UNIVERSITI PUTRA MALAYSIA

PRODUCTION RISK AND TECHNICAL EFFICIENCY OF THAI KOI (Anabas testudineus Bloch) FARMING IN SELECTED AREAS OF BANGLADESH

MD. AL AMIN SARKER

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By

MD. AL AMIN SARKER

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2015

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DEDICATION

I wish to dedicate this thesis to my parents for their selfless effort in educating me. A special dedication to my wife, Shayema for her patience and commitment, and playing the dual family role of being a mother and a father to our daughters.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

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January 2015

Chair : Professor Fatimah Mohamed Arshad, PhD

Faculty : Institute of Agricultural and Food Policy Studies

Thai *koi* production technology is relatively a new component in the aquaculture industry in Bangladesh. However, despite its impressive growth during the initial years, the industry is now experiencing volatility in terms of year to year fluctuation in production. The sharp fluctuations in production make *koi* farming a risky venture. Thus *koi* farming, as a spontaneous choice has become questionable. The overall objective of this study is to examine the production risk and technical efficiency (TE)of Thai *koi* farming in selected areas of Bangladesh. Specifically it aims at: (i)identifying the nature and extent of risk associated with the use of inputs; (ii) estimating the farm specific as well as mean TE and identifying factors affecting technical inefficiency (TIE), and (iv) assessing how feed type effects on productivity. The study utilized a total of 149cross-sectional data collected randomly from the three sub-districts of Mymensingh district in Bangladesh. The study employed .ÆEKDNDU¶V DSSURach using stochastic frontier model (SFM) to estimate the parameters of mean production, variance and inefficiency functions in a single framework. Influence of different feed types on productivity growth was investigated using Cobb-Douglas(C-D) production function and Propensity Score Matching (PSM) methods.

The findings revealed that among the productive variables, feed was the most important input influencing Thai *koi* farming. Production of *koi* was characterized by decreasing returns to scale. The estimated risk functions showed that the zeolite and pesticide are risk-reducing, while labor, feed, fingerlings and salt appeared to be risk-increasing inputs. Results of the inefficiency model indicated that labor and pond area significantly reduced the TIE. Feed, fingerlings and lime appeared to influence TE. Education of farmers¶ increased TE, while experience, training and water change affected TE negatively. The mean TE scores were 0.73 and 0.96 for the flexible risk estimate and conventional SFM estimate, respectively. The estimated TE using the flexible risk framework indicates that 27% of the potential output could be recovered by removing inefficiency. The analyses suggest that TE values are exaggerated when production variance was not included in the model. Thus, the study advocates that

production-TE modelling should be done using flexible risk framework without being illusive with high TE values estimated through conventional risk-free framework.

Floating feed showed better performance in terms of the mean daily weight gain of fish, feed conversion ratios and mean weight of table fish with less culture days as opposed to sinking and mixed feeds. The net returns and benefit cost ratio were also the highest with the floating feed. The C-D regression and PSM results confirm that farmers using floating feed produced higher quantity of fish per unit compared to those using the other feed types. However, farms using the floating feed need more investment to improve their returns.

The overall findings suggest that there was a lack of proper understanding of the technology practices. The farmers could become more efficient by adjusting input allocation with the existing technology and resources. Further development of this agri-business requires for the reduction in major variable costs and ensures its sustainability. In particular, the development of low-cost feeds would help to secure IDUPHUV SURILW PDUJLQV at a competitive level. Finally, the outlook for the Thai *koi* culture could be very positive in meeting the future demand of fish. Hence, rectifying the problems and constraints IDFHG DW WKH IDUPV OHYHO ZRXOG HQKDQFH WKH VHFW contribution to food and nutrition security in the area.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
Sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

