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EFFICIENCY, RISK AND MANAGEMENT OF FISHERIES SECTOR IN BANGLADESH

EFFEKTIVITET, RISIKO OG FORVALTNING AV FISKERISEKTOREN I BANGLADESH

MD. AKHTARUZZAMAN KHAN



NORWEGIAN UNIVERSITY OF LIFE SCIENCES • UNIVERSITETET FOR MILJØ- OG BIVITENSKAP
UMB SCHOOL UMB SCHOOL OF ECONOMICS AND BUSINESS
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MD. AKHTARUZZAMAN KHAN

DOCTOR PHILOSOPHIAE (DR. PHILOS.) THESIS 2012:62



NORWEGIAN UNIVERSITY OF LIFE SCIENCES
NO-1432 Ås, NORWAY
PHONE +47 64 96 50 00
www.umb.no, e-mail: postmottak@umb.no

Efficiency, Risk and Management of Fisheries Sector in Bangladesh

Effektivitet, Risiko og Forvaltning av Fiskerisektoren i Bangladesh

Philosophiae Doctor (PhD) Thesis

Md. Akhtaruzzaman Khan

UMB School of Economics and Business
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Dedication

This work is dedicated to the memory of my father late *Altaf Hossain Khan* and uncle late *Prof. Dr. Md. Ashraf Ali Khan*, who passed their lives in love of their families and respect for education.

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This has been long and circuitous journey that required a great deal of will, patience and resilience, none of which I can assert to have been possible if not for the ALMIGHTY ALLAH who gently guided and gave me knowledge, strength and ability. This dissertation would not have been possible without the help and inspiration of many people.

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Md. Akhtaruzzaman Khan
December, 2012
 s, Norway

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Introduction

Efficiency, Risk and Management of Fisheries Sector in Bangladesh

Md. Akhtaruzzaman Khan

UMB School of Economics and Business
Norwegian University of Life Sciences (UMB)
P.O. Box 5003, 1432, Ås Norway

1. Introduction

Fisheries sector plays an important role to ensure stable food fish supply, provide income and employment opportunities, earn foreign exchange, supply nutrition and contribute to livelihood improvement and poverty reduction around the world (Smith et al. 2010). Globally, around 44.9 million people are directly involved with fisheries and aquaculture sector while 540 million people derive their livelihood from this sector (FAO 2010). Moreover, fish contributes 15 percent of average animal protein to three billion masses across the world (FAO 2008). World fish supply has reached to 143 million tonnes in 2008 from 60 million tonnes in 1970 and the per capita fish supply is about an all time high of 17 kgs (FAO 2010).

The seafood¹ sector is playing an increasingly important role in the economic uplift of Bangladesh. It contributes 4.64% to the Gross Domestic Product (GDP), 23% to agricultural GDP and 3.0% to the foreign exchange earnings (DoF 2009-10; Ministry of Finance 2010; Sarder 2007). With annual fish consumption of about 15.4 kg/person from 2000 to 2005, fish contributes 60% - 80% of the animal protein consumed by the population, and also provide essential vitamins, minerals and fatty acids in Bangladesh (ADB 2005; Belton et al. 2011). Around 1.3 million people are directly employed and 12 million people are indirectly involved in the seafood sector. The domestic demand for fish has increased with the rapid population growth of 1.8% annually on average and has reached to 150 million in 2011. The fisheries sector comprises of inland capture, inland culture and marine fisheries contributing 35%, 47% and 18% of total fish production respectively (DoF 2009-10). Inland captured fisheries include river & estuaries, sunderbans, beels, Kaptai Lake and floodplain which comprises of about 4.03 million hectare of

¹ Seafood includes fish and shellfish harvested from capture fisheries and aquaculture production in freshwater and marine environments.

area. On the other hand, inland culture fisheries (aquaculture) comprise of freshwater aquaculture and brackish water aquaculture.

In Bangladesh, both freshwater and brackish water aquaculture has expanded tremendously during the last two decades. Brackish water aquaculture expanded in the coastal areas (southern part of Bangladesh) and contributes to foreign exchange earnings. On the other hand, expansion of freshwater aquaculture has got momentum and expanded in other parts of Bangladesh, especially in the northern and western parts of the country. During the last fifteen years, farmers (especially rice farmers) have been converting land to pond aquaculture. This is mainly due to higher profitability in fish farming than rice production. A large portion of the converted land is being used for monoculture fish farming, with pangas (*Pangasius hypophthalmus*), tilapia (*Oreochromis mossambicus*) and Koi (*Anabas testudineus*) as the main species. In addition, the yield of inland open water capture fisheries has increased due to the introduction of new management regimes, while, catch from marine fisheries increased slowly. Despite the substantial growth and development of the seafood sector, several issues have been raised which might alter further expansion such as sustainability of aquaculture farming, proper management of floodplain, overfishing and potential depletion of fishery resources, lack of institutional support etc. Challenges and constraints therefore need to be indentified for further development of this sector.

Fish farming in Bangladesh faces several challenges, fish production is more volatile than any other agricultural biological production (Tveteras 1998) . Bio-physical factors such as disease, temperature, oxygen deficiency etc. make the production process risky. Production risk is higher for the smallest farm, this is partly due to input use. Whereas some inputs reduce output risk and others increase the risk. Although, due to high profitability in fish farming compared to rice, farmers are converting land but sustainability of fish farming depends on various factors. Supplementary feed which is the main input of fish production is expensive. Therefore, a good amount of resources is needed during culture period which is sometimes difficult to manage for the small farmers who do not have access to credit in financial institutions. It is observed that due to liquidity problem during culture period some small farmers want to go back to rice farming again, which is almost impossible.

On the other hand, more than one third of Bangladesh comprises of floodplain and most of the surrounding people depend on these floodplains for their livelihood. These floodplains are

being used for habitat of natural fish during monsoon season but in dry season, it is used for rice cultivation. Cropping intensity and land productivity is low in these areas which lead to greater poverty. Department of Fisheries (DoF) and the WorldFish center has taken an initiative and implemented a series of projects where fish is being cultured in these seasonal floodplain areas during monsoon season with the help of local fisher communities. This culture system may help to increase income, reduce poverty and inequality in these areas.

Marine is also an important sub-sector of fisheries sector and contribute 18% of total seafood production. However, many fisheries have been over-exploited both biologically and economically. Management of marine fisheries is far from satisfactory level and statistics on gear, boat/vessel and production does not reflect the reality. More vessels than recognized by the Department of Fisheries (DoF) operate in the Bay of Bengal. As a consequence, excess capacity and capacity utilization is a major concern in the marine sector.

The above discussion shows that, even though, fisheries sector contributes significantly to the national economy in Bangladesh, it still suffers from several problems. By analyzing some of the problems, we can come up with better policies to address these sector specific issues so that the seafood sector may contribute better for income generation and poverty reduction. In this thesis, some of the challenges are identified and analyzed. Especially we strive to answer some of the following problems statement:

- How has the fishery sector expanded and what is the potential problem for the fisheries sector?
- After converting land from rice to fish, are all the fish farmers profit efficient? Will all size of farms sustain in the long run? (Paper-II)
- What are the risk factors that affect production among different sizes of farms? (Paper-III)
- Can Community Based Aquaculture (CBA) system enhance income and reduce poverty and inequality in the floodplain areas of Bangladesh? (Paper-IV)
- Is there any excess capacity in the marine fisheries sector? If so, is there some policy alternatives for sustainable marine resource management? (Paper-V)

2. Theoretical Framework

In this section, we briefly present some of the theoretical concept used in the thesis.

2.1 Farm efficiency

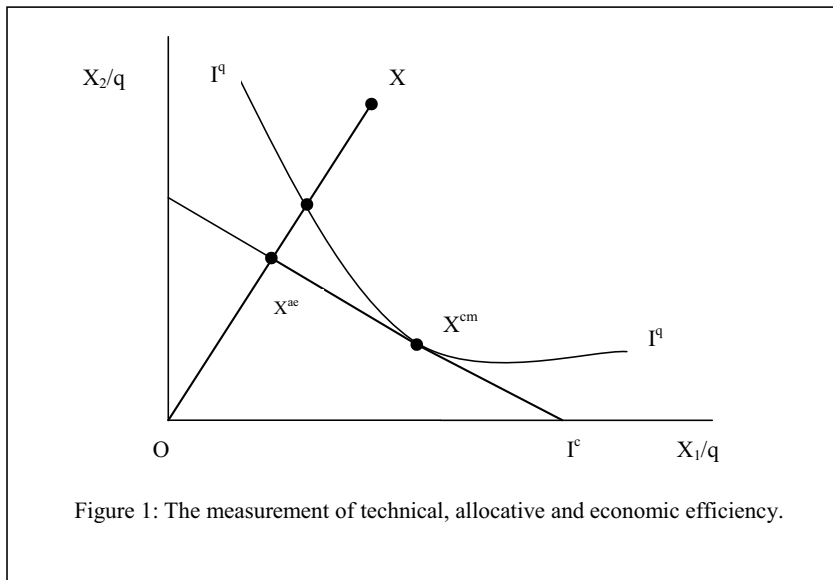
To measure the firm's performance, the terms efficiency and productivity is frequently used. Unfortunately, these two terms are often used interchangeably, but they are not precisely the same things. Productivity is defined as output(s) per unit of input(s), i.e. productivity = outputs/inputs. On the other hand, efficiency represents the maximum output attainable from each input level. Fisher (1922) and Törnqvist (1936) indices were the first productivity measures and were further developed by Malmquist (1953) and Shepard (1953), who independently introduced the notion of a distance function (Kristin 2008).

After pioneering work of M.J. Farrell (1957) on efficiency, economic efficiency measurement has become a standard in the efficiency literature. Farrell defined efficiency as "the ability to produce a given level of output at lowest cost" (input-orientated measures). Efficiency is typically divided in three components: technical, allocative and economic efficiency. Technical and allocative efficiency are pivotal factors in determining the overall economic efficiency. Technical efficiency suggests a situation where it is not possible for the firms to produce with the given knowledge (1) a larger output from the same inputs (called output-orientated measure), (2) the same output with less of one or more inputs (called input-orientated measures). Allocative efficiency reflects the ability of the firm to respond to price signals or optimal utilization of input factor given their respective prices and production technology. These two measures jointly determine total economic efficiency of a firm.

Figure 1 presents Farrell ideas of technical, allocative and economics efficiency (input-orientated measures) using two inputs (x_1 and x_2) and a single output (q) assuming constant return to scale technology. I^q represents the *isoquant* of *fully efficient* firms which permits the measurement of technical efficiency and I^c presents the *isocost* curve for the production technology. Suppose, if any firm uses X quantity of inputs to produce a unit of output, indicating that firm uses $X^{tc}X$ amount of inputs. Then a fully efficient firm and technical inefficiency could be measured by the distance $X^{tc}X$, which is the amount by which all inputs could be proportionally reduced without a reduction of output. Usually, inefficiency is expressed in percentage terms by the ratio $X^{tc}X / OX$, which presents all inputs needed to be reduced to achieve technically efficient production (Coelli book). Technical efficiency of the firm can be

measured as the ratio: $TE = OX^{te}/OX$ which is basically one minus $X^{te}X/OX$ (technical inefficiency). Now, if input price information is available, we can estimate the allocative efficiency as well as cost efficiency (in input-orientated measures, overall economic efficiency is presented by cost efficiency). Although X^{te} is a technical efficient point, the firm is not allocatively efficient here because the production cost could be reduced to point X^{cm} to produce the same amount of output (X^{cm} is its cost minimizing point or cost efficient point). Therefore, allocative efficiency can be measured as: $AE = OX^{ae} / OX^{te}$ (distance for allocative inefficiency is hence $OX^{te} - OX^{ae}$). Together, technical and allocative efficiency provide the overall economic efficiency (here cost efficiency) of the firm, which can be measured as:

$$CE = TE \times AE = (OX^{te}/OX) \times (OX^{ae} / OX^{te}) = OX^{ae} / OX$$



Another concept related to efficiency used in this thesis is profit efficiency. The ultimate objective of most producers is to maximize profit. In a cost minimizing environment, the producers' goal is to minimize cost for a given level of output. In this case, producers attempt to allocate inputs in such a way (input price and input quantities are choice variables) that it minimizes the cost of producing output. In output or production maximization environment, inputs are exogenously given and output is the only choice variable. When the producers' goal is

profit maximization, both input and output are choice variables which means that both inputs and output are chosen by the producer in such a way that it maximizes profit. If firms face different prices and have different factor endowments, the production function approach may not be appropriate to estimate economic efficiency (Ali and Flinn 1989; Yotopoulos and Lau 1973). Yotopoulos and Lau (1973) and others argued that firm-specific price and level of fixed factors should be incorporated to estimate efficiency and the incorporation of firm-specific price and resource endowments lead to the stochastic profit function model. Lau and Yotopoulos (1971) first used a stochastic profit function approach in the efficiency analysis by incorporating firm-specific price and levels of fixed factors. They argued that a firm is price efficient if it maximizes profit i.e. it equates the value of the marginal product of each variable input to its price.

Profit efficiency is defined as the ability of a firm to achieve maximum potential profit, given the level of fixed factors and prices faced by that firm (Adesina and Djato 1996). It is then the ratio of actual profit to maximum obtainable profit. Interaction between firm-specific prices and levels of fixed factors allows the profit frontier to be firm specific. Profit inefficiency in this case can be defined as loss of profit from not operating on the profit frontier (Ali and Flinn 1989). Profit frontier is represented by an industry best-practice profit for any given level of prices and fixed factors as illustrated in Figure 2. If firm is operating at point B, then, profit efficiency is defined as AB/AC and profit inefficiency as $(1 - AB/AC)$.

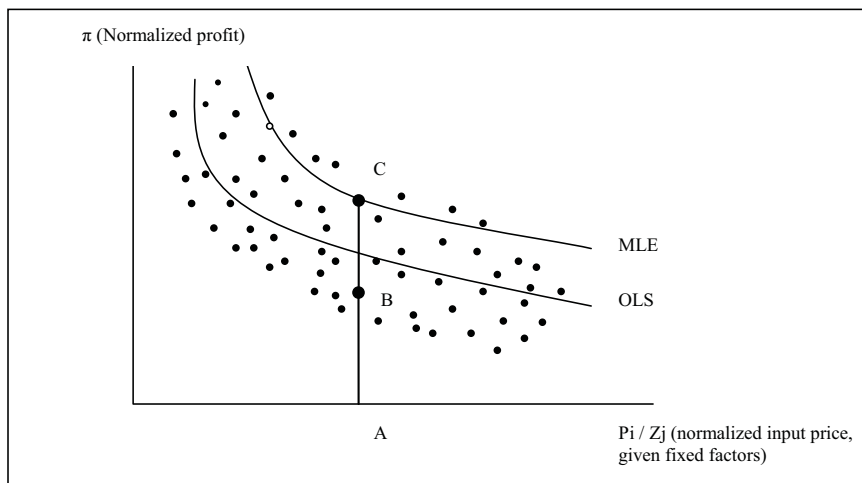


Figure 2: Frontier (MLE) and average (OLS) stochastic profit function (Adopted from Ali and Flinn (1989)).

2.2 Production Risk

Expected Utility (EU) theory is widely used in economics to explain choice under uncertainty (Rabin 2000). The standard EU model is limited to analyzing lottery-type decision problem where the economic agents can only decide whether to participate or not. If the agent chooses to participate in the gamble, he/she can only stand on the sideline and watch the dice roll, without being able to affect its outcome (Tveteras 1998). In case of firm theory, under uncertainty, the firm has a set of instruments available which affect the probability distribution of his objective function. The firm is also able to affect the mean and variance of the objective function through adjusting the input or output level. Thus, the extended EU model makes the decision problem more interesting (Tveteras 1998). The expected utility function of the competitive firm can be formulated in the following way under uncertainty.

$$\max_{\alpha} E[U\{\varphi(\theta, \alpha, W_0)\}]$$

where, $U(\cdot)$ is a von Neumann-Morgenstern utility function, α is a control variable, θ is random variable which is indirect outcome variable, W_0 is initial wealth and $\varphi(\cdot)$ is a function mapping actions α and realizations of θ into outcomes, normally taken to be wealth levels and this is called direct outcome variable.

Risk which is associated with production losses is called production risk. Production or output risk is an inherent feature in most of the biological production process (Tveteras 1999). But the extent of production risk may vary substantially across sectors. In agriculture or aquaculture production an important characteristics of production risk is that input level influence output risk where some input increase the output variability while others reduce. In the conventional stochastic firm production function, it is implicitly assumed that “if any input has a positive effect on output, then a positive effect on output variability is also imposed.” This in many cases is a suspicious assumption and does not represent the production technology. Just and Pope’s (1978) seminal paper on risk became the foundation for both theoretical and empirical research on production risk. They proposed eight postulates for the stochastic production function which is known as JP production function postulates. Just-Pope stochastic production function is as follows:

$$y = f(x) + u = f(x) + h(x)^{1/2} \zeta$$

where, x is the vector of input, $f(x)$ is mean production function, $h(x)^{1/2}$ is the variance function (risk function) and ξ is the exogenous production shock. The focal point of Just-Pope model is to allow inputs to be either risk-increasing, decreasing or constant i.e., $\frac{\partial \text{var}(\partial y / \partial x_k)}{\partial x_j} \ll 0$ possible. Therefore, this model can explain how output variability affected by input level. Figure 3 represents the mean and variance function of Just-Pope production technology.

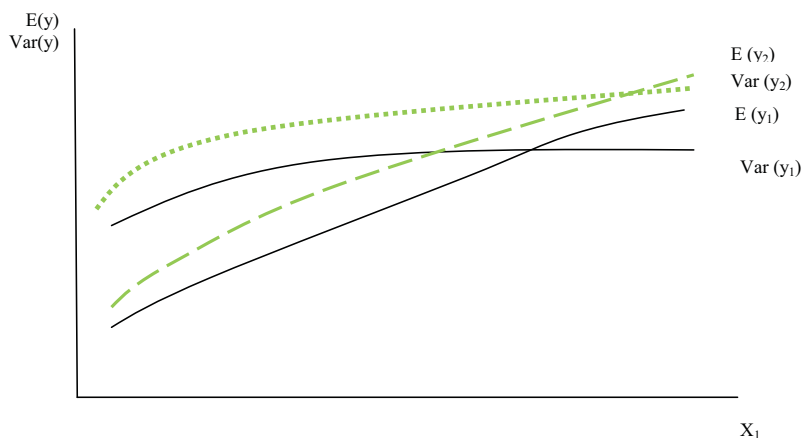


Fig 3: Mean and variance of Just-Pope production technology 1 and 2 (Adopted from Tveteras 1999)

Market imperfection might have effects on agricultural production (Janvry and Sadoulet 2006; Shiferaw et al. 2006). Imperfect credit market has negative effects on farm productivity, efficiency and production risk (Feder et al. 1990). The availability of funds to carry out timely purchased cash inputs into agricultural production can increase farm's productivity, efficiency and reduces the input use risk in small-scale agriculture. In aquaculture, supplementary feed is very important input and needs good amount of money during culture period. Therefore, perfect credit market can play vital role in the production process.

2.3 Natural resource, poverty and inequality

Around 1.4 billion people earn less than 1.25 US\$ per day and faces different types of risk. Livelihoods of these people mainly depend on natural resource (FAO 2004). But degradation of natural resources such land, water, forest, marine etc. threatens the livelihoods of people, especially the rural poor. In less developed or developing countries, per capita income depends on the availability and efficient use of these resources. Proper utilization of resources therefore became an important factor for reducing poverty in developing countries. In most of the developing countries, high population density leads to small farm size and resource scarcity. As a result, less income and high poverty exist. There is a broad agreement that income growth is a necessary condition for poverty reduction in developing countries (Greeley 1994).

“Poverty involves more than money and income. It is a complicated and multifaceted deprivation that affects individuals’ different capabilities and their overall well-being. Poverty has been described as the deprivation of different types of “freedoms” - economic, political, social, and choices that affect livelihoods”(Anderson and Nelson 2006). In this dissertation, we only consider income or food poverty. The level of income/consumption and the extent of income/consumption inequality are two measures of welfare of any community or society. Now question is income or consumption, which is better to measure poverty and inequality? One can make a case for and against each of them. Especially in the developing county, consumption is an unsatisfactory indicator of sustainable standard of living because poor people are often forced to finance current consumption by borrowing or liquidating assets. In general, poverty is expected to reduce when a certain level of per capita income is reached. On the other hand, relationship between income and inequality is not straightforward. Kuznets (1955) argued that the income distribution becomes more unequal with economic development in developing countries. He also claimed that when the aggregate per capita income reached a certain level, income inequality levels off and ultimately diminishes during the latter stages. As a consequence, the relationship between per capita income and inequality becomes an inverted-U shaped curve. In the early stages of development, the wealthy comparatively accumulate more wealth than the poor. As a result, the income distribution becomes more unequal.



Figure 4: Relationship between per capita income and inequality (Kuznets curve).

Community based nature resource management (CBNRM) used as a policy tool for poverty reduction and improving livelihoods of poor communities This management system can be considered a management strategy aiming to reduce poverty, conserve natural resources and promote good governance. Poverty reduction and natural resource conservation are closely related because poor people depend on natural resources for their livelihoods. It is therefore, important to ensure sustainable management of these natural resources. On the other hand, involvements of the communities who depend on resource are required to effective and equitable resource management. This involvements help to decentralization of authority and promote to good governance which facilitated to equitable distribution of resource benefits. Figure 5 shows CBNRM and its linkage to overall development objectives. Literature shows that community based management system can increase income and reduce poverty (Azimi and Bank 2004; Barrett et al. 2005; Blaikie 2006; Fisher 2004; Heady 1998; Kallonga et al. 2003; López-Feldman et al. 2007; Njifonjou et al. 2006).

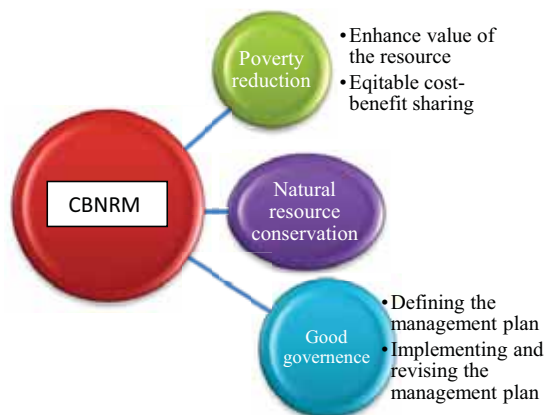


Figure 5: CBNRM and its linkages to overall development objectives

2.4 Capacity, capacity utilization and excess capacity

Capacity and capacity utilization (CU) is important concerns for a majority of marine fisheries. Kirkley and Squires (1999) note that capacity is often a short-run concept, as at least one input is held fixed at some level (e.g. vessel technology). Technical-engineering measure and a strictly economic measure are the two distinct measures of capacity (Morrison 1985). Based on the technological-engineering Johansen (1968, p 52) defined capacity as “*the maximum amount that can be produced per unit of time with existing plant and equipment, provided the availability of variable factors of production is not restricted*”. Technical-engineering measure can be estimated even when economic data is not available. In contrast, the common economics measure of capacity output assumes cost minimization of exogenous or predetermined output and is the output level corresponding to the tangency between short-run and long-run average cost curve (Berndt and Morrison 1981; Coelli et al. 2002; Klein 1960; Morrison 1985). Technical-engineering measures of capacity have received more attention than economic measures (Kirkley and Squires 1999).

However, “*Fishing capacity is the maximum amount of fish over a period of time that can be produced by a fishing fleet if fully utilized, given the biomass and age structure of the fish stock and the present state of the technology*” (FAO 1998). Simply fishing capacity is the ability of a vessel to catch fish. Capacity utilization (CU) can be defined as the ratio of observed/actual output to the capacity output or potential output. However, according to Fare et.al (1989) appropriate measure of capacity utilization is the ratio of the technically efficient output level to the capacity output level. This concept has become popular and increasingly used as the measure of capacity utilization. On the other hand, excess capacity exists when the potential output level exceeds the actual output in a given period.

3. Study Area and Data

This dissertation contains five (5) articles from three fisheries sub-sector. Table 1 shows the study area and related sample for this research. The first paper can be seen as an overview of the fisheries sector of Bangladesh. It shows production, yield and area expansion during last two and half decades. The paper should be read as a background for the rest of the thesis.

For second and third article (on pond aquaculture), data were collected from three upazila (sub-district) under Mymensingh district. Mymensingh is situated 120 kilometer north from

capital city Dhaka where agro-climatic condition is suitable for aquaculture and communication is good with other district. A total of 239 fish farmers were randomly selected from these areas who has converted rice land to fish farming. To avoid the production heterogeneity we selected only Pangas fish (*Pangasius hypophthalmus*) farmers from the study area which contribute 36 percent of total aquaculture production in Mymensingh district. The sample size is assumed to be representative in the study area. Well structured questionnaires were designed in order to collect required information according to the objectives. Questionnaires were pre-tested and changes were made following the testing.

We used three years panel (2007 to 2009) data for fourth article. Basically this data set is from WorldFish Center project which was collected by a Ph.D. student from time to time. He was involved in CBA (Community Based Aquaculture) project as research assistant. Project was implemented in three floodplain areas in Bangladesh namely, Mymensingh, Rajshahi and Rangpur. From each area two floodplains were chosen for this study of which one is treatment and another is control. Therefore, this research covers six (6) floodplains. A total of 360 households were randomly selected each year of which 180 were project households and rests of 180 were control households. Two questionnaires were developed (1 for project and another for control) for data collection and three year's data on production, income, socioeconomics characteristics were collected time to time.

Fifth paper is on marine fisheries. Chittagong, Cox-Bazar and Patuakhali are the three main marine fishing regions in Bangladesh. This study covers only Chittagong and Cox-Bazar. Data were collected from 146 fish boat randomly when the fishing boat landed. A well designed questionnaire was prepared for this study which includes boat information, catch information, and other related information regarding excess capacity. Figure 6 shows the study area of this dissertation.

Table 1: Study area and data utilization structure for each dissertation work

Dissertation includes	Research coverage year	Study area	Sample size
Paper-I	More than 25 years	Overall Bangladesh Capture, Culture and Marine sub-sector	-
Paper-II	2010	Mymensingh	239 fish farmers
Paper-III	2010	Mymensingh	239 fish farmers
Paper-IV	2007, 2008, 2009	Mymensingh, Rajshahi and Rangpur districts	360 fish farmers each year, total observation 1080 in three years
Paper-V	2010	Chittagong and Cox-Bazar	146 fish boat/vessel

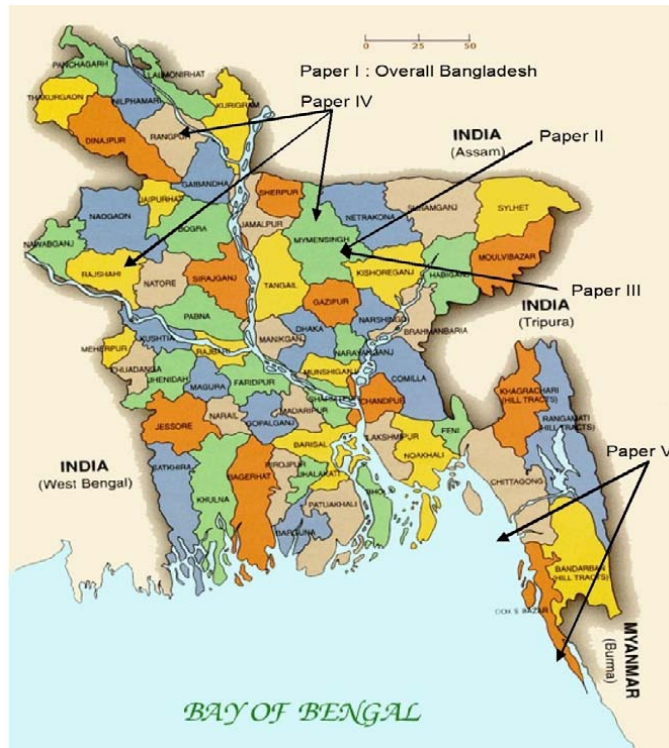


Figure 6: The map of Bangladesh showing study area of the dissertation

4. Summary of Research Findings

This section presents a summary of all the papers in the dissertation highlighting their objectives, methodology, empirical findings and main contributions.

Paper I: An Overview Of Fisheries Sector in Bangladesh: Past Trends, Present Status and Future Prospects

Fisheries and aquaculture has been expanding rapidly during the last few decades and plays a vital role in income and employment generation, poverty reduction, animal nutrition and food security over the world (FAO 2010; World Bank 2012). Bangladesh, China, Thailand, Vietnam contributes significant share to the total world production. However, Fisheries sector of Bangladesh has expanded rapidly during the last two and half decades and plays a key role in the economic development, contributes Taka 173.6 billion to GDP in 2011 and provide a vital source of foreign earning through export of fish and fisheries products. Despite the substantial growth and development, a number of issues have also raised which are impediments for the proper expansion and sustainability of the fishery sector. The paper investigates the insight of country's fisheries resources, production trends and practices, export earning, market and environment, present constraint and future prospects of Bangladesh fisheries sector using available data from secondary sources.

Bangladesh fisheries sector comprises three categories; (i) Inland capture (ii) Inland culture and (iii) Marine. The inland capture fisheries cover 4.03 million hectares comprising of 86.5% of total inland fisheries area. Annual fish production growth rate was 3.5% during 1986 to 2001 afterward; an impressive growth of 5.65% has been achieved in production due to adoption of co-management system in the floodplain areas during 2002 to 2010. Vast area of open water can contribute more with proper management system. Some factors responsible for less production of open water bodies are over-fishing, agro-chemical use, dams and embankment, siltation of rivers, irrigation and drainage system, water pollution and proper floodplain management strategies etc.

A remarkable development has been achieved in the cultured fisheries sector with respect to production, yields and technology. Freshwater pond and brackish water shrimp farms are the main sources of aquaculture production and this is easily manageable compared to capture area. The Government of Bangladesh and different NGO's have taken different initiatives to increase

the pond fish production in order to meet the domestic demand for the growing population. Due to an overall high profitability in fish farming compared to rice, farmers are more interested to culture fish in some parts of Bangladesh. Despite the substantial growth, different constraints are observed in aquaculture such as brackish water aquaculture affecting environment, ecology and human health. Capital or liquidity constraints, inbreeding, fish market and marketing system, maintaining international standard of shrimp and insufficient public budget for fisheries development are the other main problem for aquaculture.

Marine fishery is contributes 18 percent to total fish production in Bangladesh and it is growing slowly. The marine fishery is mainly dominated by artisanal fishery rather than industrial fishery with different gear types and fish species. Out of total marine fish production, 93% comes from artisanal and only 7% from industrial fishery (DoF 2009-10). Hilsha is the most important aquatic resource of marine fishery which contributed 39.4 percent of total marine catches. This sub-sector has so far been a low-priority area in the overall fisheries development program in Bangladesh and it was allocated only 3% of total fisheries development budget (Mazid 2003). Therefore, management of marine fishery is far from satisfactory level. Several constraints have been identified for marine fisheries such as over-exploitation, lack of capital, inadequate knowledge and information on fish stock, inadequate landing facilities, lack of modern landing technology/equipments, congestion of artisanal fishermen in inshore water, life risk of the fishermen during monsoon season and inadequate research on marine fisheries is another main constraint to the development of this sector.

Capture, culture and marine sub-sector have great prospects if it could be managed properly. Long-term as well as short term policies are needed to improve the fisheries sector. This overview paper may be helpful for policy maker to prepare future fisheries policies in Bangladesh and provide important insights for other countries as well.

Paper II: Profit Efficiency, Farm Size and Sustainability: An Empirical Analysis of Fish Farming Converted from Rice Fields in Bangladesh

Although, a large number of environmental and ecological problems are arising due to aquaculture expansion, rice farmers are converting land into fish farming to maximize profit and this conversion rate is high in different areas of Bangladesh. Not only large farmers but also the small farmers are shifting to fish farming due to high profit. Supplementary feed is one of the main inputs for aquaculture production and considerable amount of money is required to purchase feed during the culture period. Small farmers face institutional constraints namely limited access to credit market and training. Therefore, they cannot supply sufficient amount of feed during culture period which may affect production and profitability. Farmers believe that more feed causes more production and hence more profit. But to maximize profit, both input and output have to be chosen optimally.

On the other hand, due to liquidity constraints a considerable proportion of small fish farmers who have taken up fish farming are considering reversing fish pond to rice field which is very costly. This situation raises a number of questions. Therefore, in this paper we (i) estimate the profit efficiency level of fish farming, (ii) attempt to estimate the best input-output combination that maximize profit and finally (iii) explore how fish farming can sustain in the long run. To avoid the heterogeneous production system, only pangas fish farmers who have converted land from rice to fish farm have been selected for this study. After log-likelihood test Cobb-Douglas form of normalized stochastic frontier profit function was used on cross sectional data collected from three main fish producing upazila under Mymensingh district in Bangladesh. The parameters of the profit efficiency and inefficiency effects were estimated simultaneously using maximum likelihood estimation method.

We find that the average profit efficiency level is 0.74 that implies good potential to increase profitability and profit efficiency through improving technical, allocative and scale efficiency. Results also find inverse profitability-farm size relationship whereas productivity and profit efficiency increases with increasing farm size which contradicts the widely known inverse productivity–farm size relationship in crop production literature. Increased profit efficiency is associated with better access to credit, training and extension services, suggesting that policies to improve access to these services are essential to sustain long-run fish farming in our sample farmers.

Paper III: Production Risk of Pangas (*Pangasius hypophthalmus*) Fish Farming in Bangladesh

In most of the agricultural production process farmers face different types of risks and input use risk is one of them. Some input may reduce the level of production risk while other may increase risk. In Bangladesh, Pangas (*Pangasius hypophthalmus*) is one of the major fish species which has expanded rapidly during the last one and half decades. But production variability is observed from farm to farm and location to location. This may be due to level of input use variation. In addition, there are large differences in the socioeconomic conditions between small-scale and large framers which may lead to the input use variation in the fish production process. There is considerable scope for controlling the level of output risk through input quantities.

Giving emphasis on above issues, the main objectives of this paper is to identify the risk factors which are responsible for the production variability in the pangas production process. Secondly, we give some policy how to avoid this risk. Just-Pope stochastic production function is used to identify the factors which have positive or negative effects on production variability.

