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Towards Sustainable Development of Shrimp Farming in Bangladesh: The Economy versus the Environment

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ABSTRACT

The continuous striving for economic growth in both developing and developed countries is accompanied by a range of environmental problems that hamper sustainable development. The economic development through agricultural and industrial intensification combined with natural resource extraction has generated various environmental problems such as resource depletion, waste generation, and pollution. A proper measurement of environmental problems is a major issue in the debate on the economic growth and environmental protection. This measurement problem is closely linked to the tradeoffs between economic growth and environmental damage both of which determine overall social wellbeing. Therefore, the existing tradeoffs between rapid economic development and environmental degradation need to be taken into consideration to sustain the economic growth with least environmental damage. From this perspective, it is necessary to study the tradeoffs between economic outcomes and environmental degradation to achieve the long term 'sustainable development' goal of any production process.

In recent years, environmental performance indicators that incorporate joint production of economic and environmental goods in the production technology have been designed and applied as useful analytical tools in studying the possibilities for improvement in economic and environmental performance of productive units or industries. In particular, Data Envelopment Analysis (DEA) based non-parametric approaches are gaining popularity in the measurement of environmental performance in terms of efficiency and productivity, accounting for the presence of environmental pollution or degradation. A key advantage of DEA over other conventional economic methods is that it more easily accommodates both multiple inputs and multiple outputs including the environmental attributes in measuring relative efficiency of production units.

The concept of directional distance function is one of the approaches which have proved to be very useful in modelling production in the presence of undesirable outputs. It credits production units for simultaneous expansion of desirable outputs and contraction of undesirable outputs. The present study uses directional distance functions to measure the tradeoffs between economic benefit and environmental degradation of shrimp farming in Bangladesh. While shrimp farming in Bangladesh has great economic benefit in terms of foreign exchange earnings and livelihood improvements of coastal communities, it has been criticised for its adverse environmental effects in terms of increased soil and water salinity, loss of wild fish stock, and mangrove forest destruction. Therefore, investigation of the tradeoffs between the economic and environmental effects of shrimp farming is essential to facilitate policies aimed at achieving sustainability of this industry. Keeping this in mind, the thesis proceeds with three separate research papers. The abstract of these three papers are given below:

Paper 1: Environmental Effects of Shrimp Farming: International and Bangladeshi Perspectives

Abstract: Shrimp farming is the fastest growing aquaculture sector in the world, and it has become a major economic activity in many tropical countries over the past several decades. The support from international donor agencies in combination with potential for high profit, buoyant demand for high-value sea-food products, limitation and fluctuations in capture fisheries, and the industry's capacity to earn foreign exchange and generate employment in poor coastal areas of developing countries led to rapid expansion of shrimp farming. Although shrimp farming has brought significant economic benefit to the producing countries, it has also been criticized for an extensive environmental degradation and subsequent social conflicts. Adverse environmental effects related to shrimp aquaculture have been widely reported in the literature, questioning the sustainability of this industry. The purpose of this paper is to identify the sources of perceived tradeoffs between economic and environmental attributes of shrimp farming by reviewing previous published work. This will provide

a foundation and a synthesis of the knowledge on economic and environmental dynamics of shrimp aquaculture and will provide substantial inputs that will direct the further research to estimate the tradeoffs which can contribute to the sustainability of this industry.

Paper 2: Tradeoffs between Economic and Environmental Effects of Shrimp Farming in Bangladesh

Abstract: Shrimp farming has experienced a spectacular growth in the coastal areas of Bangladesh, benefiting the economy enormously. However, the economic benefits are paralleled with substantial environmental and natural resource degradation that can be attributed to shrimp farming. This study evaluates the economic and environmental efficiency of shrimp farms to measure the perceived tradeoffs. A directional output distance function approach is used to measure efficiency of shrimp farms in presence of 'desirable' and 'undesirable' outputs. The study covers the major shrimp farming regions in Bangladesh, and evaluates their performance at two time points, the years 2000 and 2010. Performances of farms are investigated under four different directional vectors. Moreover, Environmental Efficiency Index (EEI) is estimated using alternative assumptions of weak and strong disposability of outputs. Empirical results indicate that on average, efficiency of shrimp farms decreased in Southwest region and increased in Southeast region over the last decade. The average EEI is found to be steady between 2000 and 2010. The identified tradeoffs between the desirable and undesirable outputs (economic and environmental effects) will provide policy makers with indication on how to devise balanced policies to improve current operations and enhance sustainability.

Paper 3: Productivity Growth in the Shrimp Farming Industry of Bangladesh: A Luenberger Productivity Indicator Approach

Abstract: Shrimp aquaculture is one of the fastest growing economic activities in the coastal areas of Bangladesh and earns substantial foreign exchange for the country.

However, the environmental degradation is a major concern for the sustainable development of this industry. This paper studies the tradeoffs between the economic and environmental performance of shrimp farming in terms of productivity measurement. A directional distance function approach is employed to estimate the Luenberger total factor productivity indicators under the assumptions of weak and strong disposability of undesirable outputs. Based on average farm level data from shrimp farming, this study estimates the productivity change between the year 2000 and 2010 and compares how the different directional vectors and output sets influence the productivity. The Luenberger indicators are further decomposed into efficiency change and technical change components to explain the source of productivity change. The results show that overall the productivity of shrimp farms has decreased in most districts, except Cox's Bazar and Chittagong districts. For most of the farms, the negative productivity growth was driven by the negative technological change. The productivity growth is an indication of sustainable development. Therefore, true productivity growth including economic and environmental performance needs to be considered in developing effective policy measures to attain sustainable development of the shrimp farming industry.

Overall, the thesis overviews the initial knowledge base about the sources of perceived tradeoffs between the economic and environmental effects of shrimp farming and goes on to apply for the first time the techniques of productivity and efficiency measurement to evaluate the tradeoffs between economic benefit and environmental cost of shrimp farming in Bangladesh. The estimated efficiency and productivity measures consider the economic benefits as well as environmental degradation and therefore represent a more holistic picture of the true performance of shrimp farms. Therefore, it is expected that the result can have a significant contribution in the policy context. Sustainability of shrimp farming is a major concern for Bangladesh, which can be achieved by better economic and environmental performance of shrimp farms. The results will help the policy makers in understanding the tradeoffs between the economic (desirable) and environmental (undesirable) outputs which will assist them in designing appropriate policies.

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LIST OF ABBREVIATIONS

ADB	Asian Development Bank
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Centre for Advanced Studies
BFFEA	Bangladesh Frozen Food Export Association
BFRI	Bangladesh Fisheries Research Institute
BOBP	Bay of Bengal Programme
CBI	Centre for the Promotion of Imports from Developing Countries
CPD	Centre for Policy Dialogue
DEA	Data Envelopment Analysis
DoE	Department of Environment
DoF	Department of Fisheries
dS m^{-1}	Dissolved Solids/metre
EEI	Environmental Efficiency Index
EJF	Environmental Justice Foundation
EPB	Export Promotion Bureau
EU	European Union
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
FY	Financial Year
EC	Electric Conductivity
GAA	Global Aquaculture Alliance
GAMS	General Algebric Modeling System
GDP	Gross Domestic Product
GESAMP	Group of Experts on the Scientific Aspects of Marine Environmental Protection
GoB	Government of Bangladesh
IMF	International Monetary Fund
MAP	Mangrove Action Project

mmt	Million metric ton
MT	Metric Ton
MPEDA	Marine Products Export Development Authority
NACA	Network of Aquaculture Centres in Asia-Pacific
NGO	Non-Government Organisation
PDO-ICZMP	Program Development Office of Integrated Coastal Zone Management Plan
SAP	Structural Adjustment Programme
SEAFDEC	South Asian Fisheries Development Centre
SPARRSO	Space Research and Remote Sensing Organization
UNDP	United Nations Development Programme
UNRISD	United Nations Research Institute for Social Development
US$	US Dollar
USA	United States of America
USAID	United States Agency for International Development
WCMC	World Conservation Monitoring Unit
WTO	World Trade Organization
WWF	World Wildlife Fund

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 Introduction

Sustainable development requires that balances and tradeoffs between economic development and environmental degradation are recognised and managed. Economic growth is essential in order to meet the increasing demand of the growing human population, especially in developing countries. But, economic growth often comes at environmental cost, increasing the pressure on natural resources, and on the environment as a whole. The balance between these two needs to be ensured so that the additional loss of environmental quality due to economic growth does not exceed the additional benefit from the economic development.

The question of economic-environmental tradeoffs has become a priority since it has been recognised that the economic growth is accompanied by a range of adverse environmental effects in both developed and developing countries. Reducing the negative impacts of environmental degradation is a key issue in promoting sustainable economic development. To achieve the goal of sustained economic growth with a cleaner environment, it is important to study tradeoffs between economic growth and environmental improvement. The incorporation of environmental attributes into the measurement of the performance of the economic system ensures that economic growth might be achieved without additional impacts on environment, or the environment will be protected to the extent necessary. The measurement of environmentally adjusted productivity and efficiency is a powerful approach to address the tradeoffs between the goals of achieving high and sustainable economic growth and attaining high standards of environmental quality. At farm level, these indicators measure capability of farms for achieving high production levels with generating least amount of undesirable outputs in terms of environmental pollution or wastes (Martinez-Cordero and Leung, 2004).

The tradeoffs between economic and environmental performance can be determined by various environmental performance indexes/indicators which are considered as useful tools to quantify the overall productive efficiency. When measuring productive efficiency, 'traditional' outputs are usually considered as desirable outputs while the environmental effects are considered as undesirable outputs (Tyteca, 1996). One of the earliest studies toward incorporating environmental effects into production technology was that by Pittman (1983) who developed an adjusted Törnqvist productivity index in which environmental effects are treated as undesirable outputs whose disposability is costly. Färe et al. (1993) also treated environmental effects as undesirable outputs by specifying a deterministic translog output distance function. Hetemäki (1996) also used translog output distance function to obtain estimates of technical efficiency. However, these approaches are feasible only if undesirable outputs can be valued by their shadow prices since undesirable outputs are not generally marketed goods (Reinhard et al., 1999). In environmental accounting, shadow prices can be addressed in two different ways: as the value of the marginal disutility of the consumers of non-market outputs (Smith, 1998), and as the opportunity cost of increasing or decreasing the non-market outputs (Shaik and Perrin, 1999).

More recently, non-parametric approaches have become popular in measuring efficiency and productivity growth that account for environmental effects in the form of undesirable outputs. The basic standpoint of this environmentally adjusted measurement, as applied to environmental performance, is to compare a set of decision making units (DMUs) between themselves in terms of environmental and economic performance. This comparison is restricted to similar units (e.g. farms in a given industry) but can be extended to different geographical regions or to different periods of time.

Färe et al. (1989) proposed using a non-parametric mathematical programming technique known as Data Envelopment Analysis (DEA) to construct best practice frontier for strongly disposable and weakly disposable technology and to measure

their efficiencies. There are several advantages of non-parametric linear programming techniques over parametric stochastic techniques in measuring efficiency and productivity change. In case of parametric techniques, both the choice of functional form for specifying the technology, and the choice of the error structure influence the degree of efficiency. On the other hand, linear programming techniques envelop the data without specification of a restrictive functional form, and also are distribution free (Grosskopf, 1986). The non-parametric linear programming techniques also allow the recovery of various efficiency and productivity measures in an easily calculable manner (Domazlicky and Weber, 1997). One of the greatest advantages of DEA based non-parametric method is that it can easily include any variable that cannot be valued at market price, but is an attribute of the environment and of the production process (Charnes et al., 1985).

The use of directional distance functions for measuring environmental efficiency has recently been introduced by Chambers et al. (1996, 1998). The concept of directional distance function has proved to be extremely useful in modelling production in the presence of undesirable outputs and measuring performance accounting for such outputs (Färe and Grosskopf, 2000). Within the concept of directional distance function, undesirable outputs of a production process are accounted for by specifying a negative direction for those outputs. This enables the simultaneous expansion of desirable outputs and contraction of undesirable outputs in the measurement of performance. Thus, this function provides an adequate tool to approach economic and environmental performance in an integrated manner and the flexibility of this representation enhances its usefulness in policy-oriented applications (Picazo-Tadeo et al., 2005). The present study uses directional distance functions to measure the tradeoffs between economic benefits and environmental degradation of shrimp farming in Bangladesh.

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1.2 Research Background

Shrimp aquaculture has become a major sector worldwide in terms of occupied area and value added. Concentrated mostly in developing countries in the tropics, shrimp farming has been heavily supported by governments and international donor agencies as it is seen as having a strong potential to contribute to poverty alleviation and improving livelihoods in poor and underdeveloped regions (Mangrove Action Project, 2009). The rapid expansion of shrimp farming since 1970s fuelled by high profitability and strong demand mainly from affluent consumers in importing countries, provided an opportunity to a number of developing countries in Asia and Latin America to earn foreign exchange from shrimp exports. In both of these regions, shrimp farming has emerged as a main source of employment and income for millions of people (Lewis et al., 2003). Asia plays a leading role in shrimp farming, accounting for more than 80% of world shrimp culture production with Thailand, China, Vietnam, Indonesia, India and Bangladesh as the top producers. Because of its contribution to food security, rural livelihoods and foreign exchange, shrimp farming continues to expand in Asia and Latin America and there is a growing interest in Africa. However, shrimp aquaculture has been severely criticised for the environmental and socio-economic problems that it causes or aggravates (Beveridge et al., 1997; Primavera, 1998; Naylor et al., 2000; Rönnbäck, 2001, 2002; EJF, 2004a). The social and environmental costs generated by shrimp farming have raised major concerns about the sustainability of the industry throughout the world.

This study has particularly focused on the shrimp farming in Bangladesh. This country is situated in the low-lying Ganges–Brahmaputra River Delta, or commonly known as Ganges Delta. Geographically, it is located between 89.0ºE and 92.20ºE longitude in the Northern and Northeastern parts of the Bay of Bengal. The country comprises about 25,000 km^2 coastal areas of which 250km^2 (25,000 ha) lie in tidal areas that are naturally suitable for aquaculture (PDO-ICZMP, 2005). Coastal aquaculture in Bangladesh is dominated by shrimp farming which has grown over the past thirty years in response to expanded global demand for seafood and attempts by

governments since 1980s to liberalise and diversify the economy (Ahmed et al., 2002). Bangladesh is the sixth largest cultured shrimp producer in the world with a 4.2% share of the world's farmed shrimp production (Alauddin and Hamid, 1999). Shrimp farming has contributed significantly to the economy in terms of foreign exchange earnings and rural employment. Being an almost 100% export oriented sector, shrimp farming earns a substantial foreign exchange for the country, contributing about 3% of the value of total national export. More than 0.7 million people are engaged in shrimp farming that supports the disadvantaged coastal livelihoods enormously (DoF, 2010).

In spite of the immense economic potential of this sector, the unplanned and unregulated expansion of shrimp farming across large land areas has led to serious environmental impacts, and risks the sustainable development of this industry. Collection of wild postlarvae to stock ponds is thought to significantly impact wild shrimp and other fish stock, biodiversity, and capture fisheries production (EJF, 2004b). The salinization of ground water and salinity intrusion in the surrounding areas has appeared as a serious ecological as well as socioeconomic curse on coastal communities (Wahab, 2003). The extensive nature of shrimp farming in Bangladesh led to the conversion of large areas of land including mangrove forests (Gain, 1998; Deb, 1998). Shrimp farming is one of the major factors responsible for mangrove destruction in newly accreted coastal lands. Moreover, a large amount of area of both tidally influenced and freshwater wetlands have also been converted to shrimp farms (Azad et al., 2009). The other environmental impacts of shrimp farming include loss of crops and vegetation, loss of trees and grazing lands, irreversible changes in micro-flora and fauna, freshwater crisis, and increased incidence of gastrointestinal diseases in humans (Nijera Kori, 1996; Wahab, 2003).

While the supporters of shrimp farming see it as a valuable way of generating foreign exchange and developing the livelihood of coastal communities, those who are against it raise the concern of its environmental damage, social disruption, and rising inequalities in the shrimp farming area. The debate between these two camps has

become very polarized. In Bangladesh, many argue that the negative effects of shrimp farming far outweigh the potential gains, and that it runs contrary to the concept of sustainable development. Therefore, investigation of the tradeoffs between the economic and environmental effects of shrimp farming is essential to facilitate the policies aimed at improved sustainability of this industry.

1.3 Problem Statement

Following the "Green Revolution" in agriculture of the 1960s, commercial shrimp farming was termed as the "Blue Revolution" of the 1980s. While the "Green Revolution" was declared by FAO to promote the cereal crops in order to be self sufficient in food production, the "Blue Revolution" was supported by the international donor agencies under the rationale of poverty alleviation by earning foreign exchange and developing coastal livelihoods (Bhattacharya et al., 1999). But this revolution was soon criticised for its failure to recognize the natural ecosystem functions, and has consequently created many environmental problems. As a result, the lack of synergy between the development of shrimp aquaculture and the coastal environment has raised the concern to call this development as a "fake blue revolution" (Deb, 1998).

On the other hand, the industry is also increasingly being called the "Blue Death". It is claimed that shrimp farming in Bangladesh could not comply with its promise of providing food for the hungry. Instead, production has mostly been for export, characterized by many environmental problems, and has experienced fluctuations due to changing global demand (EJF, 2004a). Moreover, it has been claimed that Bangladesh is turning into "a desert in the delta" because of the environmental consequences of shrimp farming (Ahmed, 1997). The coastal area of Bangladesh is situated along the Ganges-Brahmaputra Delta, which is among the most fertile regions in the world (Delta Alliance, 2012). Since shrimp farming started, rice and other crop fields have become barren; trees, cattle and poultry have died; no vegetables can be grown due to the saline water; and freshwater supplies have

depleted (EJF, 2004b). These all together have led to cynically call this area as "a desert in the delta".

The lack of recognition of environmental and natural resource degradation will cause the industry to be more vulnerable over time. In view of the above arguments, there is an urgent need to investigate the performance of shrimp farming considering both the economic and environmental effects. It is necessary for the sustainable development of this industry to offer such a framework in which maximum benefit can be achieved at least environmental degradation. The estimation of tradeoffs will facilitate the goal of achieving sustainable economic growth, and at the same time attaining environmental quality. By providing the information about the efficiency and productivity of shrimp farms, the study will provide an indication of how environmentally adjusted efficiency and productivity represent the true performance of the farms, and how these can be utilized in formulating relevant policies that will satisfy the 'sustainability concept' in the coastal areas of Bangladesh.

Although several studies have been done on the shrimp industry in Bangladesh, only few studies have so far been conducted that evaluate the performance of shrimp farming incorporating both economic and environmental factors. UNEP (1999) conducted a cost-benefit analysis for the shrimp industry at national level and found a cost-benefit ratio of 0.21 on a production loss basis. Most of the literature is focused on the potential to increase profits from shrimp aquaculture in comparison to traditional agriculture. Few studies have estimated efficiency and productivity of shrimp farms, but only considered the economic factors (Gordon et al., 2009; Ahmed et al., 2011). The immediate cash benefit analysis with little consideration on environmental impacts supports the promotion of this industry but ignores the wider impacts on environment and rural communities. The environmental consequences are closely associated with the concept of sustainable development of the shrimp industry. As virtually all of the analyses concern only the short-term benefits, these fail to recognize the long term environmental security and sustainable and equitable

rural development. No single study exists for the environmentally adjusted productivity and efficiency of the shrimp farming industry in Bangladesh to date.

The present study targets this research gap and aims to examine the environmental performance of shrimp farms by incorporating both economic and environmental effects of shrimp farming in an efficiency analysis. By drawing a comparison of efficiency and productivity between shrimp farms in various regions (Southwest, Southeast and Southern regions) and between two time points (2000 and 2010), this study tests the proposed concept of using efficiency and productivity based indicators for measuring environmental performance in the context of shrimp farming.

Sustainability of shrimp farms is a major concern for Bangladesh. Stepping towards sustainability involves improving both the economic and environmental performance of shrimp farms. By evaluating the economic and environmental performances, this research will help to identify the shrimp farms and regions that create large environmental degradation and have a modest economic benefit or *vice versa* those where improvements in environmental performance can be achieved at relatively low cost. The environmentally efficient farms have lower opportunity cost to transform the production process into a more environmental friendly process. These types of enterprises can then be used as models for others to follow. The result will also provide the measurement of environmentally adjusted productivity growth on which the sustainably of the industry largely depends. The findings will provide an indication about the performance of technologies and management practices of shrimp farms and will explain how they affect environmental and economic efficiency.

These findings will be useful in designing policies to improve environmental performance of shrimp farms in conjunction with their economic performance. The derived results will also help policy makers in understanding the tradeoffs between the desirable and undesirable outputs, assisting them in devising balanced policies to improve current operations and enhance sustainability. Overall, the findings from this

study will be useful for various government organizations related to shrimp farming, NGOs, and local communities who can contribute to development of an integrated policy which is still an unfulfilled demand.

1.4 Research Questions

High economic profit is the main driving force for the farmers to adopt shrimp farming on their land. The present study considers this as an economic indicator for the shrimp farming. On the other hand, the study focuses on major environmental effects caused by the shrimp farms with emphasis on the effects on traditional agriculture, wildlife fisheries and mangrove forests. Based on the above discussion, the present study will address the following research questions:

1) What is the present status of shrimp farming in the world and in Bangladesh in terms of economic and environmental performance?
2) How can the tradeoffs between economic and environmental effects of shrimp farming in Bangladesh be measured and compared?
3) What was the environmentally adjusted productivity growth of shrimp farming in Bangladesh over the last decade?

1.5 Research Objectives

The ultimate objective of the present study is to identify those types of shrimp enterprises that are economically and environmentally efficient and can serve as a model for sustainable development. This identification will be done by measuring environmental performance of shrimp farms with the help of efficiency and productivity analyses. For this, it is essential to know the current status of shrimp farming in the world and in Bangladesh to understand the economic and environmental dynamics of shrimp farming and use this as the foundation for further analyses. Then the environmental performance of shrimp farming can be evaluated by

measuring farm efficiency that incorporates both economic and environmental indicators. Furthermore, the changes in performances of farms can be evaluated by measuring productivity growth over time for both economic and environmental aspects. To address these issues the following research objectives are set for the present study:

1) To review the present economic and environmental status of shrimp farming in the world and in Bangladesh;

2) To evaluate the possible directions for improving overall performance, either via improving economic performance, or via improving environmental performance of shrimp enterprises, or preferably via improving both; and

3) To evaluate the productivity growth of shrimp farming over the last decade considering the direction of improving economic, or environmental performance, or both.

1.6 Research Approaches and Methods

The present study focuses on the tradeoffs between economic and environmental effects of shrimp farming in Bangladesh through addressing the environmentally adjusted efficiency and productivity measurements. This was done by putting up three separate research papers that applied descriptive, conceptual and empirical analyses.

The first paper titled "Environmental Effects of Shrimp Farming: International and Bangladeshi Perspectives" reviews the present status of shrimp farming in the world and in Bangladesh with special emphasis on economic and environmental consequences of shrimp farming. Some of the environmental effects that are discussed in this paper include mangrove destruction, loss of wild fry and capture fisheries, loss of biodiversity, increased soil and water salinity, pollution, and health hazards. This paper reflects the tradeoffs between economic benefits and environmental effects by cataloguing documented experiences in various shrimp producing countries in an integrated manner.

In the second paper, "Tradeoffs between Economic and Environmental Effects of Shrimp Farming in Bangladesh", the efficiency of shrimp enterprises is measured based on the concept of a directional distance function. The efficiency was measured under four different directional distance functions (DDF) which allow evaluating performance of farms under different possible directions for economic and environmental indicators. The paper also estimates an environmental efficiency index (EEI) which provides an efficiency score at a point in time, indicating farm's ability to increase environmental performance with lower cost (similar to abatement cost in the case of pollution) or alternatively, measuring the opportunity cost of reducing undesirable outputs (Färe et al., 2005).

In measuring performance of farms with the existence of undesirable outputs in the production process, a directional distance function has been identified as a flexible tool which allows for modelling joint production of desirable and undesirable outputs. Chung et al. (1997) and Chambers et al. (1996a, 1998) offer directional distance function for estimating technical efficiency in the presence of undesirable outputs. The advantage of a directional distance function is that it simultaneously accounts for expansion of desirable outputs and reduction of undesirable outputs and serves as a measure of efficiency (Färe et al., 2005). The present study uses a directional output distance function that credits farms for increasing desirable outputs and reducing undesirable outputs at given inputs to examine the efficiency of shrimp farms by incorporating economic (desirable) and environmental (undesirable) outputs and inputs. Thus, this model can serve as an adequate measure of economic and environmental performance, and in this particular case for the shrimp farming in Bangladesh.

The paper also estimates the environmental efficiency index (EEI), defined by the ratio of two directional distance functions: one that exhibits the assumption of weak disposability of outputs, and another that exhibits the assumption of strong disposability of outputs. The value of EEI lies between 0 and 1. If the value of EEI is closer to one, the farm has lower opportunity cost in the sense that it needs to sacrifice less desirable outputs in order to reduce undesirable outputs. On the other hand, if the

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EEI value is closer to zero the farm has higher opportunity cost in terms of desirable outputs foregone to transform the production process into a more environmentally friendly process.

The third paper titled "Productivity Growth in the Shrimp Farming Industry of Bangladesh: A Luenberger Productivity Indicator Approach" estimates the productivity growth for shrimp farms using the Luenberger total factor productivity indicator. The Luenberger indicator is also based on directional distance functions and can incorporate the undesirable outputs into the productivity measurement. This paper also discusses the technological change and efficiency change aspects of shrimp farms by decomposing the Luenberger productivity indicator.

Based on the concept of a directional distance function, Chambers et al. (1998) introduced the Luenberger total factor productivity indicator as a measure of total factor productivity change. This indicator becomes vital for relevant policy measures since this productivity measures accounts for negative effects of by-products in production and is thus able to address the economic, environmental and social sustainability of farms or industry (Färe et al., 2012). In the case of the Luenberger total factor productivity indicator, the productivity measure is constructed as a difference-based indicator of directional distance functions. Following Chambers et al. (1996b), the Luenberger productivity indicator can be additively decomposed into technological change and technical efficiency change components. The efficiency change component measures "catching up" to the frontier and the technological change component measures the shift in the frontier from period to period. The paper estimates four different productivity indicators of which the first three include undesirable outputs in the production technology, and the fourth does not. These indicators signal improvements in productivity, technological change or efficiency change.

1.7 Empirical Analyses

For the purpose of measuring the productivity and efficiency of shrimp farms, the relevant variables are categorised as: desirable outputs, undesirable outputs and inputs. Gross returns for representative shrimp farms and subsistence fish catch are considered as the desirable outputs, while the total costs of representative shrimp farms are used as inputs. Gross return and total cost are the key indicators for economic performance. On the other hand, soil salinity, water salinity and loss of mangrove forests are used as undesirable outputs as they reflect the environmental damage.

The study covers major shrimp farming regions in Bangladesh. This includes the coastal areas of Khulna, Bagerhat, Satkhira and Jessore districts in the Southwest region; Chittagong and Cox'sbazar districts in the Southeast region; and Patuakhali and Pirojpur districts in the Southern region. To take into account the possible economic and environmental impacts on farm efficiency, the study focuses on two distinct time points, the year 2000 and 2010.

The analyses were conducted by applying Data Envelopment Analysis (DEA) techniques, a non-parametric mathematical programming technique for estimating technical efficiency (Färe et al., 2006). It is a well-established methodology for evaluating the relative efficiency of a set of comparable entities, called decision making units (DMUs) with multiple inputs and outputs (Ramanathan, 2003). DEA, developed by Charnes et al. (1978) has recently gained popularity in environmental performance measurement due to its empirical applicability (Zhou et al., 2008). It is used to construct a 'best practice frontier' which maps out the maximum level of desirable outputs and minimum level of undesirable outputs that could be produced for any given level of inputs based on observed outputs and inputs of DMUs. All DMUs lie either on or below the frontier (Charnes et al., 1994). It is particularly useful for farms that produce multiple outputs, both desirable and undesirable.

In the context of environmental performance measurement, DEA extends the Farrell's (1957) technical measures of efficiency from a single-input, single-output process to a multiple inputs and outputs process (Walden and Kirkley, 2000). DEA uses linear programming (LP) methods to extract information about the production process of each decision making units (DMUs). The LP method calculates a performance measure for each farm and compares this measure to similarly calculated measures for all other farms (Walden and Kirkley, 2000). The linear programmes are written in General Algebraic Modeling System (GAMS) language, a mathematical programming language which is recommended for its flexibility (Olsen and Petersen, 1996).