RISIKOPENGELUARANDANKECEKAPANTEKNIKAL PENTERNAKAN THAI *KOI* (*Anabas testudineus* Bloch) DI KAWASAN TERPILIH BANGLADESH

Oleh

MD. AL AMIN SARKER

Januari 2015

Pengerusi: Professor Fatimah Mohamed Arshad, PhD

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Teknologi pengeluaran Thai *koi* merupakan satu komponen yang baru dalam industri akuakultur di Bangladesh. Walaupun sektor ini mengalami pertumbuhan yang memberangsangkan sepanjang awal tahun, industri kini mengalami keadaan turun naik pengeluaran. Keadaan turun naik yang mendadakdalam pengeluaran menyebabkan perusahaan *koi* sangat berisiko. Oleh itu, perusahaan *koi* sebagai pilihanutama menimbulkan pertanyaan. Kajian ini bertujuan untuk menganalisis risiko pengeluaran dan kecekapan teknikal (TE) perusahaan Thai *koi*di kawasanterpilihBangladesh. Secara khusus ia bertujuan untuk: (i) mengenalpasti jenis dan tahap risiko yang berkaitan dengan penggunaan input; (ii) menganggarkan ladang khusus serta min TE dan faktor-faktor yang memberi kesan kepada ketidakcekapan teknikal (TIE); dan (iii) menilai bagaimana jenis makanan boleh menjejaskan pertumbuhan produktiviti. Kajian ini menggunakan 149 data keratan rentas yang dikutip secara rawak dari daerah Mymensingh di Bangladesh. Kajian ini menggunakan pendekatan Kumbhakar (2002) iaitu menggunakan model sempadan stokastik (SFM) untuk menganggarkan parameter min pengeluaran, varian dan fungsi ketidakcekapan dalam satu kerangka. Pengaruh jenis makanan yang berbeza ke atas pertumbuhan produktiviti disiasat dengan menggunakan fungsi pengeluaran Cobb-Douglas (CD) dan kaedah *Propensity Score Matching* (PSM).

Dapatan kajian mendapati antara pembolehubah produktif, makanan adalah input terpenting yang mempengaruhi perusahaan Thai *koi*. Ciri pengeluaran Thai *koi* adalah penurunan pulangan mengikut skala. Anggaran fungsi risiko menunjukkan bahawa zeolite dan racun perosak adalah risiko yang berkurang manakala buruh, makanan, *fingerling* dan garam menunjukkan risiko yang meningkat. Keputusan model ketidakcekapan menunjukkan buruh dan kawasan kolam dapat mengurangkan TIE secara bererti. Makanan, *fingerling* dan kapur pula mempengaruhi TE. Pendidikan petani meningkatkan TE, manakala pengalaman, latihan dan perubahan air menjejaskan TE secara negatif. Min skor TE masing-masing adalah 0.73 dan 0.96 bagi anggaran risiko fleksibel dan anggaran SFM konvensional. TE dianggarkan menggunakan kerangka kerja risiko fleksibel yang menunjukkan bahawa 27% dari

potensi output boleh diperolehi semula dengan mengatasi ketidakcekapan. Analisis menunjukkan bahawa nilai TE besar apabila varians pengeluaran tidak dimasukkan dalam model. Oleh itu, kajian mencadangkan pemodelan pengeluaran-TE perlu dilakukan dengan menggunakan kerangka kerja risiko fleksibel tanpa bayangan anggaran nilai TE yang tinggi melalui kerangka kerja risiko konvensional bebas.

Makanan terapungmenunjukkanprestasi yang lebih baikdari segi min berat badan harianikan, nisbahpenukaran makanan dan min berat ikandenganhari kultura yang lebih rendahberbanding denganmakanan campuran dan tenggelam. Pulanganbersih dan nisbahfaedah kosadalahtinggi untuk makananterapung. Keputusanregresi CD dan PSM mengesahkanbahawa petani yang menggunakanmakananterapung dapat menghasilkan kuantitiikan seunityang lebih tinggiberbanding denganmereka yang menggunakanjenismakanan yang lain. Walau bagaimanapun, kolam yang menggunakanmakananterapung memerlukan pelaburan yang lebih banyak untuk meningkatkan hasil pulangan mereka.

Secara keseluruhannya, dapatan kajian dapat membuktikan wujud kurang pemahaman yang betul tentangamalanteknologi.Petani bolehmenjadi lebih cekapdengan menyelaraskanperuntukaninputdengan teknologidan sumberyang sedia ada. Selanjutnya, pembangunan perusahaan memerlukan pengurangan kos pembolehubah utama.Terutamanya, pembangunan makanan kos rendahakan membantu petani untuk mendapatkan margin keuntungan pada tahap yang kompetitif.Akhir sekali, prospek kultura Thai *koi* adalah positifdalam memenuhipermintaan masa depanikan tersebut. Maka, usaha untuk menangani masalah dankekangan yang dihadapi oleh penternak akan menyumbang kepada sekuriti makanan dan nutrisi di kawasan ini.

