72.10±0.05^a$
DO (mg/l)	$4.97±0.03^c$	$5.13±0.03^b$	$5.33±0.03^a$
pH	$7.10±0.06^a$	$7.13±0.08^a$	$7.20±0.12^a$
CO_2 (mg/l)	$5.33±0.03^a$	$5.23±0.03^a$	$5.03±0.03^b$
Alkalinity (mg/l)	$83.03±0.03^a$	$80.23±0.08^a$	$85.20±0.12^a$
Hardness (mg/l)	$96.00±0.58^a$	$94.10±1.15^a$	$99.33±0.88^a$
NH_3-N (mg/l)	$0.77±0.03^a$	$0.70±0.06^a$	$0.60±0.06^a$

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P <0.05$)

Table 4.9: Variations in the mean values of water quality parameters under different treatments during study period

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	$26.18±2.40^a$	$26.25±2.40^a$	$26.29±2.41^a$
Transparency (cm)	$33.91±8.59^a$	$33.93±8.60^a$	$33.96±8.58^a$
DO (mg/l)	$5.38±0.14^b$	$5.75±0.15^{ab}$	$5.95±0.16^a$
pH	$7.43±0.08^a$	$7.50±0.08^a$	$7.49±0.09^a$
CO_2 (mg/l)	$6.00±0.16^a$	$5.91±0.16^a$	$5.80±0.16^a$
Alkalinity (mg/l)	$79.55±1.21^a$	$77.89±1.22^a$	$81.85±1.23^a$
Hardness (mg/l)	$90.13±3.48^a$	$89.02±3.41^a$	$91.08±3.23^a$
NH_3-N (mg/l)	$0.49±0.10^a$	$0.33±0.07^{ab}$	$0.27±0.07^b$

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P <0.05$)

Table 4.10: Variations in the mean values of weight gain and SGR under different treatments at 1st month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	25.27±0.12^{c}	31.07±0.03^{b}	42.30±0.20^{a}
SGR (%, bwd^{-1})	1.27±0.01^{c}	1.82±0.003^{b}	2.23±0.01^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.11: Variations in the mean values of SGR and weight gain under different treatments at 2nd month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	19.13±0.09^{c}	30.03±0.09^{b}	39.20±0.10^{a}
SGR (%, bwd^{-1})	1.17±0.003^{c}	1.21±0.001^{b}	1.41±0.01^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.12: Variations in the mean values of SGR and weight gain under different treatments at 3rd month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	16.17±0.09^{b}	18.33±0.09^{ab}	23.30±2.65^{a}
SGR (%, bwd^{-1})	0.58±0.003^{a}	0.55±0.003^{a}	0.58±0.06^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.13: Variations in the mean values of SGR and weight gain under different treatments at 4th month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	13.80±0.06^{b}	15.07±0.03^{b}	23.07±2.67^{a}
SGR (%, bwd^{-1})	0.42±0.003^{a}	0.39±0.001^{a}	0.49±0.006^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.14: Variations in the mean values of growth parameters under different treatments during the study period

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g/month)	18.59±2.48^a	23.63±4.06^a	31.97±5.11^a
SGR (%, bwd^{-1})	0.86±0.21^a	0.99±0.33^a	1.18±0.41^a
Final weight (g)	115.60±0.21^c	135.70±0.06^b	169.07±0.22^a
Survival rate (%)	94.67±0.33^a	95.13±0.43^a	96.00±0.58^a
Total yield (kg/cage/cycle)	21.96±0.67^a	19.41±0.67^b	16.22±0.58^c

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 4.15. Variations in the mean values of different parameters of economics under different treatments

Parameters \ Treatments	T_1	T_2	T_3
Fixed/common cost (Tk.)			
Net	500±0.00^a	500±0.00^a	500±0.00^a
Bamboo	30±0.00^a	30±0.00^a	30±0.00^a
Rope	10±0.00^a	10±0.00^a	10±0.00^a
Labour	60±0.00^a	60±0.00^a	60±0.00^a
Sub total (Tk.)	600±0.00^a	600±0.00^a	600±0.00^a
Cost/cycle (Tk.)	100±0.00^a	100±0.00^a	100±0.00^a
Variable cost (Tk.)			
Fish seed	1000.00±0.00^a	750.00±0.00^b	500.00±0.00^c
Feed	786.67±3.33^a	713.33±3.33^b	576.67±3.33^c
Sub total (Tk.)	1786.67±3.33^a	1463.33±3.33^b	1076.67±3.33^c
Total cost (Tk.)	1886.67±3.33^a	1563.33±3.33^b	1176.67±3.33^c
Return/cage/cycle (Tk.)	2520.00±0.00^a	2470.00±0.00^b	2080.00±0.00^c
Return/cage/year (Tk.)	7560.00±0.00^a	7410.00±0.00^b	6240.00±0.00^c
CBR	1.33±0.003^c	1.58±0.003^b	1.77±0.01^a

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

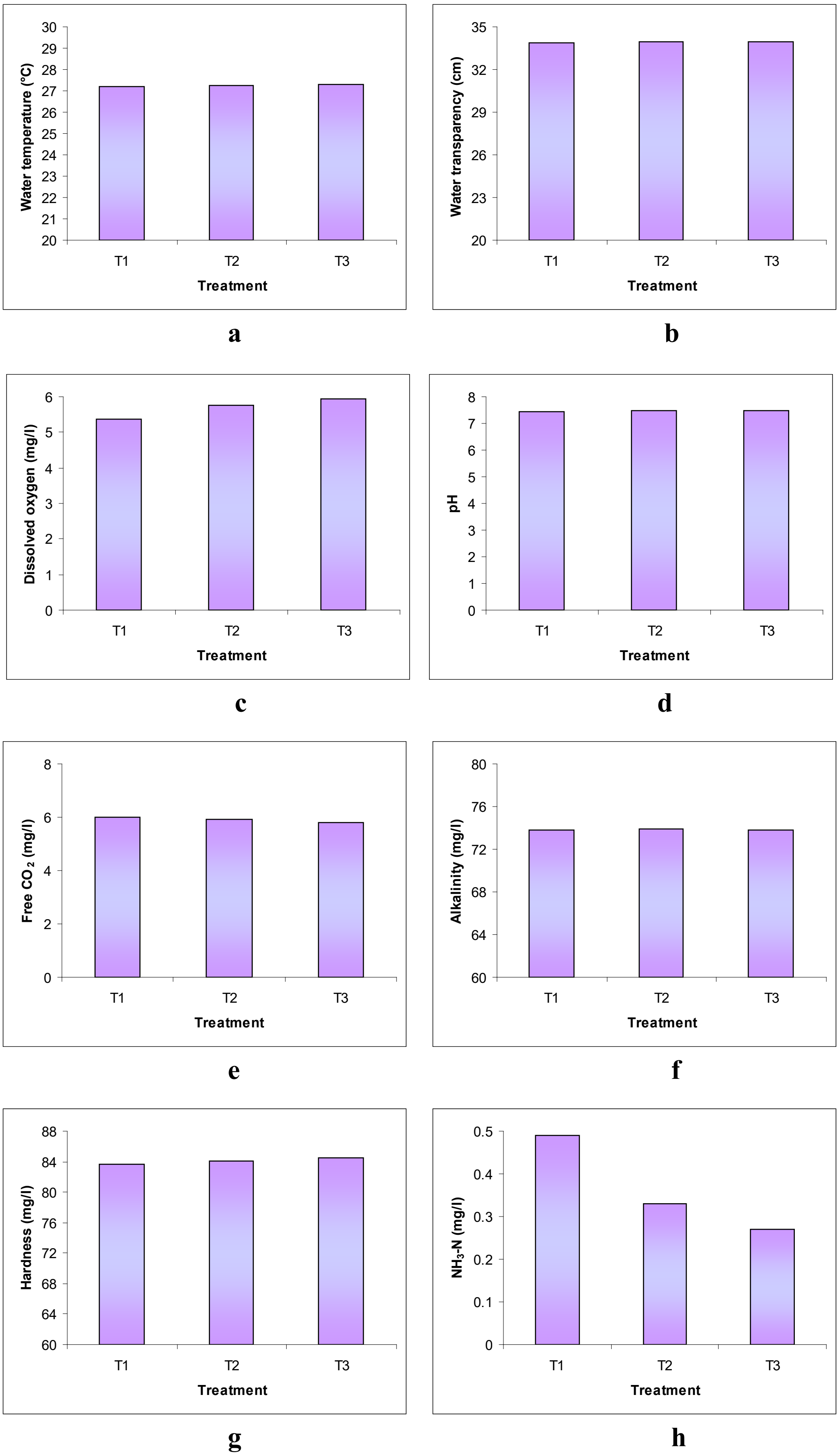
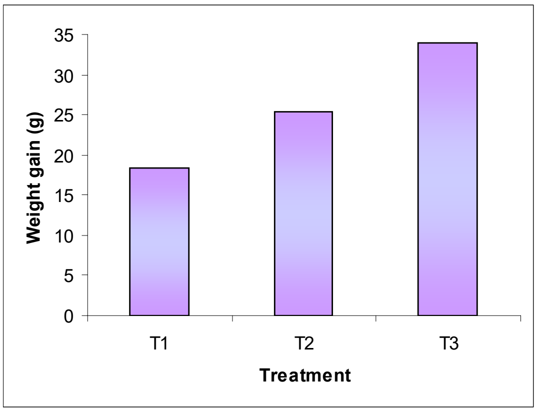
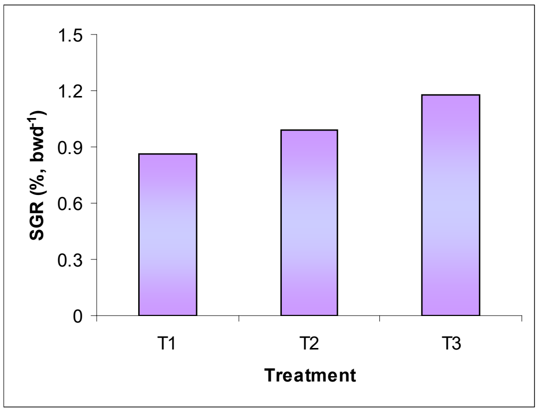
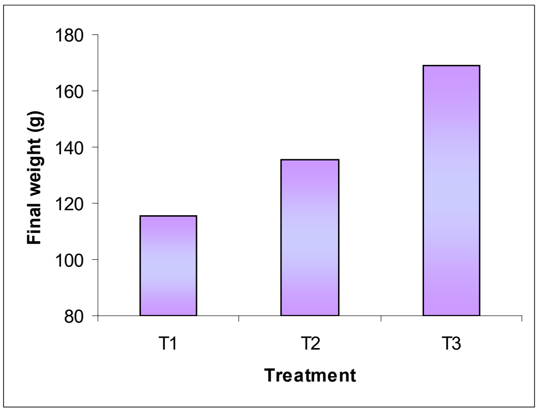


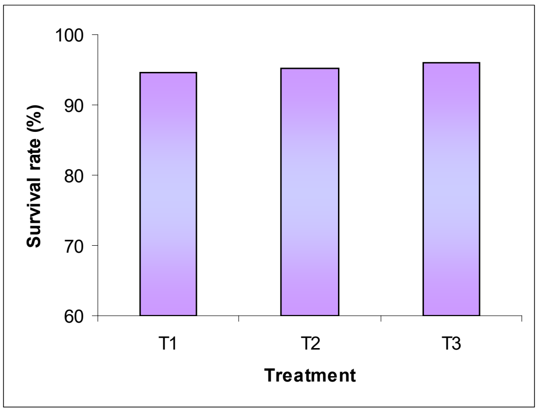
Fig. 4.1: Variations in the mean values of water quality parameters (a. water temperature; b. transparency; c. DO; d. pH; e. CO_2; f. alkalinity; g. hardness; h. NH_3-N) under different treatments during study period.