Result reveal that labor, fingerling, feed and capital significantly increase the mean production as expected. Feed and capital has risk reducing effects while fingerling has risk increasing effects for the average farm. In addition risk increases with increase of farm size as expected. Supplementary feed is the most important component of cost for pangas production which has risk-reducing effects for small farm but risk-increasing effects for large farm. This is because, large farmer use sufficient amount of feed or sometimes overfeeding can occur where fish is not able to digest all feed and excess feed is harmful for pond environment which increases the production risk. But small farmer supply less than optimal feed during culture period and feed use variation is high among the small farmers. This is happening because most of the small farmers have no access to institutional credit due to high collateral. This explanation is supported by the risk-reducing effects of credit for small and medium farms entailing that small and medium farmers having credit access may buy risk-reducing input like feed with the credit money. Training and extension service has statistically significant risk-reducing capacity on pangas production for all categories of farm except small farms. Farmers who received more training on fish culture and have contract with extension service provider can manage different risky situation during culture period.

This is the first research initiative on input use production risk in aquaculture sector in Bangladesh; therefore, this research contributes significantly to the aquaculture literature in Bangladesh. This research is also important for the fish farmers to identify factors responsible for production risk and for policy makers to make institutional and input use policies for reducing the production risk for the aquaculture sector.

Paper IV: The Impact of Community-Based Aquaculture on Poverty and Inequality: Evidence from Seasonal Floodplain Areas of Bangladesh

Over one-third of Bangladesh is composed of floodplain. Due to lack of proper management policy, these floodplains remain unused at least six months (monsoon season) in a year but millions of surrounding peoples directly depend on these floodplains for their food and livelihood. Income of the masses living in these areas depends solely upon natural fish available during the monsoon season. Therefore, overall income of the people living around floodplain areas is low compared to other rural areas; resulting into higher poverty levels. On the other hand, local power structure in this area is also hostile to the masses belonging to low income category. During fish harvesting time, the local landlords exercise their power and catch major portion of the fish from these floodplains (Islam et al. 2006), depriving landless fisher from fishing income and thus leading to higher income inequality. But these floodplains are suitable for fish culture during monsoon season. WorldFish Center has introduced a new management system with the collaboration of Department of Fisheries (DoF) where fish is cultured through community management during the monsoon season and the same land is individually used for rice cultivation during non-monsoon seasons. This system is known as Community-Based Aquaculture (CBA).

This paper investigates the impact of access to CBA management system on income, employment, poverty and inequality. Padma, Brahmaputra and Teesta river basin were chosen for the project and two floodplains were selected from each river basin, one as treatment and another as control. Therefore, these study cover total six floodplains of which three is CBA project and rest of three is as control. Three years panel data (2007, 2008 and 2009) are used for this study. Sixty (60) household from each floodplain (project and control) were randomly selected i.e. every year a total of 360 samples of which 180 come from the project and 180 from the control floodplains. Propensity score matching (PSM) method with three algorithms (Nearest neighbor,

Kernel matching and Radius marching) is used for impact evaluation. To check the robustness of results, random effect model is used. Gini index and Gini decomposition are used to examining the effect of CBA system on income inequality. In addition, FGT methods of poverty and poverty decomposition are used to estimate the impact of CBA system on poverty.

The estimated results of non-parametric PSM method show that fish income as well as total household income has increased significantly without any negative impact on non-fish income (non-fish agricultural and off- farm income) for the CBA project's participant compare to control households. In addition, on average, employment opportunity has increased 58 days during monsoon season. Random effect model exhibits consistent results with PSM method. Results also reveal that fish income distributed equally among the fisher communities after project implementation and the reduction of fish income inequality is statistically significant. This positive impact on fish income distribution has statistically significant positive effects on total income distribution in the floodplain areas. Results show that incidence of poverty and poverty gap is significantly lower for the CBA project participant compare to control and fish income has huge contribution to reduce poverty in the floodplain areas. Therefore, it can be concluded that community based aquaculture management system can reduce poverty and income inequality through enhancing the fish income in the floodplain areas of Bangladesh.

Paper V: Capacity and Factors Affecting Capacity Utilization of Marine Fisheries: A Case of Gill-net Fleet in the Bay of Bengal

Not only the developed countries but also the developing countries are facing excess capacity and over-exploitation problem in the marine fishery sector and more than 70 percent of the world fisheries are either fully or overexploited (FAO 2010). Therefore, research on capacity utilization and excess capacity turned into as an important concern to the governments, development agencies and researchers and a number of research have been done by FAO, other different research organizations and individual researchers (FAO 1998; FAO 2000; Färe et al. 2000; Kirkley et al. 2004; Kirkley et al. 2002; Kirkley et al. 2003; Pascoe et al. 2001; Squires et al. 2003; Tingley et al. 2003; Vestergaard et al. 2003). In Bangladesh, there is 710 kilometer of coast line and 166000 sq. meter marine water areas contributing 18 percent of country total fish production (DoF 2009-10). Although during the last two and half decades, the total marine fish catch has been increasing slightly in absolute term but its relative share compared to other

fisheries (aquaculture and inland capture) declining. This sub-sector is contributing significantly to employment generation and export earning but government budget on marine fisheries is very limited compared to other sectors. Management of marine fishery is far from satisfactory level and statistics on boat, gear and production does not reflect the reality. A lot more boats than recognized by the department (Department of Fisheries) operate in the marine fishery in Bangladesh. (Chowdhury et al. 1980; Khan et al. 1989; Mustafa 1999). To the best of our knowledge, there is no study on capacity and capacity utilization of any boats in the Bay of Bengal. This paper investigates the excess capacity, capacity utilization and factors affecting capacity utilization of gill-net vessel operating in the Bay of Bengal.

For this research, cross sectional primary data of 146 boats are collected in 2010 from two main marine fishing areas namely Cox- Bazar and Chittagong district in Bangladesh. Data are collected for both monsoon and non-monsoon season. Data Envelopment Analysis (DEA) approach is employed to estimate the capacity measure and Tobit regression is applied to investigate the factors affecting capacity utilization.

Research findings reveal that boat are utilized by moderate to low level of their total capacity (observed capacity) in monsoon and non-monsoon season but high level of technical inefficiency is observed in both seasons. Only 6% and 8% of the gillnetters are found to have operated at full capacity (observed capacity). However, when all inputs are used efficiently under normal condition the average capacity utilization (called unbiased CU) is 94% in monsoon and 98% in non-monsoon season. Results also reveal that high degree of excess capacity exists in both seasons and one third of total boat need to be decommissioned to eliminate these high degrees of excess capacity. Boat capacity, number of trip per month and duration per trip are the main factors affecting CU in the monsoon season. To eliminate the excess capacity, licensing restriction may be an effective instrument for auto elimination of boats from the fishery, however; this would have large distributional effect that need to be taken into account.

5. Overall conclusion

Based on the empirical results of this dissertation, the main conclusions are as follows:

❖ Although, the percentage contribution of fisheries sector to national GDP is declining, the total value addition has increased sharply. Production and yield has increased in both capture and culture fisheries. Credit, fish marketing, poor communication and less public budget are the main constraints for the aquaculture. On the other hand, proper management policies, pesticide use in agricultural production, river siltation are the main problems for capture fisheries. Large numbers of boats are operated in the inshore area but few vessels are operated in the deep sea which reflects the capital constraints in this sub-sector.

❖ In general, large farms are more productive, profitable and profit efficient compared to small farm which is due to the easy access to credit, training facilities and extension service of large farmers. The concept of more feed responsible for more production that in thus increasing more profit among farmers is misleading. Therefore, input and output need to adjust to be profit efficient. Access to credit and training are recommended for the small farmers to sustain in the long run.

❖ Significant production risk exists in pangas farming in Bangladesh. Supplementary feed usage is found to have risk decreasing effect on pangas production due to credit constraints for small farms while it has risk increasing effect for large farm. Access to credit and training is found to be risk reducing for small and medium farm. Therefore, to reduce the production risk in pangas farming, available credit and training are recommended for small scale farmers.

❖ Community Based Aquaculture (CBA) system can significantly enhance fish income as well as total household income without any negative impact on non-fish income which lead to reduce poverty (incidence of poverty and poverty gap) in the floodplain area. Benefit from floodplain has distributed equally after introducing this management system which also helped to reduce total income inequality. Therefore, we recommend to introduce the CBA management system in the floodplain areas in Bangladesh.

❖ In marine fishery, moderate and low level of capacity utilization (observed) and high level of technical inefficiency is found in both monsoon and non-monsoon seasons respectively. High degree of excess capacity is found in both seasons therefore one third of total boats need to

be decommissioned to eliminate this excess capacity. License restriction may be an effective tool to elimination of boats but distributional effect need to be taken into account to implement this policy.

The results and implications of this dissertation must be viewed in light of its limitations. Second, third and fifth paper use cross-sectional data, therefore, findings of these three papers conditional on resource condition, production practices, market situation and regulation of that particular year. These results might change using panel data which is not depicted in this present analysis. Data were collected from only one district (Mymensingh) for second and third paper which does not reflect the overall scenario of aquaculture in Bangladesh. Therefore, results of these two papers (profit efficiency, productivity and production risk measurement) might change when covering larger study area. On the other hand, in paper fifth, we use deterministic Data Envelopment Analysis (DEA) method to measure the capacity utilization measure where it is assumed that any deviation from the frontier is due to technical inefficiency. But this deviation may be induced from different other sources which may beyond the control of producer. In fourth paper, we use panel data but comparison unit was treatment and control. After and before data always better than project and control data for any impact evaluation. Finally, although this dissertation has several limitations, findings of this dissertation will be helpful to prepare future fisheries policies to promote development of overall fisheries sector in Bangladesh as well as other developing countries.

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PAPER I

An Overview of Fisheries Sector in Bangladesh: Past Trends, Present Status and Future Prospects*

Md. Akhtaruzzaman Khan

Abstract

Fishery has emerged as a fast-growing sector and contributes to nutrition, employment generation, livelihoods improvement and export earnings especially in developing countries. This paper is an attempt to present overview of fisheries sector in Bangladesh with respect to resource use, production trends and practices, export earnings, market and environment using available secondary data. Both fish production and productivity has increased for culture, capture and marine fisheries sector during the last two and half decades but tremendous development has been achieved in aquaculture. Different government organizations and research institutes have contributed significantly to develop economically viable and environmentally compatible technology and successfully transferred to the farmers. Nevertheless, fish market is far from satisfactory level in terms of space, sanitation, drainage and management. Many constraints are responsible for limited expansion and under-utilization of fisheries areas including capital, technology, extension service, proper policy, rules and regulations. Several constraints, possible solutions and future prospects for the three sub-sectors (capture, culture and marine) are discussed.

Keywords: Overview, fisheries, Bangladesh

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Introduction

Globally, the fishery sector plays a key role in income generation, livelihoods, poverty reduction, food security and export earnings. Seafood (fish and shellfish harvested from freshwater and marine) is the most highly traded food internationally which exceed the export value of rice, meat, coffee, tea, cocoa and tobacco (Smith et al. 2010b). Around 540 million people rely on fisheries, aquaculture and associated activities for their income and livelihood, of which 44.9 million people are directly employed in fisheries and aquaculture (FAO 2010). During the last three decades, employment in the fisheries sector has grown 3.6% per year which is greater than the world's population growth (growth 1.7% per year) and also greater than employment growth in traditional agriculture (FAO 2010). Fish is also an excellent source of high-quality protein, essential micronutrients including various vitamins and minerals. Globally, fish provides almost 15 percent of animal protein for more than 3.0 billion people (FAO 2010; Smith et al. 2010b).

Global demand for fish and fish product has risen with rising population and the excess demand has been met by rapid growth in production and increased global fish trade (Dey and Ahmed 2005). During the last three decades, tremendous expansion and production growth has occurred in world aquaculture (8.3% per year) whereas capture production is unlikely to increase (Dey and Ahmed 2005; FAO 2010; Smith et al. 2010b). Asia is the top contributor accounting for 66.4% of global capture production and 88.8% of aquaculture production. China is the largest fish-producing country contributing to 32.73 percent of world's fish production (FAO 2010).

Despite the substantial growth and development of fisheries sector, a number of issues have been raised which are impediment for the proper expansion such as: poor management, negative environmental impact, climate change, limited or insecure access rights to fishery resources, overfishing and potential depletion of fishery resources, lack of institutional support for the fish farmers, problem of adoption of new technologies for small-scale farmers due to their weak capital base, fish market and marketing problem for the fish producer and sustainable management for the common property resources etc. These issues are very important for the sustainability of this sector (Smith et al. 2010b).

However, fishery sector of Bangladesh has grown rapidly during the last twenty five years and contribute significantly to the global fish production. Fish production increased from 0.77 million metric tonnes in 1984-85 to 2.89 million metric tonnes in 2009-10 (DoF 2009-10) and

became as the second largest export earning sector after readymade garments. It contributes to 3% of total export earnings, 4.6 % of the national GDP and 22.2 % of agricultural GDP (BBS 2009; DoF 2009-10). Until the mid 1980s, capture fisheries was the main source of fish in Bangladesh. Afterwards, both aquaculture and capture production has increased rapidly especially aquaculture has expanded tremendously. Increased fish production in the past mainly came through the introduction and adoption of new technologies (such as genetically improved strains of fish and better management system), expansion of production area to some extent and intensification of aquaculture practices.

Favourable agro-climatic condition and extensive inland and coastal water resources offer tremendous opportunities for different types of fish production in Bangladesh. But good governance, proper policy, infrastructures, implementation of economic reform, access to property rights and political stability are very important to be expansion and sustainable in the long run of the fishery sector (Smith et al. 2010b). There are many factors which contributed for the expansion of the fisheries sector and many issues need to be solved for further expansion in Bangladesh. Therefore, the aim of this paper is to present the insight of country's fisheries resources, production practices and trend, export earning, market and environment, and also try to find out present constraint and future prospects using available data from secondary sources. This overview paper may be helpful for policy makers to prepare future fisheries policies in Bangladesh and provide important insights for other countries as well.

World versus Bangladesh Food Fish Production

World fish production expanded rapidly, reaching 145.1 million tonnes in 2009 of which 115 million tonnes was for human consumption and the per capita food fish supply was about 17 kg which is among the highest on record (FAO 2010). Global aquaculture production has increased during last one and half decades while capture production remained fairly stable. Marine fish contributes (capture and culture) to 68.9% of total world fish production and the rest of 31.1% come from inland fisheries. In 2009, only China produced 32.7% of total global fish (FAO 2010). Bangladesh is also contributing a significant proportion of fish to world production. Table 1 presents the fish production scenario for the world as well as for Bangladesh. In 1990, Bangladesh produced 0.9% of global production and it grew up to 1.9% in 2009. Bangladesh has

significant contribution to world inland (capture and culture) production (4.9 %) but marine contributes less (0.5%) which is increasing year by year.

Table1: World versus Bangladesh Fish Production (in million tonnes)

	1990	1995	2000	2005	2009
World Production					
<i>Marine</i>	84.25	96.04	100.20 (76.0)	100.10 (77.0)	100 (75.3)
<i>Inland</i>	14.76	21.24	30.20 (12.9)	36.20 (16.7)	45.1 (20.8)
<i>Total</i>	99.01	117.28	130.40 (88.9)	136.30 (93.7)	145.1 (96.1)
Bangladesh Production					
<i>Marine</i>	0.24	0.27	0.38	0.48	0.51
<i>Inland</i>	0.65	0.99	1.40	1.85	2.19
<i>Total</i>	0.89	1.26	1.78	2.33	2.70
Bangladesh's share (%)					
<i>Marine</i>	0.28	0.28	0.38 (0.50)	0.48 (0.62)	0.51 (.068)
<i>Inland</i>	4.40	4.66	4.64 (10.85)	5.11 (11.08)	4.86 (10.53)
<i>Total</i>	0.90	1.07	1.36 (2.00)	1.71 (2.49)	1.86 (2.81)

Sources: FAO 2010, DoF: 1990-91;1994-95;1999-2000;2004-05;2008-09

Figure in the parentheses indicate production and percentage excluding China

Bangladesh is the second largest inland capture fish producing country in the world after China and contributes 10.4% of world capture fish (FAO 2010). Global inland capture production was fairly stable from 2000 to 2004 but afterward it showed overall increases of 1.6 million tonnes reaching 10.2 million tonnes in 2008. In 2004, the total inland capture fish production of Bangladesh was 0.73 million tonnes but it grew up to 1.35 million tonnes in 2010 (DoF 2009-10; FAO 2010). Figure 1 shows top ten inland capture fish producing country in the world in the year 2008.

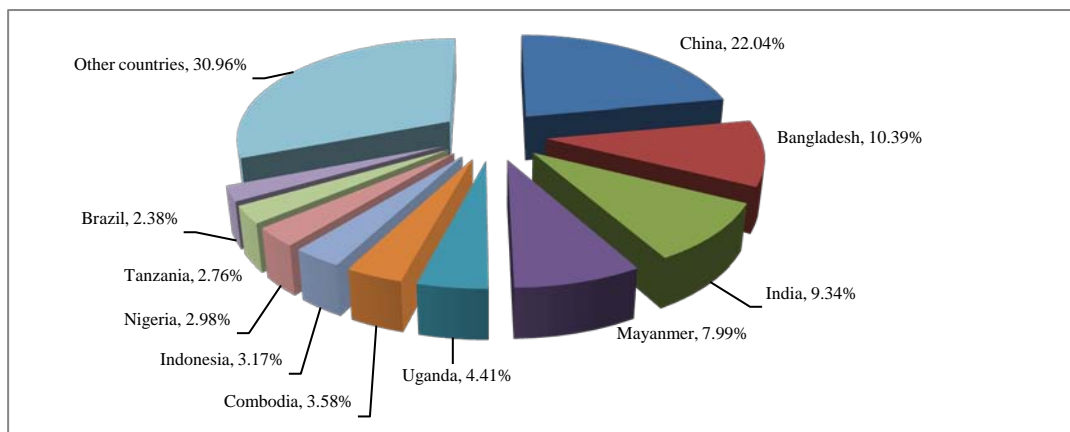


Figure 1: Top ten inland capture fish producing country in the world, 2008
Sources: FAO (2010)

Importance of Fisheries in Bangladesh

Agriculture sector plays a vital role in the economic development of Bangladesh, as it contributes to 19 percent of gross domestic product (GDP) (BBS 2009). Within the agriculture sector fisheries play significant role in the socio-cultural and economic life of Bangladeshi people. Its contribution to agriculture sector increased from 7% in 1973/74 to 22.2% in 2007/08 (BBS 2009; Dey et al. 2008b). No sub-sector of agriculture illustrates the development potentials more clearly than fisheries. The share of fisheries sector contributed to national GDP was on an increasing path until 2000/2001; afterwards it is gradually declining due to tremendous growth in readymade garments sector. Despite the decline in the percentage contribution of fisheries to national GDP, the total value addition has sharply increased from Taka 65.83 billion in 1994 to Taka 169.26 billion in 2008 (Figure 2). To be an economically developed country before 2025, Bangladesh needs to achieve at least 8-10% GDP growth, 20-25% export growth and 18-20% import reduction (Bhattacharya 2002; Planning Commission 1995). In this case, fisheries sector may contribute more in terms of national GDP and export growth if existing problems can be solved through proper policy.

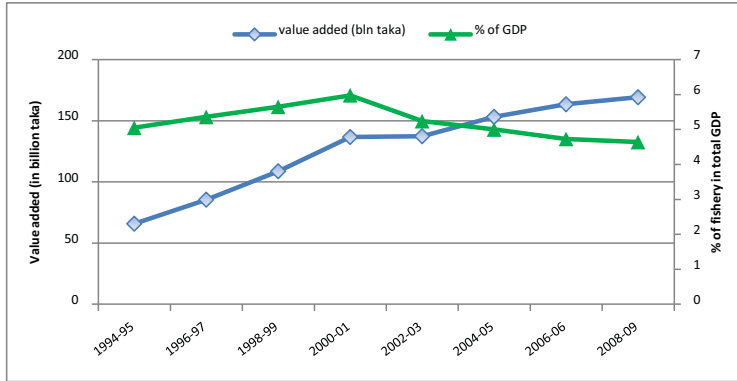


Figure 2: Value addition and share of fisheries sector to national GDP in Bangladesh
Source: BBS different issues

Fish is the main sources of protein in Bangladesh. The minimum per capita per day protein requirement has been estimated as 45.3 gram of which 15 gram should be of animal origin and fish constitutes about 63 percent of the total animal protein intake in Bangladesh (Rahman 1992). A USAID study reported that the poor rural people consume annually about 50-75 different species of fish (Ali 1997). In the rural areas, small species of fishes are by and large the sources of crucial nutrients; such as calcium, minerals, fatty acids and vitamins, especially vitamin ‘A’ which is vitally important to control blindness of children.

As a source of livelihood, fisheries (capture, culture and marine) employed 2 million people (7% of the countries’ employment) and also 12 million people gets substantial supports as income and livelihood from this sector (DoF 2002). Around 73% of the rural households are involved in freshwater aquaculture activities for their livelihood in the floodplain area in Bangladesh (Mazid 1999). Out of the total employment in fisheries, 55 percent is involved in freshwater fisheries, 36 percent in marine fisheries while only 6 percent is involved in coastal shrimp farming (Islam 2000). The Poverty Reduction Strategy Paper and National Fisheries Strategy indicated that fishery is one of the most promising sectors for income generating activities for rural poor households in Bangladesh (Planning Commission 2005; DoF 2006). Karim (2006) reported that aquaculture can open up new employment opportunities in rural areas by increasing both self-employment and demand for labor.

Bangladesh earns a considerable amount of foreign exchange every year by exporting fish and fisheries products. The main items of fisheries exports are frozen shrimp and frozen fish. The quantity of fish and fish products exported from Bangladesh increased from 22 thousand tonnes, earning 6.91% of the total export in 1991-92 to 73 thousand tonnes earning 3% in 2008-2009 (DoF 1991-92; 2009-10). During the latter half of the 1980s, fish contributed over 8% of total exports, reaching a peak of 14.65 % in 1986 (Dey et al. 2008b). Although the share of fish earning to total export has declined in recent years, the absolute value has increased gradually.

Fisheries Resources and Fish Biodiversity

Bangladesh is fortunate in having an extensive inland water resources and extensive coastal line which is very productive. Here near-shore seas, rivers, estuaries and mangroves, lakes and ponds all offer tremendous opportunities for fish farming. The soil, water and climate of Bangladesh are very favourable for inland fisheries, both open and closed water. Table 2 presents details of fisheries resources in Bangladesh. Inland fisheries covers an area of 4.65 million hectare land of which 86.5% is inland open water (capture fisheries area). The floodplain, *beels* and Kaptai lake covering more than 3 million hectare has tremendous scope to augment fish production by adopting culture-based fishery enhancement technique. Area under inland open water (river, *Beels*, Kaptai Lake, flood land) remained same over the years, but closed water (culture fisheries) area has increased at least twice as much during the last two decades. There are over 17.67 million ponds and tanks and 0.06 million *dighis* in Bangladesh. A revolutionary change has occurred in shrimp farming sector. In 1985-86, the total land area under shrimp farming was only 87 thousand hectare but it shot up to 246 thousand hectare in 2009-10. On the other hand, Bangladesh marine area is characterized by semi-enclosed tropical basin which comprises of about 710 kilometer coastline along with Bay of Bengal and an area more than 166,000 square kilometer as Exclusive Economic Zone (EEZ) for exploration, conservation and management. The entire shelf area of Bangladesh covers about 70,000 square kilometer of which the continental shelf up to 40 fathom depth zone extends over an area of 24800 Sq. km.

Table 2: Fisheries Resources in Bangladesh

Resource	Quantity (in hectare)					
	1985-86	1990-91	1995-96	2000-01	2005-06	2009-10
(A) Inland Water Area						
(i) Inland Culture						
1. Pond & Ditches	146890	146890	146890	241500	305025	350595
2. Baor	5488	5488	5488	5488	5488	8556
3. Shrimp/ Prawn farm	87300	108280	137996	141353	217877	246198
Culture Total	260558	260558	290374	388341	528390	627731
(ii) Inland Capture						
1. River and Estuaries					1031563	853863
2. Sunderbans					177700	177700
3. Beel					114161	114161
4. Kaptai Lake					68800	68800
5. Floodplain					2832792	2832792
Capture total					4047316	4024934
Total Inland		4307316	4337690	4435657	4575706	4652665
(B) Marine (Qty. in sq. miles)						
(i) Territorial Water (up to 12 nautical miles from the base line)						2640
(ii) Exclusive Economic Zone (200 nautical miles from the base line)						41040
(iii) Continental Shelf (up to 40 fathom depth) Excluding Internal and Territorial Water						24800
(iv) Coast Line						710

Sources: DoF 1985-86;1990-91;1995-96;2000-01;2005-06;2009-10

Bangladesh is also rich in fish biodiversity. There are more than 250 different species of fish in Bangladesh. Traditionally they are grouped in five broad categories- hilsa, carp, catfish, prawn and others (Khatun 2004). There are about 60 native, 13 exotic species of fish and 20 species of shrimp inhabited in inland freshwaters in Bangladesh (Dey et al. 2008a). The indigenous carp species are broadly categorized as major carps (*Catla*, *Rohu*, *Mrigel* and *Kalbaus*) and minor carps (*Bata*, *Reba*, *Nandina* and *Gonia*). However, in recent years, freshwater species are declining due to overfishing, rapid extraction of fish seed and broodstock, pollution, introduction to exotic species, losses of aquatic habitat and other anthropogenic activities (Alam 2011). About 54 inland fish species face different categories of threats, of which 28 are endangered, 14 are vulnerable and 12 are critically endangered due to overfishing or overexploitation (FAO 2002).

National Fisheries Policy

Fisheries resources need to be managed efficiently and effectively to achieve maximum sustainable production. In this regards, special attention need to be paid in resource management policy such as land or water use policy, catch policy, environmental policy etc. According to FAO (2010), about 32% of the world marine fisheries are in danger or overexploited. At the same time aquaculture is facing serious critiques in terms of management and undervalued for food safety (Smith et al. 2010a). Conservation of fisheries resources, lack of proper management, various natural calamities, man-made problems, lack of skilled manpower are the main obstacles to the development of the fisheries sector. Proper fisheries policy can solve these problems and develop the sector up to the mark. In 1986, the New Fisheries Management Policy (NFMP) was developed by the Government of Bangladesh (GoB) giving emphasis on benefit distribution among the actual fishermen and to overcome the over-exploitation problem. The Ministry of Fisheries and Livestock prepared the National Fisheries Policy (NFP) in 1998 for the overall development of fisheries sector. The specific objectives of National Fisheries Policy are (i) to enhance fisheries production, (ii) to alleviate poverty through creating self-employment and improve the socioeconomic condition of the fishers, (iii) to fulfill the demand of animal protein, (iv) to achieve economic growth through foreign export earnings from fish and fisheries product, and finally (v) to maintain ecological balance, conserve biodiversity, ensure public health providing recreational facilities (MoFL 1998). To enhance the development process of the fisheries sector, emphasis has been given on four dimensions: (a) policy for procurement, preservation and management of fisheries resources of the open water bodies, (b) policy of fish culture and management in closed freshwater bodies, (c) policy for culture shrimps in coastal regions and (d) policy for exploitation, conservation and management of marine fisheries resources. The other policies which are not directly related to fisheries but relevant to fisheries are; Environmental Policy 1992, New National Extension Policy 1996, National Water Policy 1999 and Land Use Policy 2001; all were developed by the GoB which focuses on the fisheries resource management as a major part.

In addition, Department of Fisheries (DoF) and Bangladesh Shrimp and Fish Foundation prepared a Code of Conduct for nine important segment of Aquaculture industry in March 2011, giving emphasis on environment, social and resource use conflicts and food safety. These nine segments are: (i) Black tiger shrimp (Bagda) *Penaeus monodon* hatchery, (ii) *Macrobrachium*

shrimp (Galda) hatchery, (iii) Black tiger *Penaeus monodon* shrimp farm, (iv) Galda shrimp (*Macrobrachium*) farm, (v) Shrimp depot, (vi) Ice plants, (vii) Fishing boats, (viii) Fish carrier transport van/vessel and (ix) Shrimp/fish feed mill (DoF 2011).

Overview of Fisheries Sub-Sectors

Bangladesh fisheries sector is broadly divided into three sub-sectors; (i) Inland capture (ii) Inland culture and (iii) Marine. Past status and present situation of three sub-sectors are discussed below.

Status of Inland Capture Fisheries

The inland capture fisheries includes river & estuaries, sunderbans, beels, Kaptai lake and floodplain which cover 4.03 million hectares comprising of 86.5% of total inland fisheries area. In practice, about 87% of area for capture fisheries produces 43.2% of total inland fish and rest of 56.8% fish being produced only from 13% culture fish area (figure 3). In 1985-86, capture fish share was 55.7% of total fish production but declined to 35.5% in 2009-10 (DoF 2009-10).

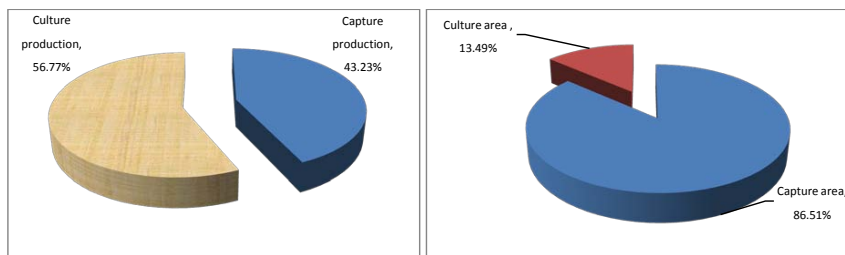


Figure 3: Share of total inland capture and culture area & production in Bangladesh
Source: DoF (2009-10)

From 1986 to 2001, annual capture fish production growth rate was 3.5%, nevertheless fish production from river and estuaries declined by 1.3% (Dey et al. 2008b; Khan et al. 2009). Afterward, an impressive progress has been achieved in production due to adoption of co-management system in the floodplain areas and production growth rate of capture fisheries grew up to 5.7 percent during 2002 to 2010.

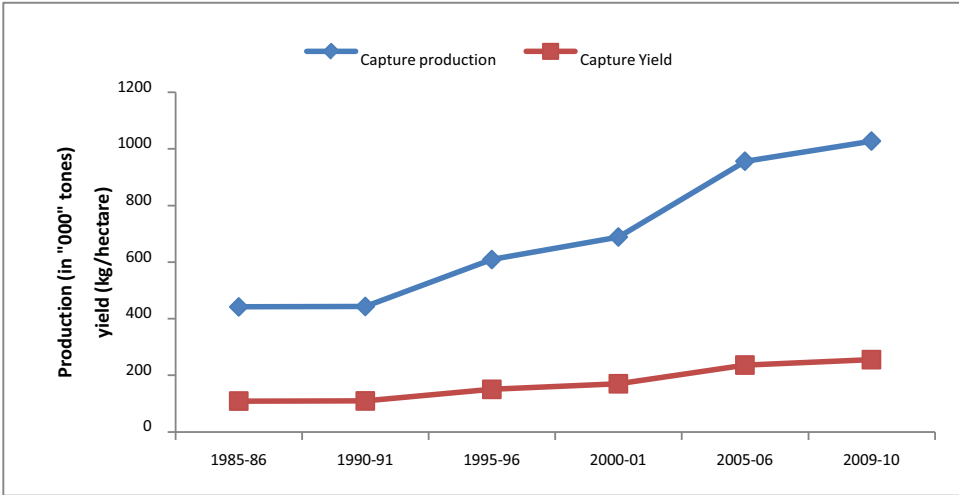


Figure 4: Production trend and yield of capture fish in Bangladesh
 Source: DoF 1985-86;1990-91;1995-96;2000-01;2005-06;2009-10

Only floodplain and *beel* constitute 73% of total capture area. Historically, fishing rights in open access (floodplain and *beel*) have been privatized by the government and usually leased out to the relatively elite non-fisher- who can acquire exclusive rights to the water body by using social power (Toufique 1997). This leasing policy was one of the main causes of low growth rate of capture fish. Barriers to the access of poor fishers in the open fisheries resources and over-exploitation by the rich leaseholders have reduced livelihood option for fishery dependent communities and created income inequality among the fisheries communities (Hossain 2006). In addition, fishers use modern technology to catch all species of fish which is threatening biodiversity and sustainability. To overcome these problems, the government of Bangladesh has implemented a number of projects funded by the Ford Foundation and the United Kingdom Department for International Development (DFID) to promote the sustainable use of fishery resources and equitable distribution of benefits by involving fishers' communities. Several research studies show that fishers' income, distribution of income among different communities, access to different assets including social, human, physical, financial and natural capitals have improved after adoption of co-management system (Islam 2010; Islam et al. 2006; Islam K. J. and Kazal 2007; Khan and Islam 2006; Sultana and Thompson 2007; Thompson 2004). From 2000 to 2010, the floodplain's production grew rate of at 8.8% annually while yield increased from 175 kg/ hectare to 310 kg/ hectare.

Status of Inland Culture Fisheries / Aquaculture

Freshwater aquaculture

Aquaculture can be divided into two as: freshwater and brackish water aquaculture. Freshwater aquaculture satisfies the domestic consumption; on the other hand, brackish water earns a considerable amount of foreign exchange. The freshwater aquaculture includes pond aquaculture, rice-fish culture on seasonal farmland, cage culture in rivers and lakes, pen culture in closed and open water bodies, and fish culture in such commonly held perennial water bodies as oxbow lakes. Annual production growth rate of culture fish was 7.2% during 1984-85 to 1994-95 and it has increased up to 11.8% in 1995-96 to 2009-10 (DoF 2009-10; Khan et al. 2009). This higher production growth rate has been achieved due to the innovation, dissemination and adoption of new technologies. Consequently, the share of aquaculture to total fish production increased from 18.2% to 46.2% during 1986 to 2009 period. Figure 5 presents the production trend and yield of culture fish of Bangladesh.