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I reserve special honour to my wife, Shayema Islam for her moral support, patience,continuous shower of love and understanding as well as her concern during my study in Malaysia.My two little princesses, Rifah and Suha, who always ask me when you will come back, baba! My dear daughters, I missed your formative years, but I am confident that this sacrifice will improve the quality of your life in the days ahead.

Lastly, this dissertation would be impossible for me to carry forward with great success without the cooperation and support of many people. This was a selfless sacrifice for me by all of you. I love you all.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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I hereby confirm that:

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TABLEOF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ADB	Asian Development Bank
AE	Allocative Efficiency
Aratdars	Commission agents
ATT	Average Treatment on Treated
Baor	Oxbow lake
BBS	Bangladesh Bureau of Statistics
BCR	Benefit Cost Ratio
Beel	Seasonally flooded large water body on dry-season cropland
Beparies/paikers	Wholesaler
BER	Bangladesh Economic Review
BFRI	Bangladesh Fisheries Research Institute
C-D	Cobb-Douglas
CE	Cost Efficiency
CRS	Constant Return to Scale
DEA	Data Envelop Analysis
DoF	Department of Fisheries
DWG	Daily Weight Gain
EE	Economic Efficiency
FAO	Food and Agriculture Organization
FCRs	Food Conversion Ratios
FGLS	Feasible Generalized Least Squares
g	Gram
GDP	Gross Domestic Product
Gher	Area of land enclosed by dikes for shrimp culture
GIFT	Genetically Improved Farmed Tilapia
ha	Hectare
Haors	Flooded basin
IRS	Increasing Returns to Scale
IUCN	International Union for Conservation of Nature
kg	Kilogram
LQ	Linear Quadratic
ML/MLE	Maximum likelihood/Maximum likelihood Estimates
Mn/Mn ha	Million/ Million Hectare
MOA	Ministry of Agriculture
MoFL	Ministry of Fisheries and Livestock
MWG	Mean Weight Gain
NGOs	Non-Government Organizations
OLS	Ordinary Least Squares
PE	Production Efficiency
PRSP	Poverty Reduction Strategy Paper
PSM	Propensity Score Matching
Qnty	Quantity
RTS	Return to Scale
SFA	Stochastic Frontier Approach/Analysis
SFM	Stochastic Frontier Model

SFP	Stochastic Frontier Production
SFPF	Stochastic Frontier Production Function
SFYP	Six Five Year Plan
Taka	Bangladeshi currency. One USD equivalent to Taka 77.7575 in August, 2013.
TE	Technical Efficiency
Thai *koi*	The species climbing perch is scientifically recognized by Bloch (1792) and termed it *Anabas testudineus.* Locally known as Thai *koi.*
TIE	Technical Inefficiency
TL	Translog
Upazila	Sub-district
VRS	Variable Return to Scale
WB	World Bank

CHAPTER 1

INTRODUCTION

1.1 Introduction

Agriculture is central to the economy of Bangladesh. It is the single largest contributor to gross domestic product (GDP) and the chief source of employment. Agriculture is the leading source of supply of raw materials for the agro-based industries. Eventually, it is also a basis of food and nutritional security as well as source of income generation in the rural areas where about 81% of its population live in rural Bangladesh (BBS, 2011). According to the World Bank (2011), agricultural growth and productivity remains the focal point to poverty reduction, particularly in poor countries, where a large share of the population relies on agriculture and agribusiness for their living. Over the last 42 years after independence, every Government has documented agriculture and rural development as the utmost priority sector for rapid poverty reduction in Bangladesh. Even the recent sixth five year plan (SFYP) gives heavy emphasis on agriculture as a strategy to address poverty and sustain economic growth (SFYP, 2011-2015). This chapter reviews the contributions of the overall agriculture sector in the economy of Bangladesh. However, more emphasis is given to the review on the fisheries sector in terms of water resources, production, aquaculture potential, income & employment generation, nutrition & food security, export earnings and poverty reduction.