1.8 Organisation of the Thesis

The thesis is organized as an accumulation of three papers. The first paper reviews the economic and environmental effects of shrimp farming in the world and in Bangladesh. The second paper measures the tradeoffs between economic and environmental effects of shrimp farming by applying directional distance function based efficiency analysis. The third paper estimates the productivity growth of shrimp farming over time by the Luenberger total factor productivity indicator and explains the technological change and efficiency change components. Finally the thesis concludes with some concluding remarks, limitations of the research and direction for further research.

CHAPTER 2

ENVIRONMENTAL EFFECTS OF SHRIMP FARMING: INTERNATIONAL AND BANGLADESHI PERSPECTIVES

CHAPTER 2

ENVIRONMENTAL EFFECTS OF SHRIMP FARMING: INTERNATIONAL AND BANGLADESHI PERSPECTIVES[1,2]

2.1 Introduction

Shrimp farming is the fastest growing aquaculture sector in the world, and it has become a major economic activity in many tropical countries over the past several decades. During the 1970s, international donor agencies (USAID, World Bank, ADB, IMF) promoted the modernization of fisheries in the 'underdeveloped' coastal countries with a view to increase output, improve food security, provide alternative sources of social and economic well-being and promote economic growth (Rivera-Ferre, 2009). In combination with other factors including: potential of high profit, buoyant demand for high-value seafood products, limitation and fluctuations in capture fisheries, and the industry's capacity to earn foreign exchange and generate employment in poor coastal areas of tropical and subtropical developing countries, this led to rapid expansion of shrimp farming (World Bank/NACA/WWF/FAO, 2002). Shrimp farming dominates aquaculture production in value terms. In 2010, the world's shrimp production was about 4 million tonnes, valued at approximately 17 billion US\$. Shrimp continues to be the largest single seafood commodity in value terms, accounting for about 15 percent of the total value of internationally traded fishery products in 2010 (FAO, 2012).

Although shrimp farming has brought significant economic benefit to the producing countries, it has also been criticized for an extensive environmental degradation and subsequent social conflicts. Adverse environmental effects related to shrimp farming

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[1] *This paper is currently being prepared for submission to an international journal.*

[2] *Part of this paper was presented at the Asia Pacific Aquaculture (APA) Conference, 17-21 January, 2011, Kochi, India.*

have been widely reported in the literature, questioning the sustainability of this industry. These include destruction of mangrove ecosystems (Rönnbäck, 1999, 2000; Primavera, 1995, 1998; Boyd and Clay, 1998; Stonich, 1995; De Walt et al., 1996; Spalding et al., 1997); habitat conversion (Lewis et al., 2003; EJF, 2004a; WWF, 2002; Páez-Osuna et al., 2003; Beveridge et al., 1997); salinization (Flaherty and Karnjakesom, 1995; Dierberg and Kiattisimkul, 1996; Primavera, 1994, 2006; Páez-Osuna, 2001a); collection of wild seed and broodstock (Primavera, 2006; Deb, 1998; De Walt et al., 1996; Naylor et al., 2000); loss of wild capture fisheries (Naylor et al., 2000; De Walt et al., 1996; Goldburg et al., 2001; Tacon, 2002; Rönnbäck, 2002); conversion of land from other valuable uses (Chua, 1992; King and Lester, 1995; Flaherty and Karnjakesom, 1995; Dierberg and Kiattisimkul, 1996); pollution by nutrients and organic matters in effluent (Phillips, 1995,1998; Hopkins et al., 1995; Neiland et al., 2001); chemicals and antibiotics used for water and disease treatment (Gräslund and Bengtsson, 2001; Holmström et al., 2003); disused ponds (Primavera, 1997; Stevenson, et al., 1999; Lewis et al., 2003); and aquaculture waste and coastal pollution (Phillips, 1995; Briggs and Funge-Smith, 1994; Páez-Osuna et al., 1997; Primavera, 1998).

Livelihoods of millions of people depend on shrimp farming around the world, especially in tropical and sub-tropical developing countries. On the other hand, failure to protect ecosystem and environment from degradation due to shrimp farming is a major concern. The long-term sustainability of this industry depends on its ability to be economically efficient, and at the same time to minimize environmental effects. Therefore, it is important to consider both the economic outcomes and various environmental effects in achieving a more sustainable industry. From this viewpoint, this paper explores the key economic and environmental aspects of shrimp farming in the world in general, and in Bangladesh in particular.

The purpose of this study is to identify the sources of perceived tradeoffs between economic and environmental attributes of shrimp farming by reviewing previous published work. The paper presents some significant evidence on how shrimp

farming is threatening the well-being of natural environment, and consequently raises the question about long-term economic development, associated to shrimp farming.

There are numerous studies on the economic and environmental effects of shrimp farming. But there is no study that brings the economic and environmental performance of shrimp farming together in a single piece of study before. The updated information of the economic and environmental performance of shrimp farming of this chapter will facilitate to understand the ultimate contribution of shrimp farming regardless some of its obvious environmental effects in major shrimp producing countries. By addressing the economic and environmental effects in details, this chapter contributes significant information to the current literature and can be used as a base study for any further empirical study.

The information presented in this chapter will provide a foundation and a synthesis of the knowledge on economic and environmental dynamics of shrimp aquaculture. This can have a significant impact in providing valuable insights into the best means of integrating this knowledge into the production system for the most efficient performance. Better understanding of the key issues around sustainable shrimp farming will encourage policy debates on management strategies, and will identify further development strategies for improved management and development of more sustainable shrimp industry. Finally, this review will provide a backdrop for the subsequent empirical analyses that explicitly evaluate the tradeoffs between economic and environmental impacts of shrimp farming in Bangladesh.

The chapter begins by documenting the status of shrimp aquaculture in relation to its economic contribution in the world, and particularly in Bangladesh with an emphasis on production, export and import, and market trends. The next section of the paper briefly reviews the various cultural systems of shrimp farming and their characteristics with a reference to their impact on the environment. The main section of the paper reviews the major environmental effects of shrimp farming based on country level experiences. These include: mangrove forest destruction; loss of wild

fish stock; biodiversity loss; salinization of soil and water; pollution by waste and effluents; and health hazards.

2.2 Overview of World Shrimp Farming

Shrimp is the most valuable product group in international seafood trade. Consumer demand for shrimp mainly comes from developed countries, whereas major production of shrimp takes place in relatively low income countries. The expansion of shrimp farming has occurred in the tropical and sub-tropical coastal lowlands, mainly in Asia and Latin America. It is estimated that 1-1.5 million hectare of coastal low lands have been converted into shrimp farms in China, Thailand, Indonesia, India, Philippines, Malaysia, Mexico, Ecuador, Honduras, Panama, and Nicaragua (Rosenberry, 1998; Páez-Osuna, 2001). The remarkably rapid phenomenon of shrimp farming development is more noticeable in Asia, where aquaculture is a traditional activity and gives the world leadership to this region in terms of shrimp culture, accounting for 70 to 80% of the total world production (Raux and Bailly, 2002). The dominant species are the Black Tiger Shrimp (*Penaeus monodon*), accounts for more than half of the total shrimp aquaculture output (Rosenberry, 1998). Other important commercial species are Whiteleg Shrimp (*P. vannamei)*, Indian Prawn (*P. indicus*), Banana Prawn (*P. merguiensis*), and Fleshy Prawn (*P. chinensis*).

Rapid growth in Asia and Latin America led to expansion of the world production of shrimp from 50,000 tonnes in the mid-1970s to about 3.6 million metric tonnes in 2011 (Raux and Bailly, 2002; GAA, 2011). There are 15 major shrimp producing countries in the world (Table 2.1). Of these, nine are from Asia and six are from Latin America. By region, the Southeast Asian countries (Thailand, Vietnam, Indonesia) lead the world production (1.72 mmt), followed by China (1.04 mmt), Latin America (527,750 mt), and India and Bangladesh (236,103 mt).

Shrimp production in Asia

In the late 1970, extensive shrimp farming began along the eastern coast in China with low yields. With the technological development in the 1980's, China's shrimp production increased at an average rate of 75% per year (ADB/NACA, 1996). This development made China the world's largest shrimp producer, accounting for around 33% of the global cultured shrimp production (GAA, 2011). China's shrimp industry suffered from diseases in 1990 and 1993, but showed evidence of recovery by the year 2000 (Biao and Kaijin, 2007). Because of a large domestic shrimp market, China acts both as exporter and importer in the international shrimp market.

Table 2.1 Production of Shrimp in Major Producing Countries

(in '000' metric tonnes)

Country	1980	2005	2006	2007	2008	2009	2010	2011	2012
China	184	1,065	1,080	1,265	1,268	1,181	899	962	1,048
Thailand	133	401	501	505	507	542	548	553	591
Vietnam	41	327	349	377	381	302	357	403	444
Indonesia	140	279	339	330	408	299	334	390	437
India	250	143	144	107	87	76	95	108	116
Bangladesh	6	64	66	64	68	106	111	116	120
Asia Total	**754**	**2,279**	**2,479**	**2,648**	**2,719**	**2,506**	**2,344**	**2,532**	**2,756**
Ecuador	17	118	149	150	150	142	145	148	152
Mexico	77	90	112	112	130	130	91	120	132
Brazil	48	76	63	65	65	65	73	82	90
Columbia	na	19	23	20	21	20	16	15	14
Honduras	na	21	27	26	26	20	31	22	22
Venezuela	na	13	22	18	16	18	20	15	15
LA Total	**142**	**337**	**396**	**391**	**408**	**395**	**376**	**402**	**425**
World Total	**896**	**2,835**	**3,118**	**3,281**	**3,399**	**3,224**	**3,062**	**3,305**	**3,578**

Source: GAA, 2011. Note: *M. rosenbergii* is not included.

Shrimp farming was largely traditional in Thailand until the 1970s, when the Thai Department of Fisheries started experimental semi-intensive farming (Katesombun, 1992). The introduction of the semi-intensive farming systems to Thailand was quickly followed by the development of intensive farming techniques. As a result of the intensification of methods and expansion of farmed area, Thailand had established itself as one of the world's largest producer of cultured shrimp. Thailand's shrimp export grew from 28,000 tonnes in 1986 to about 592,000 tonnes in 2012 (Flaherty and Vandergeest, 1998; GAA, 2011). Because of viral disease problems shrimp farms in Thailand faced a production crash in late 1990s, and consequently chose low-salinity shrimp farming technique as an alternative. However, the low-salinity shrimp farms expansion into the rice-growing areas was criticized over its environmental damage, and as a result shrimp farming was banned within non-coastal provinces (Szuster, 2006). The definitions of extensive, semi-intensive, and intensive production systems and their comparisons are made later in this chapter.

Modern shrimp farming started in Vietnam in the 1980s since the country launched economic reform and has been expanding very rapidly (Nhuong et al., 2002). Vietnam is at the top of shrimp producing countries in terms of area used, covering about 450,000 ha of land (EJF, 2003). The spread of shrimp disease in other shrimp producing countries has led to rapid expansion of shrimp production in Vietnam, that increased from under 200 tonnes in 1976 to over 100,000 tonnes in 2000, and 450,000 tonnes in 2012 (EJF, 2003; GAA, 2011). While many of the shrimp farms are intended to further intensify the production system, there are still only a small number of intensive shrimp farms (Ancev et al., 2010).

Traditional shrimp farming is an age-old practice in India and is the major commodity in the seafood export. Shrimp farming activities are taking place mainly in states on the east coast, e.g. Andhra Pradesh, West Bengal, Tamil Nadu, Kerala and Orissa. Shrimp production increased from about 30,000 tonnes per year in 1980s to 116,000 tonnes in 2012 (Vasudevappa and Senappa, 2002; GAA, 2011).

Commercial shrimp farming in Bangladesh has grown rapidly since the 1980s. A combination of rapidly expanding global demand for shrimp, and the investment from World Bank and IMF through the 'Structural Adjustment Programme' spurred the growth of this sector (EJF, 2004b). Shrimp production in Bangladesh is largely extensive and improved extensive, with low capital inputs and low yield per hectare (Ahmed et al., 2002). In 1979-80, about 20,000 ha were under shrimp cultivation (Ahmed, 1988), which has expanded to 96,000 ha in 1990 and 246,000 ha in 2010 (DoF, 1994, 2010). Shrimp industry in Bangladesh has witnessed a spectacular growth in production, from about 18,500 tonnes in 1990 to 120,000 tonnes in 2012 (DoF, 2001; GAA, 2011).

Bangladesh has certain natural factors that have favoured the growth of shrimp industry. Compared to other shrimp-producing regions, Bangladesh is fortunate to have a large inter-tidal range and broad low-lying areas of land, which means that water circulation, can be achieved through natural tidal fluctuations without artificial pumping (BCAS, 2001). Shrimp farming is mainly confined to two territorial divisions: Khulna and Chittagong. More than 80% of the shrimp farming takes place in the districts of Khulna, Satkhira and Bagerhat in the Southwest region. The rest of the farming occurs in the districts of Cox's Bazar and Chittagong in the Southeast region and Patuakhali and Pirojpur in the Southern region (Ahmed et al., 2002).

The two main shrimp species cultured in Bangladesh are—*Peneus monodon* or Black Tiger Shrimp*,* locally known as *Bagda*, and *Macrobrachium rosenbargii* or Giant Freshwater Shrimp, locally known as G*olda. Bagda* farming covers approximately 186,000 hectares of land producing 43,000 tonnes of shrimp annually, whereas *Golda* farms cover about 60,000 hectares of land producing 30,000 tonnes of shrimp per annum (DoF, 2010). Additional 8,500 tonnes of shrimp production comes from other species including *Metapenaeus monoceros* (Horiana or Brown Shrimp), *Fenneropenaeus indicus* (Chaka or Indian White Shrimp) and *Penaeus semisulcatus* (Green Tiger Shrimp). Productivity in the shrimp aquaculture of Bangladesh varies from 130 kg to 250 kg per hectare which is very low compared to other countries

where shrimp is farmed through semi intensive and intensive farming systems (Mazid, 2003).

Shrimp production in Latin America

Although Mexican fishermen have long practiced a form of rudimentary shrimp aquaculture, it has experienced a boom in 1990s following 1992's agrarian reform legislation. Approximately 94% of shrimp aquaculture farms are located around the Gulf of California, accounting for 95% of production of farmed shrimp in the country (De Walt, 2000). The production of shrimp has increased from 13,700 tonnes in 1996 to 132,500 tonnes in 2012, showing an impressive growth (Páez-Osuna, 1998; GAA, 2011).

In Ecuador, the first commercial shrimp pond was constructed in 1969, and by 1982 Ecuador had the world's largest area under shrimp production. By 1991, 132,000 ha of coastal land had been converted to shrimp ponds (Tobey et al., 1998). Some of the factors that made this rapid expansion possible were the incentives given by the Ecuadorian government to the shrimp farmers, plus the absence of clear property rights and effective management regimes for mangroves (Ocampo-Thomason, 2006). Indonesia, Malaysia, Philippines, Brazil, Honduras, and Venezuela are some of the other countries that play a significant role in global shrimp production. Undoubtedly, shrimp aquaculture has benefited the national economies of these countries by its high profitability, food supply, employment generation, and earning of foreign exchange. Table 2.2 summarizes some of the economic benefits of shrimp farming in major shrimp producing countries in the world.

2.3 International Markets and Trades

Among all seafood products traded, shrimp is the most important single commodity. In the last 20 years, the shrimp trade accounted for over 20% of the total seafood product trade (Xinhua, 2008). Largest consumers of aquaculture grown shrimp are the

United States, the countries of the European Union, and Japan. These countries comprise the final markets for more than 90 percent of cultivated shrimp. The EU is the largest single market for shrimp that imported 837 thousand tonnes of shrimp in 2010, accounting for more than 40% share of total world imports (GLOBEFISH, 2011). The US is the largest market as a single country that imported 560 thousand tonnes of shrimp in 2010, valued at US$ 4.3 billion. Japan, on the other hand, imported a total of 280 thousand tonnes (GLOBEFISH, 2011). Figures 2.1 and 2.2 present the shrimp imports in volume and value, respectively by the leading importers. Figures show that shrimp imports have increased in EU and US, but were more or less stable in Japan during the last three decade.

Table 2.2 Some Indicators of Economic Contribution of Shrimp Industry in Selected Countries

Country	Volume of export ('000' tonnes)	Export Value (US$/year)	Direct Employment (person)	Percentage of total world aquaculture production
Thailand	206	3.23 billion	200,000	16.5
Vietnam	192	2 billion	670,000	12.8
Indonesia	100	974 million	900,000	10.6
China	128	733 million	1 million	27.3
Bangladesh	56	425 million	1 million	3.1
India	127	1.4 billion	2 million	6.3
Mexico	45	360 million	23,000	2.5
Ecuador	134	828 million	250,000	3.2

Source: FAO, 2012.

Shrimp exports are significant source of foreign exchange earnings for shrimp producing countries. Continually increasing demand for shrimp products draws more countries to be engaged in shrimp production, making the shrimp trade highly competitive. Since 1990, Asian countries have become major shrimp exporters to the developed world (Xinhua, 2008).

Figure 2.1 Shrimp Imports by Major Importer Countries
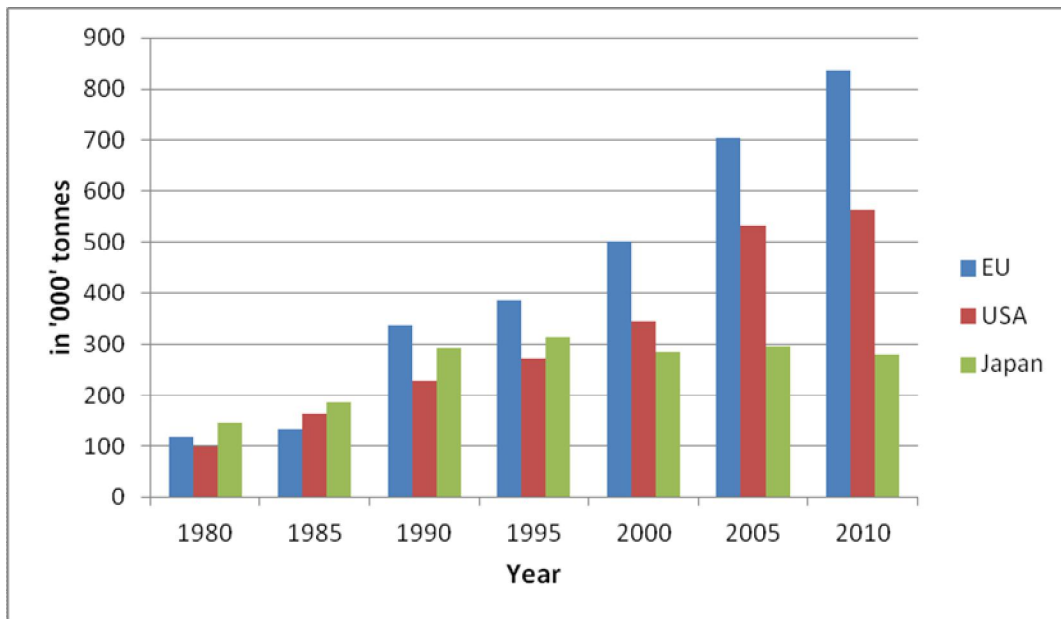
Figure 2.2 Value of Shrimp Imports by Major Consuming Countries
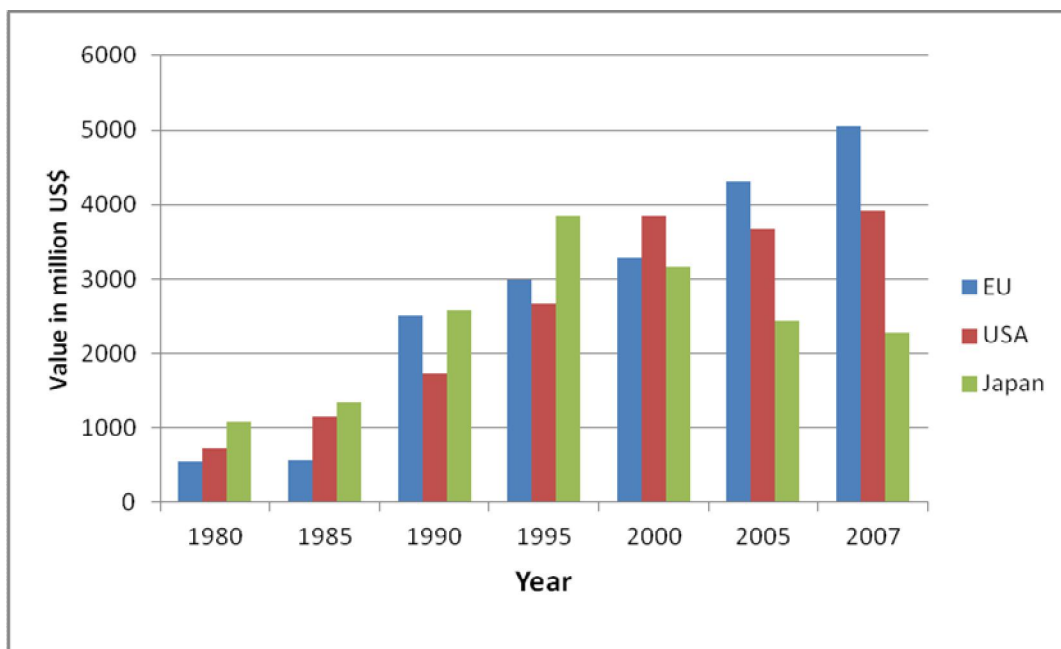
Figure 2.3 shows the shrimp export earnings by major producing countries in some previous years. Thailand and Vietnam are the top two foreign exchange earning countries from shrimp export. Shrimp export from Thailand totalled 428,000 tonnes in 2010 followed by China (275,000 tonnes) and Vietnam (241,000 tonnes) (GLOBEFISH, 2011). Thailand's export earnings are estimated at 1.5 billion US$ in 2011 for frozen shrimp, and it is estimated at over 3 billion US$ when processed shrimp was taken into account (Thailand Customs, 2012). Vietnam's export earnings from shrimp also touched the record high of 2.4 billion US$ in 2011, up from US$ 2 billion in 2010 (Vietnam Seafood Trade Magazine, 2012). During 2011-12, for the first time in the history of seafood product exports, India's export earnings have crossed US$ 3.5 billion, a 23% increase from previous year. The main reason behind this increase is the tremendous increase in Whiteleg shrimp (*P. Vannamei*) export (MPEDA, 2012). Compared to its production, China's export earnings are not very high since more of the product is consumed in the domestic market.

Figure 2.3 Shrimp Export Earnings by Major Producing Countries
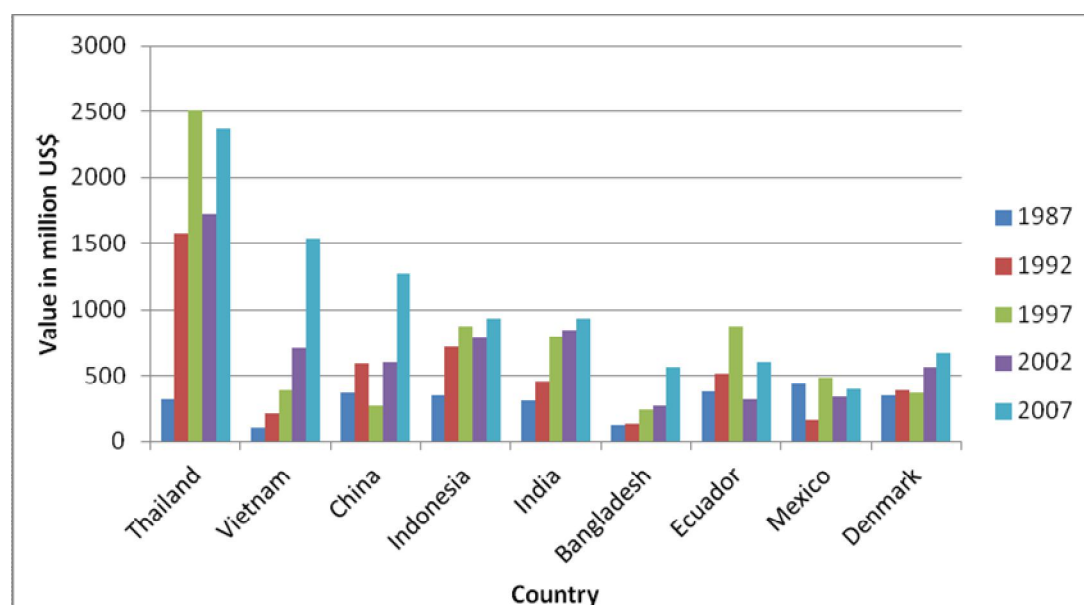
Source: GLOBEFISH, 2010.

Bangladesh has achieved a remarkable progress in export earnings of frozen food, especially, shrimp. About 90% of the cultured shrimp in Bangladesh are exported (CBI Report, 2012). It occupies the second position on the list of exportable items in terms of their total export earnings. The export earnings from shrimp shot up from US$ 262,000 in 1972-73 to US$ 350 million in 2009-10 (BFFEA, 2012). The volume of export increased around 60% within the last two decades (DoF, 2010). An increasing trend exists for both volume and value of shrimp exports in the last decades (Figure 2.4).

Figure 2.4 Value (V) and Quantity (Q) of Frozen Shrimp and Fish Exports from Bangladesh
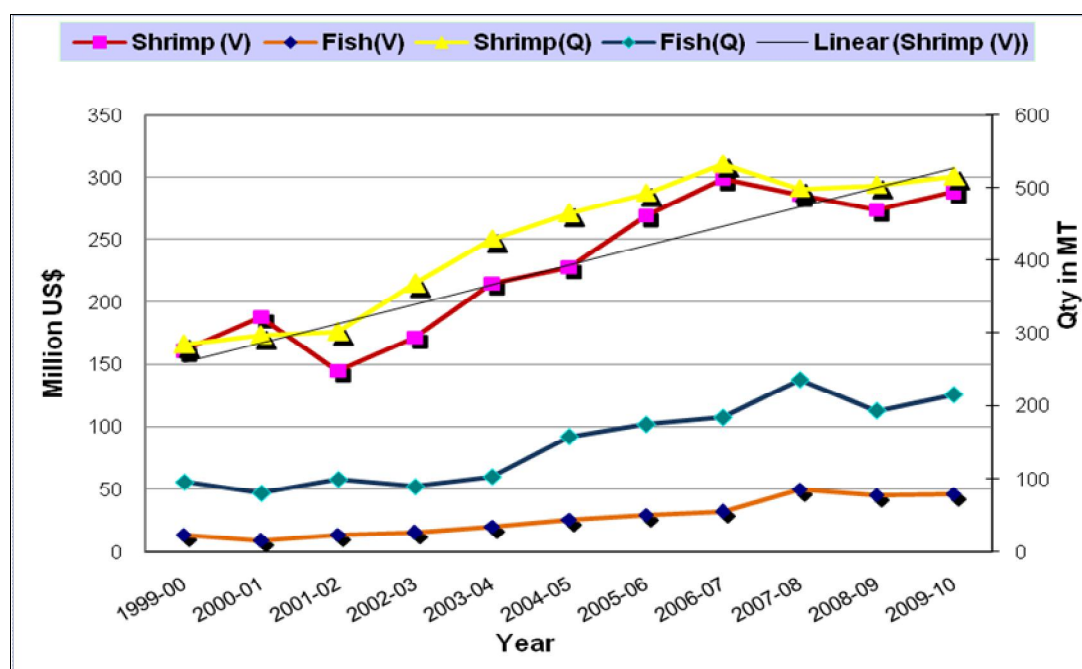
Source: DoF, 2010.

At present, the principal importers of shrimp produced in Bangladesh are EU, USA, Japan, China, Singapore, Canada, Thailand, Hong-Kong, Australia and Organization of Islamic Countries (OIC). Among them the main buyer of Bangladesh's shrimp is the EU, accounting for 75% of the total export value. The main reason that Bangladesh is so popular among EU buyers is the comparatively low price of cultured shrimp. This is mainly a result of the 10% export subsidy from the Government of

Bangladesh (CBI Report, 2012). To promote country's export, Bangladesh Government is providing cash incentives as export subsidy to the frozen shrimp and other fish export that have accelerated the increasing trend of shrimp production. The total amount of cash incentive provided to the frozen shrimp and fish export in 2007-08 was valued at US$ 52.60 million (Deb and Bairagi, 2009). For farmed shrimp, which represents the largest part of shrimp exports, Black Tiger shrimp contributes the largest share of production.

Because of the fragmented structure of international shrimp trade, it is difficult to report a single price that can be representative for most of the traded shrimp. The EU shrimp prices were higher than in the USA until 1994. Subsequently the shrimp prices have followed a similar trend in the USA and in the EU. From 2001, both the EU and US prices fell markedly, but while the US prices continued to fall, the EU prices rose again in 2002, but overall trended slightly downward (GLOBEFISH, 2005). Overall, shrimp prices showed a slight downward trend in terms of nominal price and a steep downward trend in terms of real price in the US market (Figure 2.5). In 2010, strong demand from the major markets drove up export prices of Black Tiger shrimp up to US$ 15.50/kg while the shell-on Whiteleg shrimp was priced at US$ 9.00/kg. Many domestic and regional markets in Asia and Latin America consumed more shrimp, which also kept their prices relatively high and stable (GLOBEFISH, 2011).