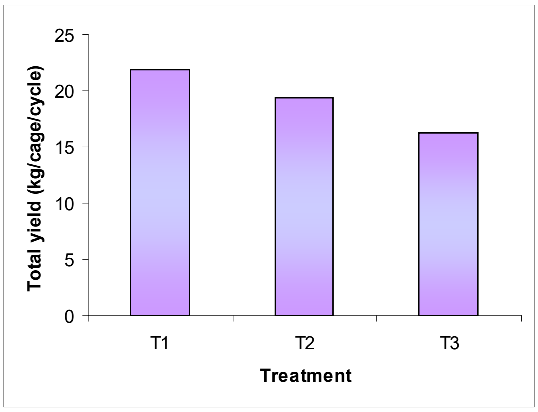


a **b**





c **d**



e

Fig. 4.2: Variations in the mean values of growth parameters (a. weight gain; b. SGR; c. final weight; d. survival rate; e. total yield) under different treatments during the study period

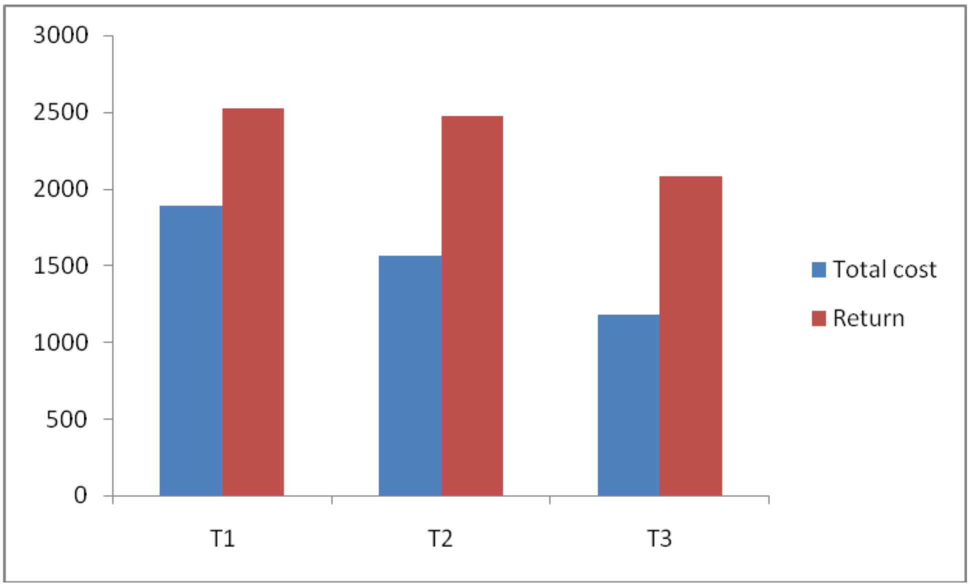


Fig. 4.3: Total cost and return under different treatments of stocking densities

4.4 Discussion

4.4.1 Water quality

4.4.2 Fortnightly variation

Temperature

In the present study, the water temperature varied from 17.53±0.03 to 34.80±0.06 °C. Temperature recorded during the experimental period is more or less similar in different treatments. The lower temperature (17.53±0.03°C) with treatment T_3 at 8^{th} fortnight (i.e. December 2009) might be due to shorter day length and cold wind indicating the influence of air temperature on water (Appendix 2).

This finding is as similar as water temperature reported by Ahmed (2004) who found 22.8 to 34.4°C in Padma river and Ahmed *et al*. (2005) who found 24.1 to 30.5°C in Meghna river. Present finding more or less agreed with Rahman *et al.* (2006) who reported the range of water temperature as 27.67±0.32 to 27.23±0.31°C. The optimum water temperature for tilapia culture is reported to be 20- 30°C or above (Islam *et al*., 2006).

Transparency

In the present study the water transparency varied from 15.07±0.06 to 72.20±0.05cm. The lowest value was recorded in 1^{st} fortnight (i.e. September) and highest in 8^{th} fortnight (i.e. December). Ahmed *et al*. (2005) found the water transparency ranged from 12 to 90cm in Meghna river. Bala *et al*. (1997) reported a transparency depth of 60 cm in a lake in June 1994.

Dissolved oxygen

The DO concentrations of the river Mahananda in cages varied from 4.75±0.08 with treatment T_1 at 5^{th} fortnight to 6.47±0.03mg/l with treatment T_3 at 1^{st} and 2^{nd} fortnight in 2009. Ahmed *et al*. (2005) in Meghna river observed DO range from 5.1 to 8.3 mg/l. Low values of DO were usually associated with organic matter (Butcher, *et al*. 1927 and Ollif, 1960). DO content, which plays a vital role in supporting aquatic life in running water, is susceptible to slight environmental changes.

pH

The values of pH in the river water ranged from 7.10±0.06 to 7.87±0.03. The highest value was recorded in the month of September at 1st forthright and lowest in December at 8th fortnight. Ahmed *et al*. (2005) obtained the vales of pH in the river Meghna ranged from 7.00-8.00. Thomas and Leonard (1995) reported that tilapia seemed to grow best in water that was near neutral or slightly alkaline. Optimal pH range for sustainable aquatic life is pH 6.5 - 8.2 (Murdock *et al.,* 2001). Aquatic organisms are affected by pH because most of their metabolic activities are pH dependent (Wang *et al*., 2002). There were no wide variations in pH values in the investigated river.

Free carbon dioxide

The values of free carbon dioxide varied from 5.03±0.03mg/l at 8th fortnight to 6.67±0.03 mg/l at 1st fortnight. The high free CO_2 content during summer was possibly due to the high temperature and heavy rainfall with heavy land drainage which speeded up the decomposition of organic matter, low photosynthetic activity which consumed free CO_2, low precipitation of free CO_2 (Islam and Bhuiyan, 2000). Ahmed *et al*. (2005) and Ashfaque (2004) recorded the free CO_2 ranged from 2.4 to 7.7 mg/l in Meghna river and 2.3±0.8 to 13.4±2.9 mg/l in Padma river, respectively. Free CO_2 is another factor that negatively affects feed intake and thereby fish growth (Tran-Duy *et al*. 2008).

Total alkalinity

The total alkalinity values obtained during the study period varied from 73.37±0.03 at 3rd fortnight 85.20±0.12 mg/l at 8th fortnight in 2009. Lowest value was recorded in the month of December and highest was in September. The findings were strongly supported with results ranged from 48.0 to 88.7 mg/l in Meghna river and 57.7±4.3 to 110.0±7.8 mg/l in Padma river found by Ahmed et. al. (2005) and Ahmed (2004), respectively. The recorded alkalinity value is also more or less similar with the findings of Sarkar *et al.* (2005) and Rahman (1999) who recorded the values ranges from 87.33-114.0 mg/l and 71.0- 175.0 mg/l, respectively. According to Boyd (1982) total alkalinity should be more than 20 mg l^{-1} in natural fertilized ponds. 77.33 to 79.33 mg/l^{-1} was acceptable for fish culture reported by Rahman *et al.* (2006).

Hardness

In the present study, the river Mahananda had the concentration of hardness ranging from 78.00±0.58mg/l at 1st fortnight to 99.33±0.88 mg/l at 8th fortnight in 2009. High concentration was recorded in the month of December and low in September. Sattar *et al* (2007) found the range of concentration of hardness from 53.33 to 124.33 mg/l at Turag river. Hossain *et al*. (1993) reported that high hardness values (75-105mg/l) were found during winter in the Bhahmaputra river due to high deposition of calcium.

Ammonia-nitrogen

Ammonia-nitrogen in river water was found to range from 0.10± 0.00 at 1st forthright to 0.77± 0.03mg/l at 8th forthright. Lowest value was recorded in the month of September and highest was in December. NH_3-N is an important parameter because very high value of it makes hazardous condition for fish. Chen (1988) found that lower than 1 mg l^{-1} of NH_3 gas content in pond was good for fish culture. Ahmed *et al.*

(2005) found the range of concentration of ammonia-nitrogen from to 0.1 to 0.8mg/l in Meghna river.

4.4.3 Mean variation

In the present study, the mean value of water temperature varied from 26.18±2.40 to 26.29±2.41°C. The average water temperature as 29.4°C was found in the Padma river observed by Ashfaque (2004), as 27.52°C in Buriganga by Islam.*et al*. (1974) and as 27.6±6.68 °C in Meghna by Ahmed *et al*. (2005). Shafi *et al*. (1978) observed average temperature as 25.8 °C of the Meghna river near Daudkaudi. Boyd (1998) reported the suitable water temperature of 25-32°C for warm water aquaculture species.

The mean value of water transparency in this study varied from 33.91±8.59cm to 34.07±8.61cm in 2009. Ahmed *et al.* (2005) found the transparency value of 34.2±1.18cm in Meghna river. Boyd (1998) reported the secchi disc reading between 30 to 45 cm as suitable for fish farming.

Mean value of dissolved oxygen content varied from 5.38±0.14 to 5.95±0.16mg/l in 2009. Ahmed *et al*. (2005) got the mean DO value as 6.7±0.8 mg/l. Banerjee (1967) and Bhuiyan (1970) reported 5.0 to 7.0 mg/l of DO content of water as fair or good in respect of productivity and water having DO less than 5 mg/l to be unproductive.

The mean value of pH varied from 7.43 ±0.08 to 7.50±0.08. Average pH value recorded as pH 7.6 by Abo-State *et al*. (2009) was suitable for tilapia culture. It was also supported by Tahoun (2007) and Khalfalla *et al.* (2008). Ahmed *et al*. (2005) recorded the mean value of pH in Meghna river as 7.8±0.18.

In the present study mean values of free CO_2 varied from 5.80±0.16 to 6.00±0.16mg/l. Result of the present study has more or less similarity with the findings of Ahmed *et al*. (2005) who obtained the CO_2 value of 4.8±0.74 mg/l in Meghna river.

The recorded mean total alkalinity varied from 77.89±1.22 to 81.85±1.23mg/l which has similarity with Ahmed (2004) who obtained the alkalinity value of 80.3±6.78 mg/l in Padma river. However, the finding also agreed with Rahman *et al*. (2006) who reported 78.5 mg /l of total alkalinity. Boyd (1998) recommended alkalinity level >20 mg/l as suitable for aquaculture.

The recorded mean total hardness varied from 89.02±3.41 to 91.08±3.23mg/l. This value in more or less similar to the findings of Ali *et al.* (2011) who got the mean value of 83.29±3.44 to 91.08±3.23 mg/l.

The recorded mean value of ammonia-nitrogen varied from 0.27±0.07 to 0.49±0.10mg/l. Ahmed *et al*. (2005) got the mean value of 0.35±0.08mg/l in Meghna river. Alam *et al.* (1997), Ali *et al.* (2011) and Asaduzzaman *et al*. (2006) who recorded ammonia nitrogen value ranged from 0.2 to 0.4, 0.29 to 0.38, and 0.203 to 0.569 mg/l, respectively.

4.4.4 Growth of fish

4.4.5 Monthly variation

Weight gain (g/month)

The monthly weight gain of tilapia varied from 13.80±0.06g with treatment T_1 at 4^{th} month to 42.30±0.20g with treatment T_3 at 1^{st} month. All the treatments varied significantly for the mean values of weight gain. The weight gain with treatment T_3 was highest in comparison to treatments T_1 and T_2 in each month. Monthly weight gain varied significantly (P<O.05) under the different treatments. The highest weight gain

was found in the month of September and the lowest value was found in the month of December. The present finding agreed with Yadav *et al*. (2007) who found mean weight gain of Nile tilapia (*O. niloticus*) in cage as 29.4 g. Chakraborty and Banerjee (2010) found 1.74±0.02g to 3.134±0.03g daily weight gain in different densities of talapia culture.

Specific growth rate (%bwd^{-1})

The mean specific growth rate (%, bwd^{-1}) of tilapia with different treatments was found to be varied from 0.39±0.003 with treatment T_2 at 4th month to 2.23±0.01 with treatment T_3 at 1st month. Significantly highest ($P<0.05$) SGR value was recorded at treatment T_3 while the lowest was obtained at T_2. The highest SGR value was found in the month of September and the lowest value was found in the month of December. Mondal *et al.* (2010) who reported mean specific growth rate (SGR) of Nile tilapia (*O. niloticus*) as 1.06%, bwd^{-1} and Freato *et al.* (2012) found mean specific growth rate of Nile tilapia (*O. niloticus*) as 1.87%, bwd^{-1}. Chakraborty and Banerjee (2010) found SGR 1.94±0.02 to 2.40±0.03 in different densities of talapia culture.

Comparatively higher values of weight gain and SGR in the month of September might be due to higher temperature causing higher metabolic activity of fishes (Boyd, 1998).