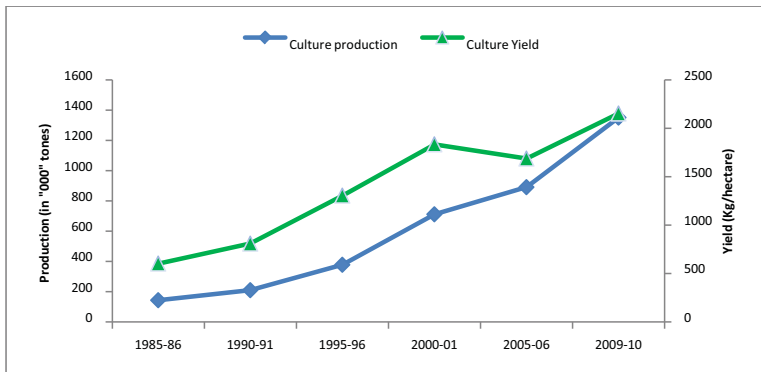


Figure 5: Production trend and yield of aquaculture in Bangladesh
Source: DoF 1985-86:1990-91:1995-96:2000-01:2005-06:2009-10

Pond is the main source of aquaculture production which contributes 84.4% of culture and 39.3% of total fish production. In order to meet the domestic fish demand for the growing population, governments of Bangladesh and different NGO's have taken different initiatives to increase the pond fish production. These initiatives contributed positively to the expansion of aquaculture area and productivity. On the other hand, due to an overall high profitability in fish farming compared to rice, farmers are more interested to culture fish in some parts of Bangladesh. The process of converting rice areas into ponds started at least one and half decades

ago for freshwater fish ponds and more than two decades for shrimp production. The main expansion has, however, taken place in the pond area. This development has received momentum and thus become visible. There is no rice within at least one kilometer from the highways on both sides of Dhaka-Mymensingh, Dhaka-Comilla, or Dhaka-Jessore. In 1984-85, area under freshwater pond was 125 thousand hectare but expansion grew rapidly up to 350 thousand hectare in 2009-10 with 9.3% annual growth rate. Generally farmers practice polyculture of Ruhi, Catla, Mrigel, Silver carp, Mirror carp, Gras carp, Bighead, Gonia etc in their ponds. During last one and a half decades monoculture of Pangus, Tilapia and Thai Kai fish has rapidly increased in the Northern part of Bangladesh. Figure 6 presents expansion of pond fish area, production trend and yield during the last two and half decades.

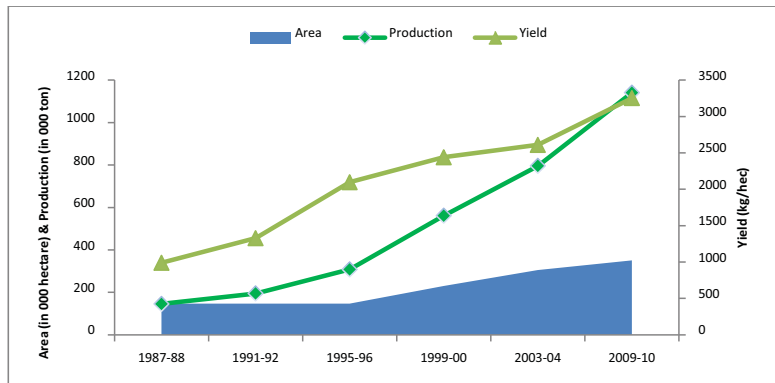


Figure 6: Expansion of pond culture area, production and yield in Bangladesh
Source: DoF 1987-88; 1991-92; 1995-96; 1999-2000; 2003-04; 2009-10

Brackish water aquaculture / Shrimp

Bangladesh is blessed with brackish water resources which cover about 21 southern districts of Bangladesh (located in Chittagong, Cox's Bazar, Khulna, Satkhira and Bagerhat belt) facing the Bay of Bengal. It is very productive as it gets lot of organic nutrient from southern mangrove (Sunderbans & others) forests. On the other hand, this area gets inorganic nutrient from the upstream river. Shrimp culture practice and production period are varies from location to location depending on water salinity level. There are mainly four types of shrimp culture system practiced in Bangladesh (i) Alternate shrimp-rice farming; (ii) Alternate shrimp-salt

farming; (iii) Year round shrimp farming and (iv) Shrimp culture alternate with fresh water aquaculture.

Due to international market demand and its contribution to foreign exchange earnings, shrimp sector has expanded rapidly. During last two and a half decades, a countable production growth rate (annual 11.3%) and yield has taken place in shrimp sector (Figure 7). Significant amount of prime quality rice land has been transformed into shrimp culture in the southwestern part of Bangladesh (Ali 2006). During 1975 to 2010 period the shrimp area has increased from 20 thousand to 246 thousand hectare (BBS 1975; DoF 2009-10). This sharp increase is due to the fact that net profit from shrimp farming is estimated to be twelve times higher than that of high yielding variety rice (Shang et al. 1998).

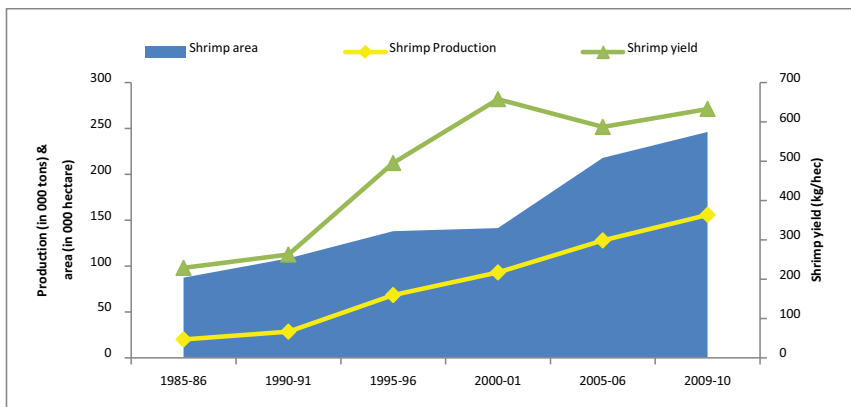


Figure 7: Expansion of shrimp area, production trend and yield in Bangladesh
Source: DoF 1985-86; 1990-91; 1995-96; 2000-01; 2005-06; 2009-10

Shrimp export and export market

Fish export earning has increased gradually until 2008, showing a decline thereafter. Only shrimp contributes 85% share of total export income from fish and fish products and it has ranged between 80 to 90 percent over last two and a half decades. Figure 8 presents export earnings and the gap between production and export (potential export). It reveals that the gap between production and export quantity has increased rapidly and grew up from 22 to 65 percent during 1985-86 to 2008-09, which implies that only 35% of total shrimp production is being exported. This gap has increased tremendously from July 1997 after imposing an import ban on shrimp by European Commission. Therefore, total revenue loss was around 14,665 million US dollar during

August – December, 1997 (Cato and Dos Santos 1998). Actually it was the short term impact but most of the forward and backward linkages in shrimp industries were affected due to import ban. The ban was imposed because Bangladeshi exporters could not maintain a minimum international safety and quality standards for the world market.

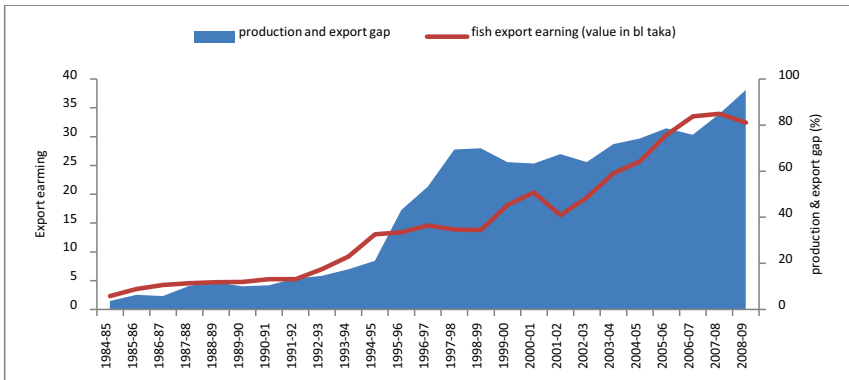


Figure 8: Fish export earning and production & export gap (potential export)
Source: DoF 1984-85 to 2009-10

The EU and the USA are the main shrimp importers from Bangladesh. In 2005-06, shrimp export to the EU was about 49.3% of the total export and about 39.5% to USA and rest of 6.9% are exported to the Southeast Asia and Middle East. Figure 9 shows the shrimp exported from Bangladesh during 2005-06 in the world market.

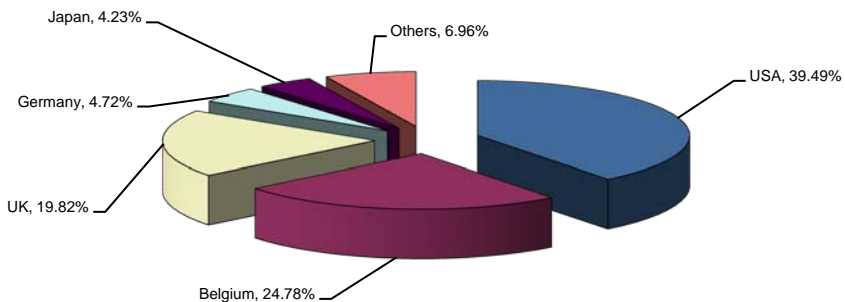


Figure 9: International shrimp market of Bangladesh
Source: DOF, 2005-06

The number of shrimp processing plants has increased with the increasing shrimp export. Until 1971, there were only nine processing industry plants with a production capacity of approximately 58.5 metric tonnes per day and all processed fish was exported in USA and EU market. Afterwards, a remarkable development has been achieved in processing industry and about 40 processing plants were constructed during 1972 to 1984 and the number grew to 124 in 1999. Until 2004, there were 131 shrimp processing plants in Bangladesh but used only 35% of their capacity which implies that 65% excess capacity exists in shrimp industry (DoF 2005-2006).

Shrimp and Environment

Although shrimp sector has been playing a vital role for curbing poverty in the coastal areas of Bangladesh, it has a number of adverse impacts on environment, ecology and human health. There are about 37 thousand small, medium farmers cultivating *bagda* (tiger shrimp) with an average farm size of 4.0 ha (DOF 2002a; Muir 2003a) where 60 thousand people are employed and generating US\$ 457 million annually (Export Promotion Bureau of Bangladesh 2006-2007). The rapid expansion of shrimp farming has resulted in a number of consequences: scarcity of post larvae, destroyed mangrove and aquatic vegetation, created scarcity of snail and shellfish, increased land salinity, created coastal water pollution, decreased agricultural land, declined livestock population, compelled people to migrate out elsewhere for jobs etc. (Haque 2003).

The salt intrusion is the major problem which has caused many problems such as loss in crop production, freshwater crisis and related gastro-intestinal diseases, loss of green vegetables, fodder etc. More than 30% of the net cultivable land of Bangladesh is located in coastal areas and are not being utilized for agricultural production mainly because of salinity problem (Wahab, 2003). Paddy yield has also been reduced because of soil salinity problems (Chowdhury et al. 2006).

The shrimp *gher* farming has also significant negative impacts on the ecology. The ecological effect of acid sulphate destroys food resources, displaces biota, releases toxic levels of aluminum, precipitates iron (which smothers vegetation and micro habitat) and alters physical and chemical properties of water (Sammut et al. 1996). Fry collectors (main inputs for shrimp *gher* farming) collect post larvae from the seas, a large number of finfish and other fries of fish are caught, most of which perish. Studies conducted by Deb et al (1994) and William & Khan

(2001) found that about 1340 other fries are caught during the collection of a single prawn post larvae (PL).

The rice-prawn farming also has significant negative impact on the ecology and livestock. Fish diversity and fish stock has decreased in the swamplands, canals and rivers, because of siltation or blockage of fish migration routes, water pollution as well as decreased swampland area due to *gher* construction (Abedin et al. 2000; Islam 2001). Williams and Khan (2001) mentioned that the women and children who crush the mud snail for prawn feed suffer from skin irritations and respiratory complaints. Kendrick (1994), William and Islam (1999) and William and Khan (2001) argued that livestock has decreased mainly due to unavailability of grazing land and unavailability of fodder crops as a result of shrimp farming.

Status of Marine Fisheries

Marine fishery contributes 18 percent of total fish production in Bangladesh (DoF 2009-10). While inland culture fish production trends have been on the sharp increase, marine fishery is growing slowly (4.03% annually during the 1984 to 2004 period) (Khan et al. 2009). The total marine catch was 207 thousand metric tonnage in 1985 and it grew up to 517 thousand metric tonnes in 2010 (DoF 2009-10). The marine fishery of Bangladesh is mainly dominated by artisanal fishery rather than industrial fishery with different gear types and fish species. Out of total marine fish production, 93% comes from artisanal and only 7% from industrial fishery (DoF 2009-10). Industrial marine fishery is based on trawl where only 40 shrimp trawlers and 101 fish trawlers operate in the vast deep sea area of EEZ. On the other hand, about 21 thousand mechanized and 23 thousand non-mechanized boats operate in the inshore area. Gill-nets (drift and fixed totaling 106 thousand), Set Bag Nets (Estuarine and Marine totaling 50 thousand) and Long Line Net (totaling 25 thousand) are the main fishing gears for artisanal fishing in Bangladesh. Gill-nets contribute largest share (62%) of total artisanal fish landing (DoF 2009-10). Hilsha, Bombay Duck, Shrimp, Pomfret and Jew fish are main marine species. Among these species *hilsha* is the most important aquatic resource of marine fishery, contributing to 39.4 percent of total marine catches (DoF 2009-10).

Fish Hatchery Development

Until late the 1980s, rivers were the main sources of carp seed. Afterwards a phenomenal growth took place in fish hatchery, especially in the private sector. During the 1970s, the public sector (government) began producing quality fish seed through artificial breeding techniques by establishing a number of hatcheries. During the mid 1980s, basic training on fish breeding and hatchery operation and management was undertaken, initially by DOF, and later by BFRI. Until 1988, the public and private sectors established only 77 and 162 hatcheries, respectively but the number has rapidly increased during 1990s with the private sector predominating in the development of hatchery. More than 95% spawn requirement is met from induced breeding. Table 3 present the number of hatchery and production scenario from public and private sector.

Table 3: Expansion of fish hatchery in Bangladesh

Year	Public		Private		Natural collection (kg)	Total quantity of hatchling produced (kg)
	No. of public hatchery	Quantity of hatchlings (4-5 days old fry) produced (kg)	No. of private hatchery	Quantity of hatchlings (4-5 days old fry) produced (kg)		
1985	NA	1010	69	3952	19362	24324
1990	89	1758	204	13014	5127	19900
1995	102	3272	533	97204	9145	109621
2000	112	3663	667	214682	1872	220217
2005	112	5128	731	315892	2123	323143
2007	77	6244	860	457288	2061	465593
2009	77	5550	854	459804	1875	467229

Source: DoF 1985-86; 1990-91; 1995-96; 2000-01; 2005-06; 2007-08; 2009-10

The species mainly cultured in freshwater and the seeds produced are: Rui, Catla, Mrigal, Silver Carp, Grass Carp, Mirror Carp, Thai Puti, Carpio, Kalibous, Bighead carp, Magur and Koi. The size and production capacity vary, ranging from 8 to 160 million spawn annually. Hatchery operators are not very technically efficient (mean technical efficiency 61%) in terms of input use (Khan and Alam 2003). On the other hand, about 60 hatcheries are in operation for shrimp sector and most of these hatcheries are located in Coz's Bazar. Fish seed has two stages of production such as spawn and fry or fingerling. Accordingly, two stages of marketing are involved: marketing of spawn from hatchery to nursery and marketing of fry and fingerling from nursery to fish farms. Figure 10 presents the marketing channels of fish seed in Bangladesh.

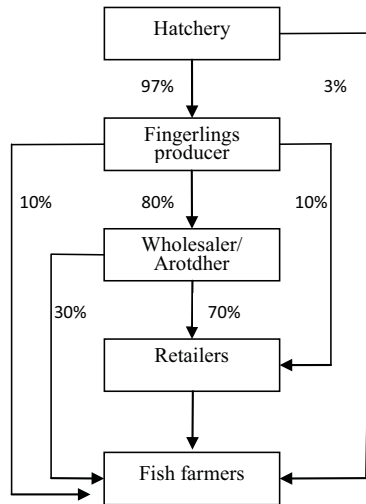


Figure 10: Typical marketing channels of fish seed in Bangladesh

Technology Practice in Fisheries Sector

There are mainly three types of fish farming system in Bangladesh; (i) extensive (no supplementary inputs are supplied, only relying on natural feed) (ii) Semi-intensive (supplemented with feed and fertilizer but relying mostly on natural feed) and (iii) intensive systems relying on nutritionally complete concentrate feed and fertilizers (Edward 1993). Traditional pond culture is characterized by semi-intensive and in some cases extensive production. However, commercial pond culture especially monoculture (Pangus, tilapia, Koi) is intensive in Bangladesh where sufficient food and supplementary inputs are used during culture period. But improved extensive (intermediate between extensive and semi-intensive) to semi-intensive carp polyculture is the dominant system practiced in Bangladesh and has been adopted in all upazilas (sub-districts).

In the aquaculture sector, fish harvesting is done by the traditional methods using nets and boats. Small fish farmers harvest own nets and equipments, but relatively in larger water bodies, harvesting is organized by contracted fishers. Boats and nets are used for harvesting in the bigger water bodies. In estuaries and offshore areas of the Bay of Bengal, fishermen commonly use crafts of various types, sizes, and designs. The most common boats/vessels used are *Dinginauka*, *Chandinauka* (this boat is extensively used for *ilisha* fishing) and *Koshanauka* (fishing in shallow

waters). *Rafts* are used in almost all the districts of Bangladesh for fishing in shallow waters, they have various local names viz, Bhela, Bhera, Chali, Bhura, etc. Rafts are prepared mainly by fastening together trunks of banana trees. Clasp nets (Khepla Jal) and Drag nets (Moya Jal) are operated by rafts. Trawlers (side trawlers and stern trawlers) are the vessels with powerful engines and machinery for dragging the trawl nets used for fishing in the sea.

Institutional Set-Up and Public Budget

Institution is considered as the key factor for the sustainable fisheries resource management (Jentoft et al. 1998; Novaczek et al. 2001). Different types of institutions have been developed for fishery management which can be grouped in three main complementary categories: management, advisory and research. In Bangladesh, at least fourteen public organizations and departments are involved in the planning, research, promotion, development, management and regulation of the fisheries sector. The Ministry of Fisheries and Livestock is primarily responsible for controlling, management and administration of the fisheries sector. The Department of Fisheries (DoF) is the main and biggest government organization under the Ministry of Fisheries and Livestock which was first established in the undivided Bengal of the British India in 1908 and since then it has contributed in the production, research, planning, and management in overall fisheries sector in Bangladesh. DoF is primarily responsible for developing the fisheries sector with the main focus on extension of fisheries technology, implementation of fisheries law and regulations and development and management.

In 1967, the Faculty of Fisheries was established in the Bangladesh Agricultural University (BAU) which is the first faculty of fisheries on the Indian subcontinent, making a significant milestone in fisheries research and education in Bangladesh. Until early nineties, capture fisheries were the main contributing component of the fisheries sector and all policy and institutional activities was capture fishing based. After establishing of Bangladesh Fisheries Research Institute (BFRI) in 1984, fisheries research received momentum and culture based fishery or aquaculture expanded significantly. Economically viable, socially acceptable and environmentally compatible technologies have been generated through the fisheries research which has made a significant contribution to the growth of aquaculture. All these technologies have been successfully transferred and distributed to farmers. As a consequence, aquaculture production has nearly doubled itself during the last 15 years. Bangladesh Fisheries Development Corporation, Ministry

of Fisheries and Livestock, Ministry of Land and Ministry of Commerce are directly involved in management, development, planning and regulation of the fisheries sector.

Bangladesh government has Five Year Plans (FYP) for all sectors including fisheries. Employment generation, nutrition and poverty alleviation are the main priorities of this sector. However, budget share and amount of allocation to the fisheries development has been declining. During the First Five Year Plans (FFYP 1973-78), the budget share was 6.7 percent which has declined to 0.30 percent in the Fifth Five Year Plans (FFYP 1997-2002). But until Fourth Five Year Plan (FFYP 1990-95), the amount of development budget increased to 21.7% before decreasing from Fourth Five Year Plans to Fifth Five Year Plans. Low budget allocation for research and development is one of the main problems for this sector. Although, there are many institutions and organization has been established for the management of fisheries sector, more institutional support such as extension service, credit service and training is very important to increase the productivity and reduce the poverty of the small-scales fisheries.

Credit Support for Fisheries in Bangladesh

Credit support is very important for fish production, especially for feed based aquaculture. Both formal and informal sources of credit exist for aquaculture. Access to credit is difficult for the small farmers due to some constraints. Only 16% to 20% pond fish farmers obtain credit from either public or private sources (Alam and Thompson 2001; Rahman and Ali 1986; Shang 1990). Even, for those with access to credit, the loan size is not sufficient according to fish farmer's requirements. Parvin et al. (2005) reported that fish farmers receive 85% of required amount and on average 51 days is required to get loan from the date of submission of application.

Informal or non-institutional credit is easy to obtain but high interest rates are charged compared to institutional credit. Alam and Bashar (1996) and Dey et al. (2008b) reported that in some parts of Bangladesh, intermediaries provide production credit to farmers conditional on output marketing, whereby the fish farmers receiving credit are obliged to sell their product to the credit suppliers at the price below the prevailing market price.

To reduce the dependence of rural fishermen on the non-institutional credit sources, the government of Bangladesh (GoB) has taken considerable efforts to expand institutional credit. Government credit is mainly channeled through Bangladesh Krishi Bank (BKB), Rajshahi Krishi Uynnayan Bank (RKUB), Bangladesh National Fishermen's Co-operative Society (BNFCS) and

National Commercial Banks (NCBS). In recent years, a good number of private banks introduced credit services for fisheries sector.

Fish Market and Marketing

In broad sense, fish market can be divided into two as: domestic and export market. These markets are mostly developed and driven by the private sector. On the basis of location, domestic markets can be categorized as primary market (located near the sources of fish production), secondary market (located upazila level), higher secondary market (located in big cities) and terminal markets. Most of the markets do not have electricity, water supply, ice, preserving and shelter facility where fishermen sell fish under the open sky. In general, the situation of urban and rural market is far from satisfactory level in respect to market spacing, stall, sanitation, drainage and management (Dey et al. 2008b).

More intermediaries take opportunity to get involved in the fish marketing channel due to lack of market information (demand, supply and price), awareness and poor communication facilities. As a consequence, marketing chain is longer and marketing margin (the difference between what the consumers pay and fishers receive) is higher (ADB 2005; Ahmed et al. 2007; Ahmed and Rahman 2005; Alam 2000; Dey et al. 2001; Dey et al. 2008b). The fish marketing margin varies from market to market, location to location and species to species. Several studies reported that marketing margin varies from 30% to 60% which implies that fish farmers receive only 40% to 70% of consumer price (Ahmed 2007; Ahmed et al. 2007; Ahmed and Rahman 2005; Alam and Thompson 2001; Alam 2000; Dey et al. 2008b; Faruque 2007; Mia 1996). This situation is comparatively better in aquaculture where commercial farmers sell fish directly to the retail market or *arats* or higher secondary markets. In this case, farmers bear all transportation cost to carry fish from farm to *aratdar's* market. Afterward, *aratdars* organize open bidding for farmers and take commission 3% to 8% of the total sale value or per unit (maund) of fish (Alam 2000; Faruque 2007). It is becoming possible because farmers shifted from subsistence to commercial farming and the social attitude has changed towards fish selling as it is no longer a dishonorable job. Intermediaries play some important role like handling, cleaning, sorting, icing, preservation and transportation which is very essential for fish marketing (Muzaffar 2001; Pokhrel and Thapa 2007). In addition, auction markets provide several services: farmers obtain

loans from auctioneers; retailers take fish from auctioneers on credit etc. Figure 11 presents low-valued cultured fish marketing channel in Bangladesh.

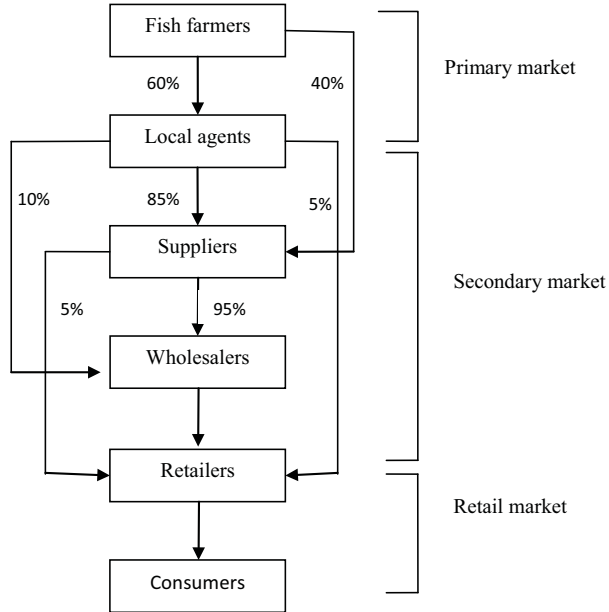


Figure 11: Low-valued cultured fish marketing systems from producers to consumers (Adopted from Ahmed (2010)).

The fish export market is dominated by shrimp and prawn which contribute to 84.6% of total exported fish and fish products (DoF 2009-10). The marketing channel of export market is completely different and separated from domestic market. All fish are processed in the processing factories before export and most of the processing factories are located in Khulna and Chittagong. The processing factories do not purchase shrimp or prawn from the farm level directly due to small quantity production at individual level. Therefore, marketing chains become long with different levels of intermediaries between producer /fish farmers and processing industry (Bayes et al. 2005). In most of the cases, shrimp or prawn marketing channel is as follows:



Figure 12 Shrimp marketing channel

Constraints and Future Prospects

Although, production and yield has been increased over last two and half decades, many factors have been identified as constraints that limit full utilization potential of fisheries resources. Some constraints and future prospects are discussed below for three sub-sectors of fisheries.

Inland Open Water/Capture Fisheries

Constraints:

According to DoF statistics, inland capture production has increased gradually, but vast area of open water can contribute more with proper management system. There are some common factors which are responsible for less production of open water bodies. These are: (i) Over-fishing; which is happening in order to meet the increased domestic fish demand for growing population. Fish farmers catch juveniles to brood stock and destroy the spawning ground, (ii) Agro-chemical use; uncontrolled use of fertilizer, pesticide and herbicide in rice and other crop fields is one of the major causes of reducing wild fish. In order to meet the food demand for the growing population, the government gives more emphasis on foodgrain production using more fertilizer which is unavoidable, (iii) Dams and embankment; construction of dams and embankment for flood control is another constraint which destroys the habitat of the different species of fish, (iv) Irrigation and drainage system; in dry season, irrigation is needed for rice, wheat and other *rabi* crops. Development of irrigation and drainage system are also a stumbling block of migration routes for fisheries, (v) Siltation of rivers; there are about 230 rivers in Bangladesh and most of the main rivers and canals became narrow due to heavy siltation which destroys the natural habitat for fish and (vi) Water pollution; water pollution by the industrial waste is another causes of reduction of habitat of fish.

Floodplain management strategy is one of the main reasons for poor production performance in open water bodies. Out of total open water area, floodplains consist of 70 percent

(2.8 million hectare) and yield only 310 kg/hectare/year (DoF 2009-10). There are three types of floodplain ownership; government, private and both. Most of the government owned floodplain water bodies are leased out to the elite people in the respective area and government earns nominal revenue as lease value. Surrounding poor fishermen are being deprived from their rights to fish. In addition, this leasing system is threat for fish biodiversity and sustainability of open water resources.

Prospects:

Out of total inland fishery area, 87 percent is under open water or capture fish which has great prospects, if it can be managed properly. Long-term as well as short term policies are needed to improve the habitat status of capture fisheries. Reduction of fertilizer, pesticide and herbicides use is almost impossible due to increasing national food demand. However, use of integrated Pest Management (IPM) technologies may help to reduce the use of agro chemicals. Strict regulation concerning catching of fish fries and brood stock are needed to reduce over-fishing, control of killing juveniles and to protect spawning ground. Industrial pollution, construction of irrigation and drainage system and flood control's dam and embankment can be reduced to some extent with proper planning and monitoring system. Hydraulic structures and sluice gates can reduce this problem, even though it has management cost after construction (Alam and Thompson 2001). Establishment of fish bypasses (to facilitate fish movement), fish sanctuaries in river and stock program in open water are some initiatives which can increase productivity of open water fisheries.

Floodplain management strategy is one of the main issues for open water fishery. From 1995, Community Based Fish Management (CBFM) system has introduced in few floodplains and recently Community Based Fish Culture (CBFC) system has started especially in the private floodplain. Floodplain production and productivity has increased considerably after introducing these management systems. Some research shows that floodplain productivity can be increased 4 to 5 times with these management systems. These two systems are highly recommended for the floodplain areas which can increase productivity and reduce poverty and income inequality of the people. Coordination between inter-government department and coordination between government and different NGO's are very important for overall development of the fisheries sector.

Inland Closed Water/ Culture Fisheries

Constraints:

Remarkable progress has been achieved in the culture fisheries sector with respect to production, yield and technology. Freshwater pond and shrimp farms are the main sources of aquaculture production and this is easily manageable compared to capture area. Out of total pond area, 52 percent are cultured pond, 31 percent are culturable (having potential for culture without any improvement) and rest of 17 percent is derelict pond (which is not suitable for culture without improvements). Different constraints for aquaculture are: (i) Artificial feed is the main input for the culture fishery which involves huge amount of costs during production period. Small and poor farmers cannot afford these costs due to liquidity constraints. Some public and private banks mainly offer fisheries credit to large farmers but not small farmers. Therefore, liquidity constraint is one of the main problems for the culture fisheries; (ii) Inbreeding is another obstacle for fish producers, which is the cause of low productivity. Most of the hatchery operators are not concerned about inbreeding; (iii) Fish market and marketing system are far from satisfactory. Due to poor communication and lack of market information, fish farmers do not get actual price and more intermediaries are taking opportunities to involve in the marketing channel; (iv) Maintaining international standard of shrimp is one of the main problems for the export market. Shrimp processing factories are poorly managed and corruption is at alarming levels. In addition, huge investment is required for cleaning, washing, processing and freezing facilities in the processing factories and (v) Public budget for fisheries development is another problem which is gradually decreasing.

Prospects:

Culture fishery is the main source to meet fish demand for growing population and export earnings. This sub-sector has expanded a lot due to high profitability compared to other crops. Research on genetic improvement, quick growing species, new farming system and scientific hatchery management are required for culture farming. Research is also needed to develop low cost nutritious feed. The government should provide credit for small and subsistence farmers without collateral.

Aquaculture sub-sector has great potentiality from different angles. At village level, each and every family has at least one pond which is culturable or derelict. These ponds could be

brought under semi-intensive or intensive culture system with the initiative by DoF and different NGO's. Farmers can produce 30 -40 tonnes/hectare/year if they follow intensive culture system. There are 1.3 million perennial ponds, hundreds of thousands of seasonal ponds (which remain under water 4-7 months in a year) and road side canals which are very potential for culture fisheries. Rice-fish culture system is another potential which has been operational since 1990s. In addition, pen and cage culture can be expanded in different regions of Bangladesh which can gradually supplement the culture fish production.

Marine fisheries

Constraints:

Although marine fisheries contributes significant share of total production of Bangladesh, this sub-sector has so far low-priority area in the overall fisheries development program in Bangladesh. During the last four decades, marine fisheries received only 3% of allocation of total fisheries development budget (Mazid 2003). Therefore, management of marine fishery is far from satisfactory. Statistics on gear, boat, vessel and production does not reflect the reality. Several constraints have been identified for marine fisheries sector; these are: (i) lack of capital, (ii) congestion of artisanal fishermen in inshore water, (iii) inadequate knowledge and information on fish stock, (iv) inadequate landing facilities, (v) lack of modern landing technology/equipments and (vi) life risk of the fishermen during monsoon season (Alam and Thompson 2001). There is no resource/stock assessment survey in the recent years on marine fisheries which is one of the main constraints. Most of the surveys were carried out in the 1960s and 1970s. Therefore, information on the resource exploitation both inshore and offshore is not available. Even there is no survey that has been conducted for pelagic and demersal beyond 40m depth. Information on productivity, breeding, migration patterns, hydrobiology and oceanography is not available for formulation of resource development policy for the marine sector (Mazid 2003). The Department of fisheries (DoF) suspects that marine fisheries are over-exploited but increasing production trends of marine fish indicate that deep-sea fishing may is not yet fully exploited. Only 40 shrimp trawlers and 101 fish trawlers (DoF 2009-10) are operating in the vast deep-sea area of EEZ which reflects the capital constraints of this sub-sector. Research budget for marine fisheries is not sufficient. Therefore, inadequate research on marine fisheries is another main constraint to the development of this sector.

Marine pollution has increased at alarming rate in recent years. Beside oil spills, there is ship washing/breaking as well as discharge of toxic and sometimes even radioactive wastes by foreign vessels.

Prospects:

There is possibility to further increase marine fish production with needed investment for proper assessment and exploitation of the high sea pelagic and demersal fish-stock. However, it is necessary to determine whether marine fisheries are really over-exploited or not. This sub-sector need to be controlled by regulating fishing boats, banning harmful fishing practices and gears, imposing closed fishing season and by implementing other regulatory measures. The prospects for exploiting deeper waters have not been explored yet. As a result the marine fishery is not in a position to contribute to its potential. The reduction of vessels could be the goal for the artisanal fishery in Bangladesh. In that case, policy makers should be more concerned about equity, that is, equity and efficiency must be balanced. Implementation of vessels decommission policy is likely to be very difficult and troublesome. Since most artisanal gillnetters who operate mainly in shore areas of the sea are mainly subsistence fisher and their livelihoods depend on this profession. Moreover, this policy will create unemployment; it is a question of survival for the fishermen in the coastal area. Therefore, socially and economically acceptable policy has to be made by the government.

Concluding Remarks

This paper provides a deep insight of Bangladesh's fisheries resources, production and yield trend, fish export situation, market structure and highlights the present constraints and future prospects. Bangladesh has significant contribution in world fish production. During the last two and half decades fisheries sectors has become one of the most productive and dynamic sectors in Bangladesh. In the early 70s, this sector was dominated by small-scale capture fisheries. Since then remarkable growth in terms of production and yield has been achieved in aquaculture due to research, innovation and dissemination of new technology. In addition, brackish water shrimp aquaculture has been expanded rapidly and took the position of second largest export earning sector in Bangladesh. On the other hand, inland capture fish production and yield has increased gradually due to changing floodplain's leasing policy and management

system and Bangladesh became the second largest inland capture fish producing country in the world. A lot more boats and vessels than recognized by the department of fisheries are operating in the Bay of Bengal that created excess capacity in the marine fishery sector.