Figure 2.5 Wholesale Price of 26/30 Count Shrimp in the US Market (1980-2012)
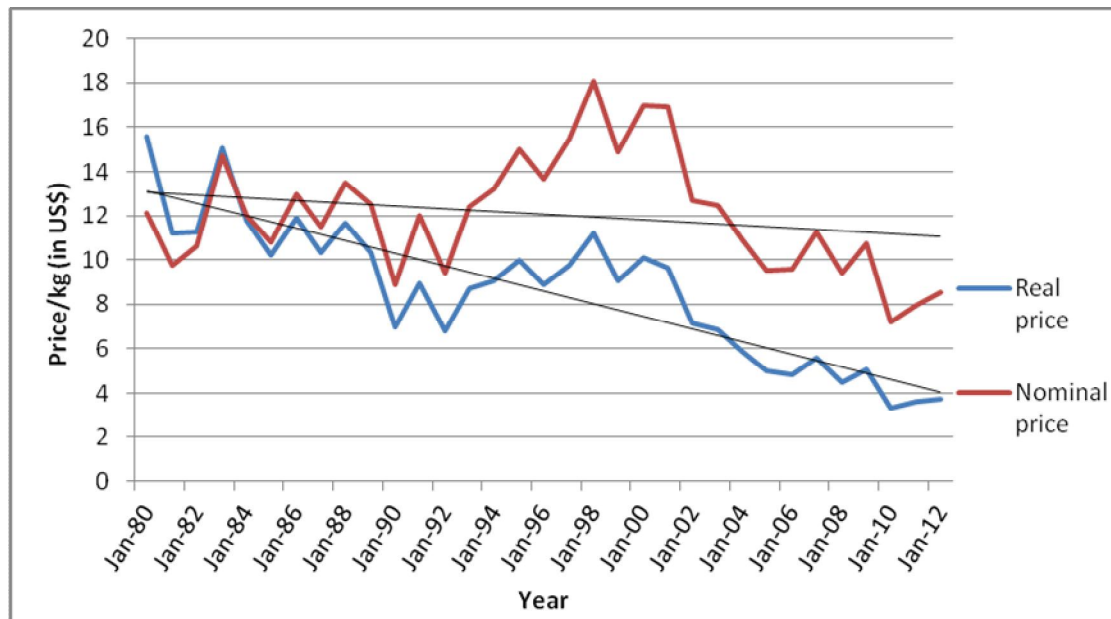
Source: Mongabay.com, 2012.

2.4 Overall Economic Contribution of Shrimp Farming

Most of the shrimp growing countries have experienced a rapid growth in shrimp production during 1980s and 1990s. Since then this industry has contributed significantly to the national economy of these countries in terms of foreign exchange earnings, employment generation, and creating income and livelihood opportunities.

Export revenues contribute directly to economic growth and reducing poverty, and can be used to import goods and service, and pay external debt. In Thailand, shrimp exports contributed to 8.9% of Thailand's total agricultural export value in 2003 which accounted for 1.1% of the country's GDP (Sub-sector strategy, 2006). In addition, this industry has created a large number of direct and indirect employment of approximately 1 million people, out of 62.4 million of Thai population, accounted for the year 2000 (Nissapa et al., 2002). In Vietnam, the fisheries sector plays an important role in the national economy, accounting for about 6.1 percent of GDP, of which about 45% comes from shrimp alone (Nhuong et al., 2002). In Vietnam,

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aquaculture does not typically attract the wealthy, and has identified as a sector of poor who have few alternatives and no resources. Therefore, the policy makers promote this sector as a means of providing rural employment, diversifying rural economy and discouraging rural-urban migration. On the other hand, Bangladesh is a highly populated country (130 million in 2000) with 35% population live below poverty line. Shrimp farming in Bangladesh has created a new employment structure in the coastal region by providing direct employment to 1.2 million people, and supporting livelihood of further 4.8 million people (USAID, 2006). Total contribution of shrimp sector to the country's GDP is estimated at 0.6%, but that frozen seafood accounts for around 6% of total export value, of which shrimp export contributes almost 90% (BCAS, 2001).

Shrimp aquaculture is contributing to food security in two ways: it supplies dietary protein to farm households and domestic consumers, and the export earnings help to pay the food import bill. Some of the shrimp producing countries have high percentage of population living below US$1 poverty line. Pro-poor interventions are required to reduce poverty, and this sector has potential to contribute in this perspective by generating income and securing employment. Overall, shrimp farming fuels the economic development and poverty reduction of the producing countries through its multiplier effects of attracting foreign direct investment, encouraging backward and forward linkages, creating direct and indirect employments, and infrastructure development.

2.5 Production System

There are mainly four categories of shrimp farming production systems, characterized by the intensity of their resource use and management practices: traditional, extensive, semi-intensive and intensive (Primavera, 1993, 1998; Dieberg and Kiattisimkul, 1996; Rönnbäck, 2002; Deb, 1998). The economic return and environmental consequences vary according to the types of production systems. These systems are described briefly below:

Traditional system

This is the simplest production system, with virtually no inputs used during the production stages. There is no particular stocking rate and very little yield is obtained from this system. Usually the ponds are connected to estuaries and channels to direct the brackish water to the shrimp pond. In this system ponds are stocked with post larvae that are either caught in nearby estuaries, or are brought into ponds on the incoming tides and trapped (WWF, 2002). No feed or extra nourishment is provided to the fry. This farming system requires low investment and consequently yields are also low (USAID, 2006).

Extensive system

This is a slight improvement to the traditional production system where small amount of stocking and feeding takes places. Liming, fertilization and chemical use is not common in this system but occasional water exchange is performed. Productivity and operational cost is higher than traditional system but much lower compared to semi-intensive and intensive systems.

This production system is mainly built in tidal areas and is extensive in nature. Therefore, it often leads to the serious impact on natural habitat and other land uses. However, since the system uses very little feed and little water exchange, very few water effluents are discharged in to the environment from this type of system. Moreover, this system does not use chemicals or pharmaceuticals in the shrimp pond, and consequently creates less pollution and health hazards (WWF, 2002).

Semi-intensive system

This system follows improved techniques such as planned pond construction, selective stocking, supplemental feeding, fertilization, improved water management and planned post-harvesting management. This production system requires more capital and technical support, and as a result produces significantly higher yields. Since the fries are stocked in higher densities, the risk of disease is higher than in the

extensive system. Although this system has less impact on other land uses, it largely affects the environment due to water management techniques that divert natural flow, production of nutrient rich effluents, heavy organic loading, and the use of chemicals and pharmaceuticals (World Bank/ WWF/NACA/FAO, 2002; USAID, 2006).

Intensive system

This system uses high density of fries, an absolute management control, high quality feed, and prophylactic treatment, and therefore leads to high production potential (Deb, 1998). Intensive ponds are usually much smaller (.01 to 5 hectares) and require far more inputs to maintain a healthy environment for the shrimp. This system can crash in a matter of hours due to small management errors. Disease has been a major problem with intensive shrimp aquaculture. Other environmental impacts associated with this system are pollution by waste and effluents, disused ponds, indiscriminate use of chemicals and pharmaceuticals, sodicity, sedimentation, and disease outbreaks. Major characteristics of different farming systems are presented in Table 2.3.

Among the shrimp producing countries, Thailand has the most intensive shrimp aquaculture. Other Asian countries often have a mix of extensive and intensive shrimp aquaculture system. On the other hand, semi-intensive production dominates Latin America (WWF, 2002). A rough distribution of farming systems across the shrimp producing countries is presented in Table 2.4.

Table 2.3 Comparative Characteristics of Four Major Shrimp Farming Systems

Criteria	Traditional	Extensive	Semi-intensive	Intensive
Pond size	1-100 ha	1-100 ha	1-25 ha	0.01-5 ha
Pond design	Not planned	No/little planned	Planned	Well-planned
Fry source	Wild	Wild+ hatchery	Hatchery	Hatchery
Stocking density (fry/m^3)	1-1.5	2-10	20-40	40-60
Survival rate (%)	50-60	60-80	70-80	70-90
Feed used	Natural	Natural+ little low cost feed	Natural and pelleted feed	Formulated complete feed
Water exchange	Tidal	Tidal, minimum pumping	Tidal, pumping	Pumping reservoir, filter
Yield(t/ha/year)	0.1-0.5	0.6-1.5	2-6	7-15
Investment	Low	Low to Moderate	Moderate to high	Very high
Fertilizer used	No	Organic fertilizer	Organic and chemical	Organic and chemical
Chemicals used	No	No	Moderate	Heavy
Management	Minimal	Minimal to moderate	Skilled	Highly skilled
Potential profit	Very low	Low	Moderate to high	High
Disease problem	Rare	Rare	Moderate	Frequent
Environmental Impact	Little or no	Relatively low	Moderate to high	High

Source: Deb, 1998; Lebel, et al., 2002; Páez-Osuna et al., 2003; Paul and Vogl, 2010; USAID, 2006.

Currently, shrimp farming practices that are followed in Bangladesh can be categorized in two systems: extensive (traditional) and improved extensive system. Large farm size, low stocking density, very low inputs, high mortality and low production are the common characteristics of shrimp farms in Bangladesh (Wahab, 2003).

Table 2.4 Distribution and Productivity of Shrimp Farms by Farming System in Asian Countries

Country	Extensive		Semi-intensive (%)		Intensive (%)	
	%	Productivity		Productivity		Productivity
China	10	421kg/ha	85	848kg/ha	5	2808kg/ha
Bangladesh	90	250-500 kg/ha/	10	1000-3000 kg/ha	0	2000-4000 kg/ha
India	70	200-500 kg/ha	25	2200 kg/ha	5	4500 kg/ha
Indonesia	45	150-240 kg/ha	45	600-1200 kg/ha	10	2000-3000 kg/ha
Philippines	35	200 kg/ha	50	600-1500 kg/ha	15	2000-5000 kg/ha
Thailand	5	300-1500 kg/ha	10	1800-3000 kg/ha	85	4000-7000 kg/ha
Vietnam	80	250-500kg/ha	15	1000-1500 kg/ha	5	2500-4000 kg/ha

Source: Shang et al., 1998; Biao and Kaijin, 2007; Mazid, 2003; Nhuong et al., 2002; Smith, 1999;

The nature and extent of environmental problems differ according to the production systems. Although quantification of environmental effects of different production systems is not straightforward, it is assumed that intensive and semi-intensive ponds have greater impact on environment in terms of pollution, and extensive systems have greater impacts at a landscape scale. The extensive farming systems require large areas of land and these areas are mainly obtained by conversion of mangrove forests, rice fields, other agricultural fields, and wetlands. It is noticeable from Table 2.4 that 90% of shrimp farms in Bangladesh are extensive in nature. These shrimp farms are mainly constructed by converting agricultural lands. Therefore Bangladesh is mostly facing environmental problems that are associated with extensive farming system. These include: problems of increasing soil and water salinity, loss of fishery stocks, loss of other crop production, and loss of natural habitat.

On the other hand, the environmental effects mainly associated with semi-intensive and intensive farming systems do not appear as major concerns in Bangladesh. Countries where the semi-intensive and intensive systems are prevalent face different forms of environmental threats. While more intensive farming systems may be

beneficial, they are more difficult to manage, and their risks are greater. They rely on artificial stocking of postlarvae, use potentially polluting chemicals and artificial water exchange systems that cause many environmental problems. These include: pollution by waste and effluents, sedimentation, abandoned ponds, and health hazards. It also requires greater skill, adequate finance, and improved technology to solve these problems. Consequently, no shrimp farming system is free from the criticism of environmental effects, and they need to be taken seriously.

2.6 Environmental Effects of Shrimp Farming

High profitability and the possibility of foreign exchange earnings, led to the rapid expansion of shrimp farming, mostly in the developing countries. However, the positive economic contribution of the shrimp aquaculture industry is associated with negative environmental and social impacts. So far, a variety of environmental effects from shrimp farming have been reported worldwide, of which loss of habitat and fish nursery areas, reduced biodiversity, reduced catch yields of commercially important species, soil salinity, alteration of water drainage pattern, contamination of ground water aquifers, competition with other user of land and water, disease outbreaks, release of nutrients, organic matter and chemical substances to water, and sedimentation, are recognised (Flaherty and Karnjakesom, 1995; Stonich, 1995; De Walt et al.., 2002; Páez-Osuna et al., 1998,1999; Boyd and Clay, 1998; Phillips, 1998). The major types of environmental degradation associated with shrimp farming are described below:

2.6.1   Mangrove Destruction

There are two categories of environmental effects from shrimp farming: environmental effects during establishment and effects during operation. Most of the shrimp farms are established in salt flats, marshes, mangrove areas and agricultural lands, and destruction of mangrove forests and marshes for shrimp pond construction is a major concern (Páez-Osuna, 2001b). Mangroves are considered as valuable

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ecological and economic resources, being used for nursery and breeding grounds for birds, fish, crustaceans, shell-fish, reptiles and mammals (Alongi, 2002). Mangrove forests also provide food, medicine, fuel wood, charcoal, and protect the shoreline from coastal erosion, cyclones and tidal surges (Mangrove Action Project, 2009). Transformation of mangroves into brackish water ponds generates some irreversible losses of ecosystem services including loss of fish/crustacean nurseries, repositories of biodiversity, wildlife habitat, coastal protection, flood control, sediment trapping, and water treatment (Primavera, 2006).

Although there are other factors that are responsible for mangrove destruction, shrimp farming expansion has been identified as a major factor for it. Conversion to shrimp farming is responsible for 38% of total mangrove loss, and it is the greatest single cause of mangrove loss (Valiela et al., 2001). Mangrove depletion is associated with shrimp aquaculture in many countries in Asia and Central America (Primavera, 1995, 1997, 1998; Boyd and Clay, 1998; Rönnbäck, 2000; Martinez-Alier, 2001; Ocampu-Thomason, 2006). The lack of investment in improving productivity and adopting better aquaculture methods leads to additional mangrove areas being cleared than is necessary (Sathirathai and Barbier, 2001).

Most of the shrimp producing countries experienced a loss of mangrove forests due to conversion into shrimp farms. Southeast Asia occupies 35% of the world's 18 million ha of mangrove forest, but this region has also suffered from the highest rate of mangrove destruction. In Thailand, most of the mangrove forest destruction took place due to conversion to large extensive culture shrimp ponds during the 1980's (Barbier and Cox, 2002; Lewis et al., 2003). The amount of mangrove conversion to shrimp farming varies, but literature suggests that 50-60% of Thailand's mangrove have been lost to shrimp farm conversion since 1975 (Dierberg and Kiattisimkul, 1996; Spalding et al., 1997; Hinrichsen, 1998; Tokrisna, 1998; Barbier, 2000; Barbier et al., 2002). The rate of mangrove loss has been estimated to be as high as 6,000 ha per year (Sathirathai and Barbier, 2001). Barbier and Cox (2004) reaffirmed the hypothesis that the profitability of shrimp farming is a very important underlying

cause of mangrove deforestation in Thailand. The welfare loss of mangrove deforestation on coastal communities in Surat Thani Province were estimated to be around US$ 27,000 to 36,000 per ha (Sathirathai and Barbier, 2001).

Over the last fifty years, Vietnam has lost 80% of its mangrove forests, accounting for a total of at least 222,000 ha (EJF, 2004a). Most of this destruction has been very recent and shrimp aquaculture is thought to represent the single greatest reason for this destruction. In Vietnam, in just four years (1983-1987), 102,000 ha of mangroves were converted to shrimp farms (EJF, 2003). In the Philippines 95% of brackish water ponds in the period 1952-1987 were converted from mangroves, accounting for approximately 150,000 ha of forests (Primavera, 2000). In Indonesia, 269,000 ha of mangroves were reportedly converted into shrimp ponds between 1960-1990, and shrimp farming remains a major threat for Indonesia's mangroves (Spalding et al., 1997; Hussain et al., 1999).

In Latin America, nearly 50% of Ecuador's mangroves have been lost over the last 30 years, and most of the loss can be attributed to shrimp farming development (Bodero and Robadue, 1995; Lacerda et al., 2002). Shrimp industry in Ecuador started in the late 1960s and experienced a rapid expansion. By 1999, about 175,000 hectares of land had been converted to shrimp farms. The Muisne region of Ecuador alone has lost nearly 90% of its mangroves (Mangrove Action Project, 2012). In Honduras, about one third of dense mangrove forest in the Gulf of Fonseca was converted to shrimp farms (Tobey et al., 1998; De Walt et al., 1996) at the rate of as high as 2,000-4,000 ha per year (Lal, 2000). Honduras has lost about 11,500 hectares of mangrove forest in the period 1973-1992, accounting for a loss of 22% of total mangrove area (Stonich, 1995; De Walt et al., 1996). In Mexico, it was found that by 1994, 10,000 ha of mangrove forest were destroyed to build shrimp ponds (Flores-Verdugo et al., 1992).

Bangladesh, India and Sri Lanka are the major shrimp producing countries in South Asia that are also the home of extensive mangrove forests. The Sundarbans, which

constitute the biggest remaining mangrove area in the world, covers about 1.2 million hectares in India and Bangladesh. In West Bengal (India), about 35,000 hectares of mainly extensive shrimp ponds have replaced mangroves in the part of Sundarbans (FAO/NACA, 1995). In the Godavari delta of Andhra Pradesh state, shrimp farms were responsible for approximately 80% of mangrove conversion in the first decade of the 21st century (Hein, 2000). A recent remote sensing survey on mangrove coverage in Sri Lanka estimated that considerable areas have disappeared in Puttalam lagoon (64%) and Dutch Bay (11%) (Senarath and Visvanathan, 2001). The loss of mangrove forests in the major shrimp producing countries is presented in Table 2.5.

Large portions of mangrove forests were converted into shrimp farms in Bangladesh, like in other shrimp producing countries (Primavera, 1998; Gain, 1998, 2002; Deb, 1998; Bhattacharya et al., 1999; Gregow, 1997; EJF, 2004b). The Sundarbans is the largest single block of mangrove forest in the world, covering an area of about 6000 km^2 (Chaffey et al., 1985) in Southwest Bangladesh. In the Sundarbans, most of the mangrove destruction occurred before the rise of shrimp farming and was associated with agricultural expansion in the mangrove areas (Richards and Flint, 1990). A study applying remote sensing technique found that between 1970s and 1990s, mangrove forest gained from aggradation (2,925 ha) nearly equalling mangrove forest lost to erosion (3,157 ha) and the net mangrove loss over the whole of the Sundarbans is about 1% as the numerous areas of loss are counterbalanced by areas of gain. This small change was generally expected based on the management and protection status of the Sundarbans, including the ban on clear cutting and forest encroachment (Giri et al., 2008). Similar result was found by Shahid and Islam (2003) who also used remote sensing and GIS techniques to measure the denudation of mangrove forest due to shrimp farming. The result shows that from 1975 to 2001, only a small area of Sundarbans (108 ha) was encroached (started before 1975) by local people and being used for shrimp farming. According to the forest department data, in 2010 the Sundarbans occupied 600,486 ha, which is an increase from 577,285 ha in 2000.

Table 2.5 Status of Mangrove Forests in the Top World Shrimp Producing Countries

Country	Land area at Starting year (in ha)	Land area at ending year (in ha)	Percentage of Destruction	Period
China	66,000	36,882	44	1980-1994
Thailand	312,723	244,085	22	1973-2000
Vietnam	320,000	252,500	21	1965-1983
Indonesia	425,4312	3,515,471	17	1982-1992
Malaysia	688,634	587,269	15	1975-1995
Philippines	220,241	127,610	42	1979-1990
India	638,818	487,100	24	1957-1997
Bangladesh	611,371	603,898	1.2	1978-1999
Mexico	700,000	488,000	30	1973-1994
Ecuador	203,625	149,688	26	1969-1999
Honduras	297,800	54,300	82	1965-1995

Source: Riverra-Ferre, 2009; SPARRSO, 2002.

However, mangrove cover in Bangladesh's Chakaria mangrove forest in Southeast region suffered from extensive degradation due to conversion of the forest to shrimp farming. The disappearance of Chakaria mangrove forests in Cox's Bazar district was largely due to shrimp cultivation and is an example of how shrimp cultivation has caused unprecedented harm to the unique mangrove systems (Gregow, 1997). The forest cover in Chakaria mangroves fell from 7,500 ha in 1976 to just 973 ha in 1988 (Hossain et al., 2001). Figure 2.6 presents a GIS based forest cover map of Chakaria mangrove forest in the 1974-1989 period. Using remote sensing and GIS technique, Shahid and Islam (2003) estimated that the total denuded forest areas for shrimp farms in Bangladesh was 9,734 ha of which 8,540 ha of loss occurred in the sub-district of Chakaria in the period 1975-1999. There was also some mangrove destruction (about 1,200 ha) on small islands of Southeast coast in the same period. Overall, the percentage of mangrove forest loss due to shrimp farming is negligible in

Bangladesh compared to other countries, but in the specific sub-district Chakaria, it is large. Overall, less than 2% of mangrove forests of the country have been lost due to shrimp farming from 1975 to 2001 (Shahid and Islam, 2003) and no further evidence of mangrove loss has identified.

Figure 2.6 Destruction of Mangrove Forest by Shrimp Farms in Chakaria Sub-district
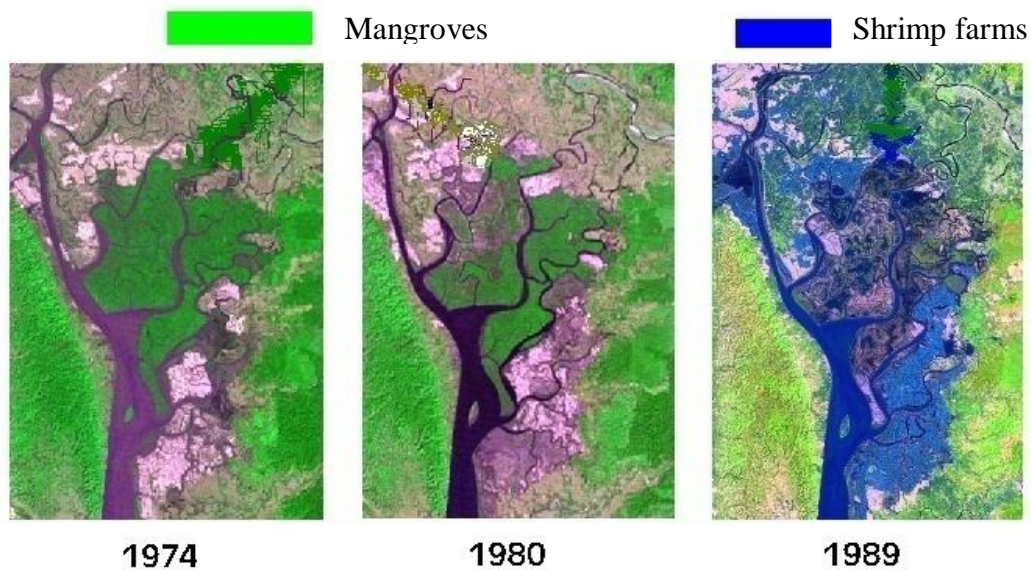
Source: SPARRSO, 2002.

2.6.2   Loss of Wild Fry and Capture Fishery Stock

Shrimp farming is responsible for the loss of wild fish stocks in three ways: by destroying the mangrove forests for shrimp farming development that provide nursery grounds for a great variety of fish; destroying other shrimp, fish and zooplankton fries during collection of wild shrimp postlarvae; and catching of wild fish to use as fishmeal or fish oil in commercial shrimp farming.

The association of shrimp farming with the loss of wild fisheries due to habitat conversion is thought to be significant and has been confirmed in the Asia-Pacific region and elsewhere (Rönnbäck, 1999; Primavera, 1995, 1998; Naylor et al., 2000).

About 70 % of commercially valuable fish and shellfish in Ecuador, Honduras and Mexico (Frías and Majía, 2005) and 33 % in Southeast Asia are dependent on the mangrove ecosystem (Naylor et al., 2000). For every hectare of mangrove converted, there is an estimated 100 kg of on-site fish biomass that is lost in Southeast Asia. In Thailand, an estimated 434 grams of fish and shrimp are lost from capture fisheries per kg of shrimp farmed in mangrove areas (Naylor et al., 2000). In Sri Lanka, lagoon fishers' average catches declined by 62% since the advent of shrimp farming (EJF, 2004a). In India, 80% of the total fish catch from the lower delta region of the Ganges and Brahmaputra rivers comes from the Indian Sundarbans and mangrove loss is significantly correlated with wild fish catch decline (Vannucci, 2002). In Mexico, it was estimated that 306 kg of commercial fish are lost for every acre of mangrove forest destruction (Juan-Carlos and Thelma, 2005). Similarly, in Campeche State, Mexico, a decline in mangroves at the rate of 200 ha per year caused a loss in fisheries, valued at US$ 140,000 between 1980-1990 (Barbier, 2000). All these figures indicate a potential significant loss in wild fish production.

While the full impacts of shrimp fry collection on biodiversity and capture fisheries production are not yet fully understood, they are assumed to be very significant (Rönnbäck, 1999; Rönnbäck et al., 2002). Catching wild shrimp postlarvae for ponds can have serious negative impacts on wild fish and shrimp stock. Although hatchery postlarvae are now available in many countries in Asia and Latin America, wild fry still provides the major source of shrimp seed (EJF, 2004a). Harvesting of wild postlarvae is highly inefficient in terms of mortality of postlarvae and discarded bycatch, and is ecologically destructive (Primavera, 1998; Battacharya and Sarkar, 2003). The bycatch (non-target species caught and often discarded) rates associated with shrimp fry collection are among the highest of any fish catches in the world (Primavera, 1998). For every fry of the tiger shrimp collection in India, it has been estimated that up to 160 fish and other shrimp fry are discarded (Naylor et al., 2000). In Malaysia and the Philippines, for every fry of tiger shrimp, up to 330-475 other shrimp fry are caught and discarded (Primavera, 2006). In Honduras, it has been estimated that approximately 3.3 billion shrimp postlarvae are used annually for pond

stocking, and 15 to 20 billion fry of other species are captured and discarded in this process (De Walt et al., 1996).

The high proportion of fish meal and fish oil used in the shrimp aquaculture as feed input has induced a loss of wild fishery stock (Primavera, 2006). Higher quantities of fish meal is needed to prepare pellet feed in aquaculture industry compared to poultry and livestock feed. For example, 5kg wild fish is used as feed to produce 1kg of carnivorous fish (Tacon and Metian, 2008). Shrimp is the top consumer of fish meal among other aquaculture products, and dependent on marine capture fisheries for this dietary. In fact, it is a net consumer of aquatic products rather than a net producer (Tacon, 2002). Shrimp farming in semi-intensive and intensive systems require large amount of feed inputs primarily in the form of fishmeal and fish oil. It has been estimated that about 2 million tonnes of fish is used as fishmeal to produce about 1 million of farmed shrimp (Naylor et al., 2000). The ratio of wild fish used as fishmeal to produce farmed shrimp has been estimated to be as high as 2.25 (Goldburg et al., 2001). Naylor et al. (2002) have also estimated that the feed conversion ratio for farmed shrimp is very high: 2.08 kg of pelagic fish is needed for the production of 1 kg of shrimp (Naylor et al., 2002). It has been estimated that global production of compound aquafeeds for shrimp was approximately 1.7-1.8 million tonnes in 1999 with an average feed conversion ratio of 2 (EJF, 2004a). The depletion of pelagic fisheries for the production of fishmeal reduces available food supplies for human use as well as for marine predators including tuna, seals, dolphins and seabirds (Naylor et al., 2000; Rönnbäck, 2002).

In Bangladesh, both brackish and freshwater shrimp production heavily depend on wild-caught fry which is thought to significantly impact wild fish stock. In 1989-1990, a total catch of two billion larvae of tiger shrimp reportedly resulted in the discard of 200 billion other organisms including other shrimp, finfish and zooplankton (FAO, 2001). Approximately 3 billion shrimp fry are collected annually from natural sources (DoF, 2002) and 40% of the collected fries die before stocking in culture facility due to poor handling and transportation (Brown, 1997). Much of

this collection (approximately 80%) takes place in the Southwest region of Bangladesh around the Sundarbans forest and there are serious concerns that removal of juveniles of commercially and ecologically important species may lead to serious problems for the fisheries of Bay of Bengal (EJF, 2004b). Silas (1987) also estimated that 10 kg of fish and shrimp larvae are killed during the collection of 1 kg of tiger shrimp postlarvae in the Sundarbans of West Bengal, India. BOBP (1990) reported that up to 5000 postlarvae of other fish and shrimp species are killed for every 100 marketable shrimp postlarvae collected in Bangladesh. Table 2.6 summarizes some of the empirical findings that have reflected the loss of fisheries due to shrimp fry collection.