4.4.6 Mean variation

Results indicated that only yield was found highest with treatment T_1. Other parameters like SGR, weight gain, final weight and survival rate were found with highest values with treatment T_3. A moderate value of almost all the growth parameters was found with treatment T_2. These variations in growth parameters might be due to the variation in stocking densities with treatments. The mean final weight of fish were inversely proportional to stocking density, i.e. fish grown at the highest density had the lowest final mean weight. Leboute *et al.* (1994) conducted a trial with all male Nile tilapia fry, *O. niloticus* to evaluate their performance in cages, stocking with 4 different stocking densities (fish/m^3): 40, 60, 80 and 100 fish/m^3. After 5 months, mean body weight gain were 140.50, 84.10, 79.80 and 71.00 at densities of 40, 60, 80 and 100 fish/m^3, respectively. The relationships between stocking density and the growth and yield parameters obtained in the present study agreed closely Chakraborty and Banerjee (2010); Daungsawasdi *et al*. (1986) and Cruz and Ridha (1989) working on tilapia farming. Similar growth and production scenarios were also observed with cat fishes (Rahman *et al.*, 2006; Chowdhury, *et al*. 2007; Teng & Chua 1979; Hogendoom & Koops 1983; Storck & Newman 1988; Engle & Valderrama 2001) and with silver perch (Rowland, *et al*. 2004). Significantly highest ($P<0.05$) SGR value was recorded at treatment T_3 while the lowest was obtained at T_1. Diana *et al*. (2004) reported that Nile tilapia stocked at a low density showed better SGR than at a higher density. Survival rates were not significantly affected by stocking density, which is consistent with other reports on tilapia as well as other species. Leboute *et al.* (1994), for example, reported that mean survival rate was 93% of Nile tilapia. Chakraborty and Banerjee (2010); El-Sayed (1999); Islam *et al*. (2006) and Daungsawasdi *et al*. (1986) reported that the mortality of Nile tilapia raised in cages was not dependent upon stocking density. Lower weight gain and final weight as achieved in the present study under the treatment T_1 also seemed to be due to accumulation of metabolic wastage of fishes originating from increased number of fishes causing growth suppression under cage culture condition. Hepher and Pruginin (1982) reported the daily weight gain of tilapia decreased when the stocking density was increased.

4.4.7 Economics

Production estimates that are based on biomass estimates adjusted for mortality and corrected for growth gain are the basis for estimating the economic revenue from fish culture operations. There was an obvious increase in the feed and fingerling costs with increasing stocking density, which resulted in the total production cost becoming higher with higher stocking density. However, as the yield increased with increasing stocking densities, the return also increased (Table 4.15). These two parameters apparently indicate that higher stocking densities are more profit yielding than lower density for the fish.

While the final harvest and production values were directly related to stocking density, there must be some density at which the mortality is higher and the growth rate is lower; when this occurs, production will be reduced. This critical level was not reached in this experiment even at the highest stocking density of 200 fish/m^3. This suggests that the fish is able to maintain high production levels when cultured at high densities, provided that suitable physical environment and nutritional conditions are met. The performance of tilapia in this study, and the costs and revenue suggest that it may be practical and commercially viable to use cages for the production of the fish. A similar opinion based on cage culture of *O. niloticus* was given by Leboute *et al.* (1994). Raising fingerling and feed costs with increasing density resulted in the higher total cost per cage. As fish are sold at different set of price per kilogram according to the fish size, the costs per kilogram are the most important determinants in farm profitability. However, as the market size of fish is sometimes an important concern, higher stocking densities may not always be suitable because individual growth rates of fish are reduced after a threshold limit of stocking density, and smaller individuals are produced after that limit. Thus, even though higher yields are produced at higher densities, farm profitability may be higher at density that produces the largest individuals, determined by the consumers choice on fish size. In the present study, the growth rate was maximum at 100 fish/m^3 cage and then reduced consistently with stocking density. However, farm return was maximum and CBR was minimum at 200 fish/m^3 cage, but moderate return was found at 150 fish/m^3 cage. This study clearly documents moderate yields, moderate production costs and moderate CBR/profitability with tilapia culture at moderate stocking densities in cages; this finding indicates that the density of 150 fingerling/m^3 (treatment T_2) produces the suitable farm output and is the moderately profitable among the densities tested. These findings more or less agreed with Rahman *et al*. (2006) who reported highest economic performance while working with *Pangasius sutchi* at a density of 150 individuals/m^3 cages. However, it does not indicate the upper limit of stocking densities for tilapia cultured in a cage system. Additional experiments could be conducted to determine the dietary protein level feed of tilapia in cages and resulting in the best possible farm economics.

4.5 Conclusion

It can be concluded that among the different parameters significant variation specially with DO was found with the treatments with almost all fortnights. Comparatively less value of DO was obtained with the treatment T_1 (ie. Higher stocking density). Comparatively higher value of NH_3-N and CO_2 was also found with the treatment T_1. Moderate yield and CBR was found with treatment T_2. In spite of having highest yield, CBR was found lowest with treatment T_1 (ie. Highest stocking density). Based on the environmental factors, production and economics, the optimum stocking density is found with treatment T_2.

4.6 Recommendation

Based on the present findings, it is recommended to conduct further research to optimize the dietary protein level for cage farming of *O. niloticus* in river ecosystem.

Chapter Five

OPTIMIZATION OF DIETARY PROTEIN LEVEL FOR CAGE FARMING OF *OREOCHROMIS NILOTICUS* IN RIVER ECOSYSTEM

5.1 Introduction

Growth, health and reproduction of fish and other aquatic animals are primarily dependent upon an adequate supply of nutrient, both in terms of quantity and quality, irrespective of the culture system in which they are grown. Supply of inputs (feeds, fertilizers etc.) has to be ensured so that the nutrients and energy requirements of the species under cultivation are met and the production goals of the system are achieved. Complete data on nutrient requirements are only available for a limited number of fish species. Protein requirements for different fish species range from 25 to 56 percent of dry diets(Table 5.1). Apparently, marine and freshwater carnivorous species require 40-55 percent dietary protein, while most freshwater omnivorous and herbivorous species require 30-40 percent of their dry diet to be made up of protein. Like finfish, most crustaceans studied to date have rather high protein requirements, ranging from 30 to 57 percent of the dry diet (Table 5.2).

Table 5.1: Dietary protein and energy levels resulting in highest growth rates in various fish species (% of dry diet)

Fish species	Crude dietary protein (%)	Gross dietary energy (kJ/g)	Protein to energy ratio (mg/kJ)
Chinook salmon (*Oncorhynchus tshawytscha*)	40-55		
Coho salmon (*Oncorhynchus kisutch*)	40		
Sockeye salmon (*Oncorhynchus nerka*)	45		
Rainbow trout (*Oncorhynchus mykiss*)	40-45	19.1-20.8	20.5-22.5
	40		
	45		
Estuary grouper (Epinephelus salmoides)	40-50	14.3	35.1
Gilthead bream (*Pagrus major*)	40	22.5	17.7
Largemouth bass (*Micropterus salmonides*)	40	18.3	21.9
Smallmouth bass (Micropterus *dolomieu*)	45	18.4	24.4
Stripped bass (*Morone* saxatilits)	47-55	24.8	22.2
Plaice(*Pleuronectes platessa*)	50		
Puffer fish (*Fugu rubripes*)	50		
Yellow tail (*Seriola* quinqueradiata)	55		
Japanese eel (*Anguillia japonics*)	44.5		
Snakehead (*Channa micropeltes*)	52		
African catfish (*Clarias gariepinus*)	40	18.6	21.5
Asian catfish (*Clarias batrachus*)	30		
Channel catfish (*Ictalurus punctatus*)	35-40	11.5-16.9	20.3-22.2
Pangas catfish (*Pangasius sutchi*)	25		
Green catfish (*Mystus* nemurus)	42		
Stinging catfish (*Heteropneustes fossilis*)*	27.7-35.4		
Common carp (*Cyprinus carpio*)	31-40.6	12.8-22.7	15.3-29.6
Indian major carp (*Labeo rohita*)**	34-36	15.5	18.5
Tilapia (*Oreochromis aureus*) fingerling	34-36	13.4	20.5
Tilapia (*Oreochromis aureus*) fry	56	19.3	27.5
Tilapia (*Oreochromis mossambicus*)	40		
Tilapia (*Oreochromis niloticus*)	30		
Tilapia (*Tilapia zilli*)	35	21.5	16.0
Red tilapia (*Oreochromis* sp.)	34.4		
Tilapia hybrid (*O. niloticus* × *O. aureus*)	30-35	17.3	30.3
Grass carp (*Ctenopharyngodon idella*) fry	41-43		
Grass carp (*Ctenopharyngodon idella*) fingerling	23-28		
Mullet (*Mugil capito*)	28		
Milk fish (*Chanos chanos*) fry	40	15.3	26.3

Data adapted from Hepher (1990), Tacon (1990) and De Silva and Anderson (1995), *Akand *et al*. (1989), **Akand *et al*. (1991) and Hasan *et al*. (1996).

Table 5.2: Dietary protein levels resulting in highest growth rates in prawn and shrimp

Species	Crude dietary protein
Prawn *Macrobrachium*	35-40
Shrimp *Penaeus indicus*	30-40
Penaeus aztecus	40-51
Penaeus setiferus	28.32
Penaeus merguiensis	34-42
Penaeus monodon	34-46
Penaeus japonicas	40-57
Palaemon serratus	30-40

Adapted from Tacon (1990)

Tilapias are considered as the best species for culture because of their high tolerance to adverse environmental conditions, their relatively fast growth and they could be easily breed (El-Sayed, 1999). Tilapia intensive culture would require the formulation of efficient food with optimum potency to meet the protein requirements in fish culture during grow-out period (Kenawy, 1993). Protein is the main constituent of the fish body thus sufficient dietary supply is needed for optimum growth. Protein is the most expensive macronutrient in fish diet (Pillay, 1990). So, the amount of protein in the diet should be just enough for fish growth where the excess protein in fish diets may be wasteful and cause diets to be unnecessarily expensive (Ahmad, 2000). Reducing feeding costs could be a key factor for successful development of aquaculture. Protein requirements for optimum growth of the fish seem to be affected by numerous factors such as temperature, salinity, fish age and size, etc. (Cowey, 1976). Most studies are confined to fry and young tilapia, although the supplementary feed is used during grow-out phase. Furthermore, understanding the protein requirement during the grow-out period is an important thing in fish culture management. Realization of the optimum protein level for cultured fish would help reduce the costs and maximize the feed conversion efficiency (Charles *et al.*, 1984; Sampath, 1984; Chiu *et al.*, 1987).

Therefore, the present study aimed at optimizing the dietary protein level for farming of Nile tilapia, *Oreochromis niloticus* in cage in river ecosystem. The specific objectives of this study were as follows:

i. to monitor the water quality parameters under different treatments of dietary protein level;

ii. to monitor the fish growth performance in terms of weight gain, SGR, survival rate, final weight and yield under different treatments of dietary protein level;

iii. to evaluate the economics of tilapia farming in cage under different treatments of dietary protein level; and

iv. to recommend suitable protein level feed for small scale cage farming of tilapia in river ecosystem.

5.2 Materials and methods

5.2.1 Duration and location of the study

The experiment was conducted for the period of four months cycle from September 2010 to December 2010.

The study site was located at Nachipur fisherman Pallai adjacent to Mahananda River in Chapainawabganj district, Bangladesh. The Mahananda River flows through two Indian states- West Bengal and Bihar, and then Bangladesh. The Mahananda originates from the Himalayas Mahaldiram hill near Chimli, east of Kurseong in Darjeeling district of India at an elevation of 2,100 meters. It enters into Bangladesh near Tetulia in Panchagarh District, flows for 3 kilometres after Tetulia and returns back to India. After flowing through Uttar Dinajpur district in West Bengal and Kishanganj district in Bihar, it enters into Maldah district in West Bengal. Finally, it joins the Ganges/Padma in Chapainawabganj district in Bangladesh

5.2.2 Experimental design

Three different protein levels were tested under three treatments namely T_1, T_2 and T_3 each having three replications.

T_1: 25% protein level feed

T_2: 30% protein level feed

T_3: 35% protein level feed

Tilapia stocking density (150 fish/m^3 cage) was same for all the treatments.