Although remarkable growth and development has been achieved in fisheries sector, however, further development and sustainable benefit to present and future generation can be ensured through conserving fisheries resources, allocating more budget, restructuring fisheries institutions, encouraging private entrepreneur, establishing private-public partnership and applying proper policies in all sub-sector of fisheries.

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PAPER II

Profit Efficiency, Farm Size and Sustainability: An Empirical Analysis of Fish Farming Converted from Rice Fields in Bangladesh*

Md. Akhtaruzzaman Khan

Abstract:

The rate of land conversion from rice fields to fish farming is high in Bangladesh due to high profitability associated with fish production. This paper investigates the profit efficiency and the sustainability potential of converted fish farming. We use a Cobb-Douglas form of stochastic frontier profit function on cross-sectional data collected from three major fish producing sub-districts in Mymensingh district in Bangladesh. On one hand our findings show that profit per acre increases with less quickly than an increase in pond size implying an inverse profitability – farm size relationship holds. On the other hand, fish productivity (quantity output per acre) increase with increasing farm size, a finding contradicting the widely known inverse productivity–farm size relationship in crop production literature. Our finding is robust even after controlling for imperfections in input markets and pond characteristics. Given that the results show that profit efficiency increases with increasing farm size, this implies that in general large fish farmers are more efficient, productive and profitable than small farmers. Increased profit efficiency is associated with better access to credit, training and extension services, suggesting that policies to improve access to these services are essential to sustain long-run fish farming in our sample farmers.

Key words: Land conversion, Fish, Profit efficiency, Sustainability, Bangladesh

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1. Introduction:

Fishery is one of the important sources of economic activity in many countries. It provides employment, livelihood, community development, food security, poverty alleviation and supply substantial share of animal protein (Smith et al. 2010). Global fish supply (from both capture and aquaculture) increased from about 60 million tonnes in 1970 to 144.6 million tonnes in 2009 (FAO 2010). However, aquaculture production increased substantially from less than 1 million tonnes in 1950 to 52.2 million tonnes in 2008 and with a sustained annual growth rate of 8.3 percent from 1970 to 2008 (FAO 2010). Developing and least developed countries contribute 92.5 percent of world aquaculture production and Asia supplies 88.8 percent of global aquaculture production. Innovation, dissemination and adoption of new technologies, well-integrated aquaculture systems, high profitability in fish farming compared to other crops, reforms in land tenure and water-user rights as well as other institutional reforms, price and market liberalization all contributed to the area-expansion for aquaculture and the growth in yield.

Tremendous growth of aquaculture production area has, however, generated debate over social and environmental cost and benefit. Unplanned expansion of aquaculture might have negative impact on environment and ecosystem. Usually, in aquaculture, fish are fed diets with high contents of protein and oil. Unused or uneaten fish feed can lead to antibiotic pathogen resistance, water eutrophication, oxygen depletion that could damage the environment (IUNC 2007). In addition, aquaculture waste may hamper adjacent water and habitat of other wild fish and escaping farmed species can compete with wild ones for food, habitat and can transfer diseases. Therefore, to ensure the sustainable aquaculture management, a large number of aquaculture regulations have been implemented worldwide.

Although a large number of environmental and ecological problems are occurring due to fish farming, area expansion for fish farming continues to accelerate worldwide especially in developing countries, because it is profitable and give people better lives. Among developing countries, Vietnam, Bangladesh and Thailand have maintained average aquaculture production growth rates of 16.4, 9.6 and 9.0 percent respectively during 1990 to 2008 (FAO 2010). The total area used for aquaculture in Vietnam is 0.9 million hectares and the country has 2 million hectares potential water surface areas (Duc 2008). In Bangladesh, aquaculture area has increased at 4.3 percent rate over the last three decades covering about 628 thousand hectares of land (DoF

2009-10, Khan et al. 2009).

In Bangladesh, farmers are taking a unique shift: farmers are shifting from rice production, which doubles as a food and commercial crop, to commercial fish farming. Because of an overall high profitability in fish farming compared to rice production, the Bangladesh farmers are more interested in fish farming than maintaining rice production in some areas. For instance, the net profit from shrimp farming is estimated to be twelve times higher than that of high yielding rice variety (Shang et al. 1998). As a result, a significant area of prime quality rice land has been converted into shrimp ponds (Ali 2006), with shrimp culture area increasing from 20 thousand to 246 thousand hectares in 1975 – 2010 periods (BBS 1976, DoF 2009-10). The main expansion has taken place in the freshwater pond area. In 1984-85, the total freshwater fish culture pond area was 125 thousand hectares but it has increased to 351 thousand hectares in 2009-10 (DoF 1986-87, 2009-10).

Fish production requires adequate supply of supplementary feeds, especially during culture periods. Acquisition of these supplementary feeds requires considerable amount of money or easy access to credit markets. However, smallholder farmers who are increasingly converting their rice fields to fish production face institutional constraints namely limited access to credit and training services. Despite these limitations, there exists two conflicting concepts among fish farmers in Bangladesh: On the one hand, majority of farmers have a belief that more feed implies more production and hence more profits. On the other hand however, because of institutional constraints a considerable proportion of smallholder farmers who have taken up fish farming are considering reversing fish ponds to rice fields, which is very costly. This situation raises a number of questions: Who attains high profitability and efficient levels of fish farming from converted rice fields? The smallholder farmers who face institutional constraints or the large farmers who have better access to institutional services especially credit? Answers to these questions form the core analysis of this paper. In particular, we use data collected from Bangladeshi farmers to analyze the profit efficiency of fish farming converted from rice fields, then we attempt to estimate best input-output combination that maximizes fish profits, and finally we explore the possibility of whether fish farming can be sustainable in the long-run.

The converted land is being used for both monoculture and polyculture fish farming system. To avoid heterogeneous production system, only Pangas (*Pangasius hypophthalmus*) fish farmers who follow monoculture system and have converted their rice land to fish farm have

been selected for this study. Of interest however, is the exponential increase of Pangas ponds converted from rice fields which started at least one and half decades ago (Ali et al. 2012). In Bangladesh, pangas fish production contributes about 10.9% of total pond fish production (DoF 2009-10), has export potential to EU and USA market and is believed to overtake shrimp export and can earn at least four billion-dollars per year (Sultana 2009, Alam 2011).

However, studies to assess the viability and profitability of fish production remain limited in Bangladesh. Ito (2002) investigates the economic transformation and agrarian structure of land conversion from rice to prawns farming in Bangladesh giving the emphasis on land ownership and institutional aspects. Ali (2006) examines the impact of shrimp farming on rice ecosystem in Bangladesh and finds that prolonged shrimp farming has increased soil salinity, acidity and depleted soil Ca, K, Mg that significantly affects the rice yield. Alam (2011) shows that Pangas production is a profitable fish enterprise, and farmers are attaining high technical efficiency (86%) and allocative efficiency (62%) levels but with relatively low cost efficiency (54%). On the other hand, Ahmed et al. (2010) show that despite Pangas production being profitable, higher net profits are obtained by producing at intensive margin rather than semi-intensive or extensive margin, and that production at intensive margin is less efficient in input use than either semi-intensive or extensive production systems. What is less understood in existing studies however is whether the profitability of fish production is sustainable (and hence Pangas farming) in the long-run.

The rest of the paper is organized as follows. Section 2 describes the analytical framework, section 3 describes study area, data collection method and summary statistics, section 4 reports results and discussion, and section 5 concludes.

2. Analytical framework

When the farmer's goal is to maximize profits, both inputs and output are choice variables. Because in this environment the farmer allocates inputs and outputs in such a way that maximizes profit, that is, the farmer not only decides on how much of various inputs to use but also how much of various outputs to produce. In the long-run, profits are zero in the competitive market environment and only efficient farmers can survive in this situation. But inefficient farmers can survive in the short-run temporarily when farm losses are less than the cost of fixed inputs. However, because we use cross-sectional data, our focus is on the short-run stochastic frontier profit function which allows us to treat some inputs as quasi-fixed inputs. We choose the stochastic frontier profit function instead of production function because when farmers face different prices and have different factor endowments, the production function approach may not be appropriate to estimate economic efficiency (Yotopoulos and Lau 1973, Ali and Flinn 1989). In the stochastic frontier profit function, it is assumed that any errors in the production process lead to the lower profits for the farmers and this loss of profit is due to technical, allocation and scale inefficiencies (Ali et al. 1994). Therefore, the stochastic frontier profit function can be used to measure the ability of a farmer to achieve the highest possible profit given input and output prices, and the level of quasi-fixed inputs, suggesting that inefficiencies come as a result of loss of possible profit due to not operating at the frontier level (Ali and Flinn 1989, Rahman 2003). In general, short-run profit can be defined as revenue less variable cost and is expressed as:

$$\pi = p f(x, q) - \sum_j w_j x_j = p \left(f(x, q) - \sum_j w_j^* x_j \right) \quad (1)$$

where p is the nominal price of output, $f(x, q)$ is the production function of a farm, x and q represent the vectors of variable inputs and quasi-fixed factors respectively, w_j is the nominal price of input j and $w_j^* = w_j / p$ is the normalized price of input j . Lau (1969) shows that maximization of profit is equivalent to the normalized profit function, which is specified as:

$$\pi^* = \pi / p = \left(f(x, q) - \sum_j w_j^* x_j \right) \quad (2)$$

If the production function is homogeneous Cobb-Douglas form, Kumbhakar and Lovell (2003) show that the dual normalized profit frontier can be written as:

$$\ln\left(\frac{\pi_i}{p_i}\right) = \ln\left\{\frac{\pi_i(w, p, q)}{p}\right\} + \xi_i \quad (3)$$

and finally the normalized profit function is given as:

$$\ln(\pi_i^*) = \delta_0 + \sum_{ji} \delta_{ji} \ln(w_{ji}^*) + \sum_{ki} \delta_{ki} \ln q_{ki} + \xi_i \quad (4)$$

where \ln is the natural logarithm, π_i^* is the normalized profit of the i^{th} farmer, w_{ji}^* is the normalized price of the j^{th} input for i^{th} farm, computed as input price divided by farm specific output price p ; q_{ki} is the level of the k^{th} quasi-fixed factor for the i^{th} farm. The error ξ_i is assumed to behave in a manner consistent with the frontier concept (Ali and Flinn 1989), that is:

$$\xi_i = v_i - u_i \quad (5)$$

where v_i is a two-sided random error term which is independently and identically distributed with $N(0, \sigma_v^2)$ and u_i is a one-sided non-negative random variables. The error terms v_i and u_i are assumed to be independent of each other. The error term u_i measures profit inefficiency or profit loss of a farmer. If $u_i = 0$, the farmer is operating on the frontier level and obtaining maximum profit given prices and quasi-fixed factors and when $u_i > 0$, the farmer is economically not efficient and cannot earn maximum profit. In empirical analysis, we estimate normalized profit frontier as Cobb-Douglas function of the following form:

$$\ln \pi_i^* = \alpha_0 + \sum_{j=1}^3 \alpha_{ji} \ln w_{ji}^* + \sum_{k=1}^2 \alpha_{ki} \ln q_{ki} + \sum_{j=1}^3 \sum_{l=1}^3 \alpha_{lij} d_{li} \ln w_{ji}^* + \sum_{k=1}^2 \sum_{l=1}^3 \alpha_{lik} d_{li} \ln q_{ki} + u_i + v_i \quad (6)$$

where w_j^* is the vector of normalized input prices of labor, fingerlings and feeds, q_k is the vector of quasi-fixed inputs including area used for fish farming and capital, d_l is the location dummy. The interaction of location dummies with input prices and quasi-fixed inputs allows us to control for variation in input prices and the distributional effects of quasi-fixed inputs across districts. $\alpha_0 - \alpha_{lik}$ are parameters to be estimated. The rest of the variables are as defined above. The structure of equation (6) is similar to stochastic production frontier model. Therefore, maximum-

likelihood procedure can be used to estimate the above normalized profit frontier function and the farmer level profit efficiency and inefficiency can be estimated using the Jondrow et al. (1982) or Battese and Coelli (1995) decomposition approach.

In addition to (6), we also assume that the variation in pangas fish farming inefficiency levels is related to some socioeconomic and institutional factors. We use a one-step maximum-likelihood approach (Battese and Coelli 1995) to identify the factors that cause variation in fish farming inefficiency levels estimated from (6). The following inefficiency equation was estimated using a frontier function to identify the factors affecting inefficiency.

$$u\pi_i = \beta_0 + \sum_{s=1}^5 \beta_{si} S_{si} + \mathcal{G}_i \quad (7)$$

where S_s is the vector of fish farmer characteristics including education level of the fish farmers (years of schooling), training in fish farming (days), experience in fish farming (years), credit access (dummy), and access to extension services (dummy). \mathcal{G}_i is the error term.

3. Study area, data and summary statistics

We use cross-sectional data collected from Bangladesh pangas fish farmers in 2010. Data collection followed three sampling stages. In the first stage, Mymensingh district was purposively selected among other districts in Bangladesh due to its good climatic conditions, improved infrastructure and its proximity to the capital city Dhaka, all of which are suitable conditions for both rice and fish culture production. Mymensingh is the second largest fish producing district after Chittagong (DoF 2009-10), but Mymensingh has relatively large pond fish culture compared to Chittagong. Pond fish culture in Mymensingh contributes approximately 41% of total fish production of which 26 % comes from pangus culture (BBS 2009, DoF 2009-10). In the second stage, based on the information obtained from District Fisheries office on land conversion to fish farming, we purposively selected three upazilas (sub-districts) out of twelve upazilas namely Trishal, Muktagachha and Phulpur, where both the production of rice and fish is relatively higher than in other upazilas. In the third stage, we randomly selected 239 pangas fish farmers from the three upazilas.

It is also instructive to mention here that both monoculture and polyculture systems of fish farming are practiced in the study area. However, the majority of the farmers who have

converted land are either engaged in pangas fish culture or tilapia fish production which is largely under monoculture fish farming system. This paper focuses on pangas fish farming for reasons mentioned in section one. Table 1 reports descriptive characteristics.

Table 1: Summary statistics of fish (Pangas) farming

Variable	Mean	S.D.	Minimum	Maximum
Output (kg/acre)	8095	3356.46	2188	16855
Output price (Taka/kg)	66	4.96	48	79.6
Profit (Taka/acre)	146304	78099	8433	355917
Labor price (Taka/man-days)	196.65	7.27	180	215
Fingerling price (Taka/ fingerling)	1.99	0.90	60	562
Feed price (Taka/kg)	26.86	4.98	13.57	41.33
Farm size (acres)	1.43	1.23	0.20	7.00
Capital (Taka/acre)	65741	36321	13080	198406
Age (years)	39.64	9.75	20	70
Education (year of schooling)	9.28	3.69	0	18
Family size (number)	5.85	2.04	2	15
Experience in fish farming (years)	6.70	2.79	1	15
Training on fish farming (days)	16.36	16.07	0	90
Credit received (dummy) (%)	0.55	-	-	-
Extension service (dummy) (%)	0.62	-	-	-
Number of observation	239			

4. Results and Discussion

4.1 Farm-specific profit efficiency

Estimation of profit efficiency preceded the choice of the functional form to estimate equation (6). We use the generalized likelihood ratio test which is commonly used in stochastic frontier analysis to determine the appropriate functional form (Battese and Coelli 1988, 1992, Coelli 1995, Battese and Hassan 1998). We use a three-step procedure to determine the functional form. In the first step, we test the null hypothesis that Cobb-Douglas half normal is superior over the translog half normal function. We fail to reject the null hypothesis in the first step. In the second step, we test the null hypothesis that the Cobb-Douglas truncated function is superior over translog truncated function, and we still fail to reject the null hypothesis. In the third step, we test the Cobb-Douglas half normal function against the Cobb-Douglas truncated function, and we again fail to reject the Cobb-Douglas half normal function. We thus estimate equation (6) using the Cobb-Douglas half normal function. Table 2 reports these test statistics.

Table 2: Functional form and efficiency test statistics

Hypothesis	LR test statistics	No. of restriction	Mixture $\chi^2_{0.01}$ critical value	Decision
1.Choice of functional form:				
a.Cobb-Douglas half-normal versus Translog half-normal	24.16	14	29.384	Accept
b. Cobb-Douglas truncated versus Translog truncated	23.88	14	29.412	Accept
c. Cobb-Douglas half-normal versus Cobb-Douglas truncated	2.41	1	5.412	Accept
2.No effects of inefficiency	10.54	1	5.412	Reject

The critical values are obtained from Kodde and Palm (1986)

Before discussing the regression results from equation (6), it would be important to look at the bivariate relationship between pangas fish profits and farm size (pond size). Note that we use farm size and pond size interchangeably. Figure 1 presents non-parametric estimations of pangas fish profits, gross value of production, quantity of fish production per acre and total quantity of fish production per farm (farmer) on pond size. We find that both fish profits and yield increase with increasing pond size. Similarly, both gross value and total quantity of fish production increase with increasing pond size. This implies that relatively large fish farms are earning more profit than small fish farms. We obtain similar results in Table 3 and Appendix 1. Appendix 1 reports determinants of pangas fish yield where we control for heterogeneity across fish ponds using pond characteristics. In Table 3 we estimate a set of regressions of pangas fish profits per acre with the aim of testing whether imperfections in input markets explain the variation in fish profits conditional farm size. Model (I) omits all possible explanatory variables except farm size. Increasing farm size by 1% increases fish profits by 1%. Inclusion of labor wage in model (II) does not affect the magnitude of the coefficient on farm size and labor wage is insignificant. However, when we include other input prices in model (III), an increase of 1% in farm size increases fish profits by 0.75%, significantly reducing the magnitude on farm size coefficient by about one third. In model (IV), we include upazila dummies interacted with other explanatory variables to control for location specific heterogeneity especially variation in input prices. We notice that now increasing farm size (pond size) by 1% significantly increases fish profits of 0.65%.

Three key findings are worth noting. One, labor wage appears to be less important in explaining fish profits implying that majority of smallholder farmers use family labor and hence

imperfections in labor market may not explain the variation in fish profits in our data. Two, imperfections in other input markets particularly supplementary feeds and fingerlings appear to cause a fairly large variation in pangas fish profits. Three, considering estimates from model (IV) as our main results, the coefficient on pond size of 0.65 is significantly less than unity suggesting that pangas fish profits increase less quickly than pond size, and hence the inverse productivity hypothesis holds (Heltberg 1998, Lamb 2003). On the contrary however, when quantity of production per unit area “operated” is regressed on the “operated” area, the inverse productivity hypothesis holds only if the coefficient on “operated” area is negative. This condition does not hold in our sample of fish farmers as evidenced in Figure 1 and Appendix 1, which show contrasting findings with existing studies on inverse productivity–farm size relationship that have used crop profits (yields) as a measure of land productivity (Deolalikar 1981, Carter 1984, Barrett 1996, Heltberg 1998, Barrett et al. 2010). The inverse productivity – farm size relation is an established concept in crop production, but this concept does not apply in fish farming in our sample when we relate fish output per acre with operated farm size.

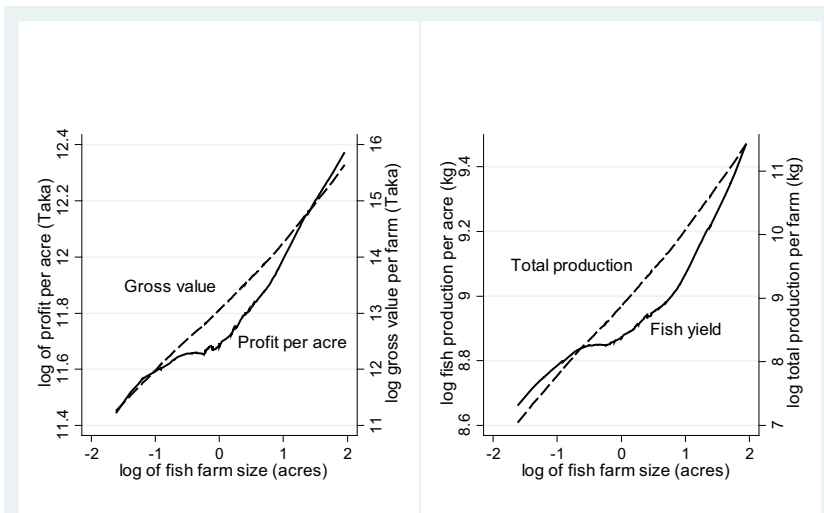


Figure 1: The left panel shows the locally weighted regressions of pangas fish profit per acre (Taka) on fish pond size (solid line) and gross value of pangus fish production (Taka) on fish pond size (dashed line). The right panel shows the locally weighted regressions of pangas fish yield (kg) on fish pond size (solid line) and total pangas production (kg) on fish pond size (dashed line).

Moving to other variables, we find expected relationship between pangas fish profits and other input prices. In particular, increasing fingerling price by 1% reduces the fish profit by about 0.20% while a one percent increase in feed price reduces fish profits by 0.37%. However, an increase in capital costs significantly increases fish profits. This means that an increase in capital costs implies an increase in investment in fishery capital equipments such as fish nets and boat, which are important in increasing profits.

Table 3: Maximum-likelihood estimates of normalized frontier profit function

<i>Profit function</i>	Model (I)		Model (II)		Model (III)		Model (IV)	
	Coef.	S.E	Coef.	S.E	Coef.	S.E	Coef.	S.E
Constant	7.94***	0.06	7.72***	0.30	4.03***	0.99	2.25***	0.76
Log of farm size	1.10***	0.35	1.10***	0.35	0.75***	0.08	0.65***	0.10
Log of labor wage			0.19	0.26	0.37	0.32	0.034	0.76
Log of fingerling price					-0.03	0.07	-0.20**	0.09
Log of feed price					-0.09	0.13	-0.37**	0.19
Log of capital cost					0.29***	0.07	0.48***	0.06
Feed × Trishal							0.61*	0.32
Labor × Muktagachha							0.19	0.86
Fingerling × Muktagachha							0.29**	0.12
Labor × Phulpur							1.05	0.81
Fingerling × Phulpur							-0.05	0.09
Feed × Phulpur							0.29	0.29
Farm size × Trishal							-0.01	0.09
Farm size × Phulpur							-0.15**	0.06
Capital × Trishal							-0.20	0.14
Capital × Phulpur							0.12	0.110
<i>Inefficiency function</i>								
Constant							0.72	0.62
Education							0.03	0.03
Experience fish farming							-0.11*	0.06
Training							-0.03***	0.01
Credit							-0.94***	0.33
Extension service							-0.61*	0.32
Mean efficiency level							0.74 (0.21)	
Number of observations	235		235		235		235	

Note that we drop four farmers that had negative profits, as negative values would be difficult to model using logarithms. The mean efficiency level is the simple arithmetic mean of the predicted efficiency score and the figure in parenthesis is the standard error. Coef. and S.E refer to coefficients and standard error respectively. ***, ** and * significance levels at 1%, 5% and 10% respectively.

Table 3 also reports estimates of factors that explain variation in profit inefficiency. As expected we find that fish farmers with easy access to extension services, more training days, access to credit services and more fish farming experience are less likely to be inefficient in fish farming. Pangas fish farming is relatively a new technology in Bangladesh, access to extension and training services are indeed important factors which can improve fish efficiency and productivity. In essence well trained farmers have a higher potential of establishing better input-output combination and hence attaining less inefficiency levels than less or untrained fish farmers. Similarly, having more experience in fish farming implies that as farmers update their knowledge and skills in fish farming over time or learning by doing, then farmers gain more information on how to reduce production inefficiencies and profit losses.

Pangas fish farming is relatively risky and highly sensitive to weather. Very often, farmers face a number of problems like fish diseases, oxygen deficiency in the water, and water color. In this case, access to extension and training services along with increased experience in fish farming are essential elements in determining inefficiencies in fish farming. Finally, in the study area, access to credit was one of the main problems for small and medium farmers. In our sample, 58% of fish farmers received credit from different private and government commercial banks as well as non-governmental organizations. As evidenced in Table 3, farmers who received credit had significant and less profit inefficiency levels than those farmers that had no access to credit. This finding is consistent with earlier research studies of Ali and Flinn (1989), Kalirajan and Flinn (1983), Abdulai and Huffman (2000) and Ogunniyi (2008). However, what remains unclear is to determine who attains high inefficiency levels? This is an issue we turn to in the next sub-section.

4.2 Profit efficiency, sustainability and farm size

As reported in Table 3, the mean profit efficiency score of the sample fish farmers is 0.74, implying that an individual fish farmer operates about 26 percent below the potential efficiency level and that there are significant opportunities to increase the profit efficiency by improving technical, allocative and scale efficiency. However, the big picture here is to identify which farms are more efficient and how sustainable they are. Given that we use cross-sectional data, we face a problem of identifying the farmers who are likely to sustain fish farming. We

however attempt to respond to the question of sustainability using data on experience in fish farming and farm size.

Since experience in fish farming is defined as the time a farmer has spent in fish farming since he/she first converted the rice fields to fish farming, it allows us to say something about sustainability in fish farming. We explain this by observing how farm size and profit efficiency levels vary with experience in fish farming in Figures 2a, and how profit efficiency varies with farm size in Figure 2b. Figure 2a shows that both profit efficiency and farm size significantly increase with increasing experience in fish farming. Figure 2b indicates that profit efficiency increases with increasing farm size. These results imply that farmers with small farm size and little experience are less efficient. This suggests that in the short-run, new pangas fish farmers are at the lower end of their learning curve and at the same time have small farm size. But as the fish farmers get more experienced, their profit efficiency levels improve while at the same time they accumulate their farm size over time. These conditions only apply when other factors are held fixed, otherwise if other factors also cause a significant variation in profit efficiency – as results in Table 3 show – then fish farming may not be sustainable in the short-run.

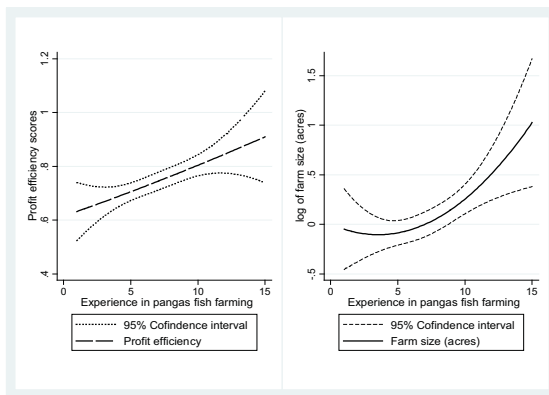


Figure 2a: Quadratic prediction of profit efficiency and fish farm size on experience in fish farming

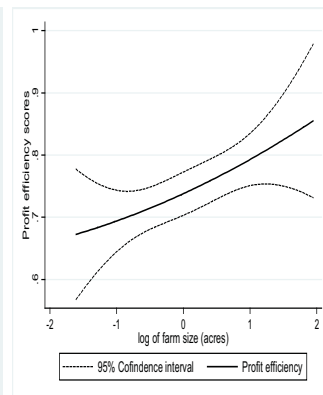


Figure 2b: Quadratic prediction of profit efficiency and fish farm size

Indeed from our field experience in data collection, we observed that farmers with small farm size not only faced credit constraints but also had limited access to fish farming training services. This suggests that unless farmers with small farm size gain access to productivity enhancing services like credit, training, among others, they may be less efficient in the short-run

and hence less sustainable. Figure 3 confirms this conjecture. Figure 3 shows that the probability to access credit increases with increasing farm size and that farmers holding relatively large farm sizes have better access to training services than farmers holding small farm sizes.

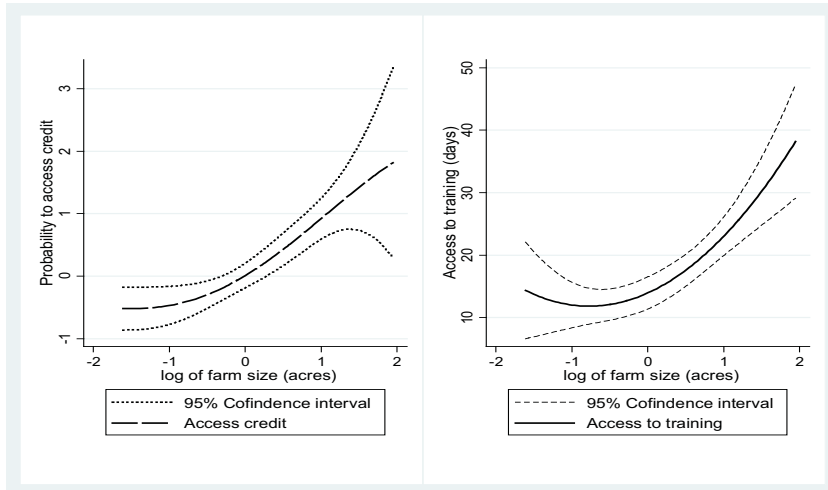


Figure 3: Fractional polynomial prediction with probit model of access to credit on farm size, and quadratic prediction of number of days of training in fish farming on farm size.

To further explain the issue of sustainability of fish farming, we examine the farmers’ belief that more supplementary feeds lead to higher production, which in turn results in more profits. The pangas farmer’s objective is to maximize profit, so the input-output combination is essential for high profits and hence sustainability in the long-run. We use a simple approach of establishing how fish farmers’ input allocation decisions lead to higher or lower profit efficiency levels. We do so by sorting fish farmers based on their profit efficiency scores, productivity and profit levels. In particular, we select the top ten farmers with the highest productivity, profitability and profit efficiency scores. Likewise, we select the bottom ten farmers with the lowest profit efficiency scores. We then summarize their input allocation levels and decisions in Table 4.

Results in Table 4 show that the average profit efficiency score for the highest top ten profit efficient fish farmers is 0.96, which is only 3 percentage points higher than the top ten most profitable farmers (0.93). However, the latter earn much higher profits than the former by 21%. It is evident from Table 4 that the highest productive farmers use more feeds and capital

and get more output but their profit level is 12% and 36% lower than the highest efficient and profitable farmers respectively. In addition, the profit to variable cost ratio is much higher for the highest efficient and profitable farmers than the most productive farmers, suggesting that the highest productive farmers can reduce their input levels and still earn the same or higher profits.

Furthermore, the lowest efficient farmers are observed to be less productive, they hold smaller farm size, use less amounts of feed and labor, have lower capital investments, but use larger amounts of fingerlings per acre than the highest efficient, productive and profitable farmers. Therefore, the concept of more feed → more production → more profit may be misleading. Even though our study does not cover all pangas producing areas in Bangladesh, our findings provide some important policy implications with respect to input-output combination. Since our study considered fish farmers that converted rice fields, our findings suggest a rice farmer intending to convert his/her rice fields to fish farming, he/she should have relatively a large farm size. For example, our results show a farmer converting less than 2.5 acres of rice fields to pangas fish farming would be less efficient, productive and profitable. After converting rice fields to pangas farming, farmers in a production year need to use approximately 16 thousand kilograms of feeds per acre of pond area, labor use should range from 128 – 132 man-days per acre, the fingerling density in an acre should be approximately 21 thousand fingerlings, and capital investment should be in a range of about 95 – 106 thousand Taka per acre to attain high efficient and profitable levels. However, to sustain these high efficient and profitable levels farmers require to have full access to credit services to obtain these inputs, have at least attained 8 years of fish farming experience or full access to extension services with a minimum of about a month for training in fish farming.

Table 4: Summary statistics of top and bottom ten profit efficient, inefficient, productive and profitable farmers

Comparison items	Highest profit efficient farm	Lowest profit efficient farm	Highest productive	Highest profitable farm
Profit efficiency	0.96	0.18	0.85	0.93
Profit (Taka/acre)	265524	32299	236364	320260
Farm size (acres)	2.52	0.90	3.43	3.06
Output (Kg/acre)	10853	4498	14871	11965
Labor use (man-days/acre)	128	102	143	132
Fingerling use/acre (number)	21000	29400	20700	21300
Feed use (Kg/ acre)	15704	7356	26171	15852
Capital investment (Taka/acre)	94997	37807	140830	105591
Training received (days)	32	5.2	32	29
Credit received (%)	100	10	90	80
Extension service (%)	80	30	80	60
Experience in fish farming	8.1	5.5	10	8
Feed conversion ratio	1.45	1.61	1.75	1.35
Profit to variable cost ratio	0.60	0.16	0.31	0.78

5. Concluding remarks:

Land conversion rate from rice fields to fish farming is continuously increasing due to high fish profits compared to crop profits in Bangladesh. The high land conversion rate is common among smallholder farmers who have converted a large proportion of their rice fields to fish culture. Farmers are also driven by the belief that using more supplementary feeds leads to high pangas fish production and hence high fish profits. This study estimates the profit efficiency status of fish farming converted from rice fields and attempts to determine whether pangas fish farming is a sustainable business among smallholders. We use normalized stochastic frontier profit function to estimate the profit efficiency level using cross-sectional data collected from three sub-districts in Mymensingh district of Bangladesh.

Results reveals that the mean profit efficiency level of pangas fish farmers after land conversion is 0.74 implying that considerable amount of profit can be increased by improving technical, allocative and scale efficiency. However, the findings indicate that profit efficiency, fish productivity and profitability per acre all increase with increasing farm size (total fish pond area). This finding is in contrast with the widely known inverse productivity–farm size relationship common in crop production literature. Our finding remains consistent even after controlling for imperfections in rural markets especially labor and input markets as well as

heterogeneity effects across fish ponds. Consequently, large fish farmers are more profitable and productive than small fish farmers. The findings also show that the widely believed concept among fish farmers in sample that “more feed→ more production → more profit” may be misleading.

In addition the results indicate that fish farmers with small farm size and little experience in fish farming are less efficient, but at the same time farm size increases with increasing experience in fish farming. This implies that new fish farmers are at the lower end of their learning curve and have small farm size, but as they gain more experience, their profit efficiency levels increase and so is their farm size. However, we find that for these implications to hold, access to institutional services especially credit and training are essential, suggesting that long-term sustainability of fish farming depends on better access to these institutional services. Thus, our findings indicate that policies aimed at improving access to credit, training and extension services especially among smallholder fish farmers are highly recommended in the study area.