Table 2.6 Loss of Shellfish and Finfish for Collection of One Tiger Shrimp Postlarvae in Coastal Areas of Bangladesh

Loss of other shrimp (no.)	Loss of Finfishes (no.)	Loss of Macrozooplankton (no.)	References
12-55	5-152	26-1636	Hoq et al. (2001)
91	86	236	BFRI (2002)
26	29	70	Deb (1998)
384	208	835	Islam & Ahmed (2001)
14	21	1631	Mahmood (1990)
26-119	9-31	64-922	Hoq (1999)
27	22	23	Rahman et al. (1997)
21	30	46	Alam (1990)

The unregulated collection of wild fry causes the destruction of many other fish species and plankton. This not only reduces biodiversity, but also affects food supply to coastal communities and more generally to Bangladesh's household consumption of fish (BCAS, 2001). Therefore, maintaining of natural populations of shrimp and fish larvae, and other aquatic flora and fauna is essential.

2.6.3   Biodiversity Loss

Besides its visible and possibly irreversible degradation of coastal ecosystems, shrimp aquaculture may have other unforeseen indirect impacts on biodiversity (UNRISD, 1996). The impacts of shrimp farming on biodiversity are multiple and closely associated with mangrove destruction and habitat conversion. Extensive shrimp farming takes place in the intertidal zone, in or adjacent to the estuaries. Most tropical estuaries are dominated by mangroves, an intertidal ecosystem of tree and shrub species adapted to the saline habitats that supports a wide range of other organism (World Bank/WWF/NACA/FAO, 2002). Expansion of shrimp farms in these areas has threatened a wide range of biodiversity. It is commonly known that mangrove has high biodiversity value which provide the habitat of wide range of plant, fish and animal species, many of which are endangered (IUCN, 2003). Mangrove forests also protect shoreline against flooding and storm and reduce erosion. Conversion of this natural habitat to agricultural land (e.g. shrimp pond) greatly threatens the biodiversity.

A number of shrimp farms have been built in or at the edge of seasonal or winter lagoons of Honduras which are the habitats for migrating waterfowl, raptor and wading birds (De Walt et al., 1996). In Sri Lanka, approximately 76% of shrimp farms have been developed in intertidal areas that were previously classified as mangroves, salt-marshes and mudflats. Similarly, Ecuador has lost a considerable area of salt marshes between 1969-1998 due to conversion to shrimp ponds (EJF, 2004a). Thousands of hectares of coastal estuaries, mud and salt flats, and wetlands in other countries have also been converted to shrimp farms, which are quite important from an ecosystem point of view. But little attention has been given to the loss of these coastal habitats in the tropics (WWF, 2002). Moreover, pumping operations for water exchange of shrimp farms can cause significant change in the hydrodynamic pattern of coastal lagoons. This might induce mortality of vast mangrove zones, particularly those species under environmental stress (Páez-Osuna et al., 2003).

The sedimentation of estuaries, often created by shrimp ponds negatively affects coral reefs and remaining mangroves, and their roles as nursery beds for numerous fish species (UNRISD, 1996). Over 95% of Vietnam's coral reefs are threatened and half of the reefs are at the risk of sedimentation (EJF, 2003). In Vietnam, a large amount of grassland and patches of *Melaleuca* forest have been replaced by shrimp farming, which are habitats for many plant and animal species. The Mekong Delta is the largest and most complex wetland system in Southeast Asia, supporting over 386 species and subspecies of birds, 260 species of fish, and hundreds of other vertebrate species (UNEP-WCMC, 1997). In the creation of shrimp farms, vast tracts of these vital wetland habitats have been destroyed and degraded (EJF, 2003). Tam Giang in Vietnam is one of the largest lagoons in Southeast Asia which provides an important aquatic environment, supporting a rich fish, invertebrate fauna and migratory waterfowl (EJF, 2003). Shrimp farm development has appeared as a threat for the rich biodiversity of this lagoon.

In Bangladesh, the ecological values of Sundarbans are enormous and significant in terms of biodiversity conservation. The forests serve as feeding, breeding, resting and roosting ground for a wide variety of plants and animals including 68 species of diverse plants, 32 species of mammals (including royal Bengal tiger, spotted dear, wild boar), 186 species of birds, 35 species of reptiles, 8 species of amphibian, and varieties of flora and fauna (Deb, 1998). The Sundarbans provide a buffer to cyclones and tidal waves. The unplanned expansion of shrimp farms in the areas adjacent to the Sundarbans silently destroys the biodiversity of this area (PDO-ICZMP, 2004). Excessive shrimp fry collection in and around Sundarbans severely impacted the aquatic ecology of the area and the physical disturbances affecting the growth and regeneration of mangroves themselves (EJF, 2004a). The destruction of Chakaria mangrove forests resulted in a reported 80% drop in fisheries catch and has devastated biodiversity (Gain, 2002).

The extensive shrimp farming system of Bangladesh has led to the conversion of large areas of land including agricultural and natural wetlands. Use of groundwater

and coastal wetlands for shrimp aquaculture has adversely impacted the ecology of Bangladesh (EJF, 2004b). Shrimp farming has been associated with declines in populations of a number of ecologically important wetland species, including frogs, snails and birds (Ahmed, 2003; DoF, 2002). The reduction of wetland habitats is also reported to have affected *beel* (shallow lake and swamp) fisheries. Additionally, canals used as common fishing ground have been converted to shrimp ponds in many areas. Conversion of these wetlands has been linked to reduced biodiversity, reduced agricultural production, and population declines of ecologically important species (EJF, 2004b).

2.6.4   Salinization of Soil and Water

Salinization of soil and water (ground and surface) is one of the crucial environmental consequences of shrimp farming faced by most of the shrimp producing countries. Saltwater intrusion from shrimp ponds and brackish water aquaculture to agricultural land (e.g. paddy fields) raises conflicts between agriculture and aquaculture practices (Raux and Bailly, 2002). While extensive farms often rely on exchanging water by using tidal ebb and flow, semi-intensive and intensive farms use large amount of freshwater to mix with sea water (World Bank/WWF/ NACA/ FAO, 2002). Pumping freshwater from groundwater contribute to the problems of saltwater intrusion into groundwater, land subsidence and loss of water supply for agricultural and domestic purposes. These effects are reported in different shrimp producing countries including Taiwan, People's Republic of China, Thailand, Indonesia, the Philippines, and Ecuador (Primavera, 1994; Clay, 1996; Flaherty et al., 1999; Dieberg and Kiattisimkul, 1996).

Pumping large volumes of underground water for shrimp ponds in the 1980s to mid-1990s led to the problems of lowering groundwater levels, emptying of aquifers, land subsidence, and salinization of adjacent land and waterways throughout Southeast Asia (Primavera, 2006). Even if there is no pumping from aquifers, the discharge of salt water from shrimp farms still cause salinization in adjoining rice and other

agricultural lands (Dieberg and Kiattisimkul, 1996). Nevertheless, shrimp farms need additional fresh and salt water supplies throughout the growing period of the culture as water is lost by seepage and evaporation (Flaherty et al., 1999; Páez-Osuna, 2001a).

In Vietnam, the increase in shrimp farming acreage resulted in a serious salinization of the surface water in the Cai Nuoc district. While the critical soil water salinity (ECe) limit for most crops is 6 dS m^{-1}(Kijne, 1996), in Cai Nuoc district, the mean value of ECe of the topsil (0-20 cm) in the wet season and the dry season was estimated at 21.86 dS m^{-1} and 53.4 dS m^{-1}, respectively (Tho et al., 2008). These figures strongly imply that rice (once the staple crop of this district) can no longer be grown (Binh et al., 2005). A remote sensing study in two provinces in southern Thailand showed that about 3,300 hectares of shrimp ponds had led to salinization of further 1,100 hectares of agricultural land, mostly rice fields (Phillips, 1995). In Chantaburi, Thailand, around 20% of agricultural farms were affected by saline water intrusion linked to shrimp pond expansion (Lewis et al., 2003). However, due to protest from community groups, academicians and NGOs against heavy salinization of agricultural land (estimated salt loading of 5.6 mt/ha/year), the government banned inland shrimp farming in Thailand in 1998 (Flaherty et al., 1999; Primavera, 2006). In South India, soil salinity in the agricultural lands, adjoining to shrimp farms was found very high. The mean EC level in these lands was estimated to range from 4.95 to 15.89 dS m^{-1} while other cultivated lands (not adjacent to shrimp farms) in the same area have an EC level ranging from 0.02 to 3.00 dS m^{-1} (Umamaheswar et al., 2009).

In Bangladesh, the coastal area covers about 20% of the country's total area, and over 30% of the net cultivable area (Haque, 2006). Salinity has long posed a problem in the coastal area, and water control measures have significantly exacerbated this more recently (EJF, 2004b). While saline intrusion is not uniquely linked to shrimp aquaculture, retention of saltwater by shrimp farms is thought to have exacerbated this problem (Wistrand, 2001; DoF, 2002; EJF, 2004b). Saltwater intrusion into

adjacent land and freshwater aquifers from shrimp farms has caused problems in terms of loss in crop production, loss in fodder, potable and irrigation water crisis and loss of freshwater species. The demand for salt water for shrimp farming is fulfilled by digging narrow canals from near the shore or river channel which transmit the salt water to the shrimp farm and during this action, salt water is spread along the coastal area (Islam, 2003; Chowdhury et al., 2006).

The soil salinity status of major shrimp farming districts in Bangladesh over the last four decades is presented in Figure 2.7. Because of the requirements of the production system, saline water is retained for a long time in the shrimp ponds, virtually leading to percolation of salts in the surrounding soil resulting in changed soil chemistry (Deb, 1998). A related study that compared salinity levels in shrimp and non-shrimp areas reported that shrimp farming could increase soil salinity levels up to 500%, and confirmed to be the 'main constraint for crop production' in shrimp areas. The study also found that the pH of the soil in shrimp *gher* (pond) sites was higher compared to control sites (non-shrimp area), which adversely affects productivity of the soil. Moreover, there was a significant difference in water quality was found between shrimp and non-shrimp areas. Water bodies near shrimp farms were found contaminated with high salinity (up to 22 parts per thousand) that does not allow growth of many fresh water organisms (Islam et al., 1999).

The saline water intrusion into large areas of agricultural land has affected the variety and abundance of crops grown and affected livestock production in shrimp farming areas (EJF, 2004b). The decreased supplies of potable freshwater driven by salinization have led to the problems of gastrointestinal infections in humans, loss of diversified crops, poultry and fodders (Ali, 2006). In a study of the Satkhira district, shrimp farming was found to be the primary cause of increase in soil salinity and has been linked to declining tree cover, with coverage falling to 68%, and gradual disappearing of salt-sensitive species such as guava, jackfruit, black plum, mango, palm tree, hog-plum and sapota during the period 1985-2000 (Dutta, 2002). In other shrimp farming areas, declining of agricultural and homestead crops (including rice,

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wheat, jute, sesame, sugarcane, cauliflower, cabbage, brinjal, chickpea, groundnut, and chillies), fruit and woody trees (mango, blackberry, jackfruit, lemon, papaya, banana, coconut, betelnut, guava and *babla*), and homestead vegetables have also been reported (Wistrand, 2001; Dutta, 2002; EJF, 2004b).

Figure 2.7 Percentage of Salinity Affected Area of Total Cultivable Land in the Shrimp Farming Districts of Bangladesh
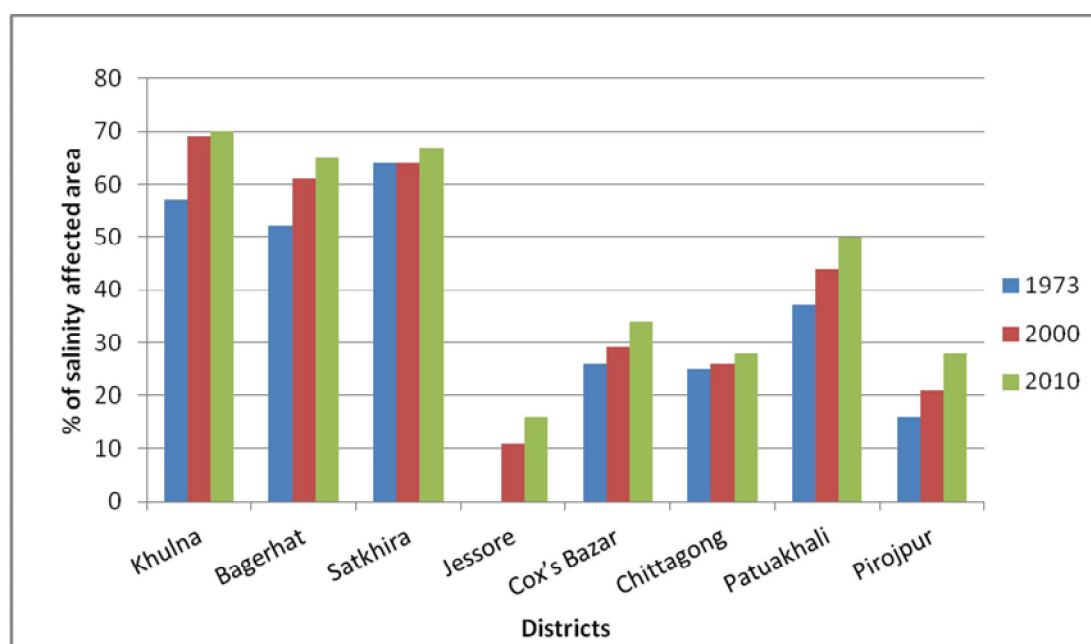
Source: SRDI, 2000; 2010.

2.6.5   Pollution and Sedimentation

Shrimp production creates large quantities of shrimp wastes, unused food and chemical substances used to treat diseases, which eventually drain into estuaries without being treated first (Ahmed et al., 2002). Extensive shrimp culture systems are characterized by low stocking densities, little or no fertilizer or supplemental feeding, and low water exchange. Consequently, extensive farms do not generate significant amounts of wastes (Phillips, 1995; Sandifer and Hopkins, 1996). On the other hand, semi-intensive and intensive shrimp farms receive more fertilizer and supplemental/complete feed and consequently produce more nutrients, more organic

matter, and other wastes that affect the water quality (Mackintosh and Phillips, 1992; Páez-Osuna, 2001a).

Excessive and unwanted use of chemicals is a concerning issue associated with shrimp farming. These chemicals are the result of used fertilizers and pesticides in shrimp ponds, unused feeds, unwanted organisms, and detritus (Flaherty and Karnjakesom, 1995; Flaherty et al., 2000; Hall, 2004). Effluents from shrimp ponds are typically rich in suspended solids, nutrients, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) (Hopkins et al., 1995). The concentration of these chemicals depends on whether the management system is intensive or semi-intensive (Gräslund and Bengtsson, 2001; Uddin and Kader, 2006). There is a clear correlation between the degree of intensification (e.g. higher stocking density, use of water, feed, and fertilizers) and waste loads. These discharged and dissolved chemicals can easily pollute the surroundings water and soil quality (Deb, 1998; Neiland et al., 2001).

Poor quality feed and poor feeding management is another main source of water pollution attributable to shrimp farming and its adjacent waters (Yang et al., 1999). Intensive shrimp ponds have the feed conversion ratio of about 2 and the feed utilization rate of about 10 % (Huang et al., 2002). Low-feed utilization rate means the great loss of organic matter that is drained into the sea. However, a great amount of unused feed remains in the shrimp ponds; some of this becomes suspended solid pellets and some releases substantial quantities of nitrogen and phosphorus upon dissolution. During the exchange of pond water, nitrogen and phosphorus rich effluents enter into the surrounding waters and cause deterioration of water quality, alteration of phytoplankton community, and eutrophication of coastal waters (Biao and Kaijin, 2007). Phosphorus and nitrogen budgets were formulated for intensive shrimp ponds in Thailand (Briggs and Funge-Smith, 1994; Thakur and Lin, 2003), semi intensive farms in Mexico (Páez-Osuna et al., 1997; Páez-Osuna et al., 1999) and extensive shrimp ponds in Bangladesh (Wahab et al., 2003).

Table 2.7 presents the amount of wastes and effluent discharges from shrimp ponds in different countries. In Thailand alone, shrimp ponds have been reported to discharge 1.3 billion cubic metres of effluent annually (Barbier and Cox, 2002). In 1988, Taiwanese shrimp industry faced a mass mortality due to re-use of waste-laden pond water discharge (Lin, 1989) and consequently between 1987 and 1989, shrimp production in Taiwan dropped from 90,000 tonnes to 20,000 tonnes (Liao, 1992). Brackish water shrimp farming was shown to contribute 90% of organic matter entering the Tulang Bawang River in Lampung, Indonesia. In addition, red tides and growth of harmful algae have also been reported for the shrimp farming areas in Lampung (Zieren et al., 1999).

Table 2.7 Average Annual Nutrients, Oxygen Demand (BOD and COD), and Total Suspended Solids (TSS) in Discharged Water from Shrimp Ponds in Various Countries

Country	Shrimp Area/quantity	Total Nitrogen (kg)	Total Phosphorus (kg)	BOD (kg)	COD (kg)	TSS (kg)
Vietnam	1 hectare	159	20	1373	4077	6201
Thailand	1 hectare	178	16	474	845	6650
Bangladesh	1 kg	78g	25g	-	-	-
Mexico	1 ha	111	32	-	-	-

Sources: Anh et al.., 2010; Dierberg & Kiattisimikul, 1996; Islam et al.., 2004; Páez-Osuna et al.., 2003.

Shrimp pond effluents contain unwanted nutrients, dissolved gases, phytoplankton and pathogens. This can lead to the adverse impact on environment by contaminating ground and surface fresh water supplies, and by polluting surrounding lands. The resulting pollution can deplete fish and shrimp stock, promote disease outbreaks, and decline farm productivity (EJF, 2004a). Moreover, shrimp ponds with high organic matter can have effluents with high BOD and COD. This results in oxygen depletion in receiving waters, causing hypernutrification and eutrophication of coastal waters, and increased sedimentation and siltation (SEAFDEC, 1989).

In Bangladesh, there are only few published work that have assessed water quality resulting from shrimp pond effluents. Islam et al. (2004) tested the water quality parameters of shrimp farms in Khulna and Cox's Bazar districts and found that on average, for each kilogram of shrimp produced in semi-intensive system, 78 grams of nitrogen was discharged and 25 grams of phosphorus was removed from the surrounding water by the system. A partial mass budget in extensive shrimp farms indicated that for a 150 days cycle, the system produced about 60 kg/ha/cycle of total nitrogen and 16 kg/ha/cycle of total phosphorus to the *ghers* (Wahab et al., 2003). In another study, Islam et al. (2004) found that on average, 44 kg/ha/culture cycle of nitrogen and 27 kg/ha/culture cycle of phosphorus were entrapped into the *gher* (pond) which were being used during the agricultural cropping. These nutrients entered to the shrimp *gher* through inlet water and are accumulated in the sediments. Since Bangladesh is mainly practicing traditional to improved extensive farming systems, insignificant amount of organic matter and nutrients are expected to be discharged to the surrounding environment.

Sedimentation is another problem that can be linked with shrimp farming. The intensification of shrimp farming comes with higher stocking density and greater use of water, feeds, and fertilizers which leads to increased waste production, which is afterwards accumulated as sediment in the shrimp ponds (Páez-Osuna, 2001a). The suspended sediment reduces primary productivity and alters the tropical structure of coastal aquatic ecosystems (De Walt et al., 1996). The undissolved phosphorus and nitrogen are released in the form of pond sediments at the end of the harvest period, which might contribute to eutrophication in the surrounding water (Deb, 1998).

From 100 to 500 tonnes of sediment per hectare per year are apparently accumulating in shrimp ponds (Rosenberry, 1994). Briggs and Funge-Smith (1994) estimated that 31% of nitrogen and 84% of phosphorus wastes from intensively managed shrimp ponds are trapped in the sediments in Thailand. In the semi-intensive ponds in Mexico, more than 27% nitrogen and 63% phosphorus are accumulated in the sediments (Páez-Osuna et al., 1997). The sedimentation of estuaries negatively affects

the coral reefs and remaining mangroves, and their roles as nursery beds for numerous fish species (UNRISD, 1996).

The pond bottom accumulates excessive organic materials such as nitrogen, phosphorus, ammonia and hydrogen sulphide as sediments which create unpleasant odour and eutrophication (Funge-Smith and Briggs, 1998). Sediments are often discarded in waterways leading into the sea, or sometimes used to build dikes. Their putrefaction inside and outside the ponds causes foul odours, hypernutrification and eutrophication, siltation, and turbidity in water courses and estuaries with detrimental implications for other water users as well as local fauna and flora (UNRISD, 1996; Páez-Osuna et al., 1998). Sedimentation further leads to problems of water pollution, salinization of soils and water, and solid waste disposal (Dierberg and Kiattisimkul, 1996).

2.6.6   Abandoned Shrimp Ponds

The average lifetime of a shrimp pond varies depending on many factors such as management practices, water quality and sediment characteristics, but a average lifetime of 7-15 years has been estimated, considering improved management (Flaherty and Karnjakesom, 1995). The 'Abandonment' problem of shrimp farming is mostly associated with intensive shrimp culture. When intensive farming is practiced, the life span of ponds does not exceed 5-10 years because of attendant problems of self-pollution and diseases (Primavera, 1997). Shrimp ponds can be abandoned for various reasons, but poor water and soil quality often leads to the ponds being abandoned.

Mangrove areas are generally not ideal for intensive or semi-intensive shrimp farming since the soils are highly organic and/or potentially acidic. In many locations in Southeast Asia, shrimp farms have been abandoned which were initially developed in mangrove areas (Lewis et al., 2003). A report by NACA (Network of Aquaculture Centres in Asia-Pacific) detailed that in 1989 about 62% of farms were operating

under capacity, and another 22% of farms were abandoned in Samut Sakhon province in Thailand. Stevenson (1997) reported that 70-80% of ponds were abandoned in Prachuap Khiri Khan, and that a similar figure can be reported for the provinces of Songkhla and Srithammarat in Thailand. An area of 40,000-45,000 ha south of Bangkok became abandoned after shrimp production collapsed in 1989-90 (Briggs and Funge-Smith, 1994). Many shrimp farms in other countries of Asia have also been abandoned since shrimp farming started: in Vietnam and Cambodia due to acid sulphate soils (Stevenson, 1997); in Taiwan, the Philippines, Indonesia and India due to diseases (Stevenson et al., 1999; Lin, 1989; Ogburn and Ogburn 1994; Sammut and Mohan, 1996); in Sri Lanka and Indonesia due to site selection and water quality problems (Jayasinghe, 1995; Stevenson, 1997). It is estimated that approximately 103,000 ha of acid sulphate soils (ASS) affected ponds and 128,000 ha of abandoned shrimp ponds exist in Indonesia (Lewis et al., 2003). In the Philippines, nearly 55,000 ha of shrimp aquaculture ponds have been abandoned and another 83,000 ha brackish water ponds have been 'idle' (Yap, 1997).

The environmental effects resulting from abandoned ponds are serious. Some of the effects include: acid sulphate soils that destroys food resources; displacement of biota; release of toxic levels of aluminium; and precipitate of iron that smothers vegetation and microhabitat, and alters the physical and chemical properties of the water (Sammut et al., 1996). The effects of abandonment also include accelerated soil erosion due to increased surface run off and subsurface flow; decrease in soil water storage capacity; reduction in biodiversity of soil fauna; transport of sediments, dissolved inorganic and organic nutrients; and depletion of soil organic matter through leaching and mineralisation (Stevenson, 1997). Abandonment of shrimp ponds represents a significant challenge to the productive use of coastal areas in the future since many of the environmental conditions for the growth of the former rice fields and mangrove forests have already been removed or severely altered, and therefore, the rehabilitation of these areas is complicated (Flaherty and Karnjakesom, 1995).

While most farmers would like to come back to traditional shrimp farming systems, they often have no real success. However, the major obstacle to the redevelopment of these ponds is not the prevalence of disease, but the remediation of acid sulphate soils which may persist for many years after abandonment (Stevenson et al., 1999). When considering options for redeveloping or restoring of disused ponds, it is important that the environmental parameters remaining in a pond are identified, and management becomes progressively more efficient (Stevenson, 1997).

2.6.7   Health Hazards

Various types of disease attack is a major obstacle for the sustainable shrimp aquaculture of which invasion of protozoa, fungi and bacteria are mentionable (Rosenberry, 1998). The major shrimp producing countries like Taiwan, China, Indonesia, India, Ecuador, Honduras and Mexico faced significant collapses in their shrimp production due to diseases between 1980s and 1990s (1987-1997). Viral diseases like White Spot Syndrome Virus (WSSV) and Yellowhead Virus caused enormous losses in shrimp farms across Asia during the 1990's (Primavera, 2006).

The high risk of disease within intensive and semi-intensive systems, and the enormous potential financial losses, leads to the intensive use of antibiotics in shrimp farms (EJF, 2004a). White spot syndrome is the leading shrimp disease, caused by *Vibrio* bacteria. If humans eat the infected shrimp, they can become sick with gastroenteritis (caused by *Vibrio parahaemolyticus*), cholera (caused by *Vibrio cholera*) or suffer from fatal septic shock (caused by *Vibrio vulnificus). V. parahaemolyticus* is the most common source of seafood food poisoning in the United States. It causes typical gastroenteritis: diarrhea, cramps, nausea, vomiting, headache and fever in healthy people.*V. vulnificus* has also the same effect, but for those with chronic illness (such as liver damage, diabetes, asthma or cancer), *V. vulnificus* can cause septic shock, resulting in death in about half of the cases. In 1996, 7% of the imported frozen shrimp to Denmark, mostly from tropical countries were contaminated with *V. Vulnificus* (Food and Water Watch, 2008).

When diseases spread out extensively, antibiotics are used as a prophylactic measure in the hatcheries. This can make shrimp larvae more susceptible when they are released in the ponds, and therefore, promote further use of antibiotics and chemicals in the ponds (GESAMP, 1997). This may results the development of antibiotic-resistance among pathogens, which compromises both human and the cultivated animal's health (Holmström et al., 2003). In several shrimp farming regions, health hazards to local population have been observed. There are numerous potential hazards to public health that are associated with various stages of shrimp chain—from production to processing. The workers employed in shrimp farms handle several potentially dangerous chemicals and are exposed to health problems (UNRISD, 1996). This includes skin dermatitis from sulphonamide exposure, or aplastic anaemia from exposure to chloramphenicol (Gräslund et al., 2003).

Health risks for aquaculture are associated with both chemical and biological contaminants. Concerns have been expressed about exposure to mercury, cadmium, organo-chlorinated pesticides, dioxins and antibiotics (Barg, 1992). This could cause health problems locally among the farmers (Holmström et al., 2003). For example, in Tamil Nadu, eight deaths were reported from an unknown disease reported on the 1500 acre of shrimp farm (Naganathan et al., 1995). Although no epidemiological data on water-borne diseases are available in Bangladesh, UNEP (1999) conducted an estimation based on value of statistical life. The study showed that the shrimp cultivation induced water pollution mortality cost is US$ 12 million which is 0.09% of the total GDP of Bangladesh and 0.26 % of the total GDP of the districts concerned.

The use of chloramphenicol, nitrofurans and penicillins in shrimp aquaculture are particularly hazardous for human health. Chloramphenicol is a broad spectrum antibiotic, used to treat bacterial meningitis and typhoid. Penicillins cause more fatal allergic reactions than any other group of antibiotics. The use of chloramphenicol, penicillin and other antibiotics pose serious threats to consumers if residues of the drugs remain in the shrimp (Food and Water Watch, 2008). In Thailand, 74% farms

use antibiotics on their shrimp (Holmström et al., 2003). In Mexico, it was found that 83% farms use food incorporating antibiotics (Páez-Osuna et al., 2003). In 2001/2002, EU food authorities detected unacceptable levels of chloramphenicol and nitrofuran antibiotics in imported shrimp from China, Vietnam, Indonesia, Thailand and India. Due to perceived health risks to the consumers, the EU, USA and Japan banned the shrimp that use these antibiotics (FDA, US, 2002).

In addition to antibiotics, shrimp farmers use large amount of chemicals to kill fish, molluscs, fungi, plants, insects and parasites in their ponds. Some of these chemicals can remain in the shrimp, potentially causing human health impacts. The cumulative effects of pesticides consumption include cancer and neurological damage that develop slowly. Food and Drug administration of the US regularly check the residues of pesticides in imported shrimp and they can refuse shipment if any residue is found over the legal limit (Food and Water Watch, 2008).