5.2.3 Cage description

The study was carried out in a river using cages (1m x 1m x 1m) made of knotless, high-density polyethylene netting of 0.5mm mesh size. The submerged volume of each cage was $1m^3$. Cage frames were made of bamboo bars. The cages were suspended from a bamboo structure fixed by cotton nylon cords to a walkway from the shore. Plastic bottles were attached along the four corners of each cage to keep them floating

5.2.4 Stocking of fingerlings

The fingerlings of *O. niloticus* (initial stocking weight 41.0 g) were collected from a rearing pond located at Nachole. Fingerlings were brought to the experimental site through oxygenated polythene bag. Fingerlings were acclimatized by letting the transport bags float in the fish cage for about 30 minutes, after which letting the fingerlings get out freely from the bags. The fishes were randomly released into different replicates of three treatments. Fish were stocked early in the morning when the water was cool.

5.2.5 Feeding

A commercial pellet feed (Quality feed, Dhaka, Bangladesh) with 25%, 30% and 35% crude protein content was used. Fish were hand-fed using feeding trays at10% of body weight at the start of the feeding trial. Feeding level was reduced to 5% of body weight by the end of the trial. Fish were fed twice a day at 09:00-10:00 hours and at 05:00-06:00 hours with 50% of the ration allocated at each time. Feed quantity was adjusted every month according to fish biomass determined by sub sampling. The cage nets and feeding trays were cleaned in each week.

5.2.6 Water quality monitoring

5.2.6.1 Monitoring of physico-chemical parameters

Water quality parameters of the experimental river namely water temperature, transparency, dissolved oxygen (DO), hydrogen ion concentration (pH), free carbon dioxide (CO_2), alkalinity, total hardness and ammonia-nitrogen (NH_3-N) were studied fortnightly between 10 am to 11 am for the present study.

- **Physical parameters**

5.2.6.2 Water temperature

Water temperature was measured by the help of a Celsius thermometer at 20 to 30 cm water depth. The temperature was expressed as °C.

5.2.6.3 Water transparency

Transparency of water was measured by a secchi disc. The secchi disc was slowly lowered into the water on a graduated line and the depth at which it became invisible was noted. The sinking of the disc was always viewed under a sunshade for considerable accuracy in result. The data, thus obtained were expressed as secchi disc depth in cm.

- **Chemical parameters**

5.2.6.4 Dissolved Oxygen (DO)

The dissolved oxygen concentration of water was determined by the aid of a water quality test kit (HACH kit FF-2, USA). Alkaline Iodide-Azide powder pillows, Manganous sulfate powder pillows, Sodium thiosulfate titration cartridge (0.2000 N), Starch indicator solution and Sulfamic acid powder pillows were used for determination of dissolved oxygen. The concentration of dissolved oxygen thus estimated was expressed in milligram per litter (mg/l) of water.

5.2.6.5 Hydrogen Ion concentration (pH)

Water pH of river was measured by using HACH kit (FF-2, USA). A colour disc, wide range pH (1919-00) and wide range 4 pH indicator solution were used for determination of water pH. A colour comparator disc ranging from 1-14 were also used for this purpose.

5.2.6.6 Free carbon dioxide (CO_2)

Free carbon dioxide was determined through digital titration by the help of a HACH kit (FF-2, USA). Phenolphthalein powder pillows and Sodium hydroxide titration cartridge (0.3636 N) were used for determination of free carbon dioxide. It was also expressed as mg/l of water.

5.2.6.7 Alkalinity

Alkalinity was determined through digital titration by the help of a HACH kit (FF-2, USA). Bromcresol Green-Methyl Red Powder Pillows, Phenolphthalein powder pillows and Sulfuric acid titration cartridge (0.1600 N) were used for total alkalinity determination. It was also expressed as mg/l of water.

5.2.6.8 Total hardness

Total hardness was measured by using a HACH kit (FF-2, USA). Man Ver Powder Pillow and 0.800 M EDTA titration cartridge were used for determination of total hardness. It was also expressed as mg/l of water.

5.2.6.9 Ammonia-nitrogen (NH_3-N)

Ammonia-nitrogen was measured by using a HACH kit (FF-2, USA). Rochelle salt solution and Nessler reagent were used to measure the NH_3-N. A colour comparator (value ranging from 0 to 3.0 mg/l) was also used for the same. The concentration of ammonia-nitrogen thus estimated was expressed in milligram per litter (mg/l) of water.

5.2.7 Growth monitoring

At least 10% (by number) of the fish in each cage were randomly sampled on a monthly basis by partially lifting the cage and removing fish with a dip net. On each sampling day, individual fish from each cage were weighed and measured. The purpose was to determine fish growth in weight and to adjust the ration. The following parameters were used to monitor the growth-

1. Weight gain (g/)

Weight gain (g) = Mean final weight (g) – Mean initial weight (g).

2. Specific growth rate (SGR, % bwd^{-1})

$$SGR = \frac{L_n\ (\text{final weight}) - L_n\ (\text{initial weight})}{\text{Culture period}} \times 100$$

(Brown, 1957)

3. Survival rate (%)

$$\text{Survival rate}(\%) = \frac{\text{No. of fish harvested}}{\text{No. of fish stocked}} \times 100$$

4. Production/ yield of fishes

Yield (Kg /cage/cycle) = Fish biomass at harvest –fish biomass at the stock

5. Economics

In order to assess the financial viability of cage culture, economic data were collected and a simple economic analysis was conducted to determine economic returns of different treatments based on market prices in Bangladesh for harvested fishes. The total cost (variable cost and fixed cost) was calculated and total return was determined from the current market prices of harvested fish. CBR was also calculated by the following equation:

CBR= Total return / Total cost

5.2.8 Statistical analysis

All the data collected during experiment were recorded and preserved on a computer spreadsheet. Data of water quality, growth and economics were analyzed statistically by one-way analysis of variance (ANOVA) using the SPSS (Statistical Package for Social Science, version-15.0). Significance was assigned at the 0.05% level. The mean values were also compared to see the significant difference through DMRT (Duncan Multiple Range Test) after Zar (1984).

5.3 Results

Water quality parameters

5.3.1 Fortnightly variation

The variations in the mean values of water quality parameters in different treatments at different fortnights are presented in Table 5.3 to Table 5.10.

Water temperature varied from 16.53±0.03°C with treatment T_3 at 8^{th} fortnight to 33.47±0.03°C with treatment T_2 at 1^{st} fortnight. Water transparency was found to range from 14.07±0.09cm with treatment T_1 at 1^{st} fortnight to 70.53±0.03cm with treatment T_3 at 8^{th} fortnight. Dissolved oxygen of water varied from 4.10±0.06mg/l with treatment T_1 at 8^{th} forthright to 6.33±0.03mg/l with treatment T_3 at 2^{nd} forthright. pH of river water varied from 6.93±0.12 with treatment T_1 at 8^{th} forthright to 7.67±0.09 with treatment T_2 at 1^{st} forthright. Free carbon dioxide was found to range from 5.03±0.03mg/l with treatment T_3 at 8^{th} forthright to 6.77±0.03mg/l with treatment T_1 at 1^{st} forthright. Total alkalinity was found to range from 76.23±0.03 mg/l with treatment T_1 at 1^{st} forthright to 89.47±0.12mg/l with treatment T_3 at 8^{th} forthright. Water hardness was found to range from 77.12±0.58 mg/l with treatment T_1 at 1^{st} forthright to 101.33±0.33mg/l with treatment T_3 at 8^{th} forthright. Ammonia-nitrogen in river water was found to range from 0.17± 0.03 mg/l with treatment T_3 at 1^{st} forthright to 0.87± 0.03mg/l with treatment T_1 at 8^{th} forthright.

Among the water quality parameters the values of transparency (at 3^{rd}, 6^{th}, 7^{th} and 8^{th} fortnights), Dissolved Oxygen (at 2^{nd}, 3^{rd}, 6^{th}, 7^{th} and 8^{th} fortnights), free CO_2 (at 4^{th}, 5^{th}, 6^{th}, 7^{th} and 8^{th} fortnights) and NH_3-N (at 3^{rd}, 4^{th}, 5^{th}, 6^{th}, 7^{th} and 8^{th} fortnights) differed significantly among the treatments.

5.3.2 Mean variation

The mean values of different water quality parameters in different treatments by the total of all fortnights are presented in Table 5.11 and Fig. 5.1.

The mean value of water temperature during the study period was found to be ranged from 26.12±2.12 to 26.20±2.33°C. The minimum value was recorded in treatment T_3 whereas the maximum value was recorded in treatment T_1. The mean value of water transparency varied from 32.49±8.04 to 32.78 ±8.13cm. The minimum value was recorded in treatment T_1 where as the maximum value was recorded in treatment T_3. The mean value of DO varied from 5.42±0.24 to 5.80± 0.20mg/l. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_3. The mean value of water pH varied from 7.28± 0.09 to 7.41± 0.08. The minimum value was recorded in treatment T_1 where as the maximum value was recorded in treatment T_3. The mean value of free carbon dioxide varied from 5.70±0.20 to 5.97±0.18mg/l. The minimum value was recorded in treatment T_3 whereas the maximum value was recorded in treatment T_1. The mean value of total alkalinity varied from 85.32±1.08 to 89.45±1.07 mg/l. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_3. The mean value of water hardness varied from 95.35±3.65 to 97.81±3.61mg/l. The minimum value was recorded in treatment T_1 whereas the maximum value was recorded in treatment T_2. The mean value of ammonia-nitrogen varied from 0.41±0.06 to 0.59±0.07mg/l. The minimum value was recorded in treatment T_3 whereas the maximum value was recorded in treatment T_1. No significant variation was found among the treatments for the mean values of all the water quality parameters.

5.3.3 Fish growth

5.3.3.1 Monthly variation

Monthly variations in the mean values of growth parameters are presented in Table 5.12 to Table 5.15.

Weight gain (g)

The monthly weight gain of tilapia with treatment T_1 varied from 15.50±0.25g at 4th month to 30.47±0.20g at 1st month. The weight gain with treatment T_2 varied from 18.93±0.22g at 3rd month to 35.50±0.40g at 1st month. The weight gain with treatment T_3 varied from 24.93±0.32g at 3rd month to 40.50±0.29g at 1st month. Among the different treatments, the lowest monthly weight gain was found with treatment T_1 whereas the highest weight gain was found with treatment T_3. Weight gain varied significantly under the different treatments in all the months.

Specific growth rate (%, bwd^{-1})

The specific growth rate (%, bwd^{-1}) of tilapia with treatment T_1 varied from 0.46±0.01 to 2.08±0.01. The minimum SGR was recorded with treatment T_1 at 4th month whereas the maximum SGR recorded with treatment T_1 at 1st month. The specific growth rate (%, bwd^{-1}) of tilapia with treatment T_2 varied from 0.51±0.02 to 2.33±0.02. The minimum SGR was recorded with treatment T_2 at 4th month whereas the maximum SGR recorded with treatment T_2 at 1st month. The specific growth rate (%, bwd^{-1}) of tilapia with treatment T_3 varied from 0.58±0.01 to 2.55±0.01. The minimum SGR was recorded with treatment T_3 at 4th month whereas the maximum SGR recorded with treatment T_3 at 1st month. Among the different treatments in same species, the lowest monthly SGR was found with treatment T_1 whereas the highest SGR was found with treatment T_3. SGR varied significantly under the different treatments in different months.

5.3.3.2. Mean variation

The variations in the mean values of different growth parameters under the different treatments during the study period are presented in Table 5.16 and Fig. 5.2.

Weight gain (g/month)

The mean weight gain(g/month) of tilapia at different treatments of dietary protein level were found as 21.35±3.20g at treatment T_1, 24.63±3.90g at treatment T_2 and 31.29±3.70g at treatment T_3.

Specific growth rate (%, bwd^{-1})

The mean specific growth rate (%, bwd^{-1}) of tilapia at different treatments of dietary protein level were found as 1.03±0.36 at treatment T_1, 1.11±0.42 at treatment T_2 and 1.26±0.45 at treatment T_3.

Final weight (g)

The mean final weight of tilapia at different treatments of dietary protein level were found as 120.50±0.29g at treatment T_1, 133.63±0.41g at treatment T_2 and 160.33±0.33g at treatment T_3. All the treatments varied significantly for the mean values of final weight.

Survival rate (%)

The survival rate (%) of tilapia at different treatments of dietary protein level were found as 93.78±0.22 at treatment T_1, 94.00±0.39 at treatment T_2 and 94.89±0.22 at treatment T_3. No significant difference was found among the treatments for the mean values of survival rate (%).