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Appendix: 1

Table A. Determinants of pangas fish yield

	Model-I		Model-II		Model-III	
	Coefficient	Robust SE	Coefficient	Robust SE	Coefficient	Robust SE
<i>Input factors</i>						
Constant	-1.02**	0.42	-1.04***	0.42	-1.07***	0.42
Farm size (pond area) (acre)	0.05***	0.02	0.04**	0.02	0.05***	0.02
Labor (man-days/acre)	0.18***	0.05	0.18***	0.05	0.16***	0.05
Fingerling (number/acre)	0.04	0.03	0.04	0.03	0.04	0.03
Feed cost (Taka/acre)	0.64***	0.04	0.63***	0.04	0.63***	0.04
Capital (Taka/acre)	0.06	0.04	0.06	0.04	0.06	0.04
<i>Household characteristics</i>						
Age (years)			0.00**	0.00	0.002**	0.001
Education (years of schooling)			0.00	0.00	-0.002	0.003
Family size (number)			0.01	0.00	0.006	0.005
Experience (Years)			0.01*	0.00	0.008**	0.004
<i>Pond characteristics</i>						
Culture type (1 if intensive, 0 otherwise)					0.07***	0.02
Depth of pond (feet)					0.00	0.01
Water color (1 if greenish, 0 otherwise)					0.10**	0.04
Re-excavation (years)					-0.00	0.01
Shading area (%)					-0.00	0.00
R ²	0.87		0.88		0.89	
F-value	216.69		123.90		92.45	

PAPER III

Production Risk of Pangas (*Pangasius hypophthalmus*) Fish Farming in Bangladesh

Md. Akhtaruzzaman Khan, Kristin H. Roll and Atle Guttormsen

Abstract

Pangas fish is relatively a new and fast growing fish species which has great potential for expansion and export earnings in Bangladesh. But production or output variability is observed from farm to farm and location to location, and indicates that production risk may be a problem in pangas farming. Traditionally small scale famers are found to be risk averse, and research on production risk is therefore of great importance. This study investigates production risk of pangas farming in selected areas of Bangladesh. Just-Pope stochastic production functions were chosen for the estimation of mean and risk function. Test result shows that significant production risk exists in pangas farming. Increased usage of fingerling increases the production risk in the studied area. Feed usage is found to have a risk-increasing effect on production for large farms, while it is opposite for small farm. This may be a result of credit restrictions small farms often suffer from, which makes them unavailable to buy the optimal amount of supplementary feed. Further, access to credit and training is found to be risk reducing in the case of small farm and medium farms. Therefore, to reduce production risk and hence increase the utility of small scale pangas farmers in Bangladesh, government should work to make credit more available also for small scale farmers, as well as arrange for adequate training programs.

Keywords: Pangas fish, Production risk, Just-pope, Bangladesh

Introduction

Production is inherently risky in agricultural, aquaculture and fisheries sector where farmer faces several types of risk in the production process (Asche and Tveteras 1999). Traditionally, small-scale farmers are often more risk averse (Eggert and Lokina 2007; Eggert and Martinsson 2004; Eggert and Tveteras 2004; Juma et al. 2003; Kumbhakar 2002b). Since the input usage often influence the risk profile, input use behavior is therefore also expected to differ between small and large farm, and research on production risk is very much important on small-scale farming system especially for developing country.

Fish production is more volatile than other agricultural biological production such as livestock production, and production variability is observed from farm to farm (Tveteras 1998). A number of stochastic biophysical factors such as diseases, temperature, and oxygen deficiency make the production process risky in the fish farming. In addition, differences production practice and use of input among the producers may create different risk profiles among the framers. This is because some input may reduce the level of output risk, while other may increase risk. An example of this is fingerlings. Increased use of fingerlings are expected to increase production, but, if the fish farmers does not know the scientific stocking density of fingerling, high densities can lead to high mortality and reduced growth rates. Feed is another example of an input that is assumed to increase the yield, but, feed quantity, frequency, and feed quality may also be causes of production variability. Therefore, there is considerable scope for controlling the level of output risk through input quantities. Furthermore, intensive learning process and improvement in labor quality is very much important for fish farming. In addition, access to institutional factors such as credit and extension service may cause the production variability between farms.

There are large differences in the socioeconomic condition between small-scale and large framers which may lead to the input use variation in the fish production process. Considerable amount of investment is needed for feed and farm management. Larger farms are also often more specialized in terms of labor, which is believed to influence the productivity and risk. Furthermore, credit restriction may also create less than optimal behavior for small farms. The usage of commercial inputs such as supplementary feed, fingerlings and specialized labor are in many cases less than optimal, and can hence create substantially production variability.

Pangas is one of the fastest growing fish and has great potential for expansion and export earnings in Bangladesh (Alam 2011; Anwar 2011). Pangas is characterized by fast growth, tolerance of higher density compared to other species, lucrative size within a few month and comparatively low market price. Therefore, it has become one of the most important species to the fish producer. The specie is also important for the consumers in Bangladesh, especially to the poor people and the domestic demand of this species is increasing day by day due to rapid population growth. Knowledge on production risk at individual farmers' level is essential to be sustainable in the long run. Giving emphasis on these issues, this paper is focused on the estimation of production risks of pangas farming in Bangladesh. The main objective is to identify the risk factors which are responsible for the production variability in pangas production for average farm, and to see if there are differences in the risk profile of small and large farms. Furthermore we investigate how small and large farm can reduce production risk by using non-optimal level of inputs. This research will provide empirical knowledge about risk reducing inputs and policy maker will able to make financial and institutional based policy for expanding the pangas fish farming in Bangladesh.

Although, production risk is very important issue for pangas farming, there are few studies on it. Recently, Javed Anwar (2011) described that price fluctuation, diseases, natural disaster (flood, cyclone and heavy rains) are the main risk factor for tilapia and pangas farming. There have also been a few studies of economic analysis (cost benefit) on pangas farming in Bangladesh. Alam (2011) showed that pangas farming is very lucrative and indeed profitable business but over use of inputs in pangas production at given prices is not justified. Therefore, farmers need to be very careful about input use. Ahmed et al.(2010), on the other hand showed pangas production and income can be increased in semi-intensive and extensive culture systems by using more inputs, and (Islam et al. 2008; Sayeed et al. 2009) illustrated how pangas-paddy culture system is more economically viable than monoculture and stocking density influenced the production of fish. While the literature so far has paid little attention on production risk of fish farming in Bangladesh, there have been several studies on production risk, risk preference and inefficiency on Norwegian salmon aquaculture. These studies showed that feed, capital, material costs are the main production risk factors (Asche and Tveteras 1999; Kumbhakar 2002a; Kumbhakar 2002b; Kumbhakar and Tveteras 2003; Tveteras 1998; Tveteras 1999).

The Just-Pope (1978) stochastic production function model is employed to estimate the production and risk function. Just-pope specification allows risk increasing as well as reducing behaviour of input which is the main lacking of traditional stochastic production function model. Therefore, this model has been widely used in applied economics literature such as Griffiths W. E. and Anderson (1982), Wan and Anderson (1990), Wan et al. (1992), Ligeon et al.(2008), Hassan and Hallam (1990), Hallam et al (1989), Love and Buccola (1991), Kumbhakar (1993) Villano and Fleming (2006), Picazo Tadeo and Wall (2011). The analysis is based on data obtained a survey of a total 239 pangas farmers which were randomly selected from three upazila (sub-district) under Mymensingh in Bangladesh. Production, input, and price data as well socio-economic condition for the farms were collected for the production year of 2009-2010.

This paper is organized as: Section 2 outlines the theoretical part of this research while section 3 presents the empirical methodology and model specification. Data, summary statistics and estimation procedure are described in section 4 and the empirical results are discussed in section 5. Conclusions are drawn in the final section.

2. Theoretical model of production risk

The natural starting point to investigate the production structure of fish farming is a production function. In general, the stochastic production function can be written as follows:

$$y = f(x; \alpha, z; \beta) + \varepsilon \quad (1)$$

where y is production/output of the farm, x is a vector of input quantities applied by the farm; z is a vector of quasi-fixed factors, α and β represents vector of unknown parameters to be estimated, ε is stochastic error which is assumed to be independently and identically distributed ($N(0, \sigma_\varepsilon^2)$). This function is homoskedastic and has some postulates such as positive production expectation, positive marginal product expectation and diminishing marginal product expectation. This stochastic production function has been used extensively in the production economics literature.

In this conventional stochastic production function, we implicitly assume that “if any input has a positive effect on output, then a positive effect on output variability is also imposed.” This is in many cases is a suspicious assumption and does not represents the production technology appropriately. Just and Pope (1978) proved that the effects of input on output should not be tied a priori to the effects of input on output variability. They proposed another

specification of stochastic production function which includes two functions; a mean production function and a variance function. In their model production variability due to input use is considered as production risk. Just – Pope (1978) production function specification can be written as:

$$y = f(x; \alpha, z; \beta) + g(x; \gamma, z; \varphi)\xi \quad (2)$$

where y is output, $f(x, z)$ represent mean production function and $g(x, z)$ presents variance function or production risk function and ξ is the stochastic error term which is assumed to be *i. i. d* $N(0, \sigma_\xi^2)$. The main feature of this function is that the effect of input use has been divided into two segments – effects on mean production and effects on output variance. This function is heteroskedastic because the variance of output is function of input use, i.e., $[(v(y|x))]$. Therefore, the conditional variance of output is:

$$\text{var}(y) = \text{var}[f(x, z) + g(x, z)\xi] = \text{var}[g(x, z)\xi] = [g(x, z)]^2 \text{var}(\xi) \quad (3)$$

and the mean output is:

$$E(y) = E[f(x, z) + g(x, z)\xi] = f(x, z) + g(x, z)E(\xi) = f(x, z) \quad (4)$$

The main purpose of use the Just-Pope framework instead of the conventional homoskedastic framework (equation 1), is to measure the production risk. Production risk implies that the production technology must be heteroskedastic. Therefore, investigation whether any production risk is present or not is the first issue of this research. If heteroskedasticity is not detected then researcher can use conventional homoskedastic production framework.

By including both the mean production and the variance, equation 2 control for heteroskedastic output risk. Homoskedastic output risk implies that any input factor increases/reduces the production by a constant quantity, regardless of the size of production. Mean and variance of output under homoskedastic risk is: $E(y) = f(x) + E(\varepsilon) = f(x) + 0 = f(x)$ and $\text{var}(y) = \text{var}(\varepsilon) = \sigma^2$ respectively. This implies marginal output risk is zero for all inputs. Furthermore this homoskedastic form of production function always violates several of the Just-Pope postulates² such as constant, increasing or decreasing marginal risk (i.e., $\partial \text{var}(y)/\partial x_k \leq 0$ possible), change in variance of marginal product due to factor change (i.e.,

² The most important characteristics of Just-Pope production function is that it satisfies eight postulates which is known as Just-Pope postulates.

$\partial \text{var}(\partial y / \partial x_k) / \partial x_j <=> 0$ possible), and constant stochastic return to scale postulates (i.e., $f(\theta x) = \theta f(x)$ possible for scalar θ). In same way, multiplicative form of homoskedastic production function [$y = f(x)\varepsilon, E(\varepsilon) = 1$] also violates the above first two postulates. The focal point of Just-Pope model is to allow inputs to be either risk-increasing or risk-decreasing. Therefore, this model can explain how output variability affected by input level which is very useful for producer in order to manage production risk using different inputs. The marginal production risk of any input can be defined as:

$$\frac{\partial \text{var}(y)}{\partial x_i} = 2g(x)g_i(x) \quad (5)$$

The magnitude of this marginal risk can be positive or negative indicating risk-increasing or risk-decreasing capacity of inputs depending on the sign of $g(x)$ and $g_i(x)$. Here $g_i(x)$ is the partial derivative of g with respect to i .

3. Empirical model specification

Just and pope has proposed two ways of estimation procedure to measure the production risk; maximum likelihood (ML) method and three step feasible generalized least square (FGLS) methods under heteroskedastic disturbance (Just and Pope 1978; 1979). Since then, most of the empirical studies on production risk have used linear or non-linear FGLS estimation methods of Just-Pope stochastic production function. For the large sample, both FGLS and ML estimates are consistent and efficient for mean function but FGLS is not efficient for variance function while ML is consistent and efficient (Tvetteras 1998; 1999). Moreover, the ML estimator is more efficient and suffers from less bias than FGLS for the small sample. In addition, FGLS is found to seriously play down the risk effects of inputs and provide biased marginal product estimates (Saha et al. 1997).

In this study, we use maximum likelihood (ML) estimation method which provides consistent and asymptotically efficient estimates of both mean production (α, β) and risk/variance (γ, φ) parameters. The log likelihood function of equation (2) is as follows:

$$\ln L = -\frac{1}{2} \left[n \ln(2\pi) + \sum_{i=1}^n \ln\{g(x; \gamma, z; \varphi)^2\} + \sum_{i=1}^n \frac{\{y - f(x; \alpha, z; \beta)\}^2}{g(x; \gamma, z; \varphi)^2} \right] \quad (6)$$

Maximization of the above likelihood functions with respect to α , β , γ and φ provides the maximum likelihood estimates of $f(\cdot)$, and $g(\cdot)$ functions.

We use Cobb-Douglas specification for both mean and variance function. Initially, we used linear quadratic functional form for mean and risk functions, but most of the square and cross-product terms are not significant. Therefore, we decide to use Cobb-Douglas functional form. Production function is specified with five inputs: labor, fingerlings, feed, capital and pond area/ farm size³. Labor, fingerling and feed are the main variable inputs for pangas fish farming. In addition, capital and farm size (pond area) is considered as quasi-fixed factor in pangas production process⁴. We also incorporated five socioeconomic variables which may influence the production variability in the production process. These socioeconomic variables are education of the farmers (year of schooling), experience in fish farming (years), training received from any institution on fish farming (number of days), credit received or not (dummy) and extension service from any government organization or NGO's (dummy).

According to above discussion, our empirical model production function is as follows.

Mean function:

$$\ln y = \alpha_0 + \sum_{i=1}^3 \alpha_i \ln x_i + \sum_{k=1}^2 \beta_k \ln z_k + \sum_{l=1}^3 \psi_l \delta_l + \eta \quad (7)$$

and risk function:

$$\ln \eta^2 = \gamma_0 + \sum_{i=1}^3 \gamma_i \ln x_i + \sum_{k=1}^2 \varphi_k \ln z_k + \sum_{s=1}^5 \phi_s S_s + \sum_{l=1}^3 \psi_l \delta_l + \Gamma \quad (8)$$

where y is total output which is measured as total output quantities (kilogram) of a farm, x_i represent variable inputs, and z_i represent the quasi-fixed factors. S_s indicate socioeconomic variables that may influence production risk and δ_l which indicates location dummies.

To investigate if there are differences in the risk profiles between large and small farms, we divided the farms as small, medium and large, and estimate the production risk among the farm categories. Small farm is defined as farms having pond area up to 100 decimal or one acre.

³ Farm size/pond area variable is excluded from the production function when we analyze according to farm size.

⁴ Fertilizer is another very important variable for fish production which produces plankton for fish in the pond. But feeding behaviour of pangas fish is slightly different from other fish species i.e. pangas can't graze plankton from the water. Even, supplementary feed itself creates huge amount of plankton which sometimes remain unutilized (Anwar, J., 2011). Therefore, farmers do not use fertilizer in the pangas pond, and we excluded fertilizer from the model.

Medium farm is categories as pond area from 101 decimal to 200 decimal and above 200 decimals is defined as large farm. In Bangladesh, there is no standard fish farm classification according to farm size⁵. Ali and Haque (2011) found mean farm size of pangas is about 261 decimal in Trishal upazila considering only 60 farms. In our survey, we found average farm size is 143 decimal. Therefore, on the basis farm survey and practical experience from the field we classified farm size as above.

4. Data and Estimation

Although pangas culture is a relatively new in Bangladesh, it has flourished within a decade. Therefore, historical data on pangas farm, production, area, growth etc. are not available before 2006⁶. According to Department of Fisheries (DoF) statistics, the total pangas production was only 9.2 thousand metric tonnes in 2006-07 but it grew up to 124.8 thousand metric tonnes in 2009-10 which consists of 9.23% of total aquaculture production and 10.94% of total pond fish production(DoF 2006-07; DoF 2009-10).

This paper is based on a cross – sectional primary data which is collected during June/2010 to August/2010 through the “personal interview” methods. Three stages sampling technique was used to select the samples in the study area. Mymensingh, Bogra, Narshingdi, Sherpur, Jamalpur, Kishorgonj and Tangail district were all appropriate districts with significant Pangas production. In first stage, Mymensingh district was purposively selected because pangas fish farm has expanded tremendously in this district due to suitable agro-climatic condition (see Figure 1 for the localization of the region). Mymensingh district is situated in the north-central part of Bangladesh and it is only 120 kilometer north from capital city of Dhaka with good communication, favorable resources, good climatic condition, abundant labor and favorable socio-economic condition for fish culture. Total area of Mymensingh district is 4363 square kilometer with a population of 4.49 million where 1.33 million acres is used as cropped land and 76825 acres for fish culture (<http://www.bbs.gov.bd/RptZillaProfile.aspx> 2007). Mymensingh is the second largest fish producing district after Chittagong where total inland fish production was

⁵ Agricultural farm size is categorized as small who have land from 51 decimal to 250 decimal, medium farm defined as 251 to 750 decimal and large is above 750 decimal. For the fish farm this classification is not acceptable because fish farms are more land intensive and require less land. By using the agricultural categorization for the fish frames more than 90 percent farm would be considered as small.

⁶ DoF (Department of Fisheries) is responsible to collect nationwide production data for all type of fish species. Pangas data is not available before 2006 in DoF statistical yearbook.

72129 metric tons in 2009 (DoF 2009-10). Around 41% fish are producing from pond culture of which 26 % is occupied only pangus culture (BBS 2009; DoF 2009-10). In second stage, secondary information was collected from “District Fisheries Office” regarding pangas fish farming. Based upon this secondary information, three upazilas (administrative unit or sub-district) namely Trishal, Phulpur and Muktagachha has been selected where pangas fish farms are available (Figure 1). Finally, to fulfill objectives, total 243 samples were randomly selected from three upazilas of which 239 samples were used for this study because 4 found as outlier.

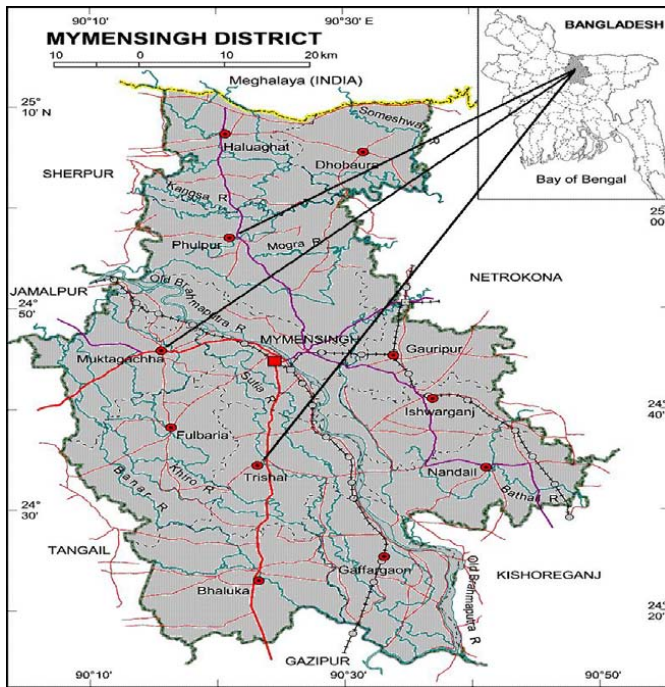


Figure 1: Map showing research area of the paper.

Table 1 presents descriptive statistics of output, input, price and socioeconomic variables of selected sample. Output is the total pangas production which is estimated as kilogram (kg). Labor is one of the important inputs for production which is measured as man-days (1man-days = 8 hours). Labor price does not vary so much location to location. Most of the small farms use family labor, but large farm need hired labor. Fingerlings are measured as the total number of fingerling per acre. Farmer also uses different types of supplementary feed from different

company which has nutritional and price variation from company to company. Therefore, the quality of feed varies between farms. Production is supposed to increase with higher quality feed and feed price are expected to reflect quality differences in feed. Feed usage is therefore weighted by feed price to control for quality differences in feed. Capital is estimated as the cost of land (pond rent per year) plus other capital expenditure of the farms. We included five (5) socioeconomic variables namely education, training, experience, credit and extension service in the risk function which may have effects on production risk. Education level of the fish farmers measured as year of schooling. Experience is quantified as how many years he is involved in the fish farming. Training is measured as how many days he has received training on fish farming from any institution. On the other hand, credit and extension service are used as dummy.

Table 1: Summary statistics of the pangas fish farmers

Variable	Average farm		Small farm		Medium farm		Large farm	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
<i>Output (kg/acre)</i>	8095	3356	7612	3270	7822	3355	9999	3001
<i>Labor (man-days/acre)</i>	117.78	27.726	110.06	28.15	115.93	23.01	143.79	16.64
<i>Fingerling (no/acre)</i>	24028	8792	25462	8057	25096	9877	17937	6034
<i>Feed (Taka)/acre</i>	315571	166229	289150	158456	309959	168658	378064	160105
<i>Capital (Taka)/acre</i>	66745	36783	57494	31296	62270	30277	101838	41830
<i>Farm size (decimal)</i>	143.29	121.36	62.76	25.54	152.863	30.95665	364.40	109.53
<i>Education (year of schooling)</i>	9.28	3.70	8.85	3.79	9.51	3.24	10.14	4.06
<i>Experience (years)</i>	6.93	2.80	6.50	2.80	7.01	2.49	8.05	3.07
<i>Training received(days)</i>	16.44	16.08	12.95	13.95	16.12	14.67	27.26	19.57
<i>Credit received (1 if credit received, otherwise 0) (%)</i>	0.55	-	0.39		0.63	-	0.88	-
<i>Extension service (1 if extension service received, otherwise 0) (%)</i>	0.62	-	0.56		0.66	-	0.71	-

In the fish production process, some inputs are expected to increase the level of output risk while others are expected to reduce risk. Increasing the use of labor is for example expected to have a risk-reducing effect because an increase in labor input will increase the ability of monitoring, controlling such as maintain high hygienic condition, maintaining temperature, discover unfavorable conditions like disease, lack of oxygen in the water, lack of feed etc. which

will reduce the variance of output, *ceteris paribus*. On the other hand, an increase in fingerling is expected to increase of production risk. More fingerlings in the pond require more oxygen and create toxic by-product such as carbon dioxide and ammonia. Therefore, a marginal increase of fingerlings in the pond will increase the variance of output. This expectation is supported by earlier work on production risk in aquaculture (Kumbhakar and Tveteras 2003; Tveteras 1998).

Supplementary feed is one of the major variable inputs for fish production which consists 71% of total variable cost in our surveyed sample. A good amount of money is needed to purchase feed during culture period. But liquidity problem is a common phenomenon for most of the pangas fish farmers especially for small farmers. Therefore, a number of farmers cannot provide sufficient amount of feed in their pond during culture period. Sufficient credit support can reduce the feed use variability among the fish farmers. In our surveyed sample, about 61 percent small fish farmers haven't received institutional credit due to some institutional barriers. Even, the amount of credit was not sufficient according to their requirement. On the other hand, 88 percent large farmers received credit. Farmers who received credit spend 55% more on feed compare to credit non-receiver. Therefore, credit might explain some of the variation in the fish production function. Consequently, we expect feed to decrease the level of output risk for the small farms because of credit constraints and risk increasing effects of feed for the large farms due to credit availability⁷.

In general, investment in capital equipment such as monitoring equipment, different feeding equipments etc, are expected to reduce the production risk. But small farm does not invest much money on capital equipment. For example, most of the small farms do not use boat for feeding and harvesting purpose. In addition, they do not invest on house for security purpose. Therefore, we do not expect risk reducing effects of capital investment for the small farmers. But large farm need to invest more in capital equipments and we expect risk reducing effects of capital. An increase in farm area, on the other side is expected to increase the risk *ceteris paribus*. This is because, when the farm area increases the time spent for each unit of area decreases and the ability of discover unfavorable conditions decreases.

The socioeconomic variables training, extension service, education and experience is directly related to the pangas production process and we expect these variables has risk-reducing

⁷ In develop country (Norway), feed is easy accessible. This means that overfeeding can occur where fish is not able to digest all the feed and excess feed is harmful for environment which increases the production risk.

effect in the pangas farming.. Trained fish farmers know better about quality of feed, feed use procedure, fish disease etc. than untrained farmers. So trained farmers can reduce risk compare to untrained farmers. Therefore we expect training has risk-reducing effect on output for average farm as well as small and large farm. Extension can remedy different types of risk that might be happened during culture period, like oxygen deficiency in the pond diseases etc. Since fisheries expert from upazila fisheries office (governmental organization) can give immediate solution which may reduce risk during culture period, we expect extension service to reduce production variability. In addition, educated farmer knows how to react to different situations, and they can manage any undesirable situation within short time period compare to less educate. Therefore, we expect that higher education can reduce the output variability for all types of farm. We expect more experienced farmers know more about the culture system and can reduce risk compare to less experienced farmers.

5. Empirical Results

To test the heteroskedasticity, the mean production function was first estimated by OLS. The estimated model was good in fit with R^2 0.914. Based on this OLS results, we performed Breusch-Pagan-Godfrey and White heteroskedasticity test and both test rejects the hypothesis of homoskedasticity at 1% significant level (χ^2 -test statistic is 60.31 and 102.02 respectively) which implies significance level of output risk is exists in pangas farming.

We also estimated log-likelihood ratio test to check the presence of production risk. In this regards, our hypothesis is that pangas production is subject to considerable production risk; besides disease and weather risk, output variance depends on the input use intensity. The null hypothesis of production risk is $H_0: \exp g(x, z, s)=0$. We performed log-likelihood ratio test for average farm as well as small, medium and large farm. Estimation results shows that all test is rejected at 1 percent significant level by means of log-likelihood ratio (LR) test which imply that production risk depends on input use intensity in the study area.

Table 2: Hypothesis test [Null: no production risk $H_0: \exp g(x, z, s)=0$]

Farm categories	Value of test statistics	No. of restrictions	Critical value at 1% level	Decision
Average farm	84.32	1	6.63	Reject
Small farm	73.35	1	6.63	Reject
Medium farm	25.97	1	6.63	Reject
Large farm	13.28	1	6.63	Reject

The critical value for the null hypothesis are obtained from Kodde and Palm (1986)

We therefore estimated equation 7 and 8 using maximum likelihood estimation procedure. Table 3 presents the parameter estimates of mean production function and risk function for average farms as well as small, medium and large farm. Since, our functional form is Cobb-Douglas; the parameters can be interpreted as elasticity. As expected in the mean production function, output elasticity is positive for all inputs for an average. This confirms that all input will increase the mean output. The coefficient of labor is positive and statistically significant implying using more labor can significant increase production. Fingerling has statistically significant effects on mean production for an average, small and large farm. According to model estimates, the highest production elasticity is found with respect to feed for all categories farm which imply pangas fish production could increase with expending more in supplementary feed. In addition, farm size (pond area) shows positive and statistically significant effect (at 1% level) on production for an average farm indicates relatively large farm can produce more compare to small farm. This implies that large farms are more productive than small.

Table 3: Parameters estimates of mean production function and risk function

	Average farm		Small farm		Medium farm		Large farm	
	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error	Coefficient	Std. error
Mean production function, $f(x, z)$								
Constant	0.022	0.014	0.025	0.033	0.056**	0.027	0.017**	0.009
Labor	0.076*	0.042	0.196***	0.042	0.062	0.093	0.176***	0.008
Fingerling	0.089***	0.026	0.117***	0.040	-0.037	0.035	0.068***	0.006
Feed	0.615***	0.026	0.672***	0.037	0.632***	0.059	0.475***	0.012
Capital	0.095***	0.027	0.059*	0.036	0.084	0.082	0.280***	0.013
Farm size (pond area)	0.169***	0.052	-	-	-	-	-	-
Trishal compared to Phulpur	-0.036*	0.019	-0.023	0.029	-0.002	0.028	-0.094***	0.004
Muktachha compared to Phulpur	0.028	0.019	0.003	0.027	0.077**	0.032	0.013	0.030
Risk function, $g(x, z, s)$								
Constant	-4.186	0.403	-4.638***	0.648	-1.742	1.252	-1.618	2.238
Labor	-0.450	0.335	-0.496	0.376	0.056	0.881	-6.013**	2.625
Fingerling	0.496*	0.280	0.947***	0.254	0.802	0.751	1.183	1.763
Feed	-0.758***	0.263	-0.790***	-0.267	0.229	1.211	6.561***	2.532
Capital	-0.552*	0.314	-0.169	0.338	-0.747	1.120	-6.454***	2.343
Farm size (pond area)	1.499***	0.486	-	-	-	-	-	-
Education	0.002	0.021	0.005	0.026	0.007	0.080	0.076	0.111
Experience	0.026	0.034	0.049	0.066	-0.020	0.080	-0.364	0.236
Training	-0.014**	0.007	-0.016*	0.009	-0.061***	0.024	-0.071***	0.026
Credit	-0.185	0.218	-0.887***	0.288	-1.340**	0.590	5.564**	2.519
Extension service	-0.352*	0.182	-0.125	0.228	-1.445***	0.514	-2.410*	1.290
Trishal compared to Phulpur	-0.084	0.223	-0.584**	0.282	-0.287	0.632	-2.191***	0.724
Muktachha compared to Phulpur	0.458**	0.205	-0.554*	0.283	0.466	0.601	2.489***	0.954
No. of observation	239		124		73		42	

* Significant at 10% level, ** significant at 5% level, *** significant at 1% level

Lower part of table 3 presents the risk function. Labor has statistically significant effect on risk reduction only for large farm as expected. Because, using more labor in the large farm may discover undesirable situation soon. On the other hand, in case of small farm labor has no significant risk reducing effects. This result is expected in Bangladesh, because most of cases small farm use family labor and labor use variability is low among the small farms. Therefore, production variability should not be affected significantly by the labor for small farm.

Fingerling is risk-increasing input for average and small farm. This is happening because small farmers stock more fingerlings into pond to get more production which reduces the oxygen and create toxic by-product such as carbon dioxide and ammonia that decreases the productivity and increased the production risk.

Capital is risk reducing input for average and large farm. This result is expected as mention earlier (section 4). Because small farmers need less investment on capital equipment but large farmers invest more on capital. Therefore, invest in capital equipment are expected to reduce the riskiness of production for large farm. On the other hand, farm size/pond area has risk-increasing effect for average farm which is significant at 1% level. This result is supported by Losinger (2006) and Bokusheva & Hockmann (2006). Farm size has risk-increasing effect imply that an increase in the use of pond area will reduce the ability to discover unfavorable condition early and therefore it is associated with increasing variability in pangas production.

Result reveals that feed has statistically significant risk-reducing effect for average and small farm and risk- increasing effect for large farm. This implies that production risk increases as large farms spend more on feed during culture period. This in accordance with the literature (Asche and Tveteras 1999; Kumbhakar 2002a; Kumbhakar 2002b; Kumbhakar and Tveteras 2003; Tveteras 1998; Tveteras 1999) and can be explained by overfeeding which occur when fish is not able to digest all the feed and excess feed is harmful for environment which increases the production risk. For smaller farms, on the other hand, the risk effect of feed is negative. This implies that small farms can reduce risk by spending more on feed, and can be explain by insufficient feed usage during culture period due to liquidity problem. In our sample, large farm spend 22 % more on feed than small farm, and for them feed scarify is not a problem. But for small farms this is a major problem. Therefore, if small farm spend more on feed and large farm less, then feed used variability become lower and production risk will be reduced.

This result is supported by the risk reducing effect of credit for small and medium farm and risk-increasing effect for large farm. While the small and medium farms who received credit might have bought risk-reducing input such as feed by the credit money and larger farms might have bought risk-increasing input (feed and fingerlings) by the credit money. This is because, about 88 percent of the large farm received credit from different financial institution and they are more financially solvent compared to small and medium farm. Therefore, they do not have problem to buy supplementary feed which is the most cost bearing input for the pangas production. By instead buying other productive inputs (such as fingerlings) by the credit money a positive significant effect of credit occur. Therefore, while credit is a very important institutional factor that can reduce risk for small and medium farm in the study area, it is not the case for larger farms, since large farmers gets credit support from different commercial bank.

Training has statistically significant risk-reducing capacity on pangas production for all categories farm except small farm. Farmers who received more training on fish culture have more knowledge about feeding behaviour of pangas compare to training non-receiver or less-receiver and they can manage different risky situation during culture period. Therefore, training can reduce risk of production. In addition, risk-reducing effect of extension service for average, medium and large farm may happen because extension service and learning have ability to reduce the risk associated with new technology.

From the above results we may suggest that comparatively small farmers should increase cost on feed and decrease fingerling to reduce the production risk. Large farmers on the other hand, should use more labor and spend more for capital but should not increase cost on supplementary feed to reduce the production risk.

6. Conclusion

Production variability is observed from farm to farm and location to location in the pangas fish farming in Bangladesh due to differences in input use behaviour and socioeconomic condition among the different farm sizes. Giving emphasis on this issue, this paper is focused on the estimation of production risks of pangas fish farming for average farm as well as small, medium and large farm. The Just-Pope (1978) model is used to investigate the influence of input use on production and risk level among pangas farmers using cross sectional data collected from Mymensingh district in Bangladesh. The result shows that, labor, fingerlings, feed and capital

significantly increase the mean production as expected. Log-likelihood ratio test reveals that significant production risk is exist in pangas fish farming. According to the estimates feed and capital have risk reducing effects while fingerlings and farm size (pond area) have risk increasing effects considering all farms. Results also reveal that training and extension service reduces the production risk significantly.