1.2 Agriculture Sector in Bangladesh

The economy of Bangladesh is broadly categorized into three sectors; agriculture, services and industry. Figure 1.1 demonstrates the sectoral contribution to the Bangladesh economy between 1960 and 2009. The figure shows that agriculture was one of the major contributors with the contribution was more than 40%. The percentage has since continually declined as the rest of the economy grew more rapidly than agriculture. Nevertheless, agriculture is the single largest private producing segment of the economy. Even though currently its GDP share is only 20%, but 47.3% of the total labor forces of the country are employed in the agriculture sector (BBS, 2010). The overall performance of the economy and the contributions of the agricultural sector to economic development and growth are highly correlated. Past data shows that a higher agricultural production would lead to higher economic growth and vice versa. For example, in 2001/02, the agriculture-forestry and fisheries sectors grew by -0.62% and 2.2%, respectively. Over the last decade, the highest GDP growth rate achieved was 6.7% in 2010/11, and that overall agriculture contributed significantly (agriculture-forestry and fishery contributes 5.1% and 5.3%, respectively) in achieving this growth (Table 1.1). Thus, the growth

performances of the agriculture and fisheries sector always play a vital role in achieving the F R X Q W U \ ¶ V R Y H U D O O G H Y H O R S P H Q W

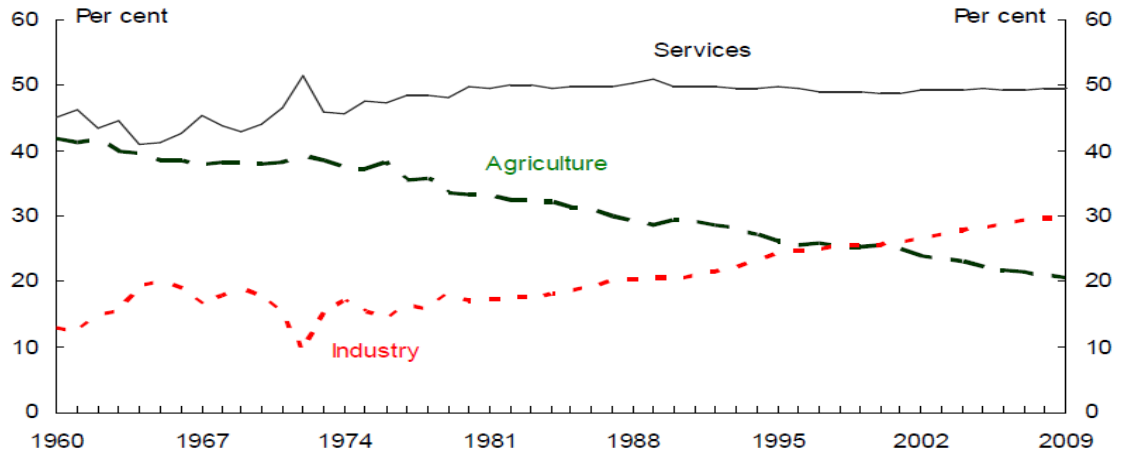

Figure 1.1. Sectoral Contribution of the Economy (%) (1960-2009)
(Source: Rahman *et al.*, 2010a)

Agriculture employs 47.3% of the total labor force of the country (BBS, 2010). There are a total of 28.67 million families involved in agriculture while, the total number of agriculture farm households is 14.72 million (BBS, 2008). Though Bangladesh agriculture is diversified, the important feature of the export basket has been its concentration on a few commodities. The main agricultural export items are: shrimp and other frozen food (47.2% of total agricultural export), raw jute (21%) and other agricultural products (31.6%). The total export earnings of agricultural commodities are USD 1,267 million (mn) in 2011-12 which was only USD 153 mn in 1973. Over the years, the volume of export from agricultural items had increased, however, its share in total exports declined from 41.2% in 1973 to 5.2% in 2011-12 (BER, 2012 and Ahmed *et al*., 2007).