2.7   Discussion and Conclusion

Understanding the tradeoffs between the economic and environmental consequences of shrimp farming is essential for the sustainable development of this industry. By assessing both the economic and environmental effects of shrimp farming, this chapter presents a clear outline of the present status, and problems for the shrimp industry. The evidence and findings suggest that the lucrative economic benefits of shrimp farming are closely associated with substantial environmental degradation in many countries in Asia and Latin America. Therefore, policy makers should consider both the economic contributions and environmental threats in designing policies for the sustainable growth of this industry.

The dimension of economic benefit and environmental degradation varies across countries. The clear, improved and well-coordinated shrimp aquaculture policy should be given priority in the Government policies, and implementation of these policies needs to be ensured. The policy implementation should incorporate the

related Government organizations, NGOs, private sector and coastal communities. In addition, institutional reform may be needed to deal with the environmental issues.

The chapter presents a better understanding of the economic and environmental dynamics of shrimp farming which can be used as the knowledge base for further research. On the basis of the knowledge of this chapter, the following chapters deal with empirical evaluation of tradeoffs between economic and environmental effects of shrimp farming in Bangladesh.

CHAPTER 3

TRADEOFFS BETWEEN ECONOMIC AND ENVIRONMENTAL EFFECTS OF SHRIMP FARMING IN BANGLADESH

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TRADEOFFS BETWEEN ECONOMIC AND ENVIRONMENTAL EFFECTS OF SHRIMP FARMING IN BANGLADESH[3,4]

3.1 Introduction

Shrimp aquaculture is the fastest growing agricultural sector in terms of value added, and the second largest export earning sector in Bangladesh. It has experienced a spectacular growth in the coastal areas of Bangladesh in the last twenty years. This expansion of shrimp aquaculture can be attributed to the suitable climatic conditions and the availability of resources such as feed, seed, water and inexpensive labour force (Islam, 2003; Wahab, 2003). The rapid increase of shrimp farming after the 1980s is due to high profitability on the back of high demand for shrimp on the international markets (Deb, 1998). The economy of Bangladesh has benefited enormously from the rapid development of aquaculture production, in particular from shrimp cultivation. In 2009/10, Bangladesh earned about US$350 million from shrimp export, which is about 3% of the value of total national export (BBS, 2010). There are about 1 million people employed directly in shrimp aquaculture, who support approximately 4.8 million dependents (USAID, 2006). The shrimp farming area in Bangladesh has increased from 51,812 hectares in 1983/84 to 246,198 hectares in 2009/10 and the production of farmed shrimp has increased from 4,386 metric tonnes to 82,044 metric tonnes for the same period (DoF, 2010).

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In the same time, it is widely reported that the rapid growth of shrimp farming has lead to adverse environmental, social and health effects during the last two decades. The excessive development of commercial shrimp farming has generated considerable national and international concerns about its environmental and social cost. Reported environmental consequences related to shrimp farming in Bangladesh are numerous and include: salinisation of soils and saltwater intrusion into freshwater aquifers, loss of wild fish stock, destruction of mangrove forest, effluent discharges of shrimp feed and waste, indiscriminate use of polluting chemicals, and spreading of human infectious diseases (NACA, 1995; Nijera Kori, 1996; Deb, 1998; Bhattacharya et al., 1999; Banks, 2002; Karim, 2003; Haque, 2004; Rahman et al., 2006).

Shrimp farming has particularly adverse effects on soil quality. The five-fold increase in soil salinity levels in many areas seriously hampers crop cultivation (Islam et al.., 1999). The effects of shrimp farming-induced salinity on paddy rice production have a significant negative impact on its productivity (Umamaheswar et al., 2009). In addition, the rapid expansion of shrimp farming has drastically reduced the stock of indigenous fish varieties and destroyed mangrove flora and fauna (Gain, 1998). Bangladesh Fisheries Research Institute (BFRI, 2002) found that during collection of shrimp fry, a substantial number of valuable aquatic organisms are being indiscriminately destroyed, and as a consequence fish catch was gradually decreasing in many shrimp farming areas. The ecological problems created by unplanned shrimp cultivation, particularly in the Chakaria Sundarbans resulted in extinction of mangroves in this area (Gregow, 1997).

Given the significant economic and environmental effects associated with shrimp farming, there is a need to examine the tradeoffs between environmental and economic benefits and costs if there are ambitions for sustainable development of this industry. Quantification of these tradeoffs can help in proposing, designing and enacting policies aimed at achieving sustainable shrimp farming. This chapter measures the tradeoffs between the economic performance and the environmental performance of shrimp farming by applying a Data Envelopment Analysis (DEA)

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model based on a directional distance function approach. This approach is particularly useful to assess the efficiency of production units that generate negative environmental effects in the course of their normal production process aimed at producing the usual, 'desirable' outputs. The approach relies on identifying and quantifying the negative environmental effects, referred to as 'undesirable' outputs that also flow from the production process. In addition, following Färe et al. (1996), this paper reports results on an Environmental Efficiency Index (EEI), which is constructed using the weak and strong disposability constraints of undesirable outputs to examine the opportunity cost (in terms of desirable outputs foregone) of reducing environmental degradation due to shrimp farming. The reminder of this chapter is organized as follows: Section 3.2 introduces the research methods. Section 3.3 describes the data and variables, followed by description of empirical methods in Section 3.4. Empirical results are presented in Section 3.5 and the final section concludes.

3.2 Research Methods

This section introduces the Data Envelopment Analysis (DEA) based directional distance function and environmental efficiency index methods. There are mainly two approaches of measuring efficiency; parametric (e.g. stochastic frontier approach) and non-parametric (e.g. DEA). Tyteca (1996) reviews common methods of measuring environmental performance and outlines conditions for aggregation, which include standardization and unit independence. DEA based distance functions satisfy these conditions and have useful qualities to measure environmental performance. Distance functions are price independent, removing the need to estimate shadow prices for typically non-marketed environmental attributes. It has ability to estimate efficiency and productivity for multiple inputs and outputs, and therefore can capture the myriad ecological attributes. DEA methods also allow the data to 'reveal' how multiple attributes contribute jointly to overall environmental performance as opposed to standard methods which impose a *priori* weighting schemes (Bellenger and Herlihy, 2009). Moreover, while calculating efficiency or productivity, DEA does not need

any specific production function, such as Cobb-Douglas or log-log production functional form. DEA only used given data for analyzing the relationship between output and input as a non-parametric estimation method.

Traditional production theory does not account for the joint production of desirable and undesirable outputs. Since the 1980's significant literature has emerged recognizing the need of taking into account both desirable and undesirable outputs of a production technology, and modifying the conventional measures of efficiency and productivity of decision-making units accordingly (Färe et al., 1989; Färe et al., 1993; Ball et al., 1994; Tyteca, 1996). More recently, directional distance function (Chung et al., 1997; Chambers, 1998; Chambers et al., 1996; Chambers et al., 1998) has been increasingly implemented as a useful functional representation of the production technology that incorporates both desirable and undesirable outputs.

Following Luenberger's benefit function (1992), Chung et al. (1997) provide the basis for representing the joint production of desirable and undesirable outputs by extending the concept of Shephard's output distance function (Shephard, 1970) to the concept of directional output distance function to measure the productivity changes in the Swedish pulp and paper industry. A directional output distance function expands (contracts) desirable (undesirable) outputs along a path that varies according to the direction vector adopted. The directional distance function provides an adequate technique that can approach the economic and environmental performance together and can provide an indication of the overall performance. The flexibility of this technique enhances its usefulness in policy-oriented applications (Picazo-Tadeo et al., 2005). Another advantage of the directional distance function is that it allows an evaluation of the levels of efficiency in any direction from the observation point, as opposed to the distance function that is used to measure the efficiency only in a fixed direction (Watanabe and Tanaka, 2007). A directional distance function as a measure of (in)efficiency represents a complete functional representation of the production technology (Chambers et al., 1998; Färe and Grosskopf, 2000).

Following Chung et al. (1997), suppose that $x = (x_1,...,x_N) \in \mathfrak{R}_+^N$ denotes a vector of inputs, $y = (y_1,...,y_N) \in \mathfrak{R}_+^M$ denotes a vector of desirable outputs, and $b = (b_1,...,b_I) \in \mathfrak{R}_+^I$ denotes a vector of undesirable outputs. Production takes place in $k = 1,...,K$ decision making units. The production technology can be described using the output set as:

$$P(x) = \{(y,b): \text{x can produce } (y,b)\} \tag{1}$$

Where *P(x)* is a convex and compact set and satisfies the standard properties of 'no free lunch', that is: $P(0) = (0,0)$; possibility of inaction, i.e. $(0,0) \in P$; and strong or free disposability of inputs and of desirable outputs, that is if $(x, y) \in P, x' \geq x$ and $y' \leq y$ then $(x', y') \in P$ (Färe and Primont, 1995).

To take into account the joint production of desirable and undesirable outputs, two additional assumptions are defined:

i) Null jointness of the output set: if $(y,b) \in P(x)$ and *b=0*, then *y=0* implying that no desirable output can be produced without producing some undesirable outputs.

ii) The desirable and the undesirable outputs are considered as being together weakly disposable: $(y,b) \in P(x)$ and $0 \leq \theta \leq 1$ imply $(\theta y, \theta b) \in P(x)$

This means that a proportional contraction of desirable and undesirable outputs is feasible and reduction of undesirable outputs is not costless and negatively influences the production level of desirable outputs. Färe and Grosskopf (2004) termed *P(x)* as 'environmental output set' when outputs are weakly disposable, that is undesirable outputs cannot be reduced without reducing desirable outputs, and desirable and undesirable outputs are null-joint. Further, assumption (ii) emphasizes the asymmetry between the desirable and undesirable outputs insofar as desirable outputs are costlessly disposable but undesirable outputs are not (Färe et al., 2001). A graphical illustration of a directional distance function is presented in Figure 3.1 afterwards.

A production technology that satisfies these assumptions can be represented by a directional output distance function (Chung et al.., 1997; Chambers et al., 1998) as:

$$\vec{D}_T(x, y, b; g_y, -g_b) = \sup\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\} \tag{2}$$

where $g = (g_y, -g_b)$ is the directional vector in which desirable and undesirable outputs can be scaled up or down. Given the production technology $P(x)$ and the direction vector g, the directional output distance function represents the maximum feasible expansion of desirable outputs in the g_y direction, and the largest feasible contraction of undesirable outputs in the $-g_b$ direction. This technology can be modeled in alternative ways with a variety of directional vectors dependent on whether the technology exhibits weak or strong disposability of bad outputs (Färe et al., 2005).

If the production technology exhibits strong disposability of outputs, the assumption (ii) above is modified to:
$(y, b) \in P(x)$ and $(y', b') \leq (y, b)$ imply $(y', b') \in P(x)$.
This assumption is used to measure the traditional technical efficiency, where disposing the undesirable output has zero opportunity cost (Färe et al., 2006).

In Eq. (2), β is an expansion factor that indicates the maximal feasible proportional expansion of desirable outputs and contraction of undesirable outputs for a given decision making unit relative to a point on the production frontier. If a decision making unit is completely efficient in maximizing desirable outputs and minimizing undesirable outputs, then the decision making unit is operating on the production possibility frontier, and β is zero. Therefore, β may be considered as a measure of the decision making unit's inefficiency, and (1- β), a measure of its efficiency (Macpherson et al., 2010).

The current study evaluates the efficiency of shrimp farms by considering the weak and strong disposability of bad outputs in the output set $P(x)$ and compares them to

identify any differences in the efficiency values under different scenarios. Under weak disposability assumption the output set includes undesirable outputs and three different directional vectors are used. In Model 1, the directional distance function $\vec{D}_o(x, y, b; 1, -1)$ is constructed so as to increase desirable outputs and to decrease undesirable outputs at the same time by the same proportion with a directional vector $g = (1, -1)$. In Model 2, $\vec{D}_o(x, y, b; 1, 0)$ is constructed to increase desirable outputs while undesirable outputs are kept at their current level with a directional vector $g = (1, 0)$. In Model 3, $\vec{D}_o(x, y, b; 0, -1)$ is constructed to reduce undesirable outputs while keeping desirable outputs at their current level with a directional vector $g = (0, -1)$. All of the above models follow the assumption of weak disposability of outputs, which explicitly stipulates that disposal of undesirable outputs is not a free activity, as commonly assumed in traditional production theory (Picazo-Tadeo et al., 2005). In contrast, model 4 follows the assumption of strong disposability of outputs that implies undesirable outputs can be costlessly disposed. Model 4 takes the form $\vec{D}_o(x, y, 0; 1)$ which excludes undesirable outputs from the output set $P(x)$ and uses the directional vector $g = (1)$. This model completely ignores the harmful characteristics of the undesirable outputs and solely reflects the increase in desirable outputs.

The output set $P(x)$ is illustrated in Figure 3.1 for the four directional output distance functions stated above. In Figure 3.1, the vertical axis shows the desirable output y, while the horizontal axis shows the undesirable output b.

$P(x)$ is the area of all feasible combinations of desirable and undesirable outputs that can be produced by an input vector x. Under the weak disposabilty assumption, the output set $P(x)$ is bounded by the line segment *0ABCE0*, representing the best practice frontier. Points *A*, *B* and *C* represent efficient production points located on the frontier of the production set $P(x)$, while point *D* within the frontier indicates an inefficient production point. Considering Model 1 based on *g=(1,-1)*, *D* is evaluated with $\vec{D}_o(x, y, b; 1, -1)$ relative to point *H* on *P(x)*. In Model 2 based on *g= (1, 0)*, *D* is

evaluated relative to point *F* on *P(x)* with $\vec{D}_o(x, y, b; 1, 0)$. Similarly in Model 3 based on *g=* (0,-1), *D* is evaluated relative to point *I* with $\vec{D}_o(x, y, b; 0, -1)$. Finally, if undesirable outputs are ignored, the feasible output set *P(x)* reduces to the line segment *0K* on the vertical axis. *K* represents the efficient desirable output level at point *B*, and *J* represents an inefficient desirable output level at production point *D*. Hence, Model 4 expands the original output vector (*y*, 0) at point *J* along the direction vector *g=* (1) to the efficient output vector at point *K*.

Figure 3.1 Production Technology *P(x)* and Directional Output Distance Functions
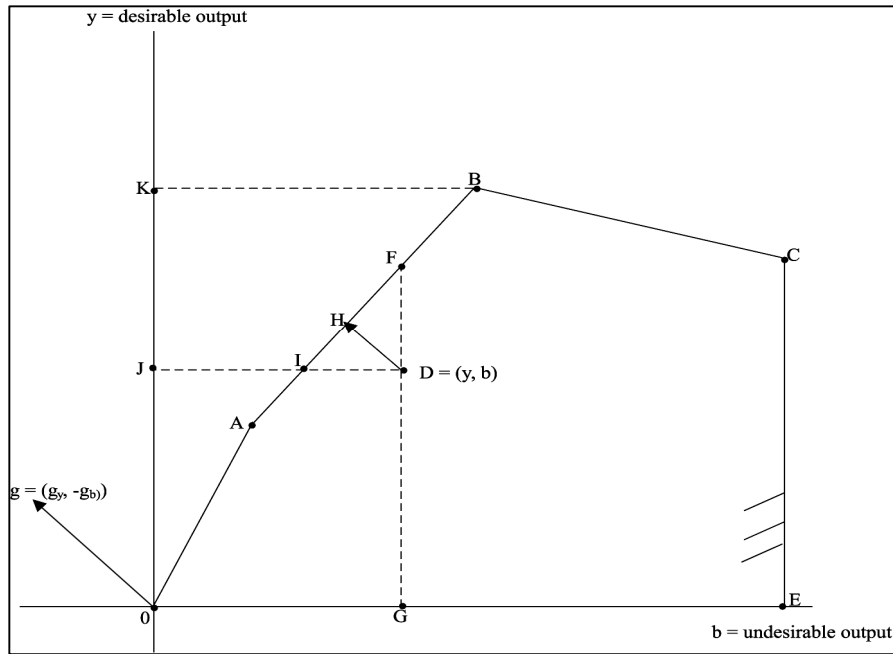
Source: Weber and Weber, 2004.

Environmental Efficiency Index (EEI)

The tradeoffs between the economic and environmental efficiency of shrimp farms can be also addressed by an environmental efficiency index (EEI). Färe et al. (1994) showed how overall productivity can be decomposed into a quality index, an efficiency index, and a technical index, provided that the distance functions they used

for this purpose were multiplicatively seperabel. Following that Färe et al (1996) develped an index of environmental performance, by decomposing overall productivity into an environmental index and a productive effeciency index. Zaim and Taskin (2000) constructed an environmental efficiency index by using hyperbolic graph measure to compute the opportunity cost of transforming the production process from one where all outputs are strongly disposable to another that is characterized by weak disposability of undesirable outputs. Färe et al. (1989) define this opportunity cost as the ratio of two hyperbolic graph measures of technical efficiencies with respect to two technologies characterized by two different disposability assumptions. In these same spirit, directional distance function was used to measure the environmental efficiency index (EEI) for 38 countries over the period 1971-92 (Kumar and Khanna, 2009) and for Environmental Management Systems (EMSs) (Khanna and Kumar, 2011).

In line with the previous literature, the present study uses directional distance functions with alternative assumtions of weak and strong disposability of outputs to measure the environmental efficiency index (EEI). The EEI can be defined as:

$$EEI = (1 + \vec{D}_o(y, b, x)) / (1 + (\vec{D}_o(y, x))) \tag{3}$$

encapsulating the extent to which a farm is constrained in increasing outputs by its potential to transform its production process from free disposability to costly disposal of undesirable outputs. EEI is constructed as a ratio of two directional distance functions: one that exhibits weak disposability $(\vec{D}_o(y, b, x))$, and another that exhibits strong disposability of undesirable outputs $(\vec{D}_o(y, x))$. When a given production unit is equally efficient irrespective of whether or not the undesirable outputs are taken into account, then $\vec{D}_o(y, b, x) = \vec{D}_o(y, x)$ and EEI is 1 (Färe et al., 1996). Since the weak disposability constraint of undesirable outputs becomes increasingly binding, the numerator in Eq. (3) decreases and the opportunities for farms to increase productive efficiency and reduce undesirable outputs diminsh.

A higher $\vec{D}_o(y,b,x)$ implies the presence of more win-win opportunities for the farm to reduce undesirable output and increase desirable output. An EEI < 1 indicates that the weak disposability constrains the production process, and its value indicates the extent to which a farm can increase its desirable output while reducing undesirable output. The closer the EEI is to 1, the smaller the percentage loss in output the farm would incur as it seeks to reduce undesirable output and increase its desirable output. Conversely, (1−EEI) indicates the extent to which a binding undesirable output constraint would reduce the potential to increase desirable output (Khanna and Kumar, 2011). It can be envisaged as an opportunity cost of transforming the production process from strong disposabilty to weak disposability of undesirable outputs. If a disposabilty (whether weak and strong) assumption has no effect, then the two measures of efficiency corresponding to EEI will provide the same value for the directional output distance function, and the EEI will equal to 1. This would imply that the hypothesized environmental constraint is not binding for the farm. A farm's EEI indicates the ratio of its output in the presence of an environmental constraint to its output in the absence of that constraint (Khanna and Kumar, 2011). For example, an EEI of 0.8 indicates that the environmental constraint reduces desirable output by 20% due to diversion of production process from a purely revenue oriented production technology, to a more environmental friendly method. Farms that are less constrained have a lower opportunity cost of transformation in the production process.

3.3 Data and Variables

This section describes the sub-district level data on shrimp production in Bangladesh. The empirical study covers major shrimp farming regions in Bangladesh. This includes the coastal areas of Khulna, Bagerhat, Satkhira and Jessore districts in the Southwest region; Chittagong and Cox's Bazar districts in the Southeast region; and Patuakhali and Pirojpur districts in the Southern region. These districts are located in the 'exposed coastal zone' area in the map in Appendix A. To take into account the possible economic and environmental effects on farms' efficiency, the study focuses

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on two distinct time points, the years 2000 and 2010. Data were collected for representative farms in 31 sub-districts within the above mentioned districts. Each sub-district is considered as an observation unit resulting with 62 observational units for the two time periods analysed.

Following Dyson et al. (2001), all considered representative units are assumed to be undertaking similar activities and producing comparable products by using common technology. This assumption can be safely made in the case of shrimp farming in the study regions in Bangladesh. Shrimp farming is commonly practiced in the coastal districts, with over 90% of all farms in Bangladesh using an extensive shrimp farming system. This is a low-input, low-output system with very little variation across space and time. Therefore, 'representative farm approach' is used which facilitates the incorporation of the environmental variables in the analysis. Modelling with individual farm level data would provide more comprehensive information about the variation in environmental efficiency and productivity scores across the shrimp farms, but farm level data for all variables were not readily available. Therefore, 'representative farm approach' is applied here that can readily captures the local features and resources more easily in the sub-district level.

For the purpose of measuring the efficiency of shrimp farming, three types of variables are considered: desirable outputs, undesirable outputs and inputs. Typically, desirable outputs are marketable goods, whereas undesirable outputs are those that may have harmful effects on environment.

Desirable outputs

To evaluate the environmental efficiency, gross return from shrimp farming was considered to be the desirable output. It is the revenue for a representative shrimp farm, expressed in US$, and was obtained by using per hectare total production of shrimp and their respective price. The average annual catch of a subsistence fishery operation per household (kg) is considered to be another desirable output. This is a valuable activity that many households in the study area are practicing. However, one

of the effects of shrimp farming is that it may result with substantial loss of finfish and shell fish as a consequence of catching tiger shrimp fry along the length of the coastline (BOBP, 1992; BFRI, 2002). Given that subsistence fish catch cannot be treated as an undesirable output – its reduction attributable to shrimp farming could, but data on that were not available – the quantity of average fish catch per household was treated as a desirable output. This ensures that in areas where subsistence fish catch has declined, the reduction in this desirable output is accounted for when calculating economic and environmental efficiency indicators. Subsistence fish catch data were collected from Fisheries Statistical Yearbooks, published by the Department of Fisheries of Bangladesh.

Input

Total cost (a price weighted quantity index of inputs) of shrimp farming is considered as input in this study. For each sub-district the total cost was calculated by adding up the costs for individual inputs. Major items that were included in the total cost are labour, land rent, post larvae (shrimp seed), feed and fertilizer.[5]Average per hectare cost and return data were collected for each sub-district from different secondary sources (Ahmed et al., 2008; Barman and Karim, 2007; BCAS, 2001; DoF, 2000, 2010; Feroz, 2009; Gordon et al., 2009; Islam, 2003; Jahan, 2008; NACA, 2006, 2010; Nuruzzaman, 2006). These average data were used to conceive a representative shrimp farm for that particular sub-district. Each observation unit in this study corresponds to a representative farm associated with each of the sub-districts. Since data for undesirable outputs were only available at sub-district level, the representative per hectare cost and return data needed to be transformed into sub-district level data, so that they correspond directly with data on undesirable outputs. Therefore, the average data for representative farm were multiplied by the total shrimp farming area of that sub-district (DoF, 2000, 2010; PDO-ICZMP, 2005) to derive a homogeneous and compatible data set. Consumer Price Index (CPI) was used to get the deflated real value for cost and return data.

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[5]The individual cost items for each sub-district are not presented here for brevity, but are available from the researcher upon request.

Undesirable outputs

It is widely perceived that shrimp farming is the main reason for increasing soil salinity, impairing soil fertility and causing land degradation in Bangladesh (Deb, 1998; Islam, 2003; Dutta and Iftekhar, 2004). Shrimp aquaculture has raised serious concern about the impact of saltwater intrusion into the surrounding agricultural lands (Flaherty and Karnjakesom, 1995; Flaherty and Vandergeest, 1998). Soil salinity in shrimp growing areas is in the order of five times higher than that of comparable soils in areas where shrimp are not grown (Islam et al., 1999). Therefore, soil salinity is considered as an undesirable output for the present study. The percentage of soil salinity is calculated by considering the saline area that have salinity level 4 ds/m to more to total land area for that sub-district. The data for soil salinity were collected from the Soil Research Development Institute (SRDI) and Bangladesh Fisheries Research Institute (BFRI).

The need of saltwater for shrimp farming is satisfied by digging narrow canals to surge the salt water from the sea to the farm in each shrimp-growing season. This practice significantly affects the surrounding freshwater bodies (BCAS, 2001; Islam, 2003; Chowdhury et al., 2006). Moreover, through seepage and inundation, the brackish water from shrimp farms infiltrates the surrounding areas, increasing the salinity of ground and surface water (EJF, 2004b; Shamsuddin et al., 2006). This is also affecting freshwater aquaculture production, irrigation, drinking water and can contribute to transmitting waterborne diseases. Therefore, surface water salinity is considered as an undesirable output in this study. Surface water salinity is measured as electric conductivity of water (ECw) in different water bodies in a particular sub-district. The data for water salinity were collected from the Department of Environment, Bangladesh Fisheries Research Institute and a study from Ahmed et al. (2010).

Shrimp culture is often regarded as the silent destroyer of mangrove forests (Primavera, 1994; NACA, 1995; Deb, 1998; Gain, 1998). Many areas of the coastal districts in Khulna, Barisal, Patuakhali and Chittagong were once ornamented with

dense mangrove vegetation but mangroves over large areas have been cleared and converted to other land uses, particularly to shrimp farming (Deb, 1998). In the south-eastern parts of Bangladesh an area of 18,200 ha of mangrove (Chakaria Sundarbans) has almost completely been destroyed to make place for shrimp aquaculture (Akhtaruzzaman, 2000). Consequently, loss of mangrove forest is considered to be one of the undesirable outputs for the present study. However, as most of the mangrove forest destruction took place before 2000, and there has been no evidence of further significant decrease of mangrove forest in Bangladesh, it is expected that this variable will have limited influence on environmental efficiency scores of shrimp farms over the considered sample period (Shahid and Islam, 2003; Emch and Peterson, 2006; Giri et al., 2008). Mangrove destruction was only counted for few sub-districts where it was proven that shrimp farming was responsible for the destruction of mangrove forest. In those cases, the percentage loss is accounted as the variable for mangrove loss. The data for mangrove forest area were collected from the Department of Forestry in Bangladesh and Bangladesh Space Research and Remote Sensing Organization (SPARRSO).

In summary, the following variables were used in the present study: gross return from shrimp farming and subsistence fish catch per household are considered as desirable outputs (y); proportion of salinity affected area, water salinity in Electric Conductivity (EC) units, and loss of mangrove forests area are considered as undesirable outputs (b); total cost of shrimp farming is considered as input variable (x). Descriptive statistics of the included variables are presented in Table 3.1.

Table 3.1 Descriptive Statistics of Shrimp Farms and their Externalities by Districts in Bangladesh

District	Shrimp area (ha)		Gross return (US$[6]/ha/year)		Total cost (US$/ha/year)		% of salinity affected area		Water salinity in ECw (ds/m)		Mangrove forest area (ha)		Annual Fish catch (kg/household)	
	2000	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**
Khulna (6)	37,630	36,235	1986	3333	1362	2287	69	70	13-27	15-34	181,600	189,993	31.26	23.61
Bagerhat (7)	42,941	46,571	1680	2778	1032	1852	61	65	0.5-22	4-26	230,919	243,145	27.4	29.21
Satkhira (6)	51,537	64,761	1919	2963	1282	1978	64	67	12-33	17-36	164,525	167,348	34.2	25.87
Jessore (2)	34	825	1704	2315	1204	1589	11	16	5-7	15-22	0	0	24.45	66.78
Cox's Bazar (5)	29,048	51,334	2088	3703	1370	2104	29	34	23-39	32-49	133,731	132,063	29.46	53.38
Chittagong (2)	1548	2895	1861	2407	1278	1709	17	28	2-3	2-6	66802	82,773	22.82	69.88
Patuakhali (2)	2821	1630	1717	2170	1149	1461	44	50	1-32	2-30	16882	33,085	53.22	42.52
Pirojpur (1)	2623	240	1623	2183	901	1391	21	28	7-9	10-12	989	2429	28.56	24.87

*Number in the parentheses indicate subdistricts.

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[6] 1 US$= 53.8 Bangladeshi Taka as of October, 2000

3.4 Empirical Methods

The purpose of using Data Envelopment Analysis (DEA) based directional distance function is to measure efficiency of shrimp farms considering both desirable and undesirable outputs in the production technology. The DEA approach can provide us with a unique indicator that associates to each decision making unit (e.g. a farm), a value that reflects its good or bad environmental performance without any *priori*, arbitrary assumption about how to weight the various impacts (Tyteca, 1996). To evaluate shrimp farms' performance in Bangladesh, this study considers four scenarios according to the Models 1-4 described above.