Feed is the most important component of cost for pangas production which is risk-reducing input for small farm but risk-increasing for large farm. This is because, large farmer use sufficient amount of feed or sometimes overfeeding can occur where fish is not able to digest all feed and excess feed is harmful for pond environment which increases the production risk. But small farm supply less than optimal feed during culture period and among the small farmers feed use varies farm to farm. This is happening because most of the small farmers have no access to institutional credit due to high collateral. This explanation is supported by the risk-reducing effects of credit for small and medium farm which reflects that among small and medium farmers who received credit may buy risk-reducing input like feed, capital with the credit money. Pangas is capital intensive farming system where a good amount of money is needed during culture period, but most of the fish farmers are not financially solvent. Even though, Bangladesh Krishi Bank has credit scheme for the fish farmers but it is not sufficient compare to demand. On the other hand, different private bank provide fish loan for the large farm with high interest rate. Therefore, government should take more initiative to provide loan especially for small and medium fish farmers with low interest rate and less collateral for expanding the pangas fish farming in Bangladesh, and reduce the risk for small scale farms

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PAPER IV

The Impact of Community-Based Aquaculture on Poverty and Inequality: Evidence from Seasonal Floodplain Areas of Bangladesh*

Md. Akhtaruzzaman Khan and A.B.M. Mahfuzul Haque

Abstract

Community-based natural resource management (CBNRM), used as a policy tool for reducing poverty and improving the livelihoods of poor communities, has become popular throughout the world, especially in developing countries. This paper explores the impact of a community-based aquaculture (CBA) system on household income, poverty, and inequality using a three-year panel of household-level data from Bangladesh. The results of our analysis suggest that the CBA management system significantly increases income from fish without any corresponding negative impact on income from other sources. The CBA system has a positive and significant impact on employment generation, but it also has an equalization effect on fish income and total household income inequality, i.e., CBA significantly reduces income inequality. Moreover, poverty analysis indicates that a CBA management system can reduce the incidence and depth of poverty in a common resource area.

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1. Introduction

About 1.4 billion people (or one-sixth of the world's population) live below the poverty line or earn less than US\$1.25 a day. Of these, about 75 percent live in rural areas and depend on natural resources for their livelihood (FAO 2004). Therefore, poverty reduction through natural resource management has become a principal focus of development efforts for development organizations, government agencies, and nongovernment organizations (NGOs) all over the world. In this regard, water is one of the most important natural resources, being a key input for many types of livelihood-generating activity. The efficient management of water resources can then contribute to the reduction of poverty in several ways, including increasing output per unit of water used and reducing water losses, enhancing income and employment, allowing input use diversification into high-value end products, and improving nutritional status (Dey et al. 2005; Namara et al. 2010) Therefore, properly managed water resources are a critical component of growth, poverty reduction, and equity.

Community-based natural resource management has been extensively promoted in recent years as way to improve sustainable resource management, increase the power and participation of marginalized groups in society, and improve the socioeconomic status of the rural poor (Kellert et al. 2000)⁸. This community-based management approach has already been used extensively in the fishery sector in developing countries to ensure the equitable distribution of benefits, sustainable use of fisheries resources, greater access to the resource and security for poor fishers, and reduction of poverty in poor fishing communities.

For the most part, quantitative research relating to the impact of natural resource management on poverty and inequality is rare. However, there are notable exceptions. To start with, Lopez-Feldman *et al.* (2007) show that natural resource extraction reduces both income inequality and poverty, while Fisher (2004) shows that forest income reduces income inequality and prevents poverty in Malawi. In other work, Njifonjou *et al.* (2006) show that the adoption of fisheries co-management practices has contributed to empowering and improving the sense of ownership of, and access to, resources among fishers and other stakeholders at Aby Lagoon in

⁸ "Co-management (CM) of natural resources is used to describe a partnership by which two or more relevant social actors collectively negotiate, agree upon, guarantee and implement a fair share of management functions, benefits and responsibilities for a particular territory, area or set of natural resources" Borrini-Feyerabend, G., Pimbert, M., Farvar, M., Kothari, A., and Renard, Y. (2004). "Sharing power." *Learning by doing in co-management of natural resources throughout the world, IIED and IUCN/CEESP/CMWG, Cenesta, Tehran.*

Cote d'Ivoire. They also find that this particular management system contributes to enhancing sustainable livelihoods and providing mechanisms for coping with poverty in communities.

This paper explores the connection between poverty reduction and water resource management and describes how a proper management system can increase income and reduce poverty and inequality in rural areas. For empirical evidence, we draw upon the community-based aquaculture (CBA) management system operating in seasonal floodplain areas of Bangladesh. Every year in Bangladesh, about 4.5 million hectares of land, known as seasonal floodplain areas, remain underwater during the monsoon season (May–October). During the monsoon, farmers are unable to use this land for cultivation, and so the floodplain serves instead as a habitat for different fish species.

However, existing evidence suggests that these waters remain considerably underutilized in terms of managed aquatic productivity (Dey and Prein 2005). Cropping intensity and land and water productivity are therefore low in these areas. The flipside of this situation is that millions of people directly depend on these floodplains for their food and livelihood, of whom 2.7 million are either poor or extremely poor (Dey and Prein 2006a; Dey et al. 2005; Rahman et al. 2010; WorldFishCenter 2005). For the most part, the income of the masses living in this area depends solely upon the fish available during the monsoon season. Conversely, farmers and fishers become unemployed because of the lack of agricultural activities during the monsoon season. Consequently, the overall income of people living around these floodplain areas is low when compared with other rural areas, resulting in higher levels of poverty.

In addition, the local power structure in this area is hostile to the masses belonging to the low-income category (Islam et al. 2006; Islam et al. 2008). During fish harvesting time, the local landlords exercise their power and catch most of the fish from these floodplains, thereby depriving landless fishers of fishing income and exacerbating income inequality (Islam et al. 2006). Given the emphasis on the above problem, the WorldFish Center with the help of the Bangladesh Department of Fisheries (DoF) established a new floodplain management approach, whereby fish were cultured under a community management scheme during the monsoon season, with the same land being used individually for rice cultivation outside the monsoon season. The system is known as community-based aquaculture (CBA).

Unfortunately, very few extant studies evaluate the impact of CBA systems, and most of these focus only on their impact on production and income. In many of these studies, a positive

impact on fish production and income is indicated (Ahmed and Luong-Van 2009; De Graaf 2003; Dey and Prein 2005; Dey and Prein 2006b; Dey et al. 2005; Hossain et al. 2010; Mustafa and Brooks 2009; Nagabhatla et al. 2012; Rahman et al. 2010; Sheriff et al. 2010; Sultana 2008; Thompson et al. 2003). The present study contributes to the literature by showing how a CBA management system can both increase household incomes and reduce poverty and income inequality. More specifically, we respond to the following questions. First, what is the impact of the CBA system in question on income from fishing and other sources, total household income, and employment generation? Second, what is its impact on the unequal distribution of income from fishing? Finally, what is the impact of the CBA management system on the incidence of poverty and on the poverty gap?

The remainder of the paper is structured as follows. Section 2 provides details of the CBA project in Bangladesh. Section 3 describes the study area and discusses the data and descriptive statistics. Section 4 describes the analytical framework we employ, and Section 5 specifies the estimation methods used. Section 6 presents and discusses the results. Finally, Section 7 provides some concluding remarks.

2. CBA project in Bangladesh

In 2005, the WorldFish Center implemented a number of CBA projects in Bangladesh, Cambodia, China, Mali, and Vietnam, with the objectives of sustainable management, a more equitable distribution of resource benefits, and a reduction in poverty. The current analysis includes only the CBA projects in Bangladesh, from which we selected three floodplain areas, namely the Padma, Brahmaputra, and Teesta river basins. The WorldFish Center and the DoF were principally responsible for project technical support and monitoring production (Sheriff et al. 2010).

This project involved the implementation of a number of different technical and institutional measures. For instance, a program of community organizing, fish stocking, and harvesting was developed in all of the selected floodplain areas (Joffre and Sheriff 2011). In each floodplain, a floodplain management committee (FMC) was formed to administer all managerial activities, including: the acquisition of fingerlings for fish stocking; the fencing, guarding, harvesting, and marketing of fish; and financial accounting. Beneficiaries selected the FMC members, who operated under written regulations. Each FMC consisted of 15 to 20 members,

including a president, a vice-president, a secretary, and a cashier. These office-bearers were responsible for solving all kinds of problems and distributing benefits among the beneficiaries. The FMC was supervised by a project implementation committee (PIC), including both WorldFish Center and DoF representatives.

In order to increase water productivity, each FMC stocked fingerlings in the floodplains. Most of the stocks were Indian and Chinese carp, usually purchased from local nurseries or from nearby commercial farms. The FMC determined the combinations of species and stocking densities of fingerlings, but only after taking into consideration the experience of the local people, the availability of fingerlings, and the growth rate of particular fish species in the specific area. During the culture period, there was no provision of artificial or commercial feed in the floodplains. It is also important to note that during the culture period, the harvesting of stocked fish was restricted to local people (including local fishers). However, those who depended solely on the floodplain for their income could continue to catch natural (nonstocked) small fish using local gear.

Benefit sharing is a complex phenomenon in floodplain areas, and income-earning opportunities are usually allocated by the PIC before the commencement of the project according to the anticipated participation levels of the beneficiaries. The distribution of income-earning opportunities takes place across the different groups of stakeholders depending on the backward and forward linkages. The FMCs ensure the employment of full-time fishers (those for whom fish are the main source of income) and seasonal fishers (those for whom floodplain fish are the main source of income during the monsoon) during the monsoon season by delegating different floodplain managerial activities, such as making the fence, guarding, harvesting, etc. In this case, participants both work as day laborers and obtain benefits from the harvested stock fish in the form of cash⁹. The landowner also receives a benefit in the form of land rents based on the land area and benefits associated with the fish harvested. After the harvesting of all the fish, the FMC estimates the profit from the floodplain and distributes it among the beneficiaries according to their levels of participation.

⁹ Fence: In order to prevent the stocked fish from escaping, fishermen placed a bamboo fence at the water inlet and outlet of the floodplains from the starting of the culture period and it is made in such a way so as to permit the entry of larvae and hatching of small indigenous species while at the same time ensuring that no fish can escape from the floodplain.

3. Study area, data, and descriptive statistics

As discussed, our study area is the WorldFish Center’s CBA project implemented from 2006 to 2009 in Bangladesh. We selected one floodplain from each of the three river basins, which were located in the Rajshahi, Mymensingh, and Rangpur districts, respectively. We designated three other floodplains that were very close to the project site and were from the same river basin as a control group. The socioeconomic and environmental conditions in these floodplains were identical to those in the CBA project floodplains. Before project implementation, DoF officials and researchers involved in the project visited the proposed sites several times in order to identify “target people.”¹⁰ Afterwards, all households that depended on the floodplains for their income became participants and were thus brought under community management. We selected households in the control group in the same manner. Table 1 details the total number of participants and households in the study sample from the project and control sites.

Table 1. Number of beneficiaries in the selected sample for CBA project and control areas

Floodplain		No. beneficiaries household	No. households in selected sample	River basin
<i>Project</i>	Beel mail (Rajshahi)	124	60	Padma
	Angrar (Rangpur)	171	60	Teesta
	Kalmina (Mymensingh)	174	60	Brahmaputra
	<i>Subtotal</i>	<i>469</i>	<i>180</i>	
<i>Control</i>	Chandpur beel (Rajshahi)	91	60	Padma
	Painlar beel (Rangpur)	121	60	Teesta
	Andola beel (Mymensingh)	97	60	Brahmaputra
	<i>Subtotal</i>	<i>309</i>	<i>180</i>	
Total		778	360	

We randomly selected 60 households from each of the six floodplains (comprising three project floodplains and three control floodplains), i.e., every year we obtained a total sample of 360 households, with half from the project floodplains and half from the control floodplains (180

¹⁰ ‘Target people’ were those who depended on the floodplain for their income. We identified the surrounding villages and communities using secondary information obtained by the local Upazila Fisheries Office through participatory rural appraisals and focus group discussions.

households each). We prepared a well-designed interview schedule to collect data on household income, inputs, outputs, and socioeconomic characteristics. Figure 1 presents a map of Bangladesh showing the locations of the study areas.

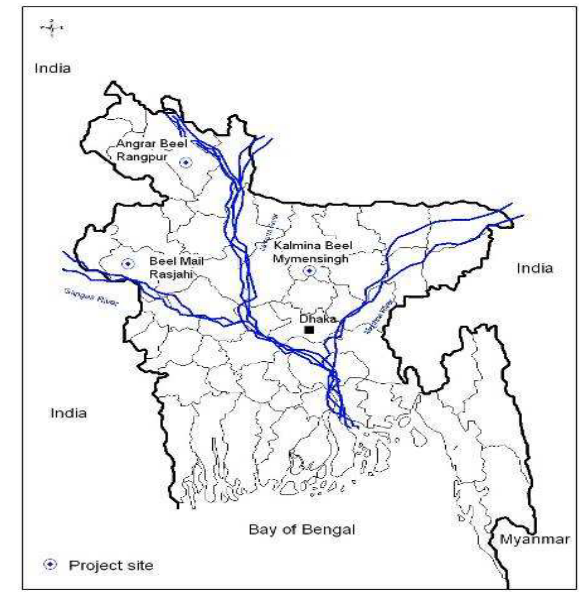


Figure 1. CBA project and control study areas

Table 2 provides summary statistics for the CBA project and control households. As shown, households from the CBA project group had a larger family size than those from the control group. The average agricultural land holdings of the project and control households were about 63 and 55 decimals,¹¹ respectively. Of these holdings, about 34 decimals for the CBA project households and 29 decimals for the control households were in floodplain areas. Fishing gear is very important in the floodplain area, especially for those who depend on income from fish for their livelihood. For the project and control households, about 91 and 85 percent of respondents, respectively, had their own fishing gear, comprising 2.26 and 2.20 items of fishing gear per household, on average.

¹¹ A decimal is a unit of area used in Bangladesh equal to approximately one-hundredth of an acre or 40.46 m².

Table 2. Summary statistics for the selected CBA project and control households

Variable	CBA project floodplains		Control floodplains	
	Mean	S.D.	Mean	S.D.
Age of the household head (years)	41.99	10.34	39.86	11.86
Family size (number)	5.44	2.06	4.72	1.93
Education of the household head (years of schooling)	3.68	3.63	3.53	4.02
Occupation of the household head (dummy variable: 1 if fisher, 0 otherwise) (percent)	0.66	–	0.66	–
Owned agricultural land (decimals)	62.47	68.30	55.34	54.86
Owned floodplain area (decimals)	33.97	54.07	30.46	38.81
Owned ditch area (decimals)	3.52	23.84	2.36	21.58
Amount of fishing gear (number)	2.261	1.79	2.20	1.34
Owned gear (dummy variable: 1 if household has own gear, 0 otherwise) (percent)	0.91	–	0.85	–
Fishing boats (number)	0.27	0.50	0.20	0.39
Cattle owned by household (number)	1.80	1.38	1.77	1.29
Poultry owned by household (number)	9.03	6.44	9.00	5.03

4. Analytical framework

To estimate the impact of the CBA system on income, we divide the sources of income into two categories: (i) “fish income” (which included income from fishing on the floodplain), and (ii) “non-fish income”. We then divide non-fish income into two further categories: non-fish agricultural income (all crop, livestock, and wage income), and (iii) off-farm income (from services and businesses).

We calculate the total household income for CBA project participants as:

$$Y_1 = y_1^f + y_1^a + y_1^{off} \quad (1)$$

where Y is total household income, which comprises fish income, non-fish agricultural income, and off-farm income, denoted by y^f , y^a , and y^{off} , respectively. Subscript “1” indicates program participants. More specifically, we rewrite equation (1) as:

$$Y_1 = \underbrace{\left\{ \sum p_\phi^f q_1^f (A_1^f L_1^f \phi_1^f R^f) - \sum [wL^f + p_\phi^f \phi_1^f + \theta R^f] \right\}}_{y_1^f} + \underbrace{\left\{ \sum p_\phi^a q_1^a (A_1^a L_1^a \phi_1^a R^a) - \sum [wL^a + p_\phi^a \phi_1^a] \right\}}_{y_1^a} + \underbrace{\sum wL_1^{off}}_{y_1^{off}} \quad (2)$$

where the total household income of the control group, i.e., CBA project nonparticipants, is defined as:

$$Y_0 = y_0^{f_0} + y_0^{a_0} + y_0^{off} . \quad (3)$$

The subscript “0” indicates the control group. Equation (3) can then be rewritten as:

$$Y_0 = \underbrace{\left\{ \sum p_q^{f_0} q_0^{f_0} \left(A_0^{f_0} L_0^{f_0} \varphi_0^{f_0} \right) - \sum \left[wL^{f_0} + p_\varphi^{f_0} \varphi_0^{f_0} \right] \right\}}_{y_0^{f_0}} + \underbrace{\left\{ \sum p_q^{a_0} q_0^{a_0} \left(A_0^{a_0} L_0^{a_0} \varphi_0^{a_0} \right) - \sum \left[wL^{a_0} + p_\varphi^{a_0} \varphi_0^{a_0} \right] \right\}}_{y_0^{a_0}} + \underbrace{\sum wL_0^{off}}_{y_0^{off}} \quad (4)$$

where the variables q^f and q^a denote fish production and other agricultural production, respectively, as functions of land (A), labor (L), and other inputs (φ). The variables p_q , p_φ , and w denote output prices, input prices, and the wage rate, respectively, while wL^{off} is off-farm income. In equation (2), the variable R is the land rental cost of the floodplains for the project area. The terms within square brackets ([.]) in equations (2) and (4) indicate the production cost of fish and agricultural goods for the project and control households, respectively.

Note that the fish species differed between the project and control floodplains because of the implementation of the CBA project, as the floodplains operated under an aquaculture system but the control sites remained capture-based fisheries. In our model, we thus assume that the project floodplains produce fish with a higher market value than do the control floodplains, i.e., $p_q^{f_1} > p_q^{f_0}$. We also assume that households can allocate their labor to fish, agricultural activities, or off-farm activities according to their needs. Accordingly, labor constraints condition household income and production as $\bar{L}_1 = L_1^{f_1} + L_1^{a_1} + L_1^{off}$ (CBA project) and $\bar{L}_0 = L_0^{f_0} + L_0^{a_0} + L_0^{off}$ (control). CBA intervention may increase the employment opportunities during the monsoon season, which implies greater demand for labor in the CBA area. Control households are more likely to participate in agricultural and off-farm activities during the monsoon season. We define the extra fish income from the floodplain as:

$$\Delta Y_f = \left\{ \sum p_q^{f_1} q_1^{f_1} \left(A_1^{f_1} L_1^{f_1} \varphi_1^{f_1} R^{f_1} \right) - \sum \left[wL^{f_1} + p_\varphi^{f_1} \varphi_1^{f_1} + \theta R^{f_1} \right] \right\} - \left\{ \sum p_q^{f_0} q_0^{f_0} \left(A_0^{f_0} L_0^{f_0} \varphi_0^{f_0} \right) - \sum \left[wL^{f_0} + p_\varphi^{f_0} \varphi_0^{f_0} \right] \right\} \quad (5)$$

and the overall impact on total household income as:

$$\Delta Y = \left[\left\{ \sum P_q^f q_i^f (A_i^f L_i^f \phi_i^f R^f) - \sum [wL^f + p_\phi^f \phi_i^f + \theta R^f] \right\} + \right] - \left[\left\{ \sum P_q^f q_0^f (A_0^f L_0^f \phi_0^f) - \sum [wL^f + p_\phi^f \phi_0^f] \right\} + \right. \\ \left. \left\{ \sum P_q^a q_i^a (A_i^a L_i^a \phi_i^a R^a) - \sum [wL^a + p_\phi^a \phi_i^a] \right\} + \sum WL_1^{off} \right] - \left[\left\{ \sum P_q^a q_0^a (A_0^a L_0^a \phi_0^a) - \sum [wL^a + p_\phi^a \phi_0^a] \right\} + \sum WL_0^{off} \right]. \quad (6)$$

The CBA project may also produce some backward and forward linkage effects on the fishing communities. To control for these effects, we selected control floodplains from the same district (where socioeconomic and environmental conditions were the same) but in different locations. Note also that, in this analysis, we only evaluate the direct impacts of the CBA project on income, employment, inequality, and poverty. Based on the discussion above, we formulate the following empirically testable hypotheses.

H1: *Access to the CBA project improves fish income.* That is, estimated fish income in the CBA floodplains should be significantly higher than in the control floodplains.

H2: *The CBA system has a positive effect on employment generation and reduces non-fish income.* As the CBA project creates a demand for labor, with the introduction of a fish culture system in place of fish capture, it generates employment opportunities during the monsoon season. Given the greater emphasis on fish production, labor allocation to other sectors may decline, and this could reduce non-fish income.

H3: *Access to the CBA project improves overall household income.* This implies that the positive impact on fish income will outweigh the negative impact on non-fish income, leading to an overall positive impact on household income.

H4: *The CBA management system reduces fish income inequality along with total income inequality.* That is, because the distribution of fish income should be more equitable in the CBA project area than in the control area, total income equality among households should also be better in the CBA communities.

H5: *Access to the CBA project reduces poverty.* We expect both the head count ratio (incidence of poverty) and the poverty gap (depth of poverty) to be lower in the CBA project area than in the control area.

5. Estimation methods

5.1. Impact evaluation

5.1.1. Nonparametric method

Several approaches can be used for impact evaluation purposes, but the main problem common to the different types of impact evaluation is to find a good counterfactual (Khandker et al. 2010).¹² This is because it is not possible to *observe* the individual effects of an intervention, as the outcomes for control observations are not known in advance. To deal with this, experimental methods construct the counterfactual by randomly assigning a group of project participants (the treatment group) and a group of nonparticipants (the control group). As the randomization process effectively eliminates the preexisting differences between the treatment and control groups, the effect of the project is isolated (Gebregziabher 2008). As an alternative, non-experimental methods derive the counterfactual through statistical techniques, whereby the benefit of any program/project can be estimated as follows (Maddala 1983):

$$Y_i = \alpha_i + \beta_i X_i + \gamma_i \delta_i + \varepsilon_i \quad (7)$$

where Y_i is the variable of interest (in this analysis, the variables of interest are fish income, total income, and employment), X_i is the vector of explanatory variables (household characteristics), δ_i is the participation indicator ($\delta = 1$ if the individual is a participant in the program; otherwise $\delta = 0$), and ε_i represents the error term that captures any unobservable factors or potential measurement errors that affect Y_i .

Simple ordinary least squares (OLS) estimation of equation (7) yields unbiased estimates when there is no problem with sample selection bias. However, if the program or project participant is self-selected, then participation becomes endogenous, and OLS provides biased estimates. Under the OLS assumption, the expected value of the error term is zero, and the unbiased estimates of the program impact imply that $E(\varepsilon|\delta = 1) = E(\varepsilon|\delta = 0) = E(\varepsilon) = 0$, which suggests that $E(Y_0|\delta = 1) = E(Y_0|\delta = 0)$ (Cobb-Clark and Crossley 2003). However, this condition is not satisfied when the selected sample is not random. This is because many other

¹² There are several approaches to impact evaluation, including randomized evaluations, propensity score matching, double-difference methods, instrumental variable methods, and the regression discontinuity and pipeline approaches.

factors, such as unobserved household characteristics, may affect participation in the program, which may in turn introduce bias into the estimated parameters.

Typically, the impact evaluation of any development program/project using household survey data suffers from selection bias, measurement error, and problems with simultaneity (Wooldridge 2002). Therefore, several approaches have been suggested to solve these problems, including propensity score matching (PSM), endogenous switching regressions, instrumental variable methods, the Heckman selection model, etc. The PSM method is widely used to estimate intervention effects when all confounders are measured (Abadie and Imbens 2009; Cobb-Clark and Crossley 2003; Heckman et al. 1998; Ravallion 2005). Rosenbaum and Rubin (1983) define the propensity score as “the conditional probability of assignment to a treatment given a vector of covariates including the values of all treatment confounders”. Put simply, the propensity score method constructs a statistical comparison group that is based on a model of the probability of participating in the program using observed characteristics, i.e., $p(x) = pr(\delta = 1 | X = x)$. The method then compares the outcomes of participating and nonparticipating households with similar propensity scores to obtain the program effect, even if the treatment is not random.

The validity of the PSM depends upon two key assumptions: (i) conditional independence and (ii) the presence of a common support. The conditional independence assumption argues that program/project outcomes are independent of participation conditional on a set of observables characteristic, i.e., $(Y_1, Y_0) \perp \delta | X$. This assumption implies that the selection is solely on observable characteristics and all variables that influence assignment, and the researcher simultaneously observes any potential outcomes. This assumption also implies that the counterfactual outcome for the project group is the same as the observed outcome for the control group, given the control variables (X). Matching also assumes that unobservable characteristics determining intervention are uncorrelated with unobserved outcomes of the project and control observations, i.e., $\varepsilon \perp (\varepsilon_1, \varepsilon_0) | X$.

In contrast, common support implies that persons with the same X values have a positive probability of being both a project participant and a control (Heckman et al. 1999). This guarantees that all “treated” (i.e., project) participants have a counterpart in the control population, i.e., $(\text{overlap}) 0 < P(\delta = 1 | X) < 1$. However, this is quite a strong assumption for

programs tightly targeted at specific groups. The common support improves the quality of the matches, as it excludes the tail of the distribution of $p(X)$, although the sample size may reduce considerably.

Balancing properties need to be satisfied, validating propensity score matching. This implies that two households with the same propensity score should have the same distribution of X , irrespective of their status. The idea behind the balancing tests is to check whether the propensity score is an adequate balancing score, that is, to evaluate if at each value of the propensity score, X has the same distribution for the project and control groups (Lee 2006).

In our study, the counterfactual outcome is the same as the outcome level that would have existed if the household had no access to the CBA project, which is:

$$E(Y_0|X, \delta = 1) = E(Y_0|X, \delta = 0) = E(Y_0|X). \quad (8)$$

The first term in equation (8) represents the counterfactual outcome of the project group, which is equal to the observed outcome of the control group. Therefore, under conditional independence, we can estimate the “average treatment effect on the treated” (*ATT*) as:

$$ATT = E(Y_1 - Y_0|X, \delta = 1) = E(Y_1|X, \delta = 1) - E(Y_0|X, \delta = 1).^{13} \quad (9)$$

Usually the determination of the propensity score employs a binary choice model. In this paper, we use a probit model for this purpose. Once we estimated the propensity score, we needed to match each participant with his/her “closest” nonparticipant. To do this, we used the nearest neighbor (NN), kernel, and radius matching methods. In the NN method, we matched each project participant with the individual in the control group with the closest propensity score. Matching could be with or without replacement. Matching with replacement means that the same nonparticipant can be used as a match for different participants, which can reduce bias and increase the quality of matching (Caliendo and Kopeinig 2008; Khandker et al. 2010). Kernel

¹³ This equation implies that $E[\Delta Y|\delta = 1] = E[(Y_1|\delta = 1)] - E[(Y_0|\delta = 0)]$. Now, adding and subtracting $E[(Y_0|\delta = 1)]$, we obtain $E[(Y_1|\delta = 1)] - E[(Y_0|\delta = 0)] + E[(Y_0|\delta = 1)] - E[(Y_0|\delta = 1)]$. Rearranging this equation, we obtain

$E[(Y_1|\delta = 1)] - E[(Y_0|\delta = 1)] + E[(Y_0|\delta = 1)] - E[(Y_0|\delta = 0)] = E[(\Delta Y|\delta = 1)] + \{E[(Y_0|\delta = 1)] - E[(Y_0|\delta = 0)]\}$. The first term in this equation denotes the impact of the CBA project, while the second term, in curly brackets, captures the bias. However, if $E[(Y_0|\delta = 1)] = E[(Y_0|\delta = 0)]$, which means that Y_0 is independent of CBA project participation, then the bias disappears. Consequently, $ATT = E[\Delta Y|\delta = 1]$ is unbiased and identified.

matching is the simple kernel density function whereby all observations in the comparison group inside the common support region are used, and the “matched household” is the weighted average of all households in the other group within a certain propensity score range. Alternatively, we used the radius method, which arose from the caliper matching method, whereby we compared the project participant not only with the individual control who had the closest propensity score within the same caliper, but also with all controls within that caliper. Although each matching method has its own strengths and limitations, such that we could have considered using any one of them for impact evaluation, their utilization in combination had the advantage of testing the robustness of the impact estimates (Becker and Ichino 2002).

5.1.2. Parametric estimation

In the nonparametric matching method, we assume that there is no measurement problem or sampling error (Sherlund et al. 2002) and therefore that nonparametric does not rely on any specific functional and distributional form. Therefore, we employed the random effects model to check the robustness of our results with the nonparametric matching method. However, we first tested whether the fixed or random effects model was appropriate for this data set using the Hausman test, and found that the random effects model provided a better fit.¹⁴ This is possibly because some of the variables, such as the education level of the household head, farm size, ditch area, etc., were time invariant, which indicates that the household-level independent variables (X_{it}) are uncorrelated with the individual effects (α_i). Therefore, in this case, the random effects model is better. We specify it as follows:

$$y_{it} = \beta_0 + \beta x'_{it} + \alpha_i + \varepsilon_{it}, \text{ where } \varepsilon_{it} \sim IID(0, \sigma_\varepsilon^2) \text{ and } \alpha_i \sim IID(0, \sigma_\alpha^2). \quad (10)$$

Our empirical model is then:

$$\begin{aligned} \ln y_{it} = & \beta_0 + \beta_1 \text{participation}_{it} + \beta_2 \text{age}_{it} + \beta_3 \text{education}_{it} + \beta_4 \text{familysize}_{it} + \\ & \beta_5 \text{farmsize}_{it} + \beta_6 \text{occupation}_{it} + \beta_7 \text{gear}_{it} + \beta_8 \text{boat}_{it} + \beta_9 \text{ditch}_{it} + \sum \gamma_t \text{year}_t + \\ & \alpha_i + \varepsilon_{it} \end{aligned} \quad (11)$$

where $\alpha_i + \varepsilon_{it}$ is treated as an error term consisting of two components: an individual-specific component, which does not vary over time, and a remainder component, which is assumed to be uncorrelated over time, allowing for the time-invariant variables to play the role of explanatory

¹⁴ In the Hausman test, H_0 (the difference in coefficients) was not systematic: $\chi^2(6) = 3.15$ and $\text{prob} > \chi^2 = 0.7896$.

variables. It is important to mention that we estimate the random effects model with common support. This ensures the exclusion of control observations that are not “nearby” to the propensity score distribution of the project observations.

5.2. Estimation of inequality and marginal effects

Among inequality measures, the Gini coefficient is the most popular and widely used method. Based on the Lorenz curve, the Gini coefficient is a cumulative frequency curve that measures equality by comparing the distribution of a specific variable (e.g., income, expenditure, etc.) with a uniform distribution, defined as:

$$G = 1 - \sum_{i=n}^N (\alpha Y_{i-1} + \alpha Y_i)(\alpha X_{i-1} - \alpha X_i) \quad (12)$$

where αY and αX represent the cumulative percentages of income and population, respectively, and N is the total number of observations.

In this paper, we evaluate firstly the impact of the CBA project on the fish income distribution and then the effect of fish income on the total income distribution across our participant. We decompose income according to income sources in order to improve our understanding about whether the different sources of income increase or decrease inequality among particular groups of individuals. Shorrocks (1982) and Lerman and Yitzhaki (1985) show that Gini decomposition by source of income can be represented as:

$$G = \sum_{f=1}^F S_f R_f G_f \quad (13)$$

where S_f denotes the proportion of the total income derived from source f , R_f ¹⁵ is the Gini correlation coefficient between income source f and the total income (which implies how income source f and the distribution of total income are correlated), G_f is the relative Gini index of source f , and G is the Gini coefficient of total income. When a particular income source is an increasing (decreasing) function of total income, then the Gini correlation R will equal 1 (–1). It will equal zero when the income source is a constant, which implies that the source’s contribution to the Gini coefficient is zero.

¹⁵ Here, $R_f = Cov\{Y_f, F(Y)\} / Cov\{Y_f, F(Y_f)\}$ where $F(Y)$ and $F(Y_f)$ represent the cumulative distributions of total income and income from source f , respectively.

Using the partial derivative of the overall Gini coefficient with respect to a percentage change in a specific income source, we can estimate the marginal effect of a particular income source on overall inequality when the other income sources are held constant (Lerman and Yitzhaki 1985):

$$\frac{\partial G}{\partial y_f} = S_f(R_f G_f - G) \quad (14)$$

Dividing equation (14) by G , which yields the marginal effect of a particular income source on the overall Gini coefficient, and rewriting yields:

$$\frac{\frac{\partial G}{\partial y_f}}{G} = \frac{S_f R_f G_f}{G} - S_f \quad (15)$$

To test the statistical significance of the inequality measure, we obtained confidence intervals using bootstrapping techniques. Mills and Zandvakili (1998) have shown that bootstrapped standard errors of the Gini coefficient are expected to perform better than asymptotic standard errors. We used the common support region to compare the project and control individuals.

5.3. Poverty estimation

We employed the Foster–Greer–Thorbecke (FGT) (1984) method of poverty measurement to estimate the incidence of poverty (the head count ratio) and the poverty gap for both the CBA project participants and the control group, and then compared the two groups to highlight the impact of fish income on poverty. We specify the FGT measure of poverty as:

$$FGT_\alpha = \frac{1}{N} \sum_{i=1}^q \left(\frac{z - y_i}{z} \right)^\alpha \quad (16)$$

where N is the total number of individuals in the population, z is the poverty line, q is the total number of poor individuals (with income below z), y_i is the per capita income of the i -th person, and α is a poverty aversion (or sensitivity) parameter. A higher (lower) value of FGT indicates that more (less) poverty exists. When $\alpha = 0$, then $FGT_0 = \frac{q}{n}$, which is known as the head count index and indicates the proportion of population that is poor. When $\alpha = 1$, then

$FGT_1 = \frac{1}{nz} \sum_{i=1}^q (z - y_i)$, which is known as the poverty gap. This measures the mean depth of poverty and implies on average how much income someone below the poverty line needs to reach to the poverty line. Alternatively, the poverty gap is the mean proportion by which the welfare level of the poor falls short of the poverty line.

To evaluate the contribution of fish income to poverty alleviation, we applied poverty decomposition by income sources using the Shapley value method. We decomposed the FGT index using:

$$FGT = \sum_{k=1}^K S_k = \frac{1}{N} \sum_{i=1}^q \left(\frac{z - y_i}{z} \right)^\alpha \quad (17)$$

where K is the total number of sources of income and S_k is the income from source k . A negative sign in a decomposition term indicates poverty reduction by that specific income source (Araar et al. 2009). Finally, to test the statistical significance of poverty, we obtained the confidence interval and p -value, and used the common support region to compare the impact on poverty between project and control individuals. We employed the World Bank poverty line to estimate the incidence of poverty and the poverty gap; the poverty line was US\$1.25 per adult per day, where (in 2007) US\$1 = 67.50 Bangladeshi taka (Tk). This poverty line reflects the minimum cost of purchasing the minimum calorific content required for subsistence (2,122 kcal) and any other necessary nonfood goods and services.