Table 1.1. Growth Rate of Agricultural Sub-sectors at Constant Prices (%) (2001/02-2011/12)

Sector/sub-sector	2001-02	2002-03	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12
Agriculture and forestry	-0.62	3.29	4.38	1.8	5.23	4.69	2.93	4.1	5.56	5.09	2.46
a. Crops & horticulture	-2.39	2.88	4.27	0.15	5.03	4.43	2.67	4.02	6.13	5.65	1.95
b. Animal farming	4.70	4.51	4.98	7.23	6.15	5.49	2.44	3.48	3.38	3.48	3.39
c. Forest	4.91	4.43	4.18	5.09	5.18	5.24	5.47	5.69	5.23	3.90	4.42
Fishing	2.22	2.33	3.09	3.65	3.91	4.07	4.18	4.16	4.15	5.25	5.39
Country's GDP growth	4.42	5.26	6.27	5.96	6.63	6.43	6.19	5.74	6.07	6.71	6.23

Source: BER (2005-2013)

Since independence, the Government has recognized food security as a prime factor in contributing to socio-economic development of Bangladesh. Agriculture is the leading source of food and nutritional security in Bangladesh. Rice is the main food that gratifies most of the nutritional necessities and it comprises over 50% by weight and nearly 80% RI WKH SHRSOH¶V HQHUJ\ LQWDNH (Hug et al., 2013). Moreover, agriculture is also the chief source of animal protein and presently supplements about 68% of animal protein/day/capita (DoF, 2013 and MoFL, 2007). Hence, the National Agriculture Policy has highlighted the efforts to increase domestic production and supply of nutritious crops and thus improve the status of food-based nutrition in Bangladesh (MoA, 1999).

Bangladesh agriculture is comprised of four sub-sectors which are: crops-horticulture, fisheries, livestock and forestry. It is dominated by crop production that presently accounts for some 56% of the sectoral value-addition. Within crop production, rice alone constitutes around 60% in terms of value-addition in this sector, thus the country can still be regarded as a rice economy (SFYP, 2011-2015). However, despite the dominance of crops, the structure of agriculture has changed gradually with some gains mainly in fisheries sector. This sub-sector currently contributes 22.6% of sectoral value addition WKDW ZDV LQ WKH ¶V /LYHVWRFN SURGXFWLRQ K forestry products recorded a small gain. The livestock and forestry sub-sectors presently contribute 12.9% and 8.6%, respectively (Figure 1.2). Among these sub-sectors, crops are cultivated principally for subsistence. Only a small percentage of total crop production makes its way into the commercial conduits. However, significant progress has been attained in poultry and fisheries sub-sectors. These two sub sectors have flourished commercially on a small-scale all over the country and created a great potential for farmers to earn higher income as well as self-employment generation.

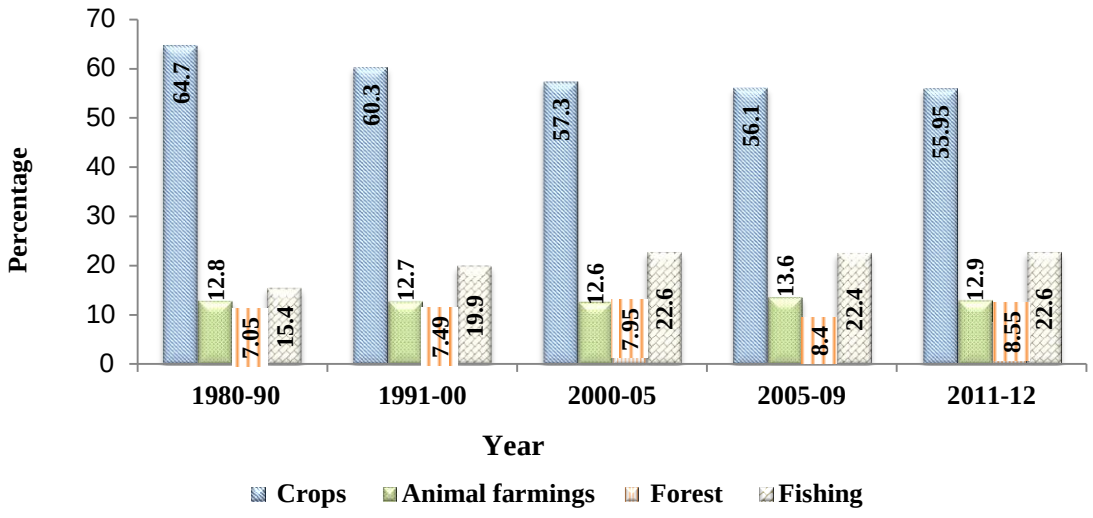

Figure 1.2. Share of Sub-sectors within Agriculture (%) (1980-90 to 2011-12)
(Source: BER, 2013 and SFYP, 2011-15)