Yield (kg/cage/cycle)

The mean yield (kg/cage/cycle) of tilapia at different treatments of dietary protein level were found as 16.95±0.08 at treatment T_1, 18.84±0.13 at treatment T_2 and

22.82±0.05 at treatment T_3. All the treatments varied significantly for the mean values of yield (kg/cage/cycle).

5.3.4 Economics

The economics of different treatments are presented in Table 5.17 and Fig. 5.3.

The total cost (Tk/cage/cycle) of tilapia at different treatments of dietary protein level were found as Tk. 862.50±0.00 at treatment T_1, Tk. 1037.50±0.00 at treatment T_2 and Tk. 1212.50±0.00 at treatment T_3. Among the different treatments, the highest cost (Tk/cage/cycle) was found with treatment T_3 whereas the lowest cost was found with treatment T_1. Total cost (Tk/cage/cycle) varied significantly under the different treatments.

The total return (Tk/cage/cycle) of tilapia at different treatments of dietary protein level were found as Tk. 1708.28±7.73 at treatment T_1, Tk. 2056.88±14.59 at treatment T_2 and Tk. 2875.32±6.34 at treatment T_3. Among the different treatments, the highest return (Tk/cage/cycle) was found with treatment T_3 whereas the lowest return was found with treatment T_1. Total return (Tk/cage/cycle) varied significantly under the different treatments.

The CBR of tilapia at different treatments of dietary protein level were found as 1.98±0.01 at treatment T_1, 1.98±0.01 at treatment T_2 and 2.37±0.01 at treatment T_3. Among the different treatments, the highest CBR was found with treatment T_3 whereas the lowest was found with treatment T_1 and treatment T_2. CBR varied significantly under the different treatments.

Table 5.3: Variations in the mean values of water quality parameters under different treatments at 1st fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	33.40±0.07[a]	33.47±0.03[a]	33.30±0.06[a]
Transparency (cm)	14.07±0.09[a]	14.10±0.06[a]	14.27±0.03[a]
DO (mg/l)	6.17±0.03[a]	6.27±0.03[a]	6.20±0.06[a]
pH	7.63±0.03[a]	7.67±0.09[a]	7.65±0.15[a]
CO_2 (mg/l)	6.77±0.03[a]	6.73±0.03[a]	6.65±0.03[a]
Alkalinity (mg/l)	76.23±0.03[a]	79.33±0.03[a]	81.40±0.10[a]
Hardness (mg/l)	77.12±0.58[a]	77.33±0.33[a]	79.02±0.33[a]
NH_3-N (mg/l)	0.19±0.03[a]	0.22±0.03[a]	0.17±0.21[a]

Table 5.4: Variations in the mean values of water quality parameters under different treatments at 2nd fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	33.50±0.06[a]	33.43±0.03[a]	33.37±0.04[a]
Transparency (cm)	15.43±0.12[a]	15.50±0.15[a]	15.33±0.18[a]
DO (mg/l)	6.03±0.03[b]	6.23±0.03[a]	6.33±0.03[a]
pH	7.43±0.03[a]	7.50±0.06[a]	7.57±0.09[a]
CO_2 (mg/l)	6.47±0.03[a]	6.42±0.03[a]	6.40±0.06[a]
Alkalinity (mg/l)	79.37±0.07[a]	77.43±0.03[a]	76.69±0.06[a]
Hardness (mg/l)	78.00±0.58[a]	79.67±0.33[a]	76.14±0.58[a]
NH_3-N (mg/l)	0.37±0.03[a]	0.28±0.04[a]	0.30±0.06[a]

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.5: Variations in the mean values of water quality parameters under different treatments at 3rd fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	30.30±0.06[a]	30.27±0.03[a]	30.23±0.02[a]
Transparency (cm)	17.80±0.06[a]	18.03±0.03[b]	18.20±0.06[b]
DO (mg/l)	5.83±0.03[c]	6.07±0.03[b]	6.23±0.03[a]
pH	7.50±0.06[a]	7.53±0.03[a]	7.63±0.03[a]
CO_2 (mg/l)	6.27±0.03[a]	6.20±0.06[a]	6.17±0.09[a]
Alkalinity (mg/l)	79.67±0.09[a]	77.73±0.03[a]	81.82±0.02[a]
Hardness (mg/l)	79.00±1.15[a]	81.67±1.20[a]	82.33±0.33[a]
NH_3-N (mg/l)	0.47±0.03[a]	0.37±0.03[ab]	0.27±0.03[b]

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.6: Variations in the mean values of water quality parameters under different treatments at 4th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	28.17±0.09^{a}	28.20±0.06^{a}	28.13±0.03^{a}
Transparency (cm)	19.30±0.06^{a}	19.47±0.03^{a}	19.37±0.09^{a}
DO (mg/l)	5.63±0.03^{c}	5.87±0.03^{b}	6.03±0.03^{a}
pH	7.40±0.06^{a}	7.43±0.03^{a}	7.53±0.03^{a}
CO_2 (mg/l)	6.07±0.03^{a}	5.93±0.03^{b}	5.77±0.03^{c}
Alkalinity (mg/l)	77.47±0.07^{a}	81.57±0.03^{a}	79.63±0.07^{a}
Hardness (mg/l)	83.00±0.58^{a}	85.00±0.58^{a}	86.00±0.60^{a}
NH_3-N (mg/l)	0.53±0.03^{a}	0.43±0.03^{ab}	0.33±0.03^{c}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.7: Variations in the mean values of water quality parameters under different treatments at 5th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	27.10±0.06^{a}	27.10±0.06^{a}	27.03±0.03^{a}
Transparency (cm)	22.17±0.09^{a}	22.17±0.06^{a}	22.27±0.03^{a}
DO (mg/l)	5.50±0.06^{b}	5.73±0.03^{a}	5.87±0.03^{a}
pH	7.13±0.03^{a}	7.27±0.09^{a}	7.33±0.07^{a}
CO_2 (mg/l)	5.83±0.03^{a}	5.67±0.03^{b}	5.50±0.06^{c}
Alkalinity (mg/l)	77.45±0.13^{a}	79.42±0.06^{a}	81.60±0.06^{a}
Hardness (mg/l)	89.67±1.45^{a}	91.83±0.44^{a}	93.83±1.16^{a}
NH_3-N (mg/l)	0.63±0.03^{a}	0.53±0.03^{ab}	0.43±0.03^{b}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.8: Variations in the mean values of water quality parameters under different treatments at 6th fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	22.10±0.06^{a}	22.13±0.07^{a}	22.07±0.03^{a}
Transparency (cm)	35.80±0.06^{b}	36.10±0.06^{a}	36.20±0.06^{a}
DO (mg/l)	5.23±0.03^{c}	5.53±0.03^{b}	5.77±0.03^{a}
pH	7.20±0.06^{a}	7.23±0.03^{a}	7.33±0.04^{a}
CO_2 (mg/l)	5.63±0.03^{a}	5.43±0.03^{b}	5.23±0.03^{c}
Alkalinity (mg/l)	78.65±0.09^{a}	76.67±0.03^{a}	79.77±0.03^{a}
Hardness (mg/l)	97.47±0.29^{a}	95.33±0.88^{a}	99.33±0.33^{a}
NH_3-N (mg/l)	0.73±0.03^{a}	0.67±0.03^{a}	0.47±0.03^{b}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.9: Variations in the mean values of water quality parameters under different treatments at 7[th] fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	18.40 ± 0.06^a	18.43 ± 0.03^a	18.33 ± 0.03^a
Transparency (cm)	65.23 ± 0.12^c	65.80 ± 0.06^b	66.10 ± 0.06^a
DO (mg/l)	4.83 ± 0.03^c	5.10 ± 0.06^b	5.33 ± 0.03^a
pH	7.03 ± 0.09^a	7.13 ± 0.03^a	7.10 ± 0.10^a
CO_2 (mg/l)	5.47 ± 0.03^a	5.33 ± 0.03^b	5.13 ± 0.03^c
Alkalinity (mg/l)	83.27 ± 0.03^a	84.37 ± 0.09^a	85.43 ± 0.12^a
Hardness (mg/l)	99.17 ± 0.60^a	97.67 ± 0.67^a	98.00 ± 0.29^a
NH_3-N (mg/l)	0.77 ± 0.03^a	0.73 ± 0.03^a	0.57 ± 0.03^b

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.10: Variations in the mean values of water quality parameters under different treatments at 8[th] fortnight

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	16.60 ± 0.06^a	16.56 ± 0.02^a	16.53 ± 0.03^a
Transparency (cm)	70.10 ± 0.06^c	70.37 ± 0.03^b	70.53 ± 0.03^a
DO (mg/l)	4.10 ± 0.06^c	4.40 ± 0.06^b	4.63 ± 0.03^a
pH	6.93 ± 0.12^a	7.03 ± 0.03^a	7.13 ± 0.03^a
CO_2 (mg/l)	5.27 ± 0.03^a	5.13 ± 0.03^b	5.03 ± 0.03^b
Alkalinity (mg/l)	85.47 ± 0.03^a	86.53 ± 0.07^a	89.47 ± 0.12^a
Hardness (mg/l)	98.50 ± 0.29^a	99.00 ± 0.58^a	101.33 ± 0.34^a
NH_3-N (mg/l)	0.87 ± 0.03^a	0.75 ± 0.03^b	0.73 ± 0.03^b

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.11: Variations in the mean values of water quality parameters under different treatments during study period

Parameters \ Treatments	T_1	T_2	T_3
Water temperature (°C)	26.20 ± 2.33^a	26.18 ± 1.93^a	$26.12\pm.2.12^a$
Transparency (cm)	32.49 ± 8.04^a	32.69 ± 8.09^a	32.78 ± 8.13^a
DO (mg/l)	5.42 ± 0.24^a	5.65 ± 0.22^a	5.80 ± 0.20^a
pH	7.28 ± 0.09^a	7.35 ± 0.08^a	7.41 ± 0.08^a
CO_2 (mg/l)	5.97 ± 0.18^a	5.84 ± 0.19^a	5.70 ± 0.20^a
Alkalinity (mg/l)	85.32 ± 1.08^a	87.38 ± 1.08^a	89.45 ± 1.07^a
Hardness (mg/l)	95.35 ± 3.65^a	97.81 ± 3.61^a	96.39 ± 3.57^a
NH_3-N (mg/l)	0.59 ± 0.07^a	0.50 ± 0.07^a	0.41 ± 0.06^a

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.12: Variations in the mean values of weight gain and SGR under different treatments at 1st month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	30.47±0.20^{c}	35.50±0.40^{b}	40.50±0.29^{a}
SGR	2.08±0.01^{c}	2.33±0.02^{b}	2.55±0.01^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 5.13: Variations in the mean values of weight gain and SGR under different treatments at 2nd month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	20.07±0.03^{c}	25.13±0.35^{b}	34.03±0.15^{a}
SGR	0.89±0.01^{c}	1.01±0.02^{b}	1.24±0.01^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 5.14: Variations in the mean values of weight gain and SGR under different treatments at 3rd month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	19.37±0.17^{b}	18.93±0.22^{b}	24.93±0.32^{a}
SGR	0.68±0.01^{a}	0.60±0.01^{b}	0.68±0.01^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 5.15: Variations in the mean values of weight gain and SGR under different treatments at 4th month

Parameters \ Treatments	T_1	T_2	T_3
Weight gain (g)	15.50±0.25^{c}	18.97±0.15^{b}	25.70±0.23^{a}
SGR	0.46±0.01^{c}	0.51±0.02^{b}	0.58±0.01^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly (P <0.05)

Table 5.16: Variations in the mean values of growth parameters under different treatments during the study period

Treatments / Parameters	T_1	T_2	T_3
Weight gain (g/month)	21.35±3.20^{a}	24.63±3.90^{a}	31.29±3.70^{a}
SGR (%, bwd^{-1})	1.03±0.36^{a}	1.11±0.42^{a}	1.26±0.45^{a}
Final weight (g)	120.50±0.29^{c}	133.63±0.41^{b}	160.33±0.33^{a}
Survival rate (%)	93.78±0.22^{b}	94.00±0.39^{ab}	94.89±0.22^{a}
Yield (kg/cage/cycle)	16.95±0.08^{c}	18.84±0.13^{b}	22.82±0.05^{a}
Yield (kg/cage/yr)	50.85±0.23^{c}	56.52±0.40^{b}	68.46±0.15^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