6. Results and discussion

6.1. Impact on income and employment

We first analyze the income of CBA project households and control households according to source, based upon the mean values of three years of income.¹⁶ As shown in Figure 2, while the average non-fish agricultural and off-farm incomes were approximately the same for both the project and control households, fish income was higher for the project group households. This implies that overall household income was higher for the CBA project participants. This could have resulted from the introduction of the CBA management system.

¹⁶ We deflated the incomes for 2008 and 2009 using the 2007 consumer price index.

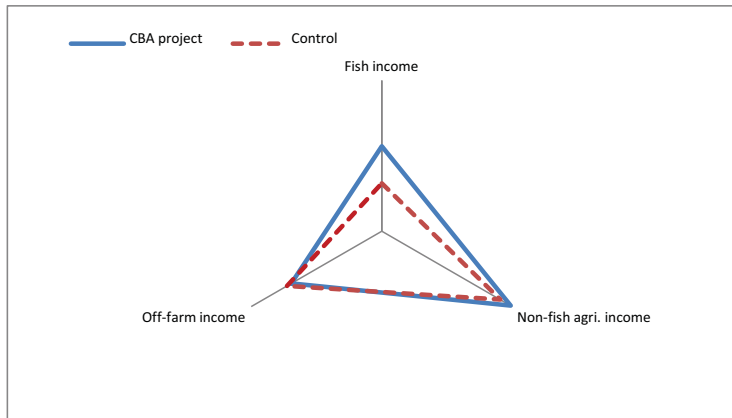


Figure 2. Income portfolios of the CBA project and control households

Table 3 details the impact of the CBA system on income and employment using the propensity score matching method. To test the validity of the propensity score (*pscore*) method (common support, balancing property), we used the probit model. The results are presented in Appendix 1. These results suggest that both the common support and balancing properties were satisfied by the data. The results also reveal that, based on NN, kernel, and radius matching methods, the average fish income of the CBA project participants increased by between Tk 11,467 and Tk 12,126 compared with the control participants. These results are statistically significant at the 1 percent level for all matching techniques. Table 4 presents the results using the random effects model, which are generally consistent with the matching method for fish income. Together, these imply that CBA project households significantly increased their fish income compared with the control (non-CBA project) households. The results also reveal that CBA project household fish income remained significantly higher than that of the control households for every year in the data sample. In addition, during 2009, the magnitude of the increase in fish income exceeded that for the previous two years. This suggests that fish income increased significantly because of the CBA management system.

This raises the question as to whether CBA project households could have allocated relatively more labor to CBA project activities, and consequently reduced their non-fish income. Hypothesis H2 suggests that access to the CBA project creates employment opportunities related

to fishing, and thus reduces non-fish income. All matching methods reveal that overall employment opportunities increased significantly (at the 1 percent level) by between 57 and 59 work-days in the CBA project area during the monsoon season compared with the control areas. The random effects model also shows that the CBA management system increased opportunities for employment by 60 work-days, a result consistent with that obtained using the nonparametric method. Moreover, as shown in Tables 3 and 4, we do not find any evidence of a negative or positive effect of the project on non-fish income. Therefore, based on this evidence, we conclude that during the monsoon season, surplus labor was used in the CBA project area and did not negatively affect non-fish income. Results of the year-by-year estimation are also in line with the overall results on employment generation.

Hypothesis H3 suggested that access to the CBA system would improve overall household income. Table 3 reveals that the average household income of CBA project participants was between Tk 9,763 and Tk 13,173 higher than that of nonparticipants, and that these differences are statistically significant at the 1 percent level. Total household income remained significantly higher for CBA project participants for every year compared with the control group. The results are also consistent between the parametric and nonparametric estimations. Our earlier finding that a corresponding reduction in non-fish income did not offset the increase in fish income from the CBA system reinforces these results, thereby suggesting that overall household income increased. Therefore, we conclude that the CBA management system can significantly increase both fish income and total household income without any corresponding negative impact on non-fish income.

Table 3. Impact of CBA project on income and employment

Matching method and outcome	2007-09		2007		2008		2009	
	ATT	t-value *	ATT	t-value	ATT	t-value	ATT	t-value
<u>Fish income</u>								
NN matching	12126	17.70	10778	14.07	10035	7.38	14713	13.59
Kernel matching	11590	23.12	10822	17.61	10077	10.77	13903	15.81
Radius matching	11467	24.40	10584	16.81	9980	11.39	13816	15.96
<u>Non-fish income**</u>								
NN matching	-2364	-0.45	3505	0.45	4698	0.62	-5015	0.61
Kernel matching	-1335	-0.39	-4298	-0.71	619	0.11	-748	-0.13
Radius matching	1706	0.61	-682	-0.14	3050	0.64	2560	0.50
<u>Total household income</u>								
NN matching	9762	1.92	14283	1.89	14733	1.96	13699	2.80
Kernel matching	10255	3.03	6524	1.69	10695	1.87	13155	2.37
Radius matching	13173	4.61	9901	2.09	13030	2.67	16377	3.16
<u>Employment</u>								
NN matching	56.63	13.75	53.81	8.14	54.05	8.09	62.07	9.17
Kernel matching	57.54	17.27	53.96	9.72	57.83	9.89	61.02	11.23
Radius matching	58.59	18.17	55.01	9.95	58.55	10.52	61.84	10.88

Notes: * t-values are bootstrapped standard errors using 500 replications. ** Non-fish income includes non-fish agricultural income and off-farm income. ATT: average treatment effect on the treated.

Table 4. Impact on income and employment using random effects model (with common support)

Variable	Impact on fish income	Impact on non-fish income	Impact on total household income	Impact on employment
Participation (dummy)	3.713*** (0.285)	0.0240 (0.049)	0.183*** (0.043)	60.51*** (3.69)
Age of the household head (years)	0.013 (0.010)	-0.001 (0.002)	-0.000 (0.001)	-0.267 (0.151)
Education of the household head (years of schooling)	-0.183*** (0.037)	0.030*** (0.006)	0.025*** (0.005)	-1.864*** (0.469)
Family size (number)	-0.063 (0.084)	0.055*** (.020)	0.059*** (0.017)	-0.623 (0.858)
Owned agricultural land (decimal)	-0.012*** (0.002)	.006*** (0.000)	0.005*** (0.000)	-0.450*** (0.028)
Occupation of household head (1 if fisher, 0 otherwise)	1.493*** (0.221)	-0.296*** (0.053)	-0.130*** (0.043)	20.34*** (5.29)
Amount of fishing gear (number)	-0.081 (0.072)	0.003 (0.013)	-0.001 (0.011)	5.297*** (1.14)
Number of fishing boats	-0.285 (0.200)	-0.009 (0.039)	-0.014 (0.035)	0.349 (1.31)
Ditch area (decimal)	0.018*** (0.002)	-0.002* (0.000)	-0.002* (0.000)	0.116 (0.080)
Year 2008	0.258*** (0.081)	0.055** (0.024)	0.076*** (0.020)	1.500** (0.718)
Year 2009	0.225*** (0.081)	0.116*** (0.026)	0.155*** (0.021)	2.856*** (0.762)
Constant	6.710*** (0.538)	10.079*** (0.10)	10.192*** (0.086)	67.793*** (6.924)
Wald χ^2 (11)	293.73	572.90	580.06	815.44
Prob. > χ^2	0.000	0.000	0.000	0.000
R ²	0.484	0.524	0.539	0.711
Number of observations	1,071	1,071	1,071	1,071

Notes: *, **, and *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively. Figures in parentheses are robust standard errors.

6.2. CBA management system and income inequality

Hypothesis H4 suggests that access to the CBA management system should reduce income inequality, especially as the distribution of fish income should be relatively equitable within participating communities. Table 5 presents the Gini index and Gini decomposition for the CBA project and control individuals. The first column (S_f) represents per capita income from source f as a proportion of total income. As shown, non-fish agriculture was the main source of income for individuals in both the CBA project and control groups. However, the contribution of fish income to total income was 23 percent for the CBA project group compared with only 8 percent for the control group. The contributions of off-farm income to total per capita income were 29 percent and 39 percent for the CBA project and control groups, respectively.

The second column, labeled G_f , presents the Gini coefficient for each income source and overall per capita income. In fact, a more equitable distribution of floodplain benefits was one of the main objectives of the CBA project. This finding is therefore very important in understanding the impact of fish income in the seasonal floodplain areas. The results show that fish income was more equally distributed (Gini index = 0.274) in the CBA project area than in the control area (Gini index = 0.60). The unequal distribution of fish income among the control individuals implies that a substantial number of people derived a very small share of their total income from the fish sector. The difference in fish income inequality between the CBA project and control areas was 0.326, suggesting that the CBA management system helped to distribute floodplain benefits 55 percent more equally in the participating communities. By contrast, non-fish agricultural income was distributed relatively unequally in both the CBA project (0.541) and control (0.536) areas. We can partly explain these high Gini coefficient values by the fact that, in both cases (the project and the control groups), many subjects owned no agricultural land and therefore worked as day laborers. Thus, agricultural income varied substantially from household to household.

The Gini correlation (R_f) between fish income and total income is 0.592, which is less than that for non-fish agricultural income (0.904), indicating that fish income favored the poor more than did non-fish agricultural income in the CBA project area. We found a similar result for the control group, which again suggests that fish income favored the poor more than did any other income source. Once again, we can prove this argument by discussing the contribution of each income source to total income inequality. In the CBA project area, the percentage

contribution of fish income to inequality (12 percent) was smaller than the percentage contribution to per capita total income (23 percent). This implies that fish income had an equalizing effect on the distribution of total income.¹⁷ In contrast, while about 49 percent of total income was from non-fish agricultural sources, these contributed to 79 percent of total income inequality. This implies that non-fish agricultural income made a greater contribution to inequality than its percentage contribution to total income would suggest. We find a similar result for the control group.

Table 5. Gini decomposition by income source for CBA project and control areas (with common support)

Category		Source's contrib. to total income S_f	Gini coeff. of income sources G_f	Gini correlation with total income R_f	Source's contrib. to income inequality	Marginal effect
CBA project area	Fish income (G_{CBAf})	0.231	0.274	0.592	0.124	-0.107 (-0.12, -0.09)
	Non-fish agricultural income	0.489	0.541	0.904	0.793	0.304 (0.28, 0.32)
	Off-farm income	0.279	0.420	0.212	0.082	-0.196 (-0.23, -0.17)
	Total income (G_{fl})		0.301 (0.284, 0.310)			
	N		980			
Control area	Fish income (G_{conf})	0.073	0.600	-0.340	-0.040	-0.114 (-0.121, -0.104)
	Non-fish agricultural income	0.536	0.542	0.886	0.686	0.157 (0.136, 0.179)
	Off-farm income	0.391	0.509	0.648	0.354	-0.043 (-0.067, -0.226)
	Total income (G_{f0})		0.370 (0.358, 0.383)			
	Number of observations		833			
Difference ($G_{f0} - G_{fl}$)			0.069 (0.049, 0.085)			
Difference ($G_{conf} - G_{CBAf}$)			0.326 (0.302, 0.356)			

Notes: 95 percent bootstrapped percentile confidence intervals in parentheses.

¹⁷ A high Gini coefficient value for any income source does not necessarily mean that it has a detrimental effect on total equality and therefore disfavors the poor. For example, López-Feldman et al. (2007) have shown that the unequal distribution of income from natural resource extraction in Mexico favors the poor.

We also estimate the marginal change in inequality produced by a 1 percent change in each individual income source. The results reveal that, all other things being equal, if fish income increases by 1 percent, the Gini coefficient of total income inequality decreases by 0.107 percent for CBA project households and by 0.114 percent for control group households. All of these changes are statistically significant. This indicates that fish income positively contributes to an egalitarian distribution of income and that the control group has relatively greater scope to reduce overall income inequality through increasing fish income. Conversely, in the CBA project area, a 1 percent increase in income from non-fish agricultural sources is associated with a 0.30 percent increase in the Gini coefficient for total income, and this is again statistically significant. However, for the control group, a 1 percent increase in non-fish agricultural income has a statistically significant unequalizing effect, with the Gini coefficient increasing by 0.15 percent.

Finally, we point out the importance of the CBA management system in reducing overall income inequality. We find reduced income inequality among CBA project participants, as the Gini coefficient is only 0.301 for the project group households compared with 0.368 for the control group households. This suggests that the Gini coefficient decreases by a statistically significant 18 percent when we adopt a CBA management system in floodplain areas.

6.3. CBA management and poverty

Hypothesis H5 suggests that access to the CBA system should reduce poverty in the floodplain areas. In order to test this hypothesis, we estimated the incidence of poverty (the head count ratio) and the poverty gap for each year. Table 6 presents the results. As shown, in every year, the incidence of poverty (as indicated by the head count ratio) was significantly lower in the CBA project area than in the control area, with the incidence of poverty decreasing by 17.5, 21.5, and 27.8 percent point in 2007, 2008, and 2009, respectively, in the CBA project area. The depth of poverty (the poverty gap) exhibits a similar pattern, which implies that the poverty gap significantly declined following introduction of the CBA management system in the seasonal floodplain area. These results strengthen our understanding that floodplain management through the community-based system has a positive impact on the reduction of poverty.

Table 6. Incidence of poverty and the poverty gap for CBA project and control individuals (with common support)

Poverty	2007		2008		2009	
	CBA project	Control	CBA project	Control	CBA project	Control
Incidence of poverty	0.475	0.576	0.439	0.562	0.412	0.555
Difference	0.101*** (0.055, 0.146)		0.122*** (0.077, 0.168)		0.143*** (0.097, 0.188)	
Poverty gap	0.168	0.267	0.144	0.230	0.108	0.226
Difference	0.099*** (0.077, 0.120)		0.086*** (0.065, 0.106)		0.118*** (0.099, 0.137)	
Number of observations	979	843	976	848	980	833

Notes: *** indicates significance at the 1 percent level. 95 percent confidence intervals are in parentheses

To test the robustness of the poverty orderings, we simulated a range of poverty lines to facilitate comparisons between the CBA project and control groups using stochastic dominance tests. Figures 3 and 4 plot the first-order (head count ratio) and second-order (poverty gap) stochastic dominance tests, respectively, when the poverty lines vary. As shown, the first-order stochastic dominance tests clearly suggest that the incidence of poverty is lower in the CBA project area than in the control area. Likewise, the plot of the second-order stochastic dominance test in Figure 4 demonstrates that the depth of poverty is unambiguously higher in the control area than the CBA project area.

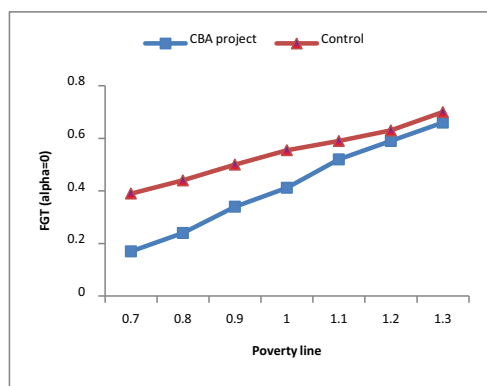


Figure 3. Incidence of poverty for CBA project and control households

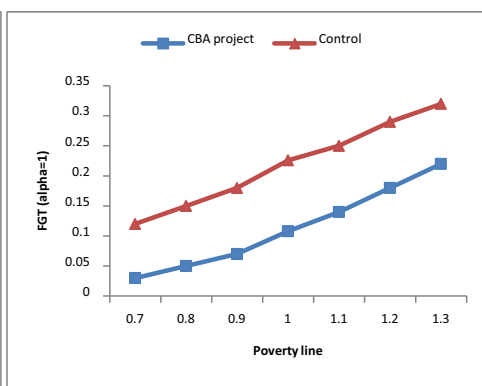


Figure 4. Poverty gap for CBA project and control households

To obtain a clear idea about the contribution of fish income to poverty reduction, we decomposed the income according to source using the data from 2009. Table 7 presents the absolute, relative, and marginal contributions of fish and non-fish income to the incidence of poverty and the poverty gap. The results reveal that in the CBA area, fish income contributed to 13 percent of the reduction in total poverty (of 58 percent overall), while the corresponding share was only 2 percent in the control area. Furthermore, the relative and marginal contributions of fish income were also much higher for the CBA project area than for the control area.

Table 7. Poverty decomposition by income source (with common support)

	Absolute contribution		Relative contribution		Marginal contribution	
	Project	Control	Project	Control	Project	Control
<u>Incidence of poverty</u>						
Fish income	-0.125	-0.018	0.180	0.043	-0.003	0.000
Non-fish agri. income	-0.335	-0.273	0.594	0.629	-0.080	-0.082
Off-farm income	-0.127	-0.142	0.225	0.327	-0.009	-0.033
<u>Poverty gap</u>						
Fish income	-0.230	-0.076	0.259	0.099	-0.102	-0.027
Non-fish agri. income	-0.369	-0.384	0.414	0.497	-0.159	-0.157
Off-farm income	-0.290	-0.312	0.326	0.403	-0.120	-0.132
Number of observations	980	833				

In a similar manner, fish income contributed to 23 percent of the reduction in the depth of poverty in the CBA area and only 8 percent in the control area. In addition, fish income made a higher marginal contribution to reducing the poverty gap in the CBA area compared with the control area. Based on the above discussion, we conclude that the CBA management system can reduce poverty through generating income from fish culture in the floodplain areas of Bangladesh.

7. Concluding remarks

In most developing countries, poor people and poor communities are relatively more dependent on natural resources for their livelihood. As a result, in recent years, community-based natural resource management has become more popular among poor communities as a way of ensuring the proper distribution of resource benefits and as a means of improving community livelihoods. This study highlights the importance of income from natural resource management in reducing poverty and inequality using a CBA system operating in seasonal floodplain areas of Bangladesh.

In Bangladesh, one-third of total land remains under water during the monsoon season (such areas are known as seasonal floodplains) and therefore remains unused because of the lack of a proper water management policy. During this period, naturally occurring fish stocks are the only source of income for local people. Therefore, low income from these floodplains creates higher poverty and income inequality. However, these seasonal floodplains can serve as a resource for aquaculture during the monsoon season, which in turn can help reduce poverty and inequality. This study analyzed the impact of a CBA system on income (especially fish income during the monsoon season and overall household income), poverty, and inequality using a three-year panel of data. We collected this data from the WorldFish Center project area. This project was executed by the WorldFish Center and the Bangladesh DoF, and was implemented across three main river basin areas in Bangladesh.

We used both nonparametric (PSM) and parametric (random effects) methods to evaluate the impact of the CBA program on income and employment. We used the Gini index and the FGT poverty measure to assess inequality and poverty, respectively. Our findings (using both nonparametric and parametric methods) showed that fish income increased significantly for CBA project households without any corresponding negative impact on non-fish income during the

project implementation period. Thus, total household income increased significantly in the CBA project households compared with the control households. The results also revealed that the CBA management system could significantly increase employment opportunities in the floodplain area during the monsoon season.

One of the major findings of this research is that this management system can distribute floodplain benefits (fish income) equitably within poor communities. Furthermore, the results reveal that fish income favors the poor relatively more than does non-fish income in the floodplain areas, and so fish income has an equalizing effect on the distribution of total household income. Overall, the CBA management system has significantly contributed to equalizing the distribution of total household income in the floodplain areas. The incidence of poverty and the poverty gap were unambiguously improved through introducing a CBA system in the floodplain area. Based on all of these results, our analysis suggests that resource management through a community-based system increases household incomes and leads to demonstrably lower levels of poverty and inequality.

During the CBA project implementation period, a number of different stakeholders—namely local fishers, the WorldFish Center, the DoF, and several NGOs—were involved in the execution of the project, and their combined efforts have contributed to the better management of the water bodies involved. In the presence of such accumulated efforts with so much involvement, a desirable outcome like this was perhaps to be expected. However, it is difficult to anticipate whether such outcomes will continue to be sustainable in the areas in question once the formal support of the DoF and the WorldFish Center is withdrawn. The CBA project officially ended in 2009. Experience with different development projects in Bangladesh does not provide good indications in terms of the sustainability of the project once support is withdrawn. Thus, we should verify the positive results indicated in this study for generalization. To be more conclusive about the sustainability of the positive results of CBA indicated in this study, we recommend further work along this line of inquiry with other water bodies.

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Appendix 1: STATA output of propensity score matching for income:

Algorithm to estimate the propensity score

The treatment is participation (pc)

beneficiary, 1= participation, 0= control	Frequency	Percent	Cum.
0	540	50.00	50.00
1	540	50.00	100.00
Total	1,080	100.00	

Estimation of the propensity score:

Probit regression				Number of obs	=	1080
				LR chi2(8)	=	108.63
				Prob > chi 2	=	0.0000
				Pseudo R2	=	0.0726
Variable	Coefficient	Std. error	Z-value	p>z	95% conf. interval	
Age of the household head (years)	0.004	0.004	0.900	0.367	-0.00415	0.01123
Education of household head (year of schooling)	-0.014	0.013	-1.100	0.273	-0.03843	0.01086
Occupation of household head (1 if fisher, 0 otherwise)	0.385	0.159	2.420	0.015	0.07323	0.69600
Family size (number)	0.210	0.035	6.030	0.000	0.14176	0.27816
Owned agricultural land (decimal)	0.003	0.001	2.530	0.011	0.00063	0.00497
Owned gear (1 if household has own gear, 0 otherwise)	0.357	0.146	2.450	0.014	0.07137	0.64183
Fishing boat (number)	0.318	0.089	3.600	0.000	0.14494	0.49203
Owned ditch area (decimal)	0.070	0.017	4.030	0.000	0.03591	0.10386
Constant	-1.792	0.267	-6.710	0.000	-2.31574	-1.26890

Note: 0 failures and 6 successes completely determined

Note: the common support option has been selected
The region of common support is [.21094282, 1]

Description of the estimated propensity score in region of common support
Estimated propensity score

	Percentiles	Smallest		
1%	0.2251077	0.2109428		
5%	0.3024358	0.2119674		
10%	0.3356954	0.212995	Obs.	1071
25%	0.3910699	0.2173741	Sum of Wgt.	1071
50%	0.4832616		Mean	0.5030298
		Largest	Std. Dev.	0.1496762
75%	0.5896727	1		
90%	0.6870446	1	Variance	0.022403
95%	0.7741766	1	Skewness	0.8228438
99%	0.9938183	1	Kurtosis	3.865737

Step 1: Identification of the optimal number of blocks

The final number of blocks is 7
 This number of blocks ensures that the mean propensity score is not different for treated and controls in each blocks

Step 2: Test of balancing property of the propensity score

The balancing property is satisfied

This table shows the inferior bound, the number of treated and the number of controls for each block.

Inferior of block of pscore	beneficiary, 1= participation, 0= control		Total
	0	1	
0.2	194	107	301
0.4	172	111	283
0.5	87	154	241
0.6	75	129	204
0.8	3	39	42
Total	531	540	1,071

Note: the common support option has been selected

 End of the algorithm to estimate the pscore

PAPER V

Capacity and Factors Affecting Capacity Utilization of Marine Fisheries: A Case of Gill-net Fleet in the Bay of Bengal*

Md. Akhtaruzzaman Khan and Atle Guttormsen

Abstract

Excess capacity and overexploitation are the main problems for the sustainability of marine fisheries around the world. This study estimates the capacity utilization, excess capacity and factors affecting capacity utilization of the multispecies gill-net boats operating in the Bay of Bengal using cross-sectional primary data collected from the two main marine fishing areas in Bangladesh. Data envelopment analysis (DEA) method is used by applying general algebraic modeling system (GAMS). Moderate to low degrees of observed capacity utilization and high levels of technical inefficiency are observed in the monsoon and nonmonsoon seasons, respectively; however, unbiased capacity utilization is close to full in both seasons. High degree of excess capacity exists in both seasons; therefore more than one-third of boats can be decommissioned. Boat capacity, number of trips per month and trip duration is the main factors affecting capacity utilization in the gill- net fishing. Licensing restrictions seem to be an effective instrument for auto-elimination of boats from the fishery; however, this will have large distributional effects that need to be taken into account.

Key words: Gill- net, Bangladesh, capacity utilization, data envelopment analysis.

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1. Introduction

According to the Food and Agriculture Organization (FAO), more than 70% of the world fisheries are either fully or overexploited (FAO 2010). This is a serious concern, especially because many of these fisheries are in developing countries and provide livelihoods as well as important export earnings for these countries (Smith et al. 2010). One of the factors that contribute to unsustainability and overexploitation in fisheries is the excessive fishing capacity, resulting in unsustainable harvest rates (Gréboval 2002; Swan and Greboval 2004). FAO has identified overcapacity as the main problem in marine capture fisheries. As a consequence, excess capacity and capacity utilization (CU) have become important issues in the marine fisheries literature (Felthoven 2004; Färe et al. 2000; Kirkley et al. 2004; Kirkley et al. 2002; Kirkley et al. 2001; Kirkley et al. 2003; Vestergaard et al. 2003). Furthermore, international organizations as well as national governments have exhibited increasing concerns about these issues (Kirkley et al. 2002). In particular, FAO addressed this issue and formulated the Technical Working Group for sustainable use of fisheries resources by eliminating excess capacity (FAO 1997; FAO 1998).

There exists substantial literature on overcapacity and CU in marine fisheries. However, most of the studies are related to fisheries in developed countries, and there is still need for more studies on this issue in developing countries. Noteworthy exceptions exist such as Kirkley *et al.* (2003) who studied excess capacity of the Malaysian purse seine fishery, and Salayo *et al.* (2008) who described how excess capacity can be managed in small-scale fisheries in Southeast Asia (Cambodia, Philippines and Thailand).

There might be several reasons for the relatively low interest in the issue for fisheries in developing countries. First, overcapacity is often seen as an issue related to the degree of mechanization and improved vessels and gear. Fisheries in developing countries are still to a large extent artisanal, and there has been little productivity improvement. Second, to undertake valid analyses on the overcapacity issue, researchers need good data, which are often not available in developing countries.

Bangladesh is a developing country with a relatively large seafood sector. It is a subtropical country situated at the apex of the Bay of Bengal with a coastal plain with 710 km of coastline and 166,000 km² of sea area. Currently, marine fishery contributes 18% to total fish production, down from 26% in 1986. Although total marine fish production increased slightly in

absolute terms, its relative share compared with other fisheries such as inland capture and inland culture is decreasing (DoF 1986-87; DoF 2009-10). On average, the growth rate of marine fish production was 4.03% during the 1984–2004 period, while culture fish production grew by 10.97% during the same period (Khan et al. 2009). If the required investment for proper assessment and exploitation of the high sea pelagic and demersal fish-stock is undertaken, there exists significant potential to further increase marine fish production.

The situation is however critical for inshore small-scale fisheries. Many more boats and vessels than recognized by the Department of Fisheries (DoF) operate in the Bay of Bengal. Official statistics by the DoF on gear, boats, vessels, production, fishing pressure, stock and catch do not reflect the reality of the situation (Alam and Thompson 2001; Chowdhury et al. 1980; Khan et al. 1989; Mustafa 1999). These fisheries are already overexploited (Hussain and Enamul 2010; Mazid 2003), and need to be controlled by regulating fishing boats, banning harmful fishing practices and gears, imposing a closed fishing season and by implementing other regulatory measures. There are also indications that catches per vessel and per trip have decreased over the last few years for both mechanized and nonmechanized boats indicating the existence of excess fishing capacity, which could lead to overexploitation and vulnerability of the marine fishery in Bangladesh (Mome 2007).

Not large amount of research works were conducted on Bangladesh's marine fisheries. Alam (1993) investigated the marine fisheries of Bangladesh and studied the cost, return and profitability of gill net, purse seine and trawlers. Marine fishing was found to be profitable as the BCRs (benefit–cost ratios) were greater than one. He also addressed the growth pattern of marine fish. Using secondary sources of data, he further reviewed the stock assessments made in the past. These assessments identified four fishing grounds, namely, 'South Patches' and 'South of South Patches' covering an area about 6,200 km², 'Middle Fishing Ground' covering 4,600 km² and 'Swatch of No Ground' covering 3,800 km². South Patches is known to be the most productive fishing ground. He underlined the need for new surveys to examine if there are new fishing grounds and if species diversity is affected.

Mome (2007) investigated the production potential of the artisanal *hilsha* (*Tenualosa ilisha*) fishery in Bangladesh using bioeconomic modeling and calculated the optimal sustainable yield of the fishery and compared it with current yields. She found that the fishing effort (measured in standardized boat units) required to make the *hilsha* fishery achieve sustainable

maximum economic benefits was about one-third of the current fishing effort. She also estimated the dynamic path that maximizes the present value of the fishery and found dramatic effort reductions for the first two years. Such a path would increase the present value of the *hilsha* fishery by approximately 10–15%.

This paper uses the DEA methodology to estimate the excess capacity and CU of gill-net boats operating in the Bay of Bengal. In the study, attempt is made to determine whether the vessels are operating at over- or undercapacity, and if so, by how much. We will also determine whether they maximize production efficiency. The results will be relevant for fleet management particularly in the expansion or contraction of the number of boats and vessels as well as in the areas of fishing regulation and the degree of regulation compliance. The DoF will be able to develop a framework for the maximum number of boats and vessels in the fishery. The findings will help to design mechanisms of regulation that control the behavior of the boats. Information on the degree of compliance to regulations by the boat operators will help determine the compliance level. All this information will provide opportunities for better management of the marine fishing industry. As no previous studies exist on production efficiency and CU in Bangladesh's marine fisheries, the results of this study will be very timely and useful.

2. Background on Gill-net Fishing in the Marine Fishery of Bangladesh

The marine fishery in Bangladesh is dominated mainly by artisanal fishery rather than industrial fishery with different gear types and fish species. The industrial marine fishery is based on trawlers and at present, about 101 fish trawlers and 40 shrimp trawlers operate in the Bay of Bengal (DoF 2009-10). The industrial marine fishery has prospects to earn foreign exchange but the carrying capacity of aquatic resources is still unknown in the Bay of Bengal. In contrast, 21,433 mechanized and 22,527 nonmechanized boats are being used for fishing in the artisanal fishery. Gill-nets (106,315 drift and fixed nets), set bag nets (50,083 estuarine and marine nets) and longline nets (24614 nets) are the main fishing gear for artisanal fishing in the Bay of Bengal (DoF 2009-10). At present, 93% of marine fish production comes from artisanal fishery and only 7% comes from industrial fishery (DoF 2009-10). Gill nets alone contributed 62% of total artisanal fish landing in 2009 (DoF 2009-10).

Different types of fishing gear are used to exploit multispecies marine resources on the basis of target species and depth of operation. Local, traditional and primitive methods of fishing are used in the artisanal fishery. Various types of gill-nets are used with different mesh size because of the different target species. *Choi suta* (local name of a type of gill-net) nets are used during the monsoon season (May–October) while *Char suta* nets are used in the nonmonsoon (November–April) season. The target species of gill-nets are Hilsha shad (*Tenualosa ilisha*), Indian salmon (*Polynemus indicus*) Pomfret (*Pampus chinensis*), mullet (*Valamugil seheli*) and jewfish. Drift gill-nets dominate the inshore areas especially for *hilsha* species. However, the horizontal as well as the vertical openings in the drift gill nets are expanding day by day for both mechanized and nonmechanized boats. These boats operate almost throughout the year. Fixed gill-nets are also used to catch *hilsa* but only for a few months in the year at the river mouth when strong currents exist in the Bay of Bengal.

Gill-net fishery in Bay of Bengal is characterized by small boats that are made of good quality wood and are operated by low horsepower motors. The boat is directed by a captain and the captain is generally the more knowledgeable and experienced person among the crew. He provides overall leadership during the fishing trip and is also responsible for the maintenance of all the fishing equipment.

3. Methodology

Estimating Capacity Output and Utilization

Studies of capacity are typically based on the “hold capacity approach,” which provides a technological limit to maximum production. Data on the number of vessels, individual hold capacity and maximum number of fishing trips are required for this approach. There are many difficulties associated with this method (Gréboval 1999). The Technical Working Group of FAO suggested two practical alternative methods of capacity measurement: peak-to-peak methods and data envelopment analysis (DEA). The peak-to-peak method capacity is measured by observed relationships between catch and fleet size over time. The peak-to-peak method requires data on landings and vessel numbers and some identification of a technological time trend (Gréboval 1999). On the other hand, DEA is a mathematical programming method that determines the optimal solutions given a set of constraining relations. DEA is well suited in situations where

there are limited amounts of data, and when data are unstructured. In effect, DEA analysis only requires data on key inputs and output. DEA is suggested as the most appropriate methodology to estimate fishing capacity because it is able to measure fishing capacity at an individual species level in a multispecies fishery (FAO 2000). Another advantage of the DEA method is that it can incorporate multiple inputs and multiple outputs in the analysis (Kirkley and Squires 2003; Pascoe 2007). Therefore, DEA has been applied in estimating the CU and technical efficiency of fisheries sectors worldwide over the last one and a half decades (FAO 1998; Kirkley et al. 2002; Kirkley and Squires 2003; Kirkley et al. 2003; Maravelias and Tsitsika 2008; Tingley and Pascoe 2005a; Tingley and Pascoe 2005b; Tingley et al. 2003; van Hoof and de Wilde 2005; Vestergaard et al. 2003).