1.3 Water Resources

&RXQWU\¶V ILVKHULHV resources are categorized broadly into three major groups: inland capture/open waters, marine waters and inland culture/aquaculture. The inland open waters comprises of rivers & estuaries, canals, lakes, *beels* (seasonally flooded large water body on dry-season cropland), *haors* (flooded basin), and seasonal floodplains. On the contrary, inland culture waters include of pond & ditches, *baors* (oxbow lake), semi-closed (flood plains) and shrimp/prawn farms. There are 4.7 million hectares (mn ha) of inland water bodies in the country, of which capture and culture fisheries consists of 4.02 and 0.68 mn ha, respectively. In addition, the republic has a 480 km long coastline and approximately 16.6 mn ha of marine water in the Bay of Bengal. The nation is also blessed with an exclusive economic zone which contains up to 200 nautical miles from the coastline (Table 1.2 and Mustafa *et al.* *7KXV WKH FRXQWU\¶V WRWD* bodies having fish production potential is of great importance. Among inland water resources, the highest or 85.6% is for capture fisheries and the rest or 14.4% of the water area is under culture fisheries. Among culture water areas, the leading area is covered by ponds & ditches (about 55%) followed by shrimp/prawn farms which is about 41% (Table 1.2).

Table 1.2. Area of Water Resources in Bangladesh (ha) (2011/12)

Water types	Water area (ha)	% of total inland
A. Inland water		
I. Capture (open) total	4,024,934	85.57
River & Estuaries	853,863	18.15
Sundarbans	177,700	3.78
Beel	114,161	2.43
Kaptai lake	68,800	1.46
Flood plain	2,810,410	59.75
II. Culture (closed) total	678,724	14.43
Pond & ditch	371,309	7.89
Semi-closed water body	25,435	0.54
Baor	5,488	0.12
Shrimp/prawn farm	276,492	5.88
Inland total (I + II)	4,703,658	
B. Marine water	166,000 km^2	

Source: DoF (2010-11) and Ali *et al.* (2010a)

Inland capture and marine waters in Bangladesh saw a continual decreasing trend of fish production. However, the country is blessed with an excellent aquaculture potential because of its vast areas of pond resources and it is expanded commercially all over Bangladesh. The challenge in the fisheries sector is productivity gains, which is the lowest in the world. Per hectare productivity of inland capture fisheries is only 262 kg, while it is 3,615 kg from pond aquaculture (DoF, 2011-12). Since management of inland capture fisheries is difficult, great stress is being laid to utilize the vast inland water areas of the country for aquaculture (Ali *et al.*, 2010b). However, as land and related

resources are limited in Bangladesh, obviously horizontal expansion of pond culture is not possible due to the paucity of land area. The availability of land/capita is declining and the loss of agricultural land is going on at the rate of about 1% per year (MOA, 2013). As the potential for pond culture has nearly been exhausted, steps should be taken to raise the productivity of pond fishery in the country (SFYP, 2011-15). Therefore, emphasis needs to be given to vertical expansion of pond aquaculture, i.e., increased productivity through applying effective management and techniques.

1.4 Fisheries Sector

Bangladesh is a country blessed naturally with hundreds of rivers and ponds. It is distinguished for being a fish-loving nation, securing the name "*Machh-e Bhat-e Bangali*" which means, "Bengali is made up of fish and rice". Fish is much preferred and is an important traditional food item treated as a staple food next to rice. Fish is a chief source of animal protein and viewed DV ³SRRU SHRSOH¶V SURWHLQ´ ,W I fishing activities are particularly associated with poorer rural dwellers, where 81% of dwelling households live in rural Bangladesh (BBS, 2011). Considering all these together, fisheries in the country have seemed as a dynamic and one of the fastest rising sub-sectors of the economy with a growth rate far in excess of any other agricultural activities (SFYP, 2011-2015 and Belton *et al.*, 2011).

Fish and fisheries are an indispensable part of life and livelihood of the people since immemorial times. Fisheries is now the second most valuable agricultural activity, playing a substantial role in nutrition, food security, employment & income generation, trade, poverty reduction and a source of foreign exchange earnings in the economy of Bangladesh. Presently, it contributes 4.4% of national GDP, 22.62% to the total agricultural GDP and 2.5% to tKH FRXQWU\¶V export earnings. Moreover, fish alone is supplementing around 60% of animal protein per capita in the daily dietary requirement (BER, 2013; DoF, 2013 and 2011b).