Table 5.17: Variations in the mean values of different parameters of economics under different treatments

Treatment / Parameters	T_1	T_2	T_3
Fixed/common cost (Tk.)			
Net	500±0.00^{a}	500±0.00^{a}	500±0.00^{a}
Bamboo	30±0.00^{a}	30±0.00^{a}	30±0.00^{a}
Rope	10±0.00^{a}	10±0.00^{a}	10±0.00^{a}
Labour	60±0.00^{a}	60±0.00^{a}	60±0.00^{a}
Fish seed	375±0.00^{a}	375±0.00^{a}	375±0.00^{a}
Sub total (TK.)	**975±0.00^{a}**	**975±0.00^{a}**	**975±0.00^{a}**
Cost/cycle (TK.)	**162.5±0.00^{a}**	**162.5±0.00^{a}**	**162.5±0.00^{a}**
Variable cost (Tk.)			
Feed	700.00±0.00^{c}	875.00±0.00^{b}	1050±0.00^{a}
Total cost (Tk.)	**862.50±0.00^{c}**	**1037.50±0.00^{b}**	**1212.50±0.00^{a}**
Return/cage/cycle (Tk.)	1708.28±7.73^{c}	2056.88±14.59^{b}	2875.32±6.34^{a}
Return/cage/year (Tk.)	6101.00±27.62^{c}	7346.00±52.12^{b}	10269.00±22.65^{a}
CBR	1.98±0.01^{b}	1.98±0.01^{b}	2.37±0.01^{a}

Figures bearing common letter(s) in a row as superscript do not differ significantly ($P < 0.05$)

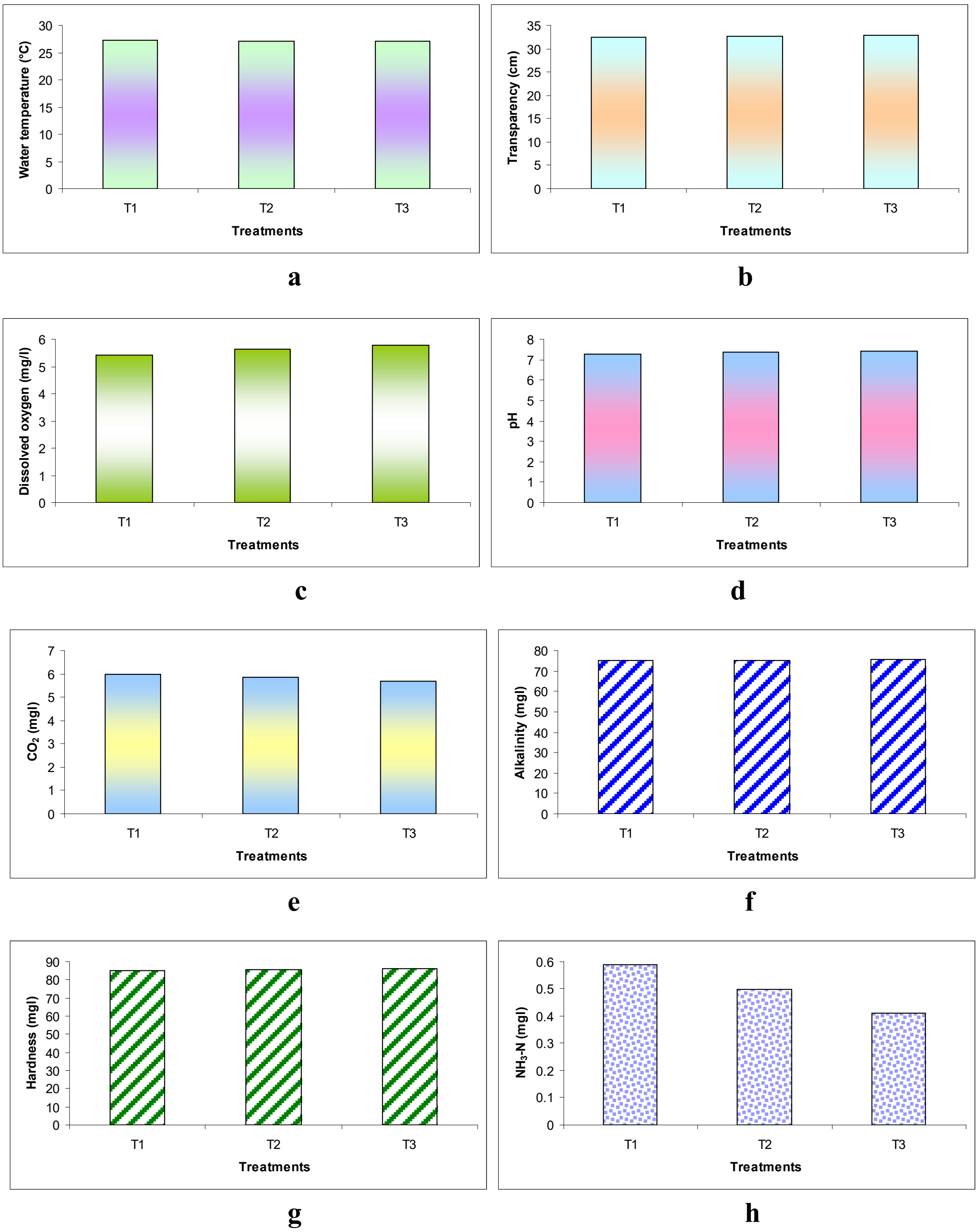
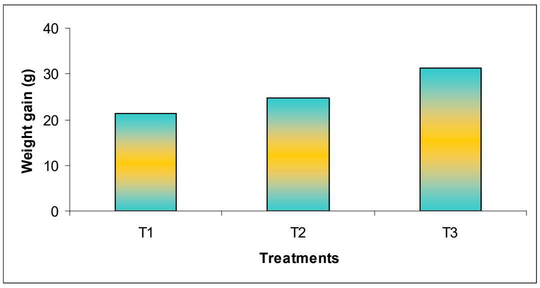
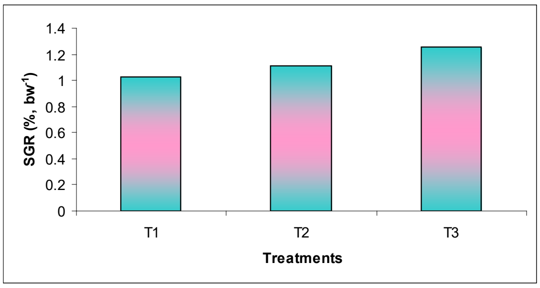
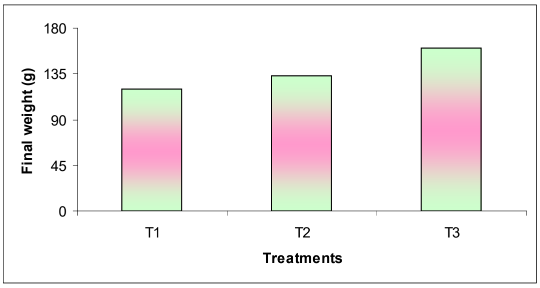


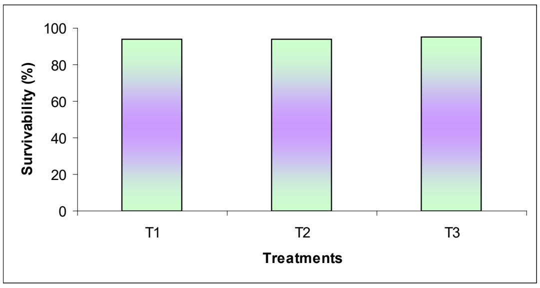
Fig. 5.1: Variations in the mean values of water quality parameters (a. water temperature; b. transparency; c. DO; d. pH; e. CO_2; f. alkalinity; g. hardness; h. NH_3-N) under different treatments during study period.





a **b**





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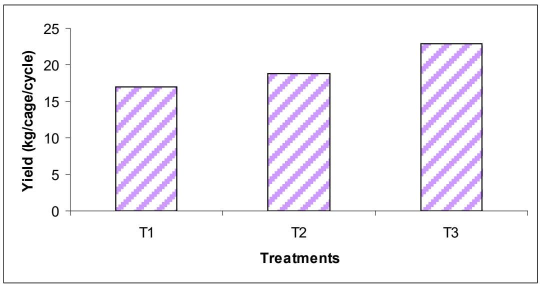

e

Fig. 5.2: Variations in the mean values of different growth parameters (a. weight gain; b. SGR; c. final weight; d. survival rate; e. total yield) under different treatments during the study period

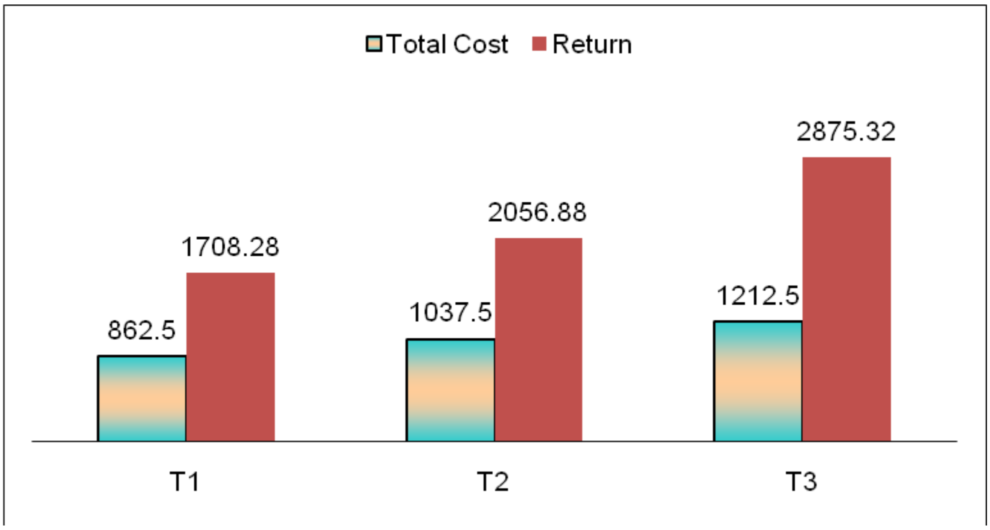

Fig. 5.3: Total cost and return under different treatments of dietary protein level

5.4 Discussion

5.4.1 Water quality parameters

5.4.2 Fortnightly variation

Temperature

In the present study the water temperature was found to vary from 16.53±0.03 to 33.47±0.03 °C. Lower temperature (16.53±0.03°C) with treatment T_3 at 8^{th} fortnight (i.e. December 2010) might be due to shorter day length and cold wind (Appendix 3). Ahmed *et al*. (2005) found water temperature varied from 24.1 to 30.5°C in Meghna river. Ashfaque, (2004) found water temperature 22.8 to 34.4°C in Padma river. All metabolic and physiological activities and life processes such as feeding, reproduction, movement and distribution of aquatic organisms are greatly influenced by water temperature (Jhingran, 1975). Preferred water temperatures for tilapia growth are approximately 29° to 31°C. Tilapias reportedly tolerate temperatures up to 40°C, but stress-induced disease and mortality are problematic when temperatures exceed 37 or 38°C (Thomas and Leonard 1995). So the water temperature measured during study period was more or less acceptable for tilapia culture which had similarity with the above referred temperature level.

Transparency

In the present study the water transparency varied from 14.07±0.09 to 70.53±0.03cm. The lowest value was recorded in 1^{st} fortnight (i.e. September) and highest in 8^{th} fortnight (i.e. December). Ahmed *et.al*. (2005) found the water transparency ranged from 12 to 90cm in Meghna river and Nyananyo et.al (2006) found water transparency between 17 to 72cm in Brass River, Nigeria that was similar to those obtained in the present study.