In Model 1, credit is given to simultaneous expansion of desirable outputs and contraction of undesirable outputs. In this case the maximization problem for the directional output distance function $\vec{D}_o(x, y, b; 1, -1)$ is solved by the following linear programming techniques:

$$\vec{D}_o(x^{k'}, y^{k'}, b^{k'}; g_y, -g_b) = \max \beta \qquad (4.1)$$

s.t.

$$\sum_{k=1}^{K} z_k y_{km} \geq (1+\beta) y_{k'm}, m = 1,..., M \qquad (4.2)$$

$$\sum_{k=1}^{K} z_k b_{ki} = (1-\beta) b_{k'i}, i = 1,..., I \qquad (4.3)$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n}, n = 1,..., N \qquad (4.4)$$

$$z_k \geq 0, k = 1,..., K \qquad (4.5)$$

Where $k = 1,...,K$ indexes the observations in the dataset, β is an (in)efficiency score to be estimated for each decision making unit. The variable z_k is an intensity or weighting variable, assigned to each observation in constructing the production possibility frontier. The non-negativity of this variable imposes an assumption of constant return to scale on technology (Chung et al., 1997). Weak disposability is

imposed by the desirable outputs' inequality constraint in (4.2) and undesirable outputs' equality constraint in (4.3). The directional output distance function takes a positive value for inefficient observations and takes a minimum value of zero for observations that are technically efficient, as they operate on the frontier of $P(x)$. The (in)efficiency score β, represents potential proportional change in desirable and undesirable outputs. If β equals zero, the decision making unit resides on the production possibility frontier. Since desirable outputs are being expanded and undesirable outputs contracted by the same proportion, the value of β is bounded between 0 and 1 (Färe et al., 2006). The model presented in Eqs. (4.1)-(4.5) is run for each observation in the dataset to identify the inefficiency levels for all decision making units, $k=1,...,K$.

In Model 2, credit is given only to the expansion of desirable outputs only when the undesirable outputs are present in the production set. In this case the maximization problem for the directional output distance function $\vec{D}_o(x, y, b; 1, 0)$ is solved by the following linear programming techniques:

$$\vec{D}_o(x^{k'}, y^{k'}, b^{k'}; g_y, 0) = \max \beta \qquad (5.1)$$

s.t.

$$\sum_{k=1}^{K} z_k y_{km} \geq (1+\beta) y_{k'm}, m = 1,...,M \qquad (5.2)$$

$$\sum_{k=1}^{K} z_k b_{ki} = b_{k'i}, i = 1,...,I \qquad (5.3)$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n}, n = 1,...,N \qquad (5.4)$$

$$z_k \geq 0, k = 1,...,K \qquad (5.5)$$

The formulation in Eqs. (5.1)-(5.5) corresponds to Model 2 which shows how much the desirable outputs can be expanded relative to the efficient benchmark on the frontier while the undesirable outputs are kept constant for a given level of inputs

with the assumption of weak disposability of outputs. The only difference between Model 1 and Model 2 is in Model 2, the undesirable outputs are not scaled by β and, therefore, credit is only given to the desirable outputs.

In Model 3, credit is only given to the contraction of the undesirable outputs while the desirable outputs are kept constant in the production set, i.e. desirable outputs are not scaled by β. In this case, the maximization problem for the directional output distance function $\vec{D}_o(x, y, b; 0, -1)$ is solved by the following linear programming techniques:

$$\vec{D}_o(x^{k'}, y^{k'}, b^{k'}; 0, -g_b) = \max \beta \tag{6.1}$$

s.t.

$$\sum_{k=1}^{K} z_k y_{km} \geq y_{k'm}, m = 1, ..., M \tag{6.2}$$

$$\sum_{k=1}^{K} z_k b_{ki} = (1 - \beta) b_{k'i}, i = 1, ..., I \tag{6.3}$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n}, n = 1, ..., N \tag{6.4}$$

$$z_k \geq 0, k = 1, ..., K \tag{6.5}$$

The formulation in Eqs. (6.1)-(6.5) corresponds to Model 3 which shows how much the undesirable outputs can be contracted relative to the efficient benchmark on the frontier while the desirable outputs are kept constant for a given level of inputs with the assumption of weak disposability of outputs.

In Model 4, credit is only giving to the expansion of the desirable outputs by fully excluding the undesirable outputs from the production technology. In this case, the maximization problem for the directional output distance function $\vec{D}_o(x, y; 1)$ is solved by the following linear programming techniques:

$$\vec{D}_o(x^{k'}, y^{k'}; g_y) = \max \beta \qquad (7.1)$$

s.t.

$$\sum_{k=1}^{K} z_k y_{km} \geq (1+\beta) y_{k'm}, m = 1,...,M \qquad (7.2)$$

$$\sum_{k=1}^{K} z_k x_{kn} \leq x_{k'n}, n = 1,...,N \qquad (7.3)$$

$$z_k \geq 0, k = 1,...,K \qquad (7.4)$$

It should be noted that by excluding the undesirable outputs from the production technology, undesirable outputs are implicitly assumed to be freely disposable (Färe et al., 2001), which constitute the main difference compared to Model1-3 where undesirable outputs are assumed weakly disposable together with desirable outputs. The General Algebric Modeling System (GAMS)/Cplex-solver was used to solve the optimisation problems. Cplex is designed to solve the majority of the LP problems and therefore appropriate for the present study (GAMS, 2011).

3.5 Results

A summary of the empirical findings on the efficiency of shrimp farms under four scenarios is presented in Table 3.2, displaying the aggregate average values for the eight districts. The detailed disaggregated results, displaying efficiency scores for all sub-districts / representative farms, from all four models are presented in Appendix C. Table 3.2 shows that the efficiency level across eight shrimp farming districts ranges between 80% to 100% in case of Model 1, $g= (1,-1)$ that credits both expansion of desirable outputs and contraction of undesirable outputs. At a disaggregate level in 2000 (Appendix C), representative farms in seven sub-districts attained the best practice frontier, while most of the sub-districts were exhibiting up to 20% inefficiency. This implies that there is a substantial productive and environmental improvement potential in the sample. For example, the average efficiency value of representative shrimp farms corresponding to the six sub-districts of the Khulna district was 80% in year 2000 (Table 3.2). The average efficiency across

representative farms in Khulna dropped to 73% in 2010, implying an efficiency loss of 7% in a decade. The other two districts of the South-West region, Bagerhat and Satkhira had average efficiency level of 93% and 84% respectively in year 2000. The efficiency scores for these two districts were 88% for both in year 2010.

On the other hand, the districts of Cox's Bazar and Chittagong in the Southeast region had average efficiencies of 86% and 81% respectively in 2000, and attained an increased level of efficiency in 2010. A positive rate of efficiency change indicates representative farm's outward shift towards the best practice frontier in a direction of more desirable outputs and fewer undesirable outputs. Since shrimp farms in these two districts are very near to the sea, they are naturally suitable for shrimp farming, and much less for other types of farming. Consequently, there is no competition for this land with other alternative uses (e.g. rice farming). More significantly, environmental degradation due to shrimp farming (e.g. increased salinity) has been of much less concern in this region. The other models also produced similar relative patterns of average efficiency scores (Table 3.2), although at different levels.

As expected, the efficiency scores vary across the four models considered. Models that take into account undesirable outputs, and either measure the potential for their reduction (Model 1), or hold them constant (Model 2), while measuring the potential to increase desirable output produce similar efficiency scores in a given time period. The efficiency scores are higher than those in the other two models where either only environmental performance (Model 3), or only economic performance (Model 4) is considered. This implies that higher efficiency gains can be achieved by considering both economic and environmental performance, rather than only focusing on one at a time.

All calculated efficiency scores were much lower when desirable outputs were held constant and only a movement towards the frontier in the direction of reducing undesirable outputs was considered (Model 3). This indicates that in general, all representative shrimp farms considered in the sample are far from the efficiency

frontier when it comes to environmental performance, and that there is a substantial room for improvement in that direction. Specifically, the representative shrimp farms comprising the Khulna district show a very poor average environmental performance (only 45% efficient in 2000), which even worsened over time (only 27% efficient in 2010). The representative farms of Jessore, Cox's Bazar, Chittagong and Patuakhali on the other hand show a better environmental performance over time. Since, the shrimp farming is relatively new in Jessore district, indicating that the environmental impacts have not yet been significant enough to be reflected in the efficiency scores.

Calculated efficiency scores when undesirable outputs are completely ignored (Model 4, corresponding to the standard technical efficiency model) are greater than those calculated under Model 3, but significantly lower when compared to Models 1 and 2. This indicates that the representative shrimp farms considered in this sample are not technically efficient, even in conventional sense, as observations are well below the efficiency frontier when considering only desirable outputs. This suggests that there is substantial room for improvement of pure technical efficiency in considered shrimp farming enterprises in Bangladesh. The farms in the districts of Southern region, Patuakhali and Pirojpur are particularly inefficient in terms of pure technical efficiency. This may explain why there has been a recent dwindling trend in shrimp farming area in these districts. For example, the shrimp farming area in Pirojpur district was 2623 ha in 2000, and it declined to 240 ha in 2010. Similarly, the shrimp farming area in Patuakhali district was 2821 ha in 2000, and dropped to 1630 ha in 2010. Farms in Chittagong also show poor economic performance, but there is an improvement over time. It is noticeable that the representative farms in Khulna show an average positive change in economic performance (Model 4), while the changes for this district are negative for the other three models where undesirable outputs are present. It indicates that despite the good economic performance, environmental degradation is a major concern for the shrimp farms in Khulna district. Conversely, shrimp farms in Cox's Bazar district are relatively efficient in both economic and environmental performance.

Table 3.2 Average Efficiency Scores across Representative Shrimp Farms within Districts Obtained From Directional Distance Function Approach

District	Model 1 (g=1,-1)			Model 2 (g=1,0)			Model 3 (g=0,-1)			Model 4 (g=1)		
	2000	2010	% change	2000	2010	% change	2000	2010	% change	2000	2010	% change
Khulna	0.796	0.732	-6.4	0.756	0.711	-4.5	0.453	0.277	-17.5	0.593	0.630	3.38
Bagerhat	0.931	0.880	-5.08	0.941	0.875	-6.5	0.716	0.504	-21.2	0.793	0.778	-1.5
Satkhira	0.839	0.879	4.05	0.819	0.867	4.8	0.519	0.406	-11.6	0.657	0.746	8.8
Jessore	1	1	0	1	1	0	1	1	0	0.939	0.727	-21
Cox's Bazar	0.855	0.932	7.7	0.852	0.931	7.8	0.518	0.713	19.6	0.680	0.727	4.7
Chittagong	0.805	1	19.4	0.560	1	43	0.676	1	32.4	0.319	0.571	25.18
Patuakhali	0.914	1	8.6	0.932	1	6.8	0.555	1	44.5	0.692	0.432	-26.03
Pirojpur	1	0.624	-37.6	1	0.532	-46.8	1	0.415	-58.4	.909	0.480	-42.85

*The efficiency scores are presented as calculation of $(1-\beta)$.

The efficiency numbers support the previous regional level studies and shrimp studies. Sharma et al. (1999), Sharma and Leung (2000), Dey et al. (2000), Gunaratne and Leung (2001), Nielsen (2011) found high efficiency scores for aquaculture production including shrimp. Martinez-Cordero and Leung (2004) also found higher technical efficiency for shrimp farming in Mexico that includes environmental variables. Although, the shrimp farms are following the same technology (extensive farming system) across regions, the bio-physical characteristics of the regions itself have impact on the technical efficiency. The siting of the shrimp farms in Southwest and Southern regions is different from that of Southeast region. In Southwest and Southern regions farms are mostly situated in the lands which have alternative uses, i.e. crop production. Therefore, environmental attributes due to shrimp farming adversely affect the efficiency. On the other hand, in Southeast region, shrimp farms are situated in the lands that are fed by natural salt water, and therefore create limited environmental consequences.

The tradeoffs between the economic and environmental performance of shrimp farms are represented by the environmental efficiency index (EEI). The EEI is constructed using the values of directional distance functions obtained from Model 1 and Model 4, where the former displays the weak disposability assumption, and the latter displays the strong disposability assumptions for undesirable outputs.

EEI provides an indication of representative farm's potential of increasing efficiency from its existing position by measuring how much desirable outputs need to be sacrificed for this improvement. The farms that have significant potential to improve their performance by increasing desirable outputs and decreasing undesirable outputs have lower opportunity cost and thereby high EEI. Conversely, those farms that are already closer to the efficient frontier need to sacrifice more desirable outputs to increase one unit of efficiency as it becomes difficult to increase the efficiency further when the farm is nearly efficient. The estimated average EEI for representative farms of the eight districts are presented in Table 3.3. The EEI for the year 2000 ranges from 70% to 94%, implying that the percentage loss in desirable outputs due to the constraint of weak disposability ranges between 6% and 30%. For the year 2010, EEI

ranges from 60% to 92%. For example, in Khulna, the EEI is 0.857 in 2000, implying that shrimp farms need to sacrifice 14% of their desirable outputs to increase their efficiency. But in 2010, the EEI for farms in Khulna increased to 0.925, implying that the percentage loss in desirable outputs became 8% to increase farm performance. Since the farms are situated relatively far away from the efficient frontier in 2010, they have more opportunity to improve their performance with lower cost.

The representative farms of Cox's Bazar and Chittagong districts have improved their performance in terms of efficiency measured by directional distance function models. Therefore, in order to improve their performance further, they need to sacrifice more desirable outputs to move even closer to the efficient frontier, and thus the EEI became smaller. For example, with an EEI of 0.867, the loss in desirable outputs for the farms in Cox's Bazar district is 13% in 2000, and it became 16% in 2010 when the EEI dropped to 0.839. This just illustrates that the EEI gives the indication of tradeoffs, or the costs of transforming the production technology from conventional, to a more environmental friendly production. When this cost is low, farms are in better position to improve their performance. Since most of the representative shrimp farms attained EEI scores that range between 80% and 90%, it is an indication that they can improve their performance by sacrificing 10% to 20% of desirable outputs (Appendix B), as it implies that overall there is a potential to divert the production process at relatively low cost.

3.6 Conclusions

The overall economic and environmental performance of shrimp farms is of great importance for Bangladesh, given the significance of this industry to the economic life of the country and to its environmental health. The estimated efficiency values in this paper reflect both the economic performance and the environmental performance of shrimp farms as the estimation considers scenarios that sequentially include and exclude undesirable outputs from the production technology. Using directional distance function, this study measured the efficiency in the shrimp farming industry. Four different directional vectors are used to evaluate the possible directions for

improving economic and environmental performance of shrimp enterprises. The results show that there is a significant variation in the efficiency when different directions of movement towards the efficiency frontier are considered.

Table 3.3 Environmental Efficiency Index (EEI) of Shrimp Farms by Districts in Bangladesh

District	$\vec{D}_o(y,b,x)$		$\vec{D}_o(y,x)$		EEI	
	2000	**2010**	**2000**	**2010**	**2000**	**2010**
Khulna	0.204	0.268	0.404	0.370	0.857	0.925
Bagerhat	0.069	0.120	0.207	0.222	0.886	0.917
Satkhira	0.161	0.121	0.343	0.254	0.865	0.894
Cox's Bazar	0.145	0.068	0.320	0.273	0.867	0.839
Chittagong	0.195	0	0.681	0.429	0.711	0.700
Jessore	0	0	0.061	0.273	0.942	0.786
Patuakhali	0.086	0	0.308	0.568	0.867	0.638
Pirojpur	0	0.376	0.090	0.519	0.831	0.906

The results also show that there is a significant room for improvement both in direction of improving economic performance, and in direction of improving environmental performance. The EEIs show that there is a potential for shrimp farms to transform the production process from strong disposability assumption to weak disposability assumption at a relatively low cost.

Existing public policy towards shrimp production in Bangladesh does not adequately address the need of the industry to improve its environmental and economic performance. The results from this study show that farm performance varies in terms of economic and environmental aspects. Environmental performance is a great concern for the Southwest region, which includes Khulna, Bagerhat and Satkhira districts. Therefore, the policy for this region should be more environmentally oriented, so that the farms can improve their overall efficiency in a sustainable

manner. Existing policy does not give farmers any incentives for reducing undesirable outputs and the farmers are not aware of this as reduction of undesirable outputs has no effect on production. Farmers should be motivated by incentive based policies to reduce undesirable outputs and to adopt and develop new environmental friendly production methods.

Conversely, farms in the Southeast region (Cox's Bazar and Chittagong districts) are doing fairly well in terms of environmental issues and more focus should be given to improve their economic performance, especially in the Chittagong district. The experience and information from the identified high performing farms (e.g. Moheshkhali and Ukhiya sub-districts) can be shared and exchanged with the low performing farms (e.g. Bashkhali and Anowara) to improve their operation. The same policy guide is applicable for Patuakhli district. For some districts (e.g. Pirojpur), policy should be focused on both the economic and environmental aspects, so the farms can be sustainable.

Policy makers can use the identified tradeoffs between the desirable and undesirable outputs (economic and environmental effects), which will allow them to devise balanced policies to improve current operations and enhance sustainability. Emphasis should be put to those sub-districts where the overall improvements can be made with lower cost in terms of shrimp revenue foregone. The results could provide the basis for implementing more region-specific policies for shrimp industry which will be useful to improve environmental performance of shrimp farms in conjunction with their economic performance.

CHAPTER 4

PRODUCTIVITY GROWTH IN THE SHRIMP FARMING INDUSTRY OF BANGLADESH: A LUENBERGER PRODUCTIVITY INDICATOR APPROACH

CHAPTER 4

PRODUCTIVITY GROWTH IN THE SHRIMP FARMING INDUSTRY OF BANGLADESH: A LUENBERGER PRODUCTIVITY INDICATOR APPROACH[7,8]

4.1 Introduction

Export oriented shrimp farming has undergone a rapid expansion in Bangladesh over the last three decades. Although shrimp aquaculture began its expansion in the 1970s, the export oriented shrimp industry truly took off in the 1980s, when large scale shrimp aquaculture in countries ahead of Bangladesh in terms of development and income, such as Thailand, Indonesia, China, the Philippines and Taiwan began to suffer from environmental and social damage (Ito, 2002). This sector contributes significantly to the GDP by earning over 350 million US dollars a year, making up about 3% of total export earnings (EPB, 2012). It has also contributed significantly to the employment and community development in the coastal region of Bangladesh. The growth of shrimp farming is attributed to the high demand for shrimp for export. The coastal areas of Bangladesh are particularly suitable for shrimp farming due to their favourable natural and agro-climatic condition and low production cost. Shrimp farming has therefore rapidly expanded in the coastal districts of Bangladesh including Khulna, Bagerhat, Satkhira, Cox's Bazar, Chittagong, Patuakhali and Pirojpur districts. Currently, there are about 250,000 hectares of land occupied with shrimp farms in these regions, producing about 156 million tonnes of shrimp annually (DoF, 2010). The shrimp production system in Bangladesh uses low input, extensive methods, and often integrates with other crops such as rice, vegetables, and finfish

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[7] *This paper is currently being prepared for submission to an international journal.*

[8] *This paper was presented at the 57th AARES Annual Conference, 5-8 February, 2013, Sydney, Australia, and to be presented at the 13th European Workshop on Efficiency and Productivity Analysis (EWEPA"13), 17-20 June 2013 Helsinki, Finland.*

depending on the local agro-climatic condition. However, productivity of shrimp culture is low due to high mortality rates of stocked fry, poor management techniques and lack of infrastructure in coastal areas. Average shrimp production is less than 200 kg/ha which is very low compared to the other shrimp producing countries in the world (Mazid, 2003, Karim, 2003). Given these existing production inefficiencies, there is high potential to increase production from improved extensive farming systems.

The rapid development of shrimp culture brought about negative environmental impacts, has to be creating major concern for environmental quality in these highly environmentally sensitive coastal areas of Bangladesh. Increasing salinity, declining productivity of land, destruction of mangrove forests, declining inland capture fishery production are some of the often cited environmental problems associated with shrimp culture (Deb, 1998; Bhattacharya et al., 1999; EJF, 2004a,b; Wahab, 2003; Gain, 2002). These environmental impacts, which could at least in part be attributed to commercial shrimp farming compromise the sustainable development of this industry. The challenge for sustainable growth of this industry is to improve the production performance and at the same time minimize its environmental effects.

The previous chapter measured efficiency of shrimp farms by applying a directional distance function for a given period. In that case the frontier that exhibit best practice input-output combination is defined in a given period and it is assumed that other observations are also using the same period input-output combinations. While it gives us an indication of farm performance considering a static time, directional distance function can also be used to measure productivity growth and can be aggregated to the industry level using time dependent Luenberger productivity indicator. To measure the productivity growth, the directional distance function has to be evaluated in different periods. The analysis of productivity growth will help to identify performance of shrimp farms over time when the production technology adjusts some inputs and outputs. Productivity growth, attained by technological progress and/or efficiency gains is an important goal for the sustainable growth of the shrimp

industry. This model can easily decompose the productivity growth into technological change and technical efficiency change components by which it is possible to identify the reasons of productivity change.

In light of this, the present chapter aims to assess the dynamics of productivity growth of shrimp farming industry in Bangladesh over time, considering both economic and environmental outcomes associated with this sector. A Luenberger productivity indicator will be applied for this purpose. This will help to identify the potential of productivity growth of this industry, and to design and propose necessary policies aimed at sustainable development of this industry.

4.2 Research Methods

Traditional productivity analysis focuses on measuring marketable outputs of firms and industries that can be expressed in monetary terms. This approach typically ignores the undesirable outputs (i.e. environmental pollution or degradation of natural resources) that are inadvertently produced in parallel with the desirable outputs. Therefore, this productivity measure often fails to provide the 'true productivity' of firms and industry (Chung et al., 1997). In one of the first attempts to alleviate these shortcomings, Pittman (1983) proposed to measure the efficiency by incorporating undesirable outputs through the introduction of shadow prices, where based upon the known prices of desirable outputs, the absolute prices for undesirable outputs can be computed (Färe and Grosskopf, 2003). While productivity changes can be modelled by both parametric and non-parametric methods (Odeck, 2007; Casu et al., 2004; Williams et al., 2011), the non-parametric approach has probably been more popular in recent studies measuring efficiency and productivity. In case of parametric approach, a well known method for measuring productivity is stochastic frontier approach. But when there is more than one output, it is difficult to estimate productivity by this approach since Cobb-Douglas or translog functional specifications are often viewed as having several limitations. On the other hand, Data Envelopment Analysis facilitates the construction of a non-parametric piece-wise

frontier over the existing data. Unlike regression, which determines a statistical relationship between dependent and independent variables at the conditional mean level, DEA determines optimal solution for every observation in the data set. Also, DEA allows flexibility in the choice of weights on the inputs and outputs. This approach can also capture any productive inefficiency, and offers a "benchmarking" perspective (Boussemart et al., 2003).

There are several indexes that can measure the total factor productivity (TFP) of any decision making unit (DMU). For example, TFP can be measured by Fisher and Törnqvist indexes. But these indexes require price information which make these indexes inappropriate for measuring productivity in the presence of non-marketable goods like environmental attributes. Later on, Caves et al. (1982, a,b) defined the Malmquist productivity index as a ratio of distance functions that could be used to measure the productivity growth. The limitation of Malmquist index is that it requires a choice to be made between an output or an input oriented perspective corresponding to revenue maximisation or cost minimisation (Boussemart et al., 2003). This limiting assumption of profit maximization or cost minimization is not needed if productivity change is estimated using the Luenberger indicator, which is a difference based indicator as opposed to the ratio-based Malmquist index (Williams et al., 2011).

The Luenberger indicator can account for output expansion and input contraction whilst assuming that sample farms maximize profit. Moreover, the empirical studies by Briec and Kerstens (2004) and Boussemart et al., (2003) showed that Malmquist productivity index overestimates the productivity change compared to the Luenberger indicator that looks for simultaneous input contractions and output expansions, compatible with the economic goal of profit maximisation (Epure, 2011). Chambers et al. (1996b) explained the Luenberger productivity indicator as a generalisation of the Malmquist index and applied to measure the productivity growth in APEC countries. They introduce the Luenberger productivity indicator as a difference of directional distance functions based on Luenberger's shortage function (Luenberger, 1992). The merit of shortage function is that it has the desirable properties of

accounting for both input and output improvements and is dual with the profit function

While the Luenberger Productivity Indicator is theoretically well developed, there is very little empirical work reported in the literature (Managi, 2004). This indicator has been used to measure the productivity growth in the banking sector (Koutsomanoli-Filippaki et al., 2009; Williams et al., 2011; Epure et al., 2011; Barros et al., 2010; Brandouy et al., 2010; Park and Weber, 2006), in the hospital sector (Barros, et al.., 2007); in hotel and tourism industry (Peypoch, 2007; Peypoch and Solonandrasana, 2006, 2008; Barros et al., 2009; Peypoch and Sbai, 2011), in educational sectors (Barros et al.., 2011), and measuring productivity of different plants (Autant-Bernard et al., 2010; Briec et al., 2011). These studies measured productivity growth using non-parametric directional distance function approach that is compatible with profit maximisation assumption, but did not account for environmental efficiency in measuring productivity. Only few papers have applied this approach including environmental effects as undesirable outputs. Weber and Weber (2004) used the Luenberger productivity indicator in measuring productivity of trucking industry and incorporated fatal accidents involving trucks as an undesirable output. More recently, Färe et al. (2012) used the Luenberger total factor productivity indicator to measure the productivity in the Swedish manufacturing industry which includes three undesirable outputs (carbon dioxide, sulfur dioxide and nitrogen oxide) in addition to typical desirable outputs and inputs in the production technology. To the best of researcher's knowledge, there have been no studies so far using the Luenberger productivity indicator in agricultural sector, and particularly in aquaculture, to measure the environmentally adjusted farm productivity. The present study applies this method including undesirable outputs to measure the productivity growth of shrimp farming industry.

This paper uses the theoretical framework based on productivity measurement, using the directional distance function and the Luenberger productivity indicator (Chambers, 1998; Chambers et al., 1996b). The directional distance function plays an

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important role in production theory and has the powerful advantage of taking into account the variation of both input and output bundles simultaneously. This function determines a distance in one direction which permits an observed production unit to reach the production frontier (Williams et al., 2011). In economic terms, the directional distance function makes it possible to evaluate the scale of the economies that can be achieved by possible improvements in production. It also provides a benchmark by defining a reference point to be reached (Barros et al., 2007).

The Luenberger productivity indicator is constructed in terms of difference between directional distance functions rather than their ratios. One of the major advantages of using the Luenberger productivity indicator is that it allows for inclusion of undesirable outputs whilst measuring productivity without requiring information on prices. This indicator can also capture the time dimensions of a production process. It credits production units for reduction of undesirable outputs, providing a measure of productivity and indicates whether the 'true' productivity has improved over time (Chung et al., 1997). However, Briec and Kerstens (2009) show that the feasibility of the Luenberger productivity indicator can in general not be guaranteed since the shortage function may not achieve its distance in the case where a point need not be part of technology and where the direction vector can take any value.

This chapter applies the Luenberger productivity indicator to estimate the productivity growth of shrimp farming in Bangladesh, when both desirable and undesirable outputs are jointly produced. In general, the Luenberger Indicator has some advantages over other productivity indicators. This additive nature of this indicator supports the more natural relationship of the profit function to the directional distance function, since directional distance function is additive in nature. Following Chambers (1996), the Luenberger productivity indicator can be additively decomposed into technological progress (the rate of change of the best practice frontier) and technical efficiency change (learning by doing, improved managerial practice as firms attempt to catch-up with industry best practice) components. This decomposition was inspired by the breakdown of the Malmquist index in Färe et al.

(1994). Given the nature of the data set which consists of two time periods, the study chose to apply the Luenberger productivity indicator since it can be aggregated to the industry level and can yield estimates of technical progress or regress from period to period. To facilitate the aggregation of the Luenberger productivity indicator, a common direction for all observations is chosen to expand and/or contract desirable and undesirable outputs respectively. The Luenberger indicator and its components can be added over farms which allows to aggregate farm indicators up to an industry indicator, when all farms are evaluated relative to a common direction (Färe et al., 2012). The additive nature of the Luenberger Productivity Indicator is particularly useful in cases where undesirable outputs are included in the model (Grosskopf, 2002). Data Envelopment Analysis (DEA) is applied to calculate the Luenberger productivity and its components (technological change and efficiency change).

In general, two special cases of the Luenberger productivity indicator can be identified—the input based and the output based indicator, based on directional input and directional output distance function respectively. In this paper, four output based Luenberger indicators are calculated for four different models of which three include undesirable outputs and one does not. The first model (Model 1) gives credit to a farm for expanding desirable outputs while contracting undesirable outputs. Model 2 credits farms only for expanding desirable outputs when undesirable outputs are still present in the production technology. Model 3 credits farm for contracting the undesirable outputs, while the desirable outputs are held constant. Model 4 excludes undesirable outputs from the production process and only considers the expansion of desirable outputs.