Over the years, the decline in the share of agriculture in the national GDP is reflected with the increasing prominence of the industrial and service sectors. In spite of the decline in the share of agriculture in GDP, the fisheries sector has maintained an average contribution of 4-6% to the national GDP (BBS, 2007). Even though the contribution of overall agriculture in GDP has decreased, the share of fisheries has increased significantly. The contribution by fisheries to agricultural GDP has increased from USD 379 mn in 1973-75 to USD 2,195 mn in 2011-12. The share of fisheries in the agricultural GDP has increased significantly from 7 to 22.6% during the last nearly four decades (BER, 2013 and Dey *et al.*, 2008).

The fisheries sector plays an important role among disadvantaged groups as a main or supplementary source of employment, livelihood and income. Presently, 16.5 million (about 11% of total) people are directly or indirectly dependent on fisheries for their livelihood, of which 1.3 million people rely exclusively on fisheries related activities. Out of the total population in the fisheries sector, about 10% are women, which are 1% of the total population (DoF, 2013 and 2011a). Most Bangladeshi poor live in rural areas with very limited employment opportunities. The coun W U\¶V poverty reduction strategy

paper (PRSP) and National Fisheries Strategy indicated that income-generating opportunities for rural households are most promising in the fisheries sector (DoF, 2006 and PRSP, 2005).

The country is endowed with vast and highly diversified fish species. About 296 fresh and brackish water fish species (including 24 freshwater prawns and 12 exotic species) and 511 marine species (including 36 marine shrimp) are available in the F R X Q W U \ ¶ V waters (DoF, 2009-10). Meanwhile, 21 fish species have become extinct in Bangladesh, and 54 have been scheduled as critically endangered and vulnerable in the red book of IUCN 2000 (Karim *et al.*, 2010).

The total fish production has gradually grown up over the last five decades. The aggregate fish production was 0.75 million tons (mn tons) in 1963, of which 0.67, 0.039 and 0.04 mn tons were inland open, inland closed and marine fisheries, respectively. The production has increased up to 3.26 mn tons in 2012, indicating an increase of more than four fold. Out of this total production, inland open water fisheries accounted for 0.96 mn tons, inland aquaculture 1.72 mn tons and marine water 0.58 mn tons. The fishery sector grew at 6.7% during the last 50 years and most of the growth took place in aquaculture (Table 1.2).

Table 1.3. Fish Production by Sources (mn tons) (1963-2012)

Sources	Fish production											
	1963		1973		1983		1993		2003		2012	
	Qnty	%	Qnty	%	Qnty	%	Qnty	%	Qnty	%	Qnty	%
Inland capture	0.67	89.2	0.66	81	0.471	63	0.57	52.6	0.71	35.5	0.96	29.34
Aquaculture	0.039	5.2	0.07	8.3	0.117	15	0.26	24.2	0.86	42.89	1.72	52.92
Marine waters	0.04	5.6	0.09	10.7	0.165	22	0.25	23.2	0.43	21.61	0.58	17.74
Total	0.75	100	0.82	100	0.75	100	1.09	100	2.00	100	3.26	100

Sources: DoF (2013) and Ali *et al.* (2010a)

The average growth of aquaculture during the last five decades was 86.5%, while inland open and marine sector grew only at 0.87 and 27% rates, respectively. The share of aquaculture and marine sources in the total fish catch was relatively insignificant in 1963, accounting for 5.2 and 5.6%, respectively as against 89% from inland open water (Table 1.3). However, after 1963, inland capture fisheries have been replaced by aquaculture as the top fish producing source. At present, the share of aquaculture in total fish production is about 53% followed by 29 and 18% for inland capture and marine waters, respectively (Figure 1.3).

Trends in fish catch shows that the contribution of culture fishery has been on the increase. However, due to over fishing and faulty management policy including other manmade concerns like massive construction of flood control structures, abstraction of water for irrigation, intensive agriculture and industrial development, reclamation of land for human settlement, aquatic pollution and natural causes like siltation of water bodies as well as soil erosion, inland open water fisheries has declined significantly during the last 3-4 decades. Marine fisheries are being exploited beyond maximum

sustainable levels with increasing fishing efforts and thereby fishers catch and income are declining (Ali *et al.*, 2010a, Ali *et al.*, 2010b and Chowdhury *et al.*, 2001).

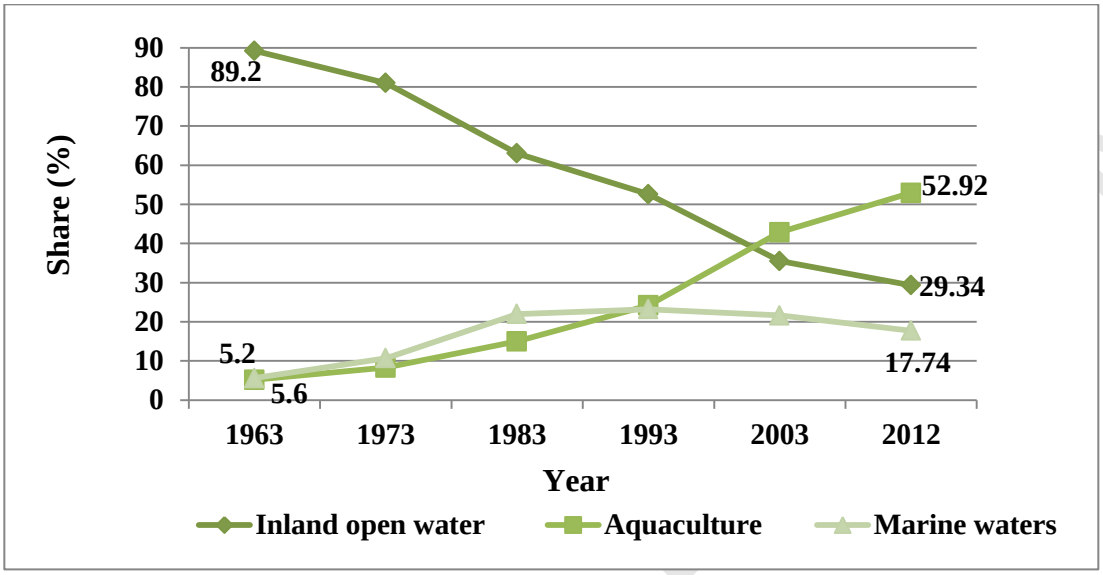

Figure 1.3. Share of Fish Production by Sources (%) (1963-2012)
(Adapted from Table 1.2)

Fisheries sector contributes in a diversity of ways to the economy, thereby earning valuable foreign exchange. The fish trade is one of the major sources of foreign currency earnings in Bangladesh and delivers benefits at both the macro and microeconomic levels (Dey *et al.*, 2005a). In fact, earnings from traditional exports of non-fish agricultural products are steadily being outpaced by fishery products (Dey *et al.*, 2008). The export statistics of fishery products are portrayed in Table 1.4.

Table 1.4. Export of Fish (tons) (million USD) (2002/03-2011/12)

Year	Frozen shrimp/prawn		Other fish products		Total		% of total export
	Quantity	Value	Quantity	Value	Quantity	Value	
2002-03	36,864	297.04	10,507.00	38.29	47,371.00	335.34	5.10
2003-04	42,943	365.28	11,198.00	35.75	54,141.00	401.03	5.71
2004-05	46,533	371.63	16,844.00	47.25	63,377.00	418.89	5.90
2005-06	49,317	402.26	19,512.00	49.42	68,829.00	451.68	4.56
2006-07	53,361	433.47	20,343.00	52.24	73,704.00	485.70	4.90
2007-08	49,907	417.47	25,392.00	77.58	75,299.00	495.05	4.04
2008-09	50,368	398.85	22,520.00	72.57	72,888.00	471.42	3.00
2009-10	51,599	417.03	26,044.00	75.64	77,643.00	492.67	2.74
2010-11	54,891	501.35	41,577.40	187.66	96,468.40	646.86	2.73
2011-12	48,007	460.22	44,471.46	134.49	92,478.46	594.71	2.46

Source: BER (2011 and 12) and DoF (2002/03-2011/12).

It shows that the quantity of exported frozen shrimp/prawn and fish products nearly doubled over the last decade. Currently, it contributes 2.5% of the c R X Q W U \ ¶ V W R