Dissolved oxygen

The DO concentrations of the river Mahananda varied from 4.83±0.03 (T_1 at 8th fortnight) to 6.33±0.03mg/l (T_3 at 2nd fortnight). Such low values might be due to high phytoplankton concentration, respiration, decomposition of bottom organic matter, inflow of oxygen deficient water, inorganic reluctant such as NH_3, Fe+2 and other oxidizable substances. Also similar assumptions were made by Ashfaque (2004) in Padma river. He observed DO range from 5.1±06 to 10.3±0.9mg/l. In spite of tilapias' ability to survive acute low DO, water body should be managed to generally maintain DO above 2 or 3 mg/l reported by Thomas and Leonard (1995). The ideal DO level for tilapia culture is 4-5 mg/l (Tran-Duy *et al*., 2008).

pH

The values of pH in the river water ranged from 6.93±0.12 to 7.67±0.09. There were no wide variations in pH values in the investigated river. The highest value was recorded in the month of September (at 1st forthright) and lowest in December (at 8th fortnight). Ahmed *et al*. (2005) obtained the values of pH in the river Meghna ranged from 7.00-8.00. Ashfaque (2004) found the water pH of Padma varied from 6.2 to 7.5. In the river Meghna, pH values obtained by Shafi *et al*. (1978) ranged from 6.79 to 8.41. Talukdar *et al*. (1994) found pH value of 8.1 in their study of the river Padma near North Western region of Bangladesh. Nile water in Egypt showed a pH range of 7.4-8.4 (Ahmed *et al*., 1986). Thomas and Leonard (1995) reported that tilapia seemed to grow best in water that was near neutral or slightly alkaline. Optimal pH range for sustainable aquatic life is pH 6.5 - 8.2 (Murdock *et al.,* 2001). According to Swingle (1967) pH of 6.5 to 9 is suitable for fish culture.

Free carbon dioxide

The mean values of free carbon dioxide varied from 5.03±0.03mg/l at 8th fortnight to 6.77±0.03 mg/l at 1st fortnight. Ahmed *et al*. (2005) and Ashfaque (2004) recorded the free CO_2 ranged from 2.4 to 7.7 mg/l in Meghna river and 2.3±0.8 to 13.4±2.9 mg/l in Padma river, respectively. The high free CO_2 content during summer was possibly due to the high temperature and heavy rainfall with heavy land drainage which speeded up the decomposition of organic matter, low photosynthetic activity which consumed free CO_2, low precipitation of free CO_2 (Islam and Bhuiyan, 2000). But, Nile tilapia can tolerate free CO_2 concentration above 20 mg/l and is unlikely to have an adverse effect on fish in intensive culture systems unless free CO_2 concentration reaches 100 mg/l (Tran-Duy *et al*. 2008).

Total alkalinity

Total alkalinity values obtained during the study period were found to vary from 76.23 ±0.03 at 1st fortnight to 89.47±0.12mg/l at 8th fortnight. Lowest value was recorded in the month of September and highest was in December. The findings were strongly supported with results ranged from 48.0 to 88.7mg/l in Meghna river and 57.7±4.3 to 110.0±7.8mg/l in Padma river found by Ahmed *et. al*. (2005) and Ashfaque (2004), respectively. The recorded alkalinity value is also more or less similar with the findings of Sarkar *et al.* (2005) and Rahman (1999) who recorded the values ranges from 87.33-114.0 mg/l and 71.0- 175.0 mg/l, respectively. According to Boyd (1982) total alkalinity should be more than 20 mg/l in natural fertilized ponds. Alkalinity of 77.33 to 79.33 mg/l was found acceptable for fish culture (Rahman *et al.,* 2006).

Hardness

In the present study, the river Mahananda had the concentration of hardness ranging from 71.00±0.58mg/l at 1st fortnight to 101.33±0.33mg/l at 8th fortnight in 2010. High concentration was recorded in the month of December and low in September. Hossain *et al*. (1993) reported that high hardness values (75-105mg/l) were found during winter in the Bhahmaputra river due to high deposition of calcium. Ahmed *et al*. (2005) found the range of concentration of hardness from 42.3 to 94.5mg/L in Meghna river. The water of the river showed higher hardness value during near winter but lower in wet season. Probably, high hardness value was occurred due to deposition of calcium components in the river.

Ammonia-nitrogen

Ammonia-nitrogen in river water was found to range from 0.17± 0.03 (with treatment T_3 at 1st forthright) to 0.87± 0.03mg/l (with treatment T_1 at 8th forthright). Lowest value was recorded in the month of September and highest was in December. Ahmed *et al*. (2005) found the range of concentration of ammonia-nitrogen from to 0.1 to 0.8mg/L in Meghna river.

5.4.3 Mean variation

In the present study, the mean value of water temperature varied from 26.12±2.12 to 26.20±2.33°C. Temperature of 27.5 °C was recorded for tilapia culture by Abo-State et.al (2009). The average water temperature as 27.52°C was found in the Buriganga river by Islam.*et al*. (1974) and as 27.6±6.68 °C in Meghna by Ahmed *et al*. (2005). Shafi *et al*. (1978) observed average temperature as 25.8 °C of the Meghna river near Daudkaudi. Patra and Azadi (1987) found the average temperature as 25°C in Halda river.

The mean value of water transparency in this study varied from 32.49±8.04cm to 32.78±8.13cm in 2010. Present finding has similarity with the findings of Ahmed *et al*. (2005) who found the transparency value of 34.2 ±1.18cm in Meghna river. Wahab *et al.* (1995) suggested that the transparency of productive water should be 40 cm or less.

However, Boyd (1998) reported the secchi disc reading between 30 to 45 cm as suitable for fish farming.

Mean value of dissolved oxygen 5.42±0.24 to 5.80±0.20mg/l in 2010, this value is more or less similar to the findings of Ahmed *et al*. (2005) who got the mean DO value of 6.7±0.8 mg/l. According to Boyd (1982) dissolved oxygen can be crucial in the tropics and sub tropics where fish growth and survival in aquatic environment is frequently oxygen limited. Banerjee (1967) and Bhuyan (1970) reported with 5.0 to 7.0 mg/l of DO content of water was fair or good in respect of productivity and water having DO less than 5 mg/l to be unproductive.

The mean value of pH varied from 7.28 ±0.09 to 7.41±0.08. pH of 7.6 was recorded by Abo-State *et al*. (2009) for tilapia culture. Ahmed *et al*. (2005) recorded the mean value of Meghna river water pH as 7.8±0.18 which was similar to the present study. In the present study the alkaline pH range in all treatments indicate good pH condition for biological production and fish culture.

Result from the study indicate that the value of free CO_2 that varied from 5.70±0.20 to 5.97±0.18mg/l has more or less similarity with the findings of Ahmed *et al*. (2005) who obtaining the CO_2 value of 4.8±0.74 mg/l in Meghna river.

The recorded mean total alkalinity varied from 85.32±1.08 to 89.45±1.07 mg/l, which has similarity with Ahmed *et al*. (2005) and Ashfaque (2004) obtaining the alkalinity value of 76.3±8.94mg/l in Meghna river and 80.3±6.78 mg/l in Padma river, respectively.

The recorded mean total hardness varied from 95.35±3.65 to 97.81±3.61mg/l. This value is more or less similar to the findings of Ahmed *et al*. (2005) and Ali *et al.* (2011) who got the mean hardness value 72.5±6.21mg/l and 83.29±3.44 to 84.13±3.47 mg/l respectively.

The recorded mean value of ammonia-nitrogen varied from 0.41±0.06 to 0.59±0.07mg/l. This value is more or less similar to the findings of Ahmed *et al*. (2005) who got the mean ammonia-nitrogen value of 0.35±0.08mg/l in Meghna river. Alam *et al.* (1997), Ali *et al.* (2011) and Asaduzzaman *et al*. (2006) recorded ammonia nitrogen value ranged from 0.2 to 0.4, 0.29 to 0.38, and 0.203 to 0.569 mg/l, respectively.

5.4.4 Growth of fish

5.4.5 Monthly variation

Weight gain (g/month)

The monthly weight gain varied from 15.50±0.25g with treatment T_1 at 4^{th} month to 40.50±0.29g with treatment T_3 at 1^{st} month. The weight gain with treatment T_3 was highest in comparison to treatments T_1 and T_2 in each month. Monthly weight gain varied significantly (P<O.05) under the different treatments. The highest weight gain was found in the month of September and the lowest value was found in the month of December.

Specific growth rate (%, bwd^{-1})

The monthly specific growth rate (%, bwd^{-1}) of tilapia with different treatments was found to be varied from 0.46±0.01 with treatment T_1 at 4^{th} month to 2.55±0.01 with treatment T_3 at 1^{st} month. Significantly highest (P<0.05) SGR value was recorded at treatment T_3 while the lowest was obtained at T_1. In all month, SGR was found to vary significantly. The highest SGR was found in the month of September and lowest in the month of December.

Comparatively higher values of weight gain and SGR in the month of September might be due to higher temperature causing higher metabolic activity of fishes (Boyd, 1998).

5.4.6 Mean variation

Dietary protein is always considered to be of primary importance in fish feeding (Jauncey and Ross, 1982), thus sufficient supply of dietary protein is needed for rapid growth (Lovell, 1989). In the present study, the results show that growth performance in terms of weight gain, specific growth rate, final weight, survival rate and total yield of *O. niloticus* were significantly affected by the experimental diets. Results of the present research suggest that 35% protein contain feed (Treatment T_1) is a suitable feed option for cage culture of *O. niloticus*. These results are in agreement with Ahmad (2000), Chowdhury *et al*. (2007) and Ng and Hanim (2007) they stating that significant growth performances were found in 35% protein content meal for *O. niloticus*. Tacon (1987) reported that dietary protein level varies from 42% for fry to 35% for growing adult of omnivorous fish. The dietary protein requirement for fish fry is high and ranges from 35% to 56% (Jauncy and Ross, 1982). Furthermore, Wilson (1989), Pillay (1990) and El-Sayed and Teshima (1991) found that dietary protein requirements decreased with increasing fish size and age. Based on various studies, Balarin and Halfer (1982) made a general conclusion that fry of tilapia <1 g requires diet with 35-50% protein, 1-5 g fish requires diet with 30-40% protein and 5-25 g fish requires diet with 25-35% protein. These results may be due to the fact that each fish size has a certain protein limit after which excess protein level could not be utilized efficiently. Many authors obtained conflicting results from their studies on the effect of dietary protein level on the growth of Nile tilapia, *O. niloticus*. The dietary protein requirements of several species of tilapia have been estimated to range between 20%

and 56% (El-Sayed and Teshima, 1991). De Silva and Perera (1985), Siddiqui *et al.* (1988) and Abdelghany (2000) reported that the optimum dietary protein level for growth of *O. niloticus* fry was 30% crude protein.

5.4.7 Economics

In the present study, higher return and CBR were found in treatment T_3 (35% protein feed) and lowest were recorded in treatment T_1 (25% protein feed). The economics in the present study clearly indicated that the 35% protein level feed (treatment T_3) was more profitable than the other treatments (T_1 and T_2). These findings support those of Ahmad (2000), Chowdhury *et al*. (2007), Ng and Hanim (2007), Ogunji *et al*. (2008) and Tavares *et al*. (2008), whose reported higher positive returns in 35% protein level feed. However, data from the present study indicated that all treatments, T_1, T_2 and T_3 were profitable above total costs because of increased yields of tilapia in response to protein %. In contrast, tilapia in T_3 had the highest margin between the current market price. These results demonstrated that 35% protein level feed could be an effective means to optimize economic returns in the production of *O. niloticus* in a cage culture system. However, as the market size of fish is sometimes an important concern, low protein level feed may not always be suitable because individual growth rates of fish are reduced due to protein deficiencies.

5.5 Conclusion

Mean water quality parameters were found more or less within the suitable range with tratments. Treatment T_3 varied more significantly for almost all the growth parameters. Total cost, return and CBR also varied more significant in treatment T_3. Considering water quality, growth and economics, treatment T_3 ie. 35% protein level diet was found suitable for tilapia cage farming in river ecosystem.

5.6 Recommendation

Based on the present findings, it is recommended to conduct future research on river based tilapia farming in large scale.