To introduce the directional distance function, consider a vector of inputs $x = (x_1,...,x_N) \in \Re_+^N$ that are employed to produce a vector of desirable outputs $y = (y_1,...,y_N) \in \Re_+^M$. Production of these outputs also results with a vector of undesirable outputs $b = (b_1,...,b_I) \in \Re_+^I$ being inadvertently produced. Let *P(x)* be the

feasible output set for the given input vector *x*. The production technology is modelled by the directional distance function and can be represented by its output set:

$$P(x) = \{(y,b): \text{x can produce } (y,b)\} \tag{1}$$

In order to describe and model the production technology in which both the desirable and undesirable outputs are jointly produced, a number of assumptions are required, which are articulated in the form of axioms.

First, it is assumed that the output set is closed and bounded set and that inputs are freely disposable (Färe and Primont, 1995), i.e. if $x' \geq x$ then $P(x') \geq P(x)$.

In addition, null jointness is assumed, so that: if $(y,b) \in P(x)$ and $b = 0$ then $y = 0$.

Null-jointness implies that a production unit cannot produce desirable outputs without producing some undesirable outputs.

An important axiom of this function is that reduction of undesirable outputs is not costless:

if $(y,b) \in P(x)$ and $0 \leq \theta \leq 1$ then $(\theta y, \theta b) \in P(x)$:

This axiom states that desirable and undesirable outputs are together weakly disposable implying that there is a cost for reducing undesirable outputs.

Another axiom is that strong disposability of desirable outputs:

if $(y,b) \in P(x)$ and $y' \leq y$ imply $(y',b) \in P(x)$

This axiom indicates that the desirable outputs can be reduced freely without reducing any other outputs. These axioms are applicable for Models 1 through 3. Based on these axioms, and letting $g = (g_y, -g_b)$ be a directional vector describing how the (*y,-b*) vector is projected onto the frontier of output set, the directional distance function is defined on *P(x)* as:

$$\vec{D}_o(x,y,b;g_y,-g_b) = \sup\{\beta : (y + \beta g_y, b - \beta g_b) \in P(x)\} \tag{2}$$

The directional distance function simultaneously expands desirable outputs and contracts undesirable outputs and its value β is bounded below by zero. An observed

output vector is technically efficient if it takes the value of zero, meaning that it is located on the frontier. Values greater than zero are associated with output vectors in the interior, indicating technical inefficiency.

Following Färe et al. (2012), the Luenberger productivity indicator compares farm performance in adjacent periods, t, and $t+1$. To calculate the Luenberger productivity indicator, four directional distance functions for each of the four models need to be specified: two functions where the reference technology and the observed output set can be compared to the technology from the same period, $\vec{D}_o^t(x^t, y^t, b^t; g_y, g_b)$ and $\vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g_y, g_b)$, and two functions where the reference technology and the observed output set are from different periods, $\vec{D}_o^t(x^{t+1}, y^{t+1}, b^{t+1}; g_y, g_b)$ and $\vec{D}_o^{t+1}(x^t, y^t, b^t; g_y, g_b)$. Given these directional distance functions, the Luenberger productivity indicator including undesirable outputs can be expressed by the following equation:

$$
\begin{aligned}
L_o\left(y^t, b^t, x^t, y^{t+1}, b^{t+1}, x^{t+1}; g_y, g_b\right) = \frac{1}{2} &\left\{ \left[\vec{D}_o^{t+1}(x^t, y^t, b^t; g_y, g_b) - \vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g_y, g_b) \right] \right. \\
&\left. + \left[\vec{D}_o^t(x^t, y^t, b^t; g_y, g_b) - \vec{D}_o^t(x^{t+1}, y^{t+1}, b^{t+1}; g_y, g_b) \right] \right\}
\end{aligned}
\tag{3}
$$

This productivity indicator compares performance in period t and period $t+1$, with superscripts indicating the relevant period. The first of the four directional distance functions on the right hand side of the equation represents an artificially constructed measure that assumes a $t+1$ period technology, but reflects t period input and output quantities. The second directional distance function on the right hand side of equation (3) assumes a $t+1$ period technology and reflects the same period input and output quantities. Similarly, the third directional distances function of equation (3) represents t period technology and reflects the same period input and output quantities. The fourth directional distance function in equation (3) represents a t period technology, but reflects $t+1$ period input and output quantities. Negative (positive) values of the

productivity indicator L(.) imply a decrease (increase) in productivity between the two periods. Chambers et al. (1996b) demonstrate that the Luenberger productivity indicator can be decomposed additively into an efficiency change component, $LECH_t^{t+1}$, and a technological change component, $LTCH_t^{t+1}$, where explicitly

$$LECH_t^{t+1} = \vec{D}_o^t(x^t, y^t, b^t; g_y, g_b) - \vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g_y, g_b) \qquad (4)$$

and

$$LTCH_t^{t+1} = \frac{1}{2}\left\{\left[\vec{D}_o^{t+1}(x^{t+1}, y^{t+1}, b^{t+1}; g_y, g_b) - \vec{D}_o^t(x^{t+1}, y^{t+1}, b^{t+1}; g_y, g_b)\right] \\ + \left[\vec{D}_o^{t+1}(x^t, y^t, b^t; g_y, g_b) - \vec{D}_o^t(x^t, y^t, b^t; g_y, g_b)\right]\right\} \qquad (5)$$

The efficiency change component measures "catching up" to the *current technology* frontier and the technological change component measures the *change in technology* itself from period to period (Weber and Weber, 2004). $LECH_t^{t+1}$ captures the efficiency change between periods t and $t+1$, i.e. catching up or falling behind relative to the best practice frontier. A positive (negative) value of $LECH_t^{t+1}$ indicates increase (decrease) in efficiency. On the other hand, $LTCH_t^{t+1}$ measures how far a period t observation (y^t, x^t, b^t) is from the period $t+1$ frontier, $P^{t+1}(x^{t+1})$, and how far a period $t+1$ observation $(y^{t+1}, b^{t+1}, x^{t+1})$ is from the period t frontier $P^t(x^t)$ i.e. it measures shifts in the production possibilities frontier itself. A positive (negative) value of $LTCH_t^{t+1}$ indicates technological progress (technological regress) between periods. If there are no changes in the efficiency or in the technology, the expressions in Eqs. (4) and (5) take the value of zero. A positive (negative) value of the indicators indicates improvement (deterioration) in the efficiency and/or technology respectively.

A graphic representation of the Luenberger productivity indicator is given in Figure 4.1. In the figure, it is assumed that the directional vector is g =(1,-1). It is also assumed that the inputs are the same in period t and $t+1$, and are represented by

$x = x^t = x^{t+1}$. Given the directional vector, $g=(1,-1)$, the directional output distance function is an estimate of the simultaneous expansion in desirable output and contraction of undesirable output. The efficiency change measures how close the observations D and D' are to the technologies $P^t(x)$ and $P^{t+1}(x)$, respectively. If there is no technical inefficiency, then D could operate at H in period t technology, and D' could operate at M in period $t+1$ technology, respectively. Thus the efficiency change indicator can be stated as $LECH_t^{t+1} = \dfrac{DH}{0g} - \dfrac{D'M}{0g}$. It captures the change in the distance of an observation to its respective best-practice frontier in periods t and $t+1$.

A value equal to zero indicates no change in efficiency. A value less than zero indicates an increase in the distance to the frontier and hence an efficiency decrease, and a value greater than zero indicates a decrease in the distance and hence an increase in efficiency. Technological change is the average distance between the two technologies (Chambers et al.., 1996) and can be stated as $LTCH_t^{t+1} = \left[\dfrac{DL}{0g} - \dfrac{DH}{0g} + \dfrac{D'M}{0g} - \dfrac{D'N}{0g} \right] = \dfrac{1}{2}\left[\dfrac{HL}{0g} + \dfrac{NM}{0g} \right]$. A value greater than zero indicates an outward shift of the best-practice frontier and hence technological progress. A value equal to zero indicates no shift and hence no technological change.

Figure 4.1 Luenberger Productivity Indicator
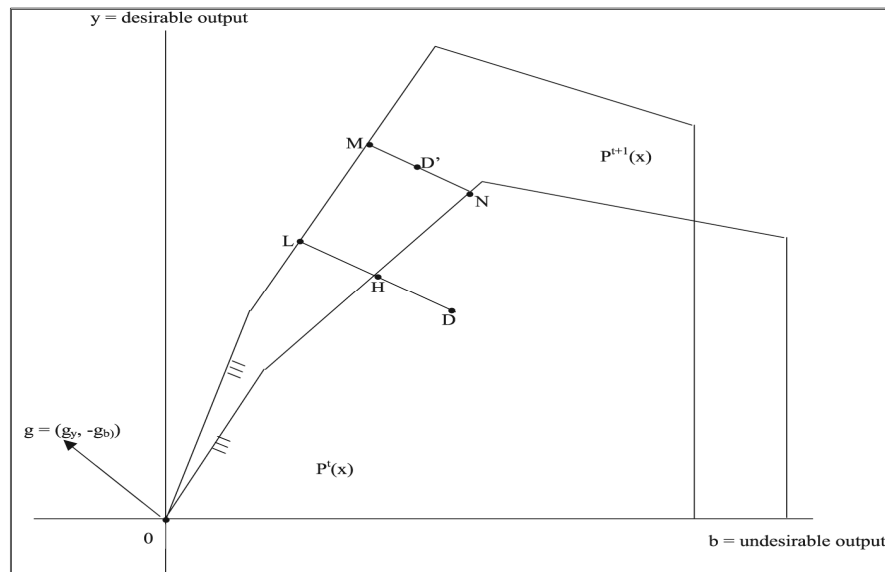
Source: Weber and Weber, 2004.

The other three models that posit different directional vectors can also be described in a very similar way. However, the technology construction of model 4 is different from other three models (Model 1− 3) to some extent. Here, Models 1– 3 use same output set *P(x)* while the Model 4 uses the output set $\hat{P}(x)$ which excludes the undesirable outputs. In Model 4, the undesirable outputs are implicitly assumed to be freely disposable (Färe et al., 2000) implying that the model completely ignores the harmful characteristics of the undesirable outputs and solely seeks to increase the desirable outputs. This constitutes the main difference compared to the Models l-3, where undesirable outputs are weakly disposable with desirable outputs. Excluding undesirable outputs, the directional distance function is defined on the output possibility set as:

$$\hat{P}(x) = \{ y : x \text{ can produce } y \} \tag{6}$$

and

$$\vec{D}_o(x, y; g_y) = \max \ \{ \beta : (y + \beta . g_y) \in \hat{P}(x) \}. \tag{7}$$

In case of model 4, the Luenberger productivity indicator is defined as:

$$\hat{L}_t^{t+1}(x, y; g_y) = \frac{1}{2} \Big[\vec{D}_o^{t+1}(x^t, y^t; g_y) - \vec{D}_o^{t+1}(x^{t+1}, y^{t+1}; g_y) + \vec{D}_o^t(x^t, y^t; g_y) - \vec{D}_o^t(x^{t+1}, y^{t+1}; g_y) \Big] \tag{8}$$

With the decomposition: $\hat{L}_t^{t+1}(x, y; g) = \hat{LECH}_t^{t+1} + \hat{LTCH}_t^{t+1}$. In this particular case the directional vector is $g = (g_y = 1)$.

4.3 Empirical Techniques

To compare the four Luenberger productivity indicators, including and excluding undesirable outputs, mathematical programming techniques for data envelopment analysis are used. For each productivity indicator, four maximization problems need to be solved; two for within-period distance functions and two for mixed-period distance functions (Färe et al., 2012). In Model 1 (*g*=1,-1), credit is given to simultaneous expansion of desirable outputs (*y*) and contraction of undesirable

outputs (*b*) while the input (*x*) is kept constant in measurement of productivity indicators. In this case, an example of the maximization problem for the mixed-period distance function, $\vec{D}_o^{t+1}(t)$, is given by:

$$\vec{D}_o^{t+1}(x^{k't}, y^{k't}, b^{k't}; 1, -1) = \max \beta \tag{9.1}$$

s.t.

$$\sum_{k=1}^{K} z_k^{t+1} y_{km}^{t+1} \geq (1+\beta) y_{k'm}^t, m = 1,...,M \tag{9.2}$$

$$\sum_{k=1}^{K} z_k^{t+1} b_{ki}^{t+1} = (1-\beta) b_{k'i}^t, i = 1,...,I \tag{9.3}$$

$$\sum_{k=1}^{K} z_k^{t+1} x_{kn}^{t+1} \leq x_{k'n}^t, n = 1,...,N \tag{9.4}$$

$$z_k^{t+1} \geq 0, k = 1,...,K \tag{9.5}$$

In addition to the weak disposability and null-jointness axioms, constant returns to scale holds since the intensity variables, $z_k, k = 1,...,K$ are required to be non-negative. The above representation is directly relevant for $\vec{D}_o^{t+1}(t)$, but the maximization problems for $\vec{D}_o^{t+1}(t+1)$, $\vec{D}_o^t(t+1)$, and $\vec{D}_o^t(t)$ can be posited and solved in a very similar way.

In Model 2 (g = 1,0), undesirable outputs are present in the production technology but credit is not given for their reduction. For this Model, the maximization problem for the mixed-period distance function $\vec{D}_o^{t+1}(t)$ is given by:

$$\vec{D}_o^{t+1}(x^{k't}, y^{k't}, b^{k't}; 1, 0) = \max \beta \tag{10.1}$$

s.t.

$$\sum_{k=1}^{K} z_k^{t+1} y_{km}^{t+1} \geq (1+\beta) y_{k'm}^t, m = 1,...,M \tag{10.2}$$

$$\sum_{k=1}^{K} z_k^{t+1} b_{ki}^{t+1} = b_{k'i}^t, i = 1,...,I \tag{10.3}$$

$$\sum_{k=1}^{K} z_k^{t+1} x_{kn}^{t+1} \leq x_{k'n}^t, n = 1, ..., N \tag{10.4}$$

$$z_k^{t+1} \geq 0, k = 1, ..., K \tag{10.5}$$

The only difference of Model 2 compared to Model 1 is explicitly that undesirable outputs are not scaled by β, and therefore the undesirable outputs restriction become $\sum_{k=1}^{K} z_k^{t+1} b_{ki}^{t+1} = b_{k'i}^t, i = 1, ..., I$. However, undesirable outputs are still assumed weakly disposable together with desirable outputs in this Model. Again the maximization problems for $\vec{D}_o^{t+1}(t+1)$, $\vec{D}_o^t(t+1)$, and $\vec{D}_o^t(t)$ can be posited and solved in a very similar way.

Similarly, in Model 3 ($g = 0,-1$), desirable outputs are present in the production technology but credit is not given for their expansion, i.e. desirable outputs are kept constant. Therefore, the desirable outputs restrictions become $\sum_{k=1}^{K} z_k^{t+1} y_{km}^{t+1} \geq y_{k'm}^t, m = 1, ..., M$ since the assumption of increasing desirable outputs is not applicable in this case. For Model 3, the maximization problem for the mixed-period distance function $\vec{D}_o^{t+1}(t)$ is given by:

$$\vec{D}_o^{t+1}(x^{k't}, y^{k't}, b^{k't}; 1, 0) = \max \ \beta \tag{11.1}$$

s.t.

$$\sum_{k=1}^{K} z_k^{t+1} y_{km}^{t+1} \geq y_{k'm}^t, m = 1, ..., M \tag{11.2}$$

$$\sum_{k=1}^{K} z_k^{t+1} b_{ki}^{t+1} = (1-\beta) b_{k'i}^t, i = 1, ..., I \tag{11.3}$$

$$\sum_{k=1}^{K} z_k^{t+1} x_{kn}^{t+1} \leq x_{k'n}^t, n = 1, ..., N \tag{11.4}$$

$$z_k^{t+1} \geq 0, k = 1, ..., K \tag{11.5}$$

The difference between Model 3 to Model 1 is explicitly that desirable outputs now are not scaled by β and, therefore, credit is only given to contraction of undesirable outputs. Again, undesirable outputs are assumed weakly disposable together with desirable outputs here.

On the other hand, in Model 4, credit is only given to expansion of desirable outputs, while undesirable outputs are completely excluded from the production technology. In this case, the maximization problem for the mixed-period distance function, $\vec{D}_o^{t+1}(t)$ is:

$$\vec{D}_o^{t+1}(x^{k't}, y^{k't};1) = \max\ \beta \tag{12.1}$$

s.t.

$$\sum_{k=1}^{K} z_k^{t+1} y_{km}^{t+1} \geq (1+\beta) y_{k'm}^t, m = 1,...,M \tag{12.2}$$

$$\sum_{k=1}^{K} z_k^{t+1} x_{kn}^{t+1} \leq x_{k'n}^t, n = 1,...,N \tag{12.3}$$

$$z_k^{t+1} \geq 0, k = 1,...,K \tag{12.4}$$

In this model, the undesirable outputs are assumed to be freely disposable, and therefore the constraints for undesirable outputs are dropped. The maximum value of β for Model 4 shows how much the desirable outputs can be expanded relative to the efficient benchmark on the frontier at given input levels while undesirable outputs are completely ignored. Similarly, the maximization problems for other three components of $\hat{L}(.)$, $\vec{D}_o^{t+1}(t+1)$, $\vec{D}_o^t(t+1)$, and $\vec{D}_o^t(t)$ can be posited and solved in a very similar way.

4.4 Data and Variables

For the purpose of the study, data on representative shrimp farms from eight districts are used to measure the productivity of shrimp farming industry in Bangladesh. A representative farm is constructed for each of the 31 sub-districts. Representative

shrimp farms from every sub-district are considered as the decision making units for the empirical analysis. Each sub-district is considered as an observation unit resulting with 62 observational units for the two time periods analysed. 'Representative farm approach' is useful for the current study as it can incorporate the regional level environmental variables in the analysis. There are other studies that have used representative farm level data (e.g. Helfand, 2003; Azad and Ancev, 2010; Culpit, 2011; Kuosmanen et al., 2013) in estimating efficiency and productivity of agricultural enterprises. The following are some of the main features of the data used:

Study area: The study includes 8 shrimp farming districts in Bangladesh, which account for roughly 98% of the Bangladesh's shrimp production. These districts are mainly situated in the coastal region of Bangladesh and can be classified as Southwest, Southeast and Southern coastal regions. The selection of sub districts was based on the existence of shrimp farming in that area. The sub districts which have at least 100 hectares of land engaged in shrimp farming operation are considered for the study. Following this, 6 sub-districts from Khulna, 7 sub-districts from Bagerhat, 6 sub-districts from Satkhira, 2 sub-districts from Jessore, 5 sub-districts from Cox's Bazar, 2 sub-districts from Chittagong, 2 sub-districts from Patuakhali and 1 sub-district from Pirojpur district were selected for the present study. Shrimp farming districts are shown on a map of Bangladesh in Appendix C.

Time period: Dynamic productivity analysis using time series data is a great way to identify the productivity growth of farms or industry. Luenberger productivity analysis is capable of measuring the productivity growth between two time periods when undesirable outputs are also encompassed in the production technology. The paper presents the productivity change results for the shrimp farming between two time points, 2000 and 2010, when the environmental effects of shrimp farming have identified as a concern. The analysis is restricted to only these two years rather than a series of years since the data were not readily available for the undesirable outputs for other years.

Desirable outputs: Gross revenue from shrimp farming is considered as the main desirable output for the analysis. It is the average per hectare revenue from shrimp farming, derived from the per hectare total production of shrimp and their respective prices. These average data were used to envisage a representative shrimp farm for that particular sub-district. Although 'representative farm approach' does not answer the organization, resource management, and internal management of large commercial farms, it can be used as a useful educational tool to typify a rather narrow or specialized farming (Becker, 1963), i.e. shrimp farming in Bangladesh that follows the same farming system pattern throughout an area. The average per hectare data for shrimp farms were collected from different secondary sources (Ahmed et al., 2008; Barman and Karim, 2007; BCAS, 2001; DoF, 2000, 2010; Feroz, 2009; Gordon et al., 2009; Islam, 2003; Jahan, 2008; NACA, 2006, 2010; Nuruzzaman, 2006).

Another desirable output used in the analysis is subsistence annual fish catch (kg). It is assumed that shrimp farming has caused a decline of capture fishery in the shrimp farming districts by destroying a large number of finfish and shell fish as a result of collecting the tiger shrimp fry (BOBP, 1992; BFRI, 2002). The quantity of average fish catch per household was treated as a desirable output in this study as it was explained in the previous chapter. Subsistence fish catch data were collected from Fisheries Statistical Yearbooks for 2000 and 2010.

Input: Per hectare total cost (a price weighted quantity index of inputs) was considered as input in this study. For each sub-district the total cost was calculated by adding up the costs for individual inputs. Labour, land rent, seed (shrimp post larvae) and feed are the major components of total cost. Similar to gross return, average per hectare cost data were collected from different secondary sources. Since the data for undesirable outputs were only available at sub-district level, to compose a compatible data set, the average per hectare cost and return data for representative farms were then multiplied by the total shrimp farming area of that sub-district (DoF, 2000, 2010; PDO-ICZMP, 2005).

Undesirable outputs: With the development of commercial shrimp farming, this industry has been responsible for significant environmental degradation. The most reported environmental effects of shrimp farming are salinisation of soils and saltwater intrusion into freshwater aquifers, loss of wild fish stock, destruction of mangrove forest, effluent discharges of shrimp feed and waste, indiscriminate use of polluting chemicals, and spreading of human infectious diseases (Nijera Kori, 1996; Deb,1998; Bhattacharya et al.,1999; Banks, 2002; Karim, 2003; Rahman et al., 2006). Based on the availability of the data three variables were considered as undesirable outputs for this study. These are: soil salinity measured as the percentage of the salinity affected area, water salinity measured as Electrical Conductivity units, and loss of mangrove forest area. Although loss of mangrove forest was considered as an undesirable output, it has a very limited influence on environmental performance as there is no significant evidence of mangrove destruction after 2000 (Shahid and Islam, 2003; Emch and Peterson, 2006; Giri et al., 2008).

The data for soil salinity were collected from the Soil Research Development Institute (SRDI) and Bangladesh Fisheries Research Institute (BFRI). The data for water salinity were collected from the Department of Environment, Bangladesh Fisheries Research Institute and a study from Ahmed et al. (2010). The data for mangrove forest area were collected from the Department of Forestry in Bangladesh and Bangladesh Space Research and Remote Sensing Organization (SPARRSO).

The study uses the same data set that used in chapter 3. However, for the convenience of readers' the same data of the descriptive statistics of some economic and environmental indicators of shrimp farming that have been used in this study are presented in Table 4.1.

Table 4.1 Descriptive Statistics of Shrimp Farms and their Externalities by Districts in Bangladesh

District	Shrimp area (ha)		Gross return (US$[9]/ha/year)		Total cost (US$/ha/year)		% of salinity affected area		Water salinity in ECw (ds/m)		Mangrove forest area (ha)		Annual Fish catch (kg/household)	
	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010	2000	2010
Khulna (6)	37,630	36,235	1986	3333	1362	2287	69	70	13-27	15-34	181,600	189,993	31.26	23.61
Bagerhat (7)	42,941	46,571	1680	2778	1032	1852	61	65	0.5-22	4-26	230,919	243,145	27.4	29.21
Satkhira (6)	51,537	64,761	1919	2963	1282	1978	64	67	12-33	17-36	164,525	167,348	34.2	25.87
Jessore (2)	34	825	1704	2315	1204	1589	11	16	5-7	15-22	0	0	24.45	66.78
Cox's Bazar (5)	29,048	51,334	2088	3703	1370	2104	29	34	23-39	32-49	133,731	132,063	29.46	53.38
Chittagong (2)	1548	2895	1861	2407	1278	1709	17	28	2-3	2-6	66802	82,773	22.82	69.88
Patuakhali (2)	2821	1630	1717	2170	1149	1461	44	50	1-32	2-30	16882	33,085	53.22	42.52
Pirojpur (1)	2623	240	1623	2183	901	1391	21	28	7-9	10-12	989	2429	28.56	24.87

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[9] 1 US$= 53.8 Bangladeshi Taka as of October, 2000

The average district level data show that Southwest region (Khulna, Bagerhat, Satkhira) comprises most of the shrimp farming area of the country. In Southeast region, Cox's Bazar district occupies the maximum of shrimp farming area for this region. In terms of revenue earnings, Cox's Bazar is in better position compared to other districts while the cost is more or less the same for all the districts. The revenue and cost items are presented in real value terms. Again, Southwest region is mostly affected by salinity, where almost 60-70 % of cultivable area became saline affected. There is no significant decrease of mangrove forests found for the sample time period. On the other hand, the annual fish catch/household varies across districts and time.

4.5 Results

A summary of the empirical findings of productivity growth and its components under four models is presented in Table 4.2. In case of model 1 (which credits farm for increasing desirable outputs and simultaneously decreasing undesirable outputs), the average productivity indicator for all representative farms has a value of -.031, indicating that the productivity growth of the shrimp farming industry has decreased by -3.1% over a decade between 2000 to 2010. The decomposition of this productivity provides a negative technological change of -5.6% and a positive efficiency change of 2.5%. This indicates that the dwindling technological progress is mainly responsible for this negative productivity change.

A comparison across districts indicates that farms in Khulna and Bagerhat districts in Southwest region experienced a negative growth, -7.3% and -4.1% respectively during the sample time period. Again, this negative growth is mainly driven by the negative technological growth (-9.4% in Khulna and -8% in Bagerhat), though the farms in Bagerhat district are slightly in better position than the farms in Khulna. Farms in Satkhira district surprisingly experienced a positive productivity growth (4.3%), which is mainly due to positive technical efficiency change (13.5%).

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On the other hand, farms in Cox's Bazar and Chittagong districts of the Southeast region have experienced a positive productivity growth, 3.9% and 13.8% respectively during the sample time period. The positive productivity growth of these districts was led by the positive technical efficiency change component. Despite the use of traditional technologies in these farms, better management practices may lead to achieve the positive technical efficiency change in this region.

The farms in the Southern region (Pirojpur and Patuakhali districts) have experienced a negative productivity growth, without any improvement, neither in technological features, nor in technical efficiency attributes. Farms in Jessore also experienced the similar result as Patuakhail district, i.e., no improvement.

The results suggest that the present farming system (low input-low output system) is not efficient enough to achieve positive productivity growth for most of the farms, especially in the Southwest and Southern regions. The farms follow the traditional production system with only modest upgrading. The innovations and adoption of new technologies are very limited in the industry that lead to the negative technological change in most of the cases. If the farms can adopt new technologies that are efficient both in maximizing the production of targeted output and minimizing the environmental degradation, they will be able to experience an upward shift to the frontier. For this, technologies used in the shrimp farms should be more sophisticated and environmentally friendly so that they have less environmental effects in spite of increasing output. On the other hand, negative or zero efficiency change implies that farms need to invest more on planning, technical experience, management and organization attributes. These can help farms to perform better in both economic and environmental attributes. Lack of emphasis on these issues restricts farms to achieve the desired sustainable productivity growth. Therefore, improvements should be made both in the optimum use of inputs and outputs (technological improvement), and in the organization and management practices (efficiency change).

Table 4.2 Average Productivity Change, Efficiency Change and Technological Change of Shrimp Farms by Districts in Bangladesh

District	Model 1(g=1, -1)			Model 2 (g=1, 0)			Model 3 (g= 0,-1)			Model 4 (g=1)		
	PC	EC	TC	PC	EC	TC	PC	EC	TC	PC	EC	TC
Khulna	-0.073	0.021	-0.094	-0.071	0.039	-0.109	-0.271	-0.258	-0.012	-0.122	-0.076	-0.047
Bagerhat	-0.041	0.039	-0.080	-0.035	0.048	-0.083	-0.141	0.097	-0.239	-0.127	-0.059	-0.068
Satkhira	0.043	0.135	-0.092	0.051	0.159	-0.108	-0.098	-0.027	-0.071	-0.141	-0.169	0.028
Cox's Bazar	0.039	0.068	-0.029	0.042	0.070	-0.028	0.050	0.024	0.026	-0.011	0.130	-0.041
Chittagong	0.138	0.162	-0.024	0.307	0.392	-0.084	0.240	0.277	-0.037	-0.008	-0.001	-0.007
Jessore	-0.067	0.000	-0.067	-0.136	0.000	-0.136	-0.293	0.000	-0.293	-0.140	-0.043	-0.097
Pirojpur	-0.262	-0.227	-0.036	-0.345	-0.253	-0.092	-0.527	-0.583	0.056	-0.465	-0.299	-0.167
Patuakhali	-0.024	0.000	-0.024	0.001	0.000	0.001	0.161	0.425	-0.264	-0.411	-0.290	-0.122
Average	-0.031	0.025	-0.056	-0.023	0.057	-0.080	-0.110	-0.006	-0.104	-0.178	-0.100	-0.065

*PC = Productivity change/ Luenberger productivity indicator

EC= Efficiency change

TC= Technological change

Overall, it can be said that there is a room for improvements in the productivity for the shrimp farming industry. The farms in Southeast region (Cox's Bazar and Chittagong districts, where moderate environmental impacts have been experienced) can be used as the model for the improvement of performance in other districts. Imposing ban to the extension of shrimp farms in agricultural land and inland freshwater bodies could be one of the options for reducing the environmental degradation.