In this study, an output-oriented version of DEA is used to estimate capacity output and CU empirically. Fare *et al.* (1989; 1994) used DEA technique to estimate firm capacity and capacity output. They demonstrated that capacity output could be measured using the technical efficiency of the output-oriented DEA method¹⁸. This DEA framework allows all variable inputs to vary and be fully utilized, whereas fixed inputs are fixed at their observed level. Let, $j=1, \dots, J$ be the firms/boats producing M outputs (different fish species) using variable and fixed factors; and u_{jm} is the m^{th} fish species catch (output) by firm/boat j . It is assumed that each input is used by some firms/boats i.e., for each input n , $\sum_{j=1}^J x_n^j > 0$. and each firm/boat uses some inputs, i.e., $\sum_{n=1}^N x_n^j > 0$. It is also assumed that each firm/vessel produces (catches) some output (fishes), i.e., $u^j > 0$ for all j . Under these assumptions, Fare et al. (1989) proposed the following DEA problem:

$$\text{Max}_{\theta, z, \lambda} \theta_1$$

subject to

$$\theta_1 u_{jm} \leq \sum_{j=1}^J z_j u_{jm}, \quad m = 1, 2, \dots, M,$$

$$\sum_{j=1}^J z_j x_{jn} \leq x_{jn}, \quad n \in \alpha, \quad (\text{fixed inputs constraint})$$

¹⁸ Output-oriented technical efficiency measures the frontier production i.e., the maximum possible output or potential output given the current use of inputs. This DEA technique of frontier production depicts the best combination or most technically efficient combination of inputs and outputs in a deterministic way.

output and CU (Segerson and Squires 1990). As a consequence, this multiple-output problem switches to a single-output problem and this ray measure corresponds to a Farrell (Farrell 1957) measure of output-oriented technical efficiency associated with the radial expansion of outputs (Vestergaard et al. 2003).

Fare *et al.* (1994) argued that this ray measure may be biased downward, because the observed output that we use to calculate the CU measure may not be produced in a technically efficient manner. In order to obtain the technically efficient measure, both fixed and variable inputs need to be constrained to their current levels. We can solve the following linear programming DEA problem to obtain technically efficient capacity output and CU measures:

$$\begin{aligned}
 & \text{Max}_{\theta_2, z} \theta_2 \\
 & \text{subject to} \\
 & \theta_2 u_{jm} \leq \sum_{j=1}^J z_j u_{jm}, \quad m = 1, 2, \dots, M, \\
 & \sum_{j=1}^J z_j x_{jn} \leq x_{jn}, \quad n = 1, 2, \dots, N, \\
 & \sum_{j=1}^J z_j = 1 \\
 & z_j \geq 0, \quad j = 1, 2, \dots, J, \dots \dots \dots
 \end{aligned} \tag{2}$$

where θ_2 shows by how much production can be increased if the production procedure is technically efficient. The technically efficient output can be estimated by multiplying θ_2 by the observed production for each output. The technically efficient or “unbiased” ray measure of CU is then the determined as:

$$\text{CU (efficient)} = \frac{CU}{TE} = \frac{1/\theta_1}{1/\theta_2} = \frac{\theta_2 u}{\theta_1 u} = \frac{\theta_2}{\theta_1}.$$

This output-oriented capacity measure can be used in different ways such as for each boat, according to gear type, or for different fish species (multispecies case). The general optimization package called the general algebraic modeling system (GAMS) is used for this DEA model (Brook et al. 1992). The fixed factors considered in this analysis are gross registered tonnage, engine horsepower and net length. Variable inputs are number of crew on board and

fishing time measured in days. Average trip-specific data have been used to estimate the capacity.

4. Data and Summary Statistics

Cross-sectional data collected in face-to-face interviews are used in this study. A pretested questionnaire was administered to collect information from the gill-netters operating in the Bay of Bengal. The questionnaire contains information on the personal characteristics of the captain (operator), boat tonnage, engine horsepower, nets and associated boat equipment used for fishing, fishing trips, fish catch, variable input costs and information on the share system of earnings of the boat/gill-net vessels. Lists of gill-net operators fishing in Chittagong and Cox's Bazar port were obtained from the Marine Office of the Department of Fisheries, Chittagong. A total of 146 gill-netters comprising 52 from Chittagong and 94 from Cox's Bazar were included following a random sampling procedure. The survey was conducted during July–September 2010.

Monsoon is the peak season for gillnetters as their target species is the *hilsha*. Although the *hilsha* catch is concentrated in the monsoon season, it is also caught throughout the year to a limited extent. However, some other target species such as Bombay duck (*Harpadon nehereus*), Ribbon fish (*Trichiurus haumela*), Dogfish shark (*Scoliodon sorrakowah*), Shrimp (*Penaeus monodon*), and Climbing perch (*Anabas testudineus*) are also caught throughout the year. In this analysis we have classified the multiple fish species into two groups namely, *hilsha* and other species (all other species except *hilsha*).

As the catch during the nonmonsoon months is smaller, many operators discontinue fishing during the nonmonsoon season. In our sample of 146, 25 gillnetters abstained from catching fish during the nonmonsoon season. Therefore, we had to analyze 146 samples for the monsoon season and 125 for the nonmonsoon season. Because of the different sample sizes for the monsoon and nonmonsoon seasons, we could not undertake a pooled estimate of the combined data sets. The distribution of the gill-net boats sample is given in table 1.

Table 1: Distribution of Gill-net Boats Sample in Monsoon and Nonmonsoon Seasons

GRT group	Monsoon		Nonmonsoon	
	No.	%	No.	%
≤ 10	19	13.0	10	8.0
11 ≤ 20	87	59.6	77	61.6
21 ≤ 32	40	27.4	38	30.4
All groups	146	100.0	125	100.0

Table 2 presents sample summary statistics of different variables of gill-net fishing in Bay of Bengal. Fishers working in gill-net fishing are aged 42 years on average but their average schooling is only two years. However, 18% respondents did not have any formal schooling. The average length, breadth and depth of gill-net boats is 48 feet, 13 feet and 8 feet, respectively. Average GRT is 18.58 in the monsoon season and 19.33 in the nonmonsoon season, ranging from 3.2 to 32. The average catch of the target species, *hilsha*, is 2069 kg per trip in the monsoon season while it is 1207 kg in the nonmonsoon season. The total catch per trip of the gillnetters is thus 2660 kg in the monsoon season and 2042 kg in the nonmonsoon season. The gillnetters make on average two trips per month and the average duration of a fishing trip is eight and nine days in the monsoon and nonmonsoon months, respectively.

Table 2: Summary Statistics of Different Variables for Gill-net Fishing Data

Variables	Monsoon		Nonmonsoon	
	Mean	Std. dev	Mean	Std. dev
Age	42.21	6.73	41.93	6.56
Education	2.18	2.31	2.15	2.34
Fishing experience	23.68	7.01	21.69	7.93
Family size	6.90	2.41	6.91	2.41
Length of boat (feet)	47.80	6.42	47.94	6.48
Breadth of boat (feet)	12.61	2.83	12.75	2.92
Depth of boat (feet)	7.73	2.07	7.72	2.13
Boat capacity (Gross registered tonnage)	18.58	5.87	19.33	5.38
Engine horsepower	56.36	23.07	58.40	23.11
Length of net (feet)	285.79	65.38	271.35	60.22
<i>Hilsha</i> catch per trip (kg)	2069.04	1181.55	1207.20	805.56
Catch of other species per trip (kg)	590.47	468.86	834.94	705.43
Total catch per trip (kg)	2659.52	1281.61	2042.18	1136.24
Fishing duration per trip (days)	8.02	2.00	9.05	2.10
No. of trips per month	2.15	0.43	1.99	0.92
No. of hauls per trip	1.94	0.23	1.73	0.68
No. of crew on board per trip	18.29	3.42	18.51	3.19
Depth at points of operation (feet)	165.08	48.64	147.42	60.37
Ground distance (km)	224.45	86.20	222.94	121.71

The boats are more traditional in nature with minimal equipment. Each boat has a compass for monitoring its direction at sea. There is no GPS, echo sounder, sonar, net hauler or winch, but everyone has mobile/radio/wireless devices. All boats are equipped with life jackets, searchlights and a generator.

5. Results and Discussion

5.1 Capacity and CU

CU (observed and unbiased) and technical efficiency (TE) are estimated from the product of expansion factors θ_1 and θ_2 obtained by solving linear programming problems with the help of DEA. In addition, capacity output, technically efficient output and unbiased capacity output are measured from θ_1 and θ_2 .¹⁹ Capacity output relates to the potential output of a boat given its fixed factors of production. Technically efficient output on the other hand refers to potential output of a boat using both fixed and variable factors in a technically efficient configuration (Tingley et al. 2003). Table 3 presents CU and TE of the gill-net vessels according to season and GRT size.

Table 3: CU and Technical Efficiency of the Gill-net Vessels in Bay of Bengal

GRT group	Monsoon			Nonmonsoon		
	CU (obs)	TE	CU (unb)	CU (obs)	TE	CU (unb)
≤ 10	0.69	0.71	0.96	0.47	0.47	0.99
$11 \leq 20$	0.56	0.60	0.94	0.51	0.52	1.00
≥ 21	0.57	0.59	0.95	0.60	0.65	0.92
All groups	0.58	0.61	0.94	0.35	0.55	0.98

The results show considerable variation in average CUs and TEs within and across seasons and GRTs. The gill-netters seem to be operating at 58% of full capacity with 61% TE in the monsoon season and at 35% capacity with 55% TE in the nonmonsoon season. In the monsoon season, both CU (obs) and TEs tend to show roughly a negative association with the GRT groups, which is opposite to the situation in the nonmonsoon season. This result does not necessarily mean that smaller boats are more efficient than larger boats in the monsoon season, rather it means that fishing with small boats works efficiently during monsoon seasons compared with large boats and vice versa during nonmonsoon seasons.

Given that all inputs are used efficiently under normal conditions, the average CU (unb) is 94% in the monsoon season and 98% in the nonmonsoon season. On average, vessels are

¹⁹ Capacity output = $\theta_1 \times$ observed output or catch, technically efficient output = $\theta_2 \times$ observed output or catch and unbiased capacity output = $(\theta_1 / \theta_2) \times$ observed output or catch.

catching 36% (monsoon season) and 63% (nonmonsoon season) less output than technically feasible output levels given the inputs they possess (table 3). Dupont *et al.* (2002) estimated the CU (obs) to vary between 0.649 and 0.724. Vestergaard *et al.* (2003) estimated the average CU (obs) and CU (unb) to be 0.88 and 0.92, respectively, which is even higher than those estimated by Dupont *et al.* (2002). Tsitsika (2008) estimated the average CU (obs) to range from 0.53 to 0.67 and the average CU (unb) from 0.76 to 0.81. Asche *et al.* (2005) studied CU for different fisheries in the UK and found the CU (obs) to vary from 0.53 to 0.68 for otter trawlers and 0.54 for seiners. The TE varies from 0.59 to 0.79 for otter trawlers and 0.67 for seiners. Taking all boats into consideration, they found the CU (obs), TE and CU (unb) to be 0.60, 0.69, and 0.87, respectively. Although the average CU (obs) estimates in the present study are considerably lower than these estimates, however, the fact remains that similarity across the studies is that boats on average exhibit excess capacities.

The distributions of CU (obs and unb) are presented in figures 1 and 2. The CU (obs) scores seem to be concentrated in the 50–60% range in the monsoon season and their distribution is bell-shaped. In the monsoon season, 137 out of 146 boats, i.e., 94%, had an average CU (obs) score of less than one, while only 6% of them had CU (obs) scores equal to one. The distribution of CU (unb), however, is slightly different. About 23% of boats have a CU (unb) score equal to one. The highest CU (unb) concentration is within the 91–99% range. There is virtually no boat operated at less than 70% CU (unb) (figure 1).

The distributions of CU (obs) and CU (unb) for the nonmonsoon season are similar to those for the monsoon season. Most CU (unb) concentrations are in the 91–99% range for the monsoon season (figure 2). However, the percentage of boats with CU (unb) equal to one is about 33%. The overwhelming majority of the boats had CU (unb) higher than 90% in the nonmonsoon season. These distributions of CU (obs and unb) scores suggest that a large part of the gill-net sample had a relatively low to moderate level of CU. This holds more for the CU (obs) score.

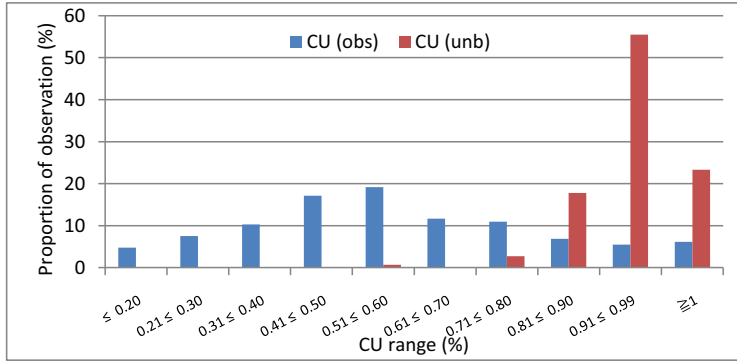


Figure 1. Distribution of CU Scores of the Gill-net Boats of Bangladesh in the Monsoon Season

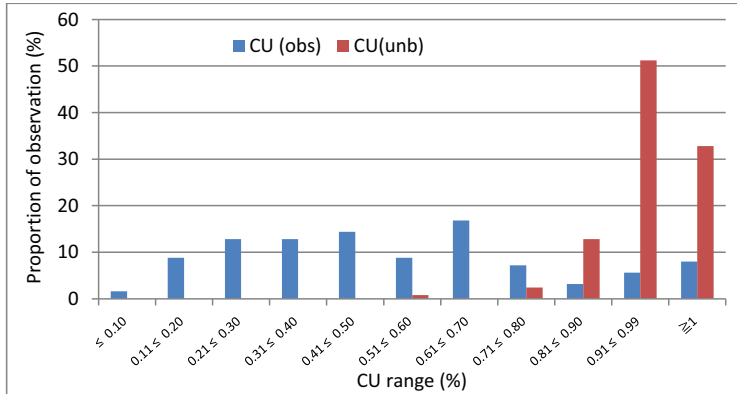


Figure 2. Distribution of CU Scores of the Gill-net Boats of Bangladesh in the Nonmonsoon Season

Variation in catch and CU between boats of similar size is not only for diverse levels of input usage but also for dissimilarities in technical efficiency (Pascoe et al. 2001; Tingley et al. 2003; Tsitsika et al. 2008). The capacity output of a boat is basically the quantity obtained if boat operates at the optimum efficiency level. Therefore, any extra output above the observed output indicates overcapacity of that boat (van Hoof and de Wilde 2005). Table 4 displays observed output, capacity output, and excess capacity for different species caught by the gillnetters for both the monsoon and nonmonsoon seasons.

The results reveal that both the monsoon and nonmonsoon season boat of all sizes operated below their output capacity level indicating that output can be increased considerably through proper utilization of inputs. In the monsoon season, observed output could have been increased by about 78% for both of the two species categories, i.e., *hilsha* and other species, if all boats had been fully utilized. However, in the nonmonsoon season, output could have increased by about 90% on average. This increase was more likely because of technical efficiency improvements rather than an increase in CU. The authenticity of this statement is reflected through the findings of potential increases in technical efficiency and potential increases in unbiased capacity (table 4). The results show output could have increased by only 7% (5%) in the monsoon season (nonmonsoon) by increasing CU alone if boats maintain the estimated level of technical inefficiency. Furthermore, output could have increased by approximately 68% and 81% through improvements in technical efficiency in the monsoon and nonmonsoon seasons, respectively.

Table 4. Gill-net Capacity Output, Technical Efficiency Output and Potential Increase of Capacity

	GRT group ≤ 10		GRT group $11 \leq 20$		GRT group ≥ 21		All groups	
	Monsoon	Nonmonsoon	Monsoon	Nonmonsoon	Monsoon	Nonmonsoon	Monsoon	Nonmonsoon
Catch								
<i>Hilsha</i>	1206	454	2133	1158	2340	1505	2069	1207
Other	449	385	581	805	678	1014	590	835
All	1655	839	2714	1963	3018	2519	2659	2042
Capacity output								
<i>Hilsha</i>	1843	879	3855	2295	4263	2500	3706	2244
Other	656	969	1050	1579	1262	1907	1057	1630
All	2499	1848	4905	3874	5525	4406	4762	3874
TE output								
<i>Hilsha</i>	1756	877	3594	2211	4029	2368	3474	2152
Other	635	969	979	1518	1189	1771	992	1551
All	2391	1846	4573	3729	5218	4139	4466	3703
Unbiased capacity output								
<i>Hilsha</i>	1262	455	2296	1205	2465	1595	2208	1264
Other	463	385	628	836	713	1089	630	877
All	1725	840	2924	2041	3178	2684	2838	2141
Potential increase in capacity (%)								
<i>Hilsha</i>	52.82	93.61	80.73	98.19	82.18	66.11	79.12	85.92
Other	46.10	151.69	80.71	96.15	86.14	88.07	79.15	95.21
All	51.00	120.26	80.73	97.35	83.07	74.91	79.09	89.72
Potential increase in TE (%)								
<i>Hilsha</i>	45.85	93.17	68.50	90.93	72.18	57.34	67.91	78.29
Other	41.43	151.69	68.50	88.57	75.37	74.65	68.13	85.75
All	44.47	120.02	68.50	89.96	72.90	64.31	67.96	81.34
Potential increase in unbiased capacity (%)								
<i>Hilsha</i>	4.64	0.20	7.67	4.08	5.34	5.41	6.72	4.67
Other	3.09	0.00	8.19	3.90	5.11	7.40	6.72	5.05
All	4.22	0.14	7.78	4.00	5.29	6.53	6.72	4.83

Increases in excess capacity and potential output differ across the different GRT groups. In the monsoon season, larger boats could have produced more output compared with smaller boats when all boat sizes are fully utilized. In contrast, in the nonmonsoon season, small vessels could have increased output by more than large boats. More specifically, in the monsoon season, for boats in the ≤ 10 GRT group, *hilsha* and other species could have increased by 53% and 46%, respectively, with an average of 51%. For the largest GRT group (≥ 21 GRT), the catch could

have increased by 82% for *hilsha* and 87% for other species, with an average of 84%. In contrast, in the nonmonsoon season, the fish catch could have increased by 120% for the smallest GRT group, whereas it was 75% for largest GRT group. These findings differ considerably from those of Vestergaard *et al.* (2003) who found that excess capacity varied from 7.7% to 17% across the different species. However, the present estimates of excess capacities are similar to those of Squires *et al.* (2003), where estimated excess capacities for the medium purse seiners, mini purse seiners and long-liners are 151.90%, 86.29% and 206.61%, respectively. They also found that average annual CU (obs) is only 0.399 for the medium purse seiners, 0.530 for the mini purse seiners and 0.308 for the long-liners, which are close to the present estimates.

Policy makers are sometimes interested in removing some boats in order to eliminate excess capacity. As this data set is cross-sectional (only one year of data), we obtain point estimates of boat excess capacity. There are two ways to estimate the number of boats that could be removed to eliminate excess capacity: one is by ordering boats from highest to lower capacity and removing the boats first with highest capacity (Squires *et al.* 2003). This approach involves minimum decommissioning implying fewer boats would be removed, leaving the largest fleet size for the target catch. Another approach is by ordering the boats from lowest to higher capacity and remove the lowest capacity first. In this case, a larger number of boats would need to be removed, leaving the minimum number of boats for the catch. In this study, we use the former approach.

The number of boats to be decommissioned to remove excess capacity is presented in table 5. Severe excess capacity is observed in both the monsoon and nonmonsoon seasons when capacity output is determined by both technical inefficiency and inappropriate variable input usage. The results reveal that in the monsoon season about 34% of existing boats are required to be decommissioned to eliminate the excess capacity. In contrast, in the nonmonsoon season, 47% vessels need to be decommissioned from the sea. Comparatively larger sized boats (belonging to the higher GRT groups) need to be removed in the monsoon season (table 5).

Table 5: Boat Capacity, Excess Capacity and Decommissioned

	GRT group ≤ 10		GRT group $11 \leq 20$		GRT group ≥ 21		All groups	
	<i>Monsoon</i>	<i>Non monsoon</i>	<i>Monsoon</i>	<i>Non monsoon</i>	<i>Monsoon</i>	<i>Non monsoon</i>	<i>Monsoon</i>	<i>Non monsoon</i>
<i>Allowing technical inefficiency</i>								
Vessel total catch	31460	8388	236095	151146	120735	95735	388290	255269
Vessel capacity output	47466	18486	426756	298321	221843	167446	696065	484253
Vessel excess capacity	16006	10098	190673	147172	100275	71945	306955	229214
% excess capacity	50.88	120.38	80.76	97.37	83.74	75.15	79.26	89.79
Total no. of vessels	19	10	87	77	40	38	146	125
No. of vessels removed	4	4	31	32	15	13	49	47
% of vessels removed	21	40	36	42	38	34	34	38
<i>Removing technical inefficiency</i>								
Vessel capacity output	32788	8400	254463	157206	127123	101984	414375	267590
Vessel excess capacity	1328	12	18368	6060	6388	6249	26085	12321
% excess capacity	4.22	0.14	7.78	4.00	5.29	6.53	6.72	4.83
No. of vessels removed	0.00	0.00	3	1	1	1	4	2
% of vessels removed	0.00	0.00	3	1	3	3	3	2

On the other hand, there appears to be no need for boat decommissioning if inputs are utilized at full capacity (all boats are technically efficient). The results reveal that only 3% and 2% of boats need to be removed during monsoon and nonmonsoon seasons, respectively, to eliminate excess capacity when boats operate efficiently.

5.2 Variable Input Utilization Rate (VIUR)

Variable input utilization outcome measures the ratio of optimal use of variable inputs use to observed inputs. The optimal (max) variable inputs use is the variable input level that gives full technical efficiency at the full capacity output level (Färe et al. 1994; Vestergaard et al. 2003). If the ratio of the optimal variable input level to the observed input level exceeds 1 in value, there is a shortage of the *ith* variable input currently used and the vessel should expand use of that input. If λ is less than 1, then there is a surplus of the *ith* variable input currently used and the vessel should contract use of that input (Pascoe et al. 2001).

Variable utilization rates for crew and fishing day are presented in table 6. The table reveals that the average variable input utilization rates for both the number of crew and fishing days are higher in the monsoon season compared with the nonmonsoon season. Figures 3 and 4 present the distribution of crew and fishing day utilization rates, respectively. The average Crew UR (utilization rate) < 1 is in the range 30–31% across the seasons. The percentage of boats with Crew UR = 1 is 6% and 8% in the monsoon and nonmonsoon seasons, respectively. More than 60% of the boats had Crew UR > 1 . Regarding the number of fishing days, 28% and 43% boats has less than 1 UR in the monsoon and nonmonsoon seasons, respectively. About 66% of the boats had an average fishing day UR > 1 in the monsoon season and only 51% in the nonmonsoon season. The above analysis shows that 50% to 70% of the boats have variable input UR higher than 1 suggesting that there are considerable shortages of both crewmen and fishing days in gill-net fishing operations. Therefore, gillnetting in Bangladesh marine fishing does have the capacity to absorb more crew and fishing days in both seasons profitably.

Table 6: Variable Input Utilization Rates of the Gill-net Boats in Bangladesh by GRT

GRT group	Monsoon		Nonmonsoon	
	No. of crew	Fishing days	No. of crew	Fishing days
≤ 10	1.149	1.064	0.755	0.737
$11 \leq 20$	1.305	1.450	1.109	1.000
≥ 21	1.169	1.383	1.264	1.267
All groups	1.247	1.381	1.128	1.061

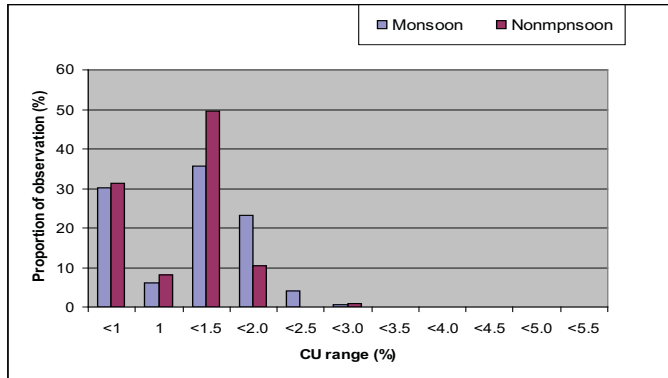


Figure 3. Distribution of Crew Utilization (CU) Rates in the Two Seasons for the Gill-net Boats of Bangladesh

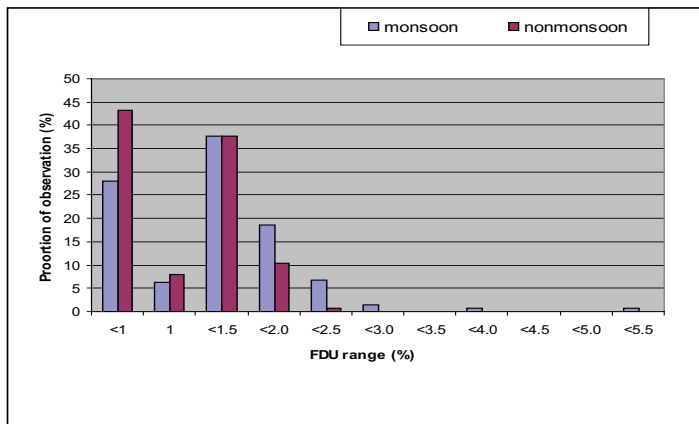


Figure 4. Distribution of Fishing Day Utilization (FDU) Rates in the Two Seasons for the Gill-net Boats of Bangladesh

The optimal crew size and fishing days, presented in table 7 are both higher than their observed level. It is to be noted that the optimal crew size is 23.09 (21.08) in the monsoon (nonmonsoon) seasons as compared with their observed level of 18.29 (18.51). In contrast, the average optimal number of fishing days was 10.47 (9.41) days in the monsoon (nonmonsoon) season while their observed levels were 8.02 (9.05) days. Thus, the observed levels of variable inputs used are lower than their optimal levels. These indicate that gill-net vessels should expand the use of variable inputs and improve the CU.

Table 7: Optimal Variable Input Size for the Gill-net Boats in Bangladesh by GRT

GRT group	Monsoon		Nonmonsoon	
	No. of crew	Fishing days	No. of crew	Fishing days
≤ 10	16.39	7.89	9.33	4.09
11 ≤ 20	24.79	11.11	21.08	9.25
≥ 21	22.55	10.30	24.18	11.13
All groups	23.09	10.47	21.08	9.41

5.3 Factors Affecting CU

We used a Tobit regression (because of the censored nature of the dependent variable) to investigate the factors affecting CU. Unbiased CU (unb) scores that we derived from the DEA are regressed on some independent variables. Table 8 represents the factors affecting unbiased CU for both the monsoon and nonmonsoon seasons. In the monsoon season, boat capacity is highly significant and has a positive relation with CU. This indicates that boats with higher capacity are used effectively compared with lower capacity boats. In contrast, boat capacity is negatively and significantly related to CU in the nonmonsoon season. This result is also expected because during the nonmonsoon season fish availability is lower, therefore large boats cannot catch enough according to their capacity. The fish carrying capacity of boats has significant negative effects on CU. This is because boats with larger fish capacities catch proportionally less fish compared with those who have smaller carrying capacities.

The engine horsepower has negative and highly significant (1% level) effects on CU in the monsoon season which might be due to the less effectively use of engine power by the large boat. The rough weather and risks associated with this during the monsoon season might be some other important reason for this kind of relationships. Net length has a positive and significant (5% level) effect on CU as expected. Longer nets can cover more water area compared with smaller nets; therefore, they might catch more fish than smaller nets. The number of trips per month and trip duration have positive and highly significant (1% level) effects on CU. If weather conditions are normal, then more days at sea means more fishing and thus a larger catch. Therefore, positive effects of trips per month and duration per trip on CU are expected. Trips per month are also significant in the nonmonsoon season.

In addition, hauls per day has a positive and significant (5% level) effect on CU in the monsoon season, which is expected. Other things remaining the same, more netting means a greater catch, which increases the CU. The depth of water also has positive and significant effects (5% level) on CU. Normally, fish availability in the deep sea is greater compared with closer to the shore. Therefore, boats that can fish in the deep sea might catch more fish compared with other boats, which has positive effects on CU.

Table 8: Tobit Model Regression of Unbiased CU

	Monsoon		Nonmonsoon	
	Coefficient	Std. error	Coefficient	Std. error
Constant	0.624***	0.092	0.860***	0.174
Port (dummy)	0.014	0.010	-0.009	0.026
Fishing experience (years)	0.001	0.001	0.001	0.001
Boat capacity (tonnes)	0.006***	0.002	-0.003***	0.003
Fish carrying capacity (tonnes)	-0.004*	0.002	0.006	0.006
Boat used (years)	-0.001	0.001	0.001	0.003
Engine horsepower	-0.002***	0.000	-0.002	0.001
Engine age (years)	0.000	0.001	0.001	0.002
Net length (feet)	0.000**	0.000	0.000	0.000
Mesh size (inches)	-0.009	0.009	-0.001	0.021
Number of crew	-0.001	0.002	0.009	0.004
Trips per month (no.)	0.041***	0.011	0.001**	0.024
Trip duration (days)	0.017***	0.002	0.001	0.006
Hauls per day (no.)	0.056**	0.027	0.037	0.053
Haul duration (hours)	0.007	0.005	0.003	0.007
Water depth (meters)	0.000**	0.000	0.000	0.000
Log likelihood value	239.03		104.40	
χ^2 value	95.61		27.69	

6. Conclusions and Policy Implications

The purpose of this study was first to measure the CU and excess capacity of the artisanal gill-net fleet in the Bay of Bengal and second to develop an effective policy for policy makers as well as fishermen that will maximize the economic benefit of fishermen and ensure the sustainability of marine fishery. Output-oriented DEA was used in our analysis. Cross-sectional primary data for both monsoon and nonmonsoon seasons for the year 2010 were collected from the two main marine fishing areas in Bangladesh.

The estimated average CU appears to be low in both seasons and varies between seasons. This indicates that observed output is significantly lower than capacity output, implying the existence of severe overcapacity in Bangladesh gill-net fishing. An overwhelming majority of boats operate with $CU < 1$. In addition, high levels of technical inefficiency also exist in both seasons. Poor CUs are mainly a result of low levels of variable inputs relative to their capacity and high levels of technical inefficiency. Variable input utilization rates are lower than is optimal. High degrees of excess capacity exist in the monsoon as well as the nonmonsoon seasons, which should be the major concern for policy makers. Under the condition that remaining boats are fully utilized, withdrawal of around a one-third of the operating boats/vessels might seem a reasonable management measure toward reducing overexploitation and attaining sustainable fisheries in the Bay of Bengal. More days at sea with large capacity boats is highly recommended for improving the CU in the Bay of Bengal.

License restrictions appear to be a preferred policy for reducing boat/vessel sizes. However, it is not the best solution, and may be the second-best option. Because a policy to decommission vessels does not fully establish Pareto-improving incentives, this policy may be Pareto efficient. In this case, policy makers should be more concerned about equity, that is equity and efficiency must be balanced. Implementation of a boat decommissioning policy is likely to be very difficult and problematic for most artisanal gillnetters who primarily operate close to shore, because most artisanal gill-net operators earn a subsistence living, and their livelihoods depend on their profession. As a consequence, this policy would create an unemployment problem that threatens the survival of fishermen in the coastal areas. Therefore, a socially and economically acceptable policy must be implemented by the government.

To ensure their livelihood, income-generating activities outside the sector could be used to rehabilitate the decommissioned vessels. One possible option may be to create alternative

employment opportunities through agriculture-based industry development by the government as well as the private sector in coastal areas. Banned or decommissioned boats/vessels could be used in alternate ways. Therefore, a comprehensive plan is required that outlines the best use of the banned boats. In this case, one potential policy may involve the transportation of people and goods or tourism in coastal areas.

High levels of technical inefficiency exist in both seasons, and the variable input utilization rate is also lower than its optimal level in the artisanal gill-net fishery. In this case, community-based marine fishery management might be successful where local people work under a management system and take all management responsibility. In group meetings, fishermen can use integrated indigenous knowledge of fishery to design proper management strategies. These proposed solutions are useful; however, further research is required on procedures to eliminate excess capacity, new license restriction policy and creation of alternative employment to ensure the sustainability of artisanal marine fisheries in Bangladesh.

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Md. Akhtaruzzaman Khan



Akhtaruzzaman Khan was born in Barisal, Bangladesh in 1977. He was awarded a B.Sc. degree in Agricultural Economics from Bangladesh Agricultural University (BAU) in 1999 and a M.Sc. Degree in Agricultural Economics (Finance) from the same university in 2003.

This dissertation consists of an introduction and five independent papers on Bangladesh fisheries sector. The first paper investigates how the fishery sector has developed and identifies the potential problems faced by the fisheries sector. Findings show that both fish production and productivity have increased for aquaculture and capture fisheries. Several problems, possible solutions and future prospects for fisheries sector are discussed in this paper. The second paper estimates the profitability and productivity-farm size relationship in aquaculture and investigates how smallholder farmers can sustain fish farming in the long run. It shows that the inverse profitability-farm size relationship holds but in general large fish farmers are more efficient, productive and profitable compared to small farmers. Access to credit and training are essential to sustain fish farming in the long-run. The third paper determines the production risk of pangas fish farming in Bangladesh. Results reveal that significant production risk exists in pangas farming. The use of large amount of fingerlings has risk increasing effects for all types of farms (small, medium and large farms) but feed usage is found to have a risk-increasing effect on production for large farms only, while the reverse holds in case of small farms. Findings suggest that access to credit and training in the fish farming can reduce production risk for smallholders. The fourth paper is on floodplain aquaculture where the impact on poverty and inequality of community-based aquaculture (CBA) system is investigated. We find that fish income and total household income is significantly and equally distributed after adopting this management system. Moreover, CBA management system can reduce the incidence and depth of poverty in the common resource areas. The fifth and last paper investigates whether excess capacity exists in gill-net fleet in the Bay of Bengal. If it does, then to what extent? And what are the policy alternatives for sustainable marine resource management? Results depict that the high degree of excess capacity exists in both monsoon and nonmonsoon seasons and more than one third of boats can be decommissioned. Licensing restrictions appear to be an effective instrument to eliminate the excess capacity from the fishery. However, this will have large distributional effects that need to be taken into account.

UMB School of Economics and
Business
Norwegian University of Life Sciences
P. Box 5003
N- 1432 Ås
NORWAY

Telephone: +47 6496 5700

Fax: +47 6496 5701

E-mail: ior@umb.no

<http://www.umb.no/ior>

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Professor Atle Guttormsen was Khan's main supervisor and Associate Professor Kristin H. Roll was co-supervisor.

Md. Akhtaruzzaman Khan is currently Assistant Professor in the Department of Agricultural Finance in Bangladesh Agricultural University, Mymensingh, Bangladesh.

E-mail: azkhan13@yahoo.com