Chapter Six

SUMMARY, CONCLUSION AND RECOMMENDATIONS

Cage aquaculture in river ecosystem has been demonstrated to be one of the easiest methods of fish production requiring less capital and labour which improves sustainability, productivity and profitability of the farm. The aim of the present study was to explore the feasibility of small scale cage fish farming in river ecosystem in Mahananda river in Chapainawabganj district towards the increase in water productivity which can provide economic and nutritional security of rural fishers. A total of 3 experiments were conducted in 3 separate years (2008, 2009 and 2010) in river ecosystem in Mahananda river of Chapainawabganj district, Bangladesh. In experiment 1, three most commonly used aquaculture species in three treatments like T_1: Prawn (*Macrobrachium rosenbergii)* T_2: Nile tilapia (*Oreochromis niloticus*), and T_3: Thai Sarpunti (*Barbodes gonionotus*) were tested in small scale cage culture in river ecosystem to find out suitable species. Considering the best performance of aquaculture species found in experiment 1, experiment 2 optimized the stocking density for cage farming of tilapia (*Oreochromis niloticus*) in river ecosystem. For this purpose, three different stocking densities of tilapia under three different treatments (T_1: 200 fish/1m^3 cage, T_2: 150 fish/1m^3 cage and T_3: 100 fish/1m^3 cage) were tested in cages. Based on the suitable stocking density of tilapia culture found in experiment-2, experiment 3 optimized the dietary protein level for cage farming of tilapia (*Oreochromis niloticus*) in river ecosystem under three different treatments (T_1: 25% protein level feed T_2: 30% protein level feed; T_3: 35% protein level feed). Each treatment had three replications for all the experiments.

In case of all experiments the cages were suspended from a bamboo structure fixed by cotton nylon cords to a walkway from the shore. Plastic bottles were attached along the four corners of each cage to keep them floating. Initial stocking weight of aquaculture species were 5.5g in experiment 1, 41.0g in experiment 2 and 15.0g in experiment 3. Fish feed was supplied twice a day at morning between 09:00-10:00 hours and at evening between 05:00-06:00 hours with 50% of the ration allocated at each time. Fishes were grown for a period of four months (September to December) in cages in river ecosystem in each experiment. Water quality parameters (temperature, secchi disc transparency, pH, dissolved oxygen, free CO_2, alkalinity, total hardness and ammonia- nitrogen (NH_3-N)) were fortnightly whereas fish growth parameters (weight gain and specific growth rate) were also monitored monthly. A simple cost-benefit analysis was done to explore the economics of small scale cage farming system.

In **first experiment**, the mean values of water temperature, secchi disc transparency, pH, dissolved oxygen, free CO_2, alkalinity, total hardness and ammonia- nitrogen (NH_3-N) varied from 26.90±2.32 to 27.04± 2.31°c, 33.63±8.72 to 33.71 ± 8.75cm, 5.27±0.07 to 5.39± 0.08mg/l, 7.10± 0.09 to 7.12± 0.10, 3.36±0.14 to 3.47±0.14mg/l, 74.07±1.43 to 74.09±1.44 mg/l, 83.29±3.44 to 84.13±3.47 mg/l and 0.29±0.07 to 0.38±0.07 mg/l, respectively. No significant difference was found among the treatments for the mean values of all the water quality parameters. Among the three species the highest mean weight gain (15.84±1.70g/month) was observed in *Oreochromis niloticus* (T_2) followed by *Barbodes gonionotus* (7.28±1.34g/month) and *Macrobrachium rosenbergii* (5.82±0.61g/month), respectively. The mean specific growth rate (%, bwd^{-1}) of *O. niloticus, B. gonionotus* and *M. rosenbergii* were 2.16±0.85, 1.57±0.51 and 1.38±0.39, respectively. The highest final weight gain (g) was found in *O. niloticus* (68.67±1.86g) followed by *B. gonionotus* (34.33±1.86g) and *M. rosenbergii* (28.67±2.19g), respectively. The highest survival rate (%) was found in *O. niloticus* (95.67±0.33%) followed by *B. gonionotus* (82.50±3.82%) and *M. rosenbergii* (85.67±4.84%), respectively. Among the three species the highest fish yield (kg/cage/cycle) was found in *O. niloticus* (13.14±0.33kg) followed by *B. gonionotus* (5.64±0.03kg) and *M. rosenbergii* (4.87±0.08kg), respectively. The total return was estimated lowest (550.00±0.00Tk/cage/cycle) in treatment T_3 (Thai sarpunti) and the highest (1583.33±41.67 Tk/cage/cycle) was found in treatment T_2 (tilapia). The highest cost benefit ratio (CBR) was observed in treatment T_2 (2.60±0.04) whereas the lowest CBR was found in treatment T_1 (0.90±0.07). Total return and CBR varied significantly with the treatments. Considering the water quality, growth and economics, treatment T_2 (tilapia) was found the best over the other treatments.

In the **second experiment**, the mean values of water temperature, secchi disc transparency, pH, dissolved oxygen, free CO_2, alkalinity, total hardness and ammonia-nitrogen (NH_3-N) varied from 26.18±2.40 to 26.29±2.41°C, 33.91±8.59 to 33.96 ±8.58cm, 5.38±0.14 to 5.95± 0.16mg/l, 7.43± 0.08 to 7.50± 0.08, 5.80±0.16 to

6.00±0.16mg/l, 77.89±1.21 to 81.85±1.23mg/l, 89.02±3.41 to 91.08±3.23mg/l and 0.27±0.07 to 0.49±0.10mg/l, respectively. Mean values of dissolved oxygen and ammonia-nitrogen varied significantly under the different treatments. Production of tilapia (21.96±0.0.67kg/cage/cycle) was higher at a stocking density of 200/1m^3 cage (T_1) in comparison to those of 150/1m^3 cage (T_2) and 100/1m^3 cage (T_3). Higher survival rate was observed in lower stocking density of tilapia (100/1m^3 cage) and lower survival rate was recorded in highest stocking density of tilapia (200/1m^3 cage). In the present study, better growth performance of tilapia in terms of weight gain, SGR, final weight gain and survival rate was obtained with lower stocking density (T_3) but lower survival number of fish in this treatment resulted in lower yield of tilapia. Comparatively, higher fish yield was obtained in treatment T_1 (21.96±0.0.67kg/cage/cycle) which might be due to higher survival number of fish in this treatment that increased fish yield than the other treatments. The highest economic return (2550±0.00Tk/cage/cycle) was found in treatment T_1. But moderate CBR (1.58±0.003) and return (24700±0.00Tk/cage/cycle) was found in treatment T_2. Considering the water quality, production and economics, treatment T_2 was found best over other treatments.

In the **third experiment**, the mean values of water temperature, secchi disc transparency, pH, dissolved oxygen, free CO_2, alkalinity, total hardness and ammonia-nitrogen (NH_3-N) varied from 26.12±2.12 to 26.20±2.33°C, 32.49±8.04 to 32.78 ±8.13cm, 5.42±0.24 to 5.80± 0.20mg/l, 7.28± 0.09 to 7.41± 0.08, 5.70±0.20 to 5.97±0.18mg/l, 85.32±1.08 to 89.45±1.07mg/l, 95.35±3.65 to 97.81±3.61mg/l and 0.41±0.06 to 0.59±0.07mg/l, respectively. There were no significant difference into mean values of water quality parameters among the treatments. In the present study, higher fish production was obtained in treatment T_3 (22.82±0.05kg/cage/cycle) where protein level was 35%. The higher economic return and CBR (cost-benefit ratios) was also found in treatment T_3. So, regarding the highest values of different growth parameters and high economic return, it can be concluded that treatment T_3 was found the best over the other treatments. So, 35% protein feed was found as an effective option for tilapia cultivation in cage farming in river ecosystem.

The findings of this study will provide improved knowledge on the potential for cage fish farming in river ecosystem. Despite the fact that small scale cage farming in river ecosystem seems to be a profitable activity for farmers, adoption to date remains marginal in Bangladesh. A favorable policy framework is needed to promote cage farming practices on national level. Cages of small size were used for the present study. Future research is needed to explore the production and economics of fish farming in large cage in river ecosystem.

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ANNEXURE

Annexure 1. Meteorological data of Chapainawabganj district in the year of 2008

Date	September		October		November		December	
	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature
1	25	35	25	33	18.5	32	15	28
2	25	37	27	36	20	32	15	28
3	25	37	24	34	18.5	32	14	27
4	30	35	23	36	18.5	30.5	15	28
5	25	35	22.5	35	19	30.5	14.5	27.5
6	23	35	22.5	33	18.5	30	15	27.5
7	32	36	21.5	33.5	19	31	14	26
8	31	32	29	34	18	30.5	15	26
9	32	37	23	34	16.5	30	16	27
10	32	38	22.5	33	15.5	29.5	15	26.5
11	24	38	22	35	15.5	29.5	15	27
12	24	38	22	35	16	29	15	26
13	32	39	22.5	34.5	14.5	28	15.5	26.5
14	24	38	22.5	35	15	28	14	24.5
15	32	36	21.5	35	14.5	28	12.5	22
16	31	36	22	35	14	28.5	13	22.5
17	31	36	21.5	34	13.5	28	15	18
18	24	36	22	34.5	14.5	28	19	20
19	25	36	21	32.5	15	29	14	19
20	35	37	19.5	34.5	16	29	13	18
21	24	36	20.5	34.5	13	28	14	18
22	30	35	19.5	34	12	28.5	14.5	20
23	30	35	22	34	12.5	28	13.5	22.5
24	30	36	21	33	12	27	11	21.5
25	23	35	20	33	12	26.5	10	22
26	32	34	18	32	14	28	11	21
27	24	32	18	25	17	27	10	22
28	26	35	18.5	29	14	28	10	24
29	30	37	22.5	31.5	14	28	11	23
30	30	37	19	32	15	27.5	12	22
31	30	37	18.5	33			12	22

Annexure 2. Meteorological data of Chapainawabganj district in the year of 2009

Date	September		October		November		December	
	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature
1	26	36	26	37	26	36	23	32
2	26	37	26	36	24	35	27	30
3	26	37	25	37	23	34	28	32
4	28	37	26	37	22	31	28	30
5	25	35	26	37	27	36	27	31
6	24	35	27	37	23	30	25	29
7	30	38	26	36	24	32	25	29
8	30	38	27	37	23	29	26	29
9	30	37	26	37	25	28	25	29
10	30	38	26	36	24	30	25	29
11	25	37	27	37	26	34	27	28
12	26	37	26	36	25	32	25	28
13	31	39	27	37	22	30	19	30
14	30	38	27	36	24	35	16	24
15	32	39	27	37	23	32	25	29
16	30	37	26	36	25	34	26	29
17	30	37	27	37	24	32	25	28
18	26	37	26	36	26	34	27	29
19	25	37	26	36	23	30	24	30
20	27	37	26	35	23	32	20	26
21	25	36	26	36	21	30	18	24
22	29	36	26	36	25	32	15	20
23	29	36	26	35	22	28	15	18
24	29	36	26	36	23	29	16	22
25	26	35	27	37	22	28	17	20
26	28	36	26	36	20	26	18	24
27	25	35	25	35	20	26	12	24
28	26	35	25	34	22	28	11	24
29	29	36	26	36	23	26	10	23
30	30	37	25	34	24	27	12	22
31	30	37	25	35			10	22

Annexure 3. Meteorological data of Chapainawabganj district in the year of 2010

Date	September		October		November		December	
	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature	Lowest Temperature	Highest Temperature
1	26	35	26	35	22	35	12	22
2	26	35	25	36	21	34	10	22
3	26	36	25	34	21	33	11	23
4	27	37	26	32	22	34	10	21
5	26	36	26	35	27	35	11	22
6	27	37	25	32	24	32	10	21
7	27	37	24	33	23	32	9	22
8	28	39	25	34	21	35	9.5	19
9	27	37	25	32	21	34	9	18
10	26	35	26	33	23	30	9	19
11	29	39	25	32	22	31	8	19
12	27	37	26	34	21	30	9	20
13	28	38	26	35	20	29	8	19
14	25	34	26	37	20	27	11	21
15	25	34	27	37	21	26	10	19
16	25	34	26	36	22	24	9	18
17	25	34	26	34	21	27	9	19
18	25	34	26	35	20	26	10	18
19	25	34	27	36	23	27	10	19
20	26	36	27	35	22	26	9	18
21	25	35	26	34	21	24	7.5	17
22	25	34	25	33	23	26	8	21
23	25	34	25	34	21	27	8	22
24	24	34	25	35	22	28	7.5	21
25	25	34	26	34	24	27	8	20
26	26	36	25	33	23	28	8.5	20
27	25	34	23	36	19	27	8	24
28	26	36	24	34	17	24	8.5	19
29	27	37	23	32	15	26	8	18
30	26	36	24	34	13	24	10	22
31	26	35	25	35			10	21

Source: Department of Agriculture Extension, Chapainawabganj