In case of Model 2 (which credits farms only for increasing desirable outputs), the average productivity growth for all representative farms is estimated at -0.023, indicating a -2.3% decrease in productivity of the shrimp farming industry between the sample time period. When decomposing this total factor productivity into technological change and technical efficiency change components, it shows a negative technological growth of -8.0% and a positive technical efficiency change of 5.7%. The results showed a similar pattern as of Model 1. Farms in Khulna, Bagerhat, Jessore and Pirojpur districts have experienced a negative productivity growth while farms in Cox's Bazar, Chittagong, and Satkhira districts have experienced a positive productivity growth. Again, it indicates that the positive productivity growth was led by the positive efficiency change and negative productivity growth was led by the negative technological change component.

In case of Model 3 (which credits farms only for decreasing undesirable outputs), the average productivity growth for all representative farms is estimated at -0.110, indicating a decrease in productivity by 11.0% for the industry between the sample time period. The model shows negative growth both for technological change and technical efficiency change components, -10.4% and -0.6% respectively. The productivity estimates under this model show the worst development among all the four models. The results of this model imply that it is very difficult to increase productivity growth only by decreasing undesirable outputs. This also implies that the farms need to do significant improvements in its performance if they targets to pull off the positive productivity growth only by decreasing undesirable outputs. This may

need substantial investment and may not be an efficient policy measure for the development of farms. Therefore, to achieve the best possible productivity growth, technologies and management practices associated with both desirable and undesirable outputs need to be improved.

Under Model 4 (the presence of undesirable outputs are ignored), the average productivity value of -0.178 indicates that the productivity change for the shrimp industry was -17.8% from 2000 to 2010 and this negative growth was due to higher negative value of both efficiency change and technological change components. This model shows poorer productivity growth in comparison with Model 1 and Model 2, implying that if the undesirable outputs are not included in the productivity measurement, farms are expected to generate poorer productivity change if in reality farms are compromising the desirable outputs for reducing undesirable outputs. This statement can be explained by the fact that farms in Bangladesh are following extensive farming system that is using less feed, fertilizer and chemicals which are the major sources of environmental pollution. Although the productivity is low under this system, one of the reasons of following this system is to create less pollution to the environment. Alternatively, it can be said that farms are sacrificing some desirable outputs for the less environmental degradation. Since this Model ignores these activities by excluding undesirable outputs, the productivity measurement underestimates productivity growth from a welfare point of view.

The results also suggest that the farms in Southwest region (Khulna, Bagerhat, Satkhira and Jessore districts) and Southern region (Patuakhali and Pirojpur districts) have experienced a highly negative productivity growth and this negative change was due to both negative efficiency change and negative technological change. However, the farms in Cox's Bazar and Chittagong districts experienced a relatively lower negative productivity change, implying that the production of desirable outputs are not much associated with environmental concerns. The negative efficiency change and negative technological change imply that there is an opportunities for farms to increase their productivity by improving both the technological and managerial

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aspects. Adoption of improved technologies and skilled management system can assist farms to achieve this goal. Figure 4.2 displays the productivity, efficiency and technological change under four models for representative farms for the study period. The figure suggest that although technological change is negative for all the four models, Model 1 and Model 2 produce better results in terms of productivity and efficiency change where undesirable outputs were treated as weakly disposable.

Although the analyses generate a mixed response of productivity change across farms, overall the farms have experienced negative productivity growth in the Southwest and Southern regions and positive productivity growth in Southeast region. In particular, the performance was not satisfactory for the farms in Pirojpur and Pataukhali districts of Southern region. One of the significant reason for productivity decline between two time points, 2000 and 2010 can be explained by the two major cyclones called 'Sidr' and 'Aila' which hit these areas in 2007 and 2009 respectively. Besides other environmental damages, these cyclones have washed out shrimp ponds, equipments, stores of feed and so on, having a severe direct impact on shrimp farms. In fact, Pirojpur and Patuakhali districts were particularly hard hit by the cyclones and can be supported by the results here. The area of shrimp farms in Pirojpur and Patuakhali districts actually have declined from 2000 to 2010 which can be interpreted by this negative productivity growth. Moreover, almost all the farms are showing negative technological change in all the four models implying that farms are not efficient in using inputs and outputs, and there is a scope to improve their technological prowess, particularly in relation to more environmentally friendly technologies. Farms which are showing positive productivity growth are mainly due to positive efficiency change, i.e. good management practices. However, if some improvements can be done in terms of technology and management practices, farms can perform better, and more investment in technology and management is required to achieve this goal. The productivity growth of shrimp farms have been estimated based on the sub-district level data from eight shrimp farming districts. A detailed sub-district wise productivity growth and the value of its technological change and technical efficiency change components are presented in Appendix E.

4.6 Conclusions

Using a directional distance function approach, this paper calculated four versions of the Luenberger productivity indicator that allows accounting for the joint production of desirable and undesirable outputs. The estimated Luenberger productivity indicators suggest that on average, the farms have a negative productivity growth for all four models. Decomposing productivity growth into technological and technical efficiency change components showed that the negative productivity growth is mainly driven by the negative technological change and the positive productivity growth is mainly driven by the efficiency improvements. The application of productivity growth measurement with undesirable outputs is a comparatively new technique which can effectively address the productivity of farms and industry in the sustainable development perspective. The capability of this approach to include the environmental outputs in the analyses allows us to identify the true productivity growth which is necessary to devise appropriate policy measures. This paper extends the use of this technique in agriculture/aquaculture field that has not been conducted in any previous studies.

The results obtained from the Luenberger productivity indicators imply that the traditional technologies that are currently being used in the shrimp farming industry in Bangladesh need to be improved for the better performance of the industry; otherwise the sustainability of this industry will be in question. At the same time attention should be given to reduce the negative impacts of shrimp farming on environment by providing environmentally friendly technologies. The productivity measures are essential for the farm operators as well as for the policy makers for further initiatives to achieve the sustainable development goal. When this measures incorporate the environmental attributes it can provides the right indication for future actions.

Bangladesh does not have any specific policy for shrimp aquaculture. A well-defined shrimp policy which will focus on new environmental friendly technologies can

ensure the sustainability of this vital industry. Experiences from other countries along with the local environmental and social characteristics should be taken into consideration to develop the new technologies. In conclusion, the present study indicates the necessity of measuring environmentally adjusted productivity growth for the sustainable development of the shrimp industry and the government, business and academic communities can draw some lessons from it to take further necessary actions. Hopefully, this will greatly help to promote the industry's sustainable development by enhancing the efficiency and productivity of shrimp farm business.

CHAPTER 5

CONCLUSION

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5.1 Conclusions

The aim of the present study was to evaluate the environmentally adjusted economic performance of shrimp farms in Bangladesh, which will help understand the tradeoffs between economic and environmental effects of shrimp farming. In attaining this goal, the thesis was presented as accumulation of three separate papers. The first paper provided an overview of the shrimp farming industry in the world and in Bangladesh where attention was put on documenting the environmental effects of shrimp farming. This was then followed by an empirical study that evaluated economic and environmental efficiency of shrimp farms in Bangladesh, which enabled determination of environmentally adjusted economic performance of shrimp farms. The final paper focused on evaluating productivity growth of shrimp farming in Bangladesh over the last decade in light of the both economic and environmental performances. Based on the findings of the study, the following conclusions can be drawn:

1. Shrimp farming has been a lucrative economic activity in tropical and sub-tropical developing countries during the past several decades, and has experienced an increasing trend for both volumes of production and export earnings. However, the unplanned and unregulated development of shrimp farming has led to adverse environmental effects. The significant evidence of threats to natural environment raises the question of sustainability of this industry. Therefore, this export-driven industry requires careful management in overcoming its environmental consequences to ensure the sustainable growth of this industry.

2. The determined environmental efficiency scores provide an indication of the tradeoffs between economic and environmental impacts of shrimp farming in

Bangladesh. This makes it possible to identify those types of shrimp farms that are creating modest environmental degradation, but are contributing significantly in terms of economic benefit. For example, farms in Moheshkhali and Ukhiya sub-districts of Cox's Bazar district can be used as a benchmark on which to model the improvement of economic-environmental performance of other farms.

3. The performance of shrimp farms varies across regions and between two time points. Overall, the farms have experienced highest efficiency scores when both increasing desirable outputs and decreasing undesirable outputs is credited. It could subsequently be concluded, that there is an opportunity to increase farms' performance in a sustainable manner that ensures achieving high production and minimizing environmental externalities at the same time. Farms in the Southwest region of Bangladesh have in general experienced a decline in efficiencies from the year 2000 to 2010, while the efficiencies have increased for most of the farms in Southeast region. One of the factors of this difference can be attributed to the expansion of shrimp farming to the agricultural lands in Southwest region while the shrimp farming in Southeast region is restricted to the naturally suitable lands near the sea.

4. The calculated Environmental Efficiency Index (EEI) scores provide an indication of farms' ability to increase environmental performance at relatively lower cost. The sample shrimp farms in general scored a high EEI, indicating that farms can improve their environmental performance without sacrificing significant amount of desirable outputs. These findings can be articulated in devising balanced policies that target more sustainable shrimp farming without significant loss in economic outputs.

5. The Luenberger total factor productivity indicators provide an estimation of productivity growth of shrimp farms over the last decade. The farms in Khulna, Bagerhat, Jessore, Pirojpur and Patuakhali districts have experienced a negative productivity growth which was driven by technological regress. In

other districts, the experienced positive productivity growth by shrimp farms was driven by the positive technical efficiency change. Overall, the industry has experienced a negative productivity growth. Low input-low output oriented extensive culture system is thought to be the main reason for such negative technological change. Alternatively, better management practice has led to the positive efficiency change in the sample shrimp farms. However, it is evident that there is considerable room for improving productivity of shrimp farms. The existing production system of shrimp farming is not commensurate with sustainable growth of the industry, and therefore specific policy is required to recommend appropriate use of technologies and improved management systems based on scientific studies.

6. Sustainable development is a long term goal that is closely associated with the overall social wellbeing. Evaluating the performance of farms with environmentally adjusted indicators can greatly help policy makers in achieving this goal. The policy can target region-specific or technology specific attributes to improve the current operation and enhance sustainability. The indication of economic-environmental tradeoffs can provide the right direction for future actions aiming for sustainable development of the industry.

5.2 Limitations of the Research

Although the study has attempted to minimise the limitations in terms of methodology and extent of the research, there are several limitations remaining that should be acknowledged. These limitations, mostly related to data availability, are discussed below:

1. Representative shrimp farm for each sub-district was modelled in the present study. Modelling with individual farm level data would provide more comprehensive information about the variation in environmental efficiency and productivity scores across the shrimp farms, but farm level data for all

variables were not readily available. However, representative farms approach can capture local features and resources more easily since the knowledge about local conditions are acquired in the creation of each farm.

2. In evaluating environmentally adjusted efficiency and productivity, the study uses data for two time points, the year 2000 and 2010. It would be more useful if more years can be included in the model. However, the techniques that have been used in the present study required data for environmental attributes that were considered as undesirable outputs. There were no data available on environmental parameters except these two years to use in the present study. Adequate data, especially on environmental attributes are not available in Bangladesh.

3. The degree of social effects is another important component of sustainable development which was not considered in the present study. The inclusion of social attributes would provide more comprehensive results, but was beyond the scope of the study due to the proposed techniques, limited time, and resources.

4. The analyses of the study were restrictive to certain assumptions and constraints. The relaxation of the assumptions and constraints would add complexity to the analyses, which is beyond the scope of the study. The study could also apply some other parametric and non-parametric techniques to compare the results, but the limited time of the study did not permit this.

5.3. Policy Implications

1. The obtained environmentally adjusted efficiency measures indicate that shrimp farms in Bangladesh could be managed in a way to achieve high economic efficiency, and to be environmentally efficient at the same time. Key environmental impacts from shrimp farming relate to the salinisation of soil and water. Management implications from this finding indicate the need

for appropriate siting of shrimp farms in the first place. Racing to establish shrimp operations, many farm managers have sited their shrimp farms on land previously occupied by traditional crops typically found on higher ground. It is in areas where large conversion of rice fields further inland has recently occurred (i.e. the Southwest coastal regions of the Bay of Bengal) that the highest incidence of increased soil and water salinity occurs. Conversely, regions where shrimp farms are situated in low lying coastal lands and are naturally fed by tidal waters (i.e. the Southeast region)show greater economic and environmental efficiency.

2. Previous studies have suggested that shrimp farming can be designated to those areas where removal of vegetation is not required, and preferably in areas that are naturally fed by tidal condition (Barbier and Cox, 2004; Páez-Osuna et al., 2003). Our results for Bangladesh echo these findings. In light of this, a possible policy or an industry based managerial approach could be to block the establishment of new shrimp farms in areas where rice and other crops are growing successfully.

3. The productivity results suggest that in general shrimp farms have experienced negative productivity growth mainly due to low input-low output traditional production system. There is a need of innovation and adoption of new technologies that are efficient both in maximizing the production of targeted output and minimizing the environmental degradation. Local environment and social characteristics should be taken into consideration to develop new technologies.

4. Shrimp farms need to invest more on planning, technical experience, management, and organizational attributes to achieve both the economic and environmental efficiency. Lack of emphasis on these issues restricts farms to achieve the desired sustainable productivity growth.

5. There is no specific shrimp farming policy in Bangladesh. There is a need to develop a shrimp policy which will ensure the efficiency and productivity of this farming. The results suggest that regional based policy instrument would be more appropriate for the effective improvement of this industry. Experiences from other countries can be taken into consideration to develop the policy guideline.

5.4 Further Research

The directional distance function is a useful approach in evaluating performances of farms that are characterized with joint production. For example, this approach has been used successfully to evaluate the effect of environmental pollution or environmental regulations on production process. Nevertheless, the use of this approach is still limited in the economic research of the agriculture and aquaculture industries, where joint production is a common occurrence, and environmental externalities are often noted. More research is required in agricultural, fishery and aquaculture sectors that will use this approach to evaluate the performances of these sectors.

The study can be extended for individual farm level performance. This will require specific data collection for individual farms, especially for the environmental parameters. The study can incorporate different techniques to get more accurate data, e.g. GIS and remote sensing technique. Moreover, it would be useful to include subsequent years in measuring productivity growth.

This environmentally adjusted efficiency and productivity approaches can be applied in other shrimp producing countries where environmental problems are more diversified. This approach can also be applied for semi-intensive or intensive farms where feed, chemicals and fertilizers are heavily used and generate multiple environmental problems. Thus, comparisons can be made for different farming

systems in inter country or intra-country perspectives. Moreover, the economic and environmental variables can be extended to capture a broader scenario.

The study has only used directional distance function approach and Luenberger indicators to measure the environmental performance. There are other indexes available to use for the same purposes. It would be interesting to apply other indexes and compares them to see the variation in results derived from the different approaches. Both the parametric and non-parametric methods can be applied for similar type of studies to validate the results.

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APPENDICES

Appendix A. Coastal Zone and Shrimp Farming Areas of Bangladesh
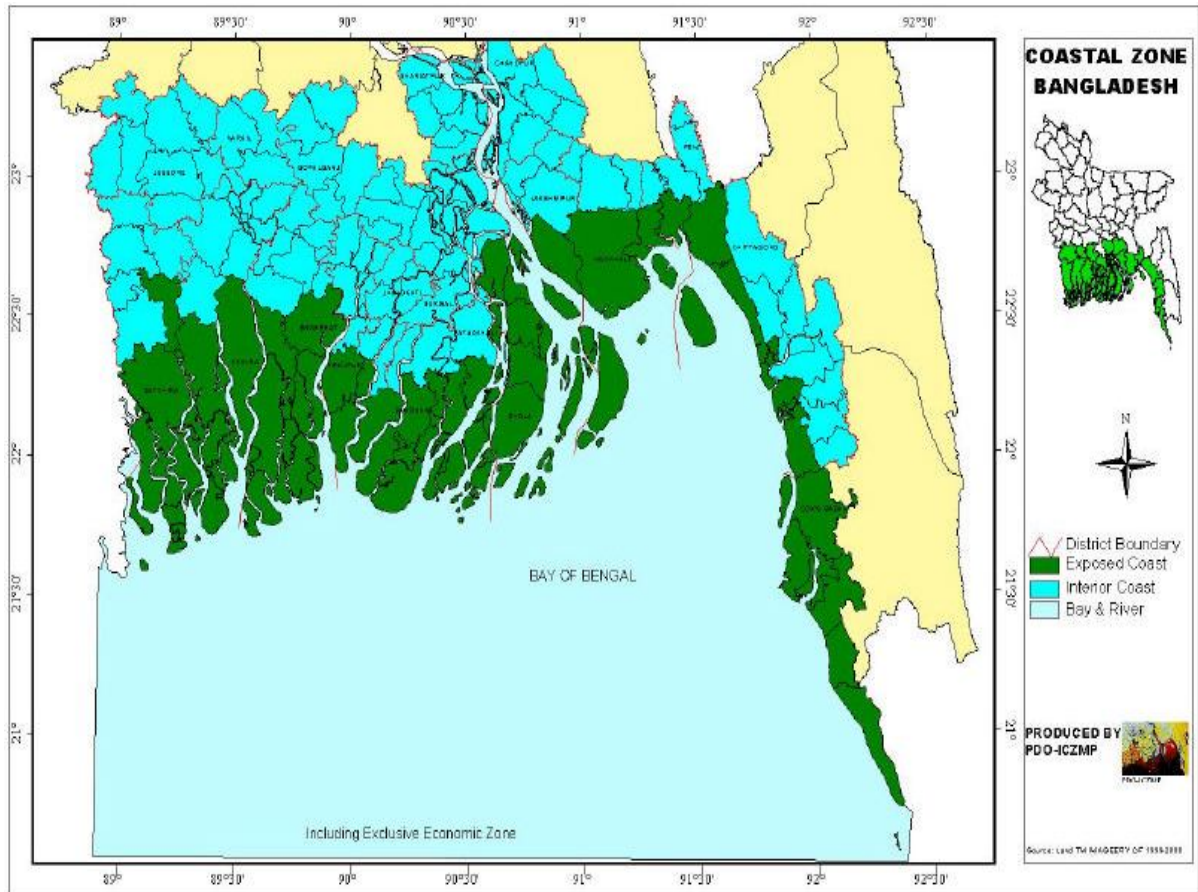
Source: PDO-ICZMP, 2003.

Appendix B. Efficiency of Shrimp Farms in Different Sub-districts of Bangladesh

District	Sub-district	Model 1	Model 2	Model 3	Model 4	EEI
2000						
Khulna	Paikgacha	0.971	0.941	0.944	0.632	0.752
	Dacope	0.842	0.823	0.571	0.618	0.838
	Koyra	0.758	0.722	0.293	0.644	0.916
	Dumuria	0.765	0.711	0.390	0.629	0.900
	Batiaghata	0.704	0.682	0.214	0.636	0.950
	Rupsa	0.736	0.660	0.305	0.415	0.797
Bagerhat	Bagerhat sadar	0.952	0.946	0.663	0.769	0.852
	Rampal	0.964	0.961	0.728	0.774	0.845
	Mongla	0.915	0.901	0.469	0.780	0.890
	Mollahat	1.000	1.000	1.000	1.000	1.000
	Chitalmari	0.837	0.971	0.516	0.676	0.879
	Morelganj	1.000	1.000	1.000	0.783	0.821
	Kochua	0.846	0.807	0.637	0.769	0.938
Satkhira	Satkhira sadar	0.793	0.789	0.334	0.692	0.923
	Tala	0.739	0.702	0.450	0.609	0.906
	Debhata	0.847	0.825	0.512	0.651	0.855
	Asasuni	0.884	0.868	0.646	0.657	0.831
	Shyamnagar	0.882	0.862	0.564	0.667	0.838
	Kaliganj	0.886	0.867	0.610	0.667	0.835
Cox's Bazar	Chakaria	0.936	0.928	0.769	0.691	0.813
	Moheshkhali	0.943	0.936	0.780	0.685	0.804
	Cox's Bazar sadar	0.799	0.793	0.314	0.703	0.926
	Teknaf	0.782	0.781	0.302	0.667	0.913
	Ukhiya	0.816	0.822	0.418	0.655	0.880
Chittagong	Bashkhali	0.841	0.637	0.725	0.289	0.677
	Anowara	0.770	0.483	0.626	0.350	0.745
Jessore	Keshobpur	1.000	1.000	1.000	0.878	0.891
	Avaynagar	1.000	1.000	1.000	1.000	1.000
Pirojpur	Nazirpur	1.000	1.000	1.000	0.909	0.917

Patuakhali	Galachipa	1.000	1.000	1.000	0.692	0.765
	Kalapara	0.827	0.863	0.110	0.692	0.896
2010						
Khulna	Paikgacha	0.865	0.843	0.614	0.626	0.826
	Dacope	0.651	0.652	0.119	0.639	0.991
	Koyra	0.720	0.706	0.206	0.633	0.937
	Dumuria	0.801	0.763	0.390	0.625	0.872
	Batiaghata	0.656	0.626	0.127	0.615	0.971
	Rupsa	0.701	0.675	0.210	0.638	0.954
Bagerhat	Bagerhat sadar	0.913	0.899	0.483	0.778	0.889
	Rampal	0.933	0.923	0.555	0.769	0.867
	Mongla	0.884	0.862	0.381	0.763	0.902
	Mollahat	0.850	0.831	0.567	0.784	0.945
	Chitalmari	0.899	0.876	0.613	0.824	0.936
	Morelganj	0.920	0.907	0.524	0.775	0.882
	Kochua	0.759	0.829	0.404	0.756	0.997
Satkhira	Satkhira sadar	0.844	0.841	0.362	0.739	0.917
	Tala	0.847	0.844	0.357	0.754	0.925
	Debhata	0.877	0.854	0.381	0.747	0.896
	Asasuni	0.905	0.890	0.447	0.747	0.874
	Shyamnagar	0.885	0.865	0.391	0.741	0.886
	Kaliganj	0.917	0.906	0.498	0.746	0.864
Cox's Bazar	Chakaria	0.979	0.976	0.881	0.730	0.804
	Moheshkhali	1.000	1.000	1.000	0.735	0.790
	Cox's Bazar sadar	0.852	0.848	0.269	0.762	0.928
	Teknaf	0.831	0.830	0.417	0.700	0.899
	Ukhiya	1.000	1.000	1.000	0.709	0.774
Chittagong	Bashkhali	1.000	1.000	1.000	0.538	0.684
	Anowara	1.000	1.000	1.000	0.605	0.717
Jessore	Keshobpur	1.000	1.000	1.000	0.697	0.768
	Avaynagar	1.000	1.000	1.000	0.757	0.804
Pirojpur	Nazirpur	0.624	0.532	0.415	0.480	0.906
Patuakhali	Galachipa	1.000	1.000	1.000	0.341	0.603
	Kalapara	1.000	1.000	1.000	0.523	0.677

Appendix C. Shrimp Farming Districts in Bangladesh

Map: 1

Shrimp Farming Districts of Bangladesh

LEGEND:
Shrimp Farming Districts
District Boundary

Source: WARPO and CEGIS data

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Appendix D. Productivity Change, Efficiency Change, and Technological Change Indicators of Shrimp Farms by Sub-districts

District	Sub-district	Model 1(g=1, -1)			Model 2 (g=1, 0)			Model 3 (g= 0,-1)			Model 4 (g=1)		
		PC	EC	TC	PC	EC	TC	PC	EC	TC	PC	EC	TC
Khulna	Paikgacha	-0.097	-0.078	-0.019	-0.125	-0.101	-0.024	-0.225	-0.153	-0.072	-0.144	-0.076	-0.068
	Dacope	-0.152	0.014	-0.166	-0.123	0.042	-0.165	-0.660	-0.499	-0.161	-0.140	-0.093	-0.046
	Koira	-0.027	0.101	-0.129	-0.017	0.127	-0.144	-0.105	-0.091	-0.013	-0.145	-0.076	-0.069
	Dumuria	0.024	0.117	-0.092	0.035	0.167	-0.133	0.041	0.071	-0.030	-0.135	-0.060	-0.075
	Batiaghata	-0.029	0.125	-0.154	-0.036	0.148	-0.184	-0.092	-0.093	0.001	-0.150	-0.074	-0.076
	Rupsa	-0.158	-0.153	-0.006	-0.159	-0.151	-0.007	-0.583	-0.785	0.201	-0.021	-0.074	0.053
Bagerhat	B. sadar	-0.023	0.047	-0.070	-0.028	0.052	-0.080	-0.126	0.210	-0.336	-0.112	-0.048	-0.064
	Rampal	-0.016	0.036	-0.052	-0.019	0.039	-0.058	-0.080	0.177	-0.257	-0.124	-0.059	-0.065
	Mongla	-0.023	0.067	-0.090	-0.027	0.081	-0.108	-0.192	0.104	-0.296	-0.120	-0.039	-0.081
	Mollahat	-0.090	-0.031	-0.060	-0.099	-0.030	-0.069	-0.284	-0.160	-0.125	-0.185	-0.004	-0.181
	Chitalmari	-0.051	0.000	-0.051	-0.062	0.000	-0.062	0.034	0.000	0.034	-0.073	-0.104	0.030
	Morrelganj	-0.040	0.000	-0.040	-0.046	0.000	-0.046	-0.234	0.000	-0.234	-0.111	-0.031	-0.080
	Kochua	-0.043	0.154	-0.197	0.037	0.193	-0.156	-0.109	0.351	-0.459	-0.164	-0.130	-0.034
Satkhira	S. sadar	0.050	0.190	-0.140	0.052	0.193	-0.141	0.099	0.110	-0.011	-0.173	-0.196	0.023
	Tala	0.111	0.242	-0.130	0.133	0.278	-0.146	0.035	0.113	-0.078	-0.106	-0.148	0.042
	Debhata	0.048	0.127	-0.079	0.049	0.148	-0.099	-0.145	-0.088	-0.057	-0.134	-0.162	0.028

	Assasuni	-0.004	0.087	-0.091	0.000	0.109	-0.110	-0.264	-0.068	-0.197	-0.138	-0.166	0.028
	Shyamnagr	0.017	0.079	-0.062	0.025	0.111	-0.086	-0.201	-0.179	-0.022	-0.149	-0.172	0.023
	Kaliganj	0.036	0.087	-0.051	0.048	0.117	-0.070	-0.111	-0.050	-0.061	-0.147	-0.172	0.026
Cox's Bazar	Chakaria	0.018	0.021	-0.004	0.028	0.030	-0.002	-0.014	-0.055	0.041	-0.009	0.139	-0.148
	Moheshkhali	0.020	0.000	0.020	0.021	0.000	0.021	0.110	0.000	0.110	0.005	0.157	-0.152
	C. sadar	0.045	0.170	-0.125	0.047	0.173	-0.126	0.063	0.164	-0.101	0.009	0.152	-0.144
	Teknaf	0.073	0.146	-0.073	0.077	0.146	-0.069	0.194	0.012	0.182	-0.034	0.099	-0.133
	Ukhiya	0.037	0.000	0.037	0.037	0.000	0.037	-0.102	0.000	-0.102	-0.026	0.104	-0.130
Chittagong	Bashkhali	0.104	0.124	-0.020	0.234	0.284	-0.050	0.189	0.221	-0.033	0.024	0.059	-0.036
	Anowara	0.171	0.200	-0.029	0.380	0.500	-0.119	0.291	0.333	-0.042	-0.040	-0.061	0.021
Jessore	Keshobpur	0.061	0.000	0.061	0.000	0.000	0.000	0.109	0.000	0.109	-0.145	-0.038	-0.107
	Avaynagar	-0.196	0.000	-0.196	-0.272	0.000	-0.272	-0.695	0.000	-0.695	-0.136	-0.048	-0.087
Pirojpur	Nazirpur	-0.262	-0.227	-0.036	-0.345	-0.253	-0.092	-0.527	-0.583	0.056	-0.466	-0.299	-0.167
Patuakhali	Galachipa	-0.050	0.000	-0.050	0.000	0.000	0.000	-0.099	0.000	-0.099	-0.426	-0.297	-0.129
	Kalapara	0.003	0.000	0.003	0.002	0.000	0.002	0.420	0.850	-0.430	-0.397	-0.282	-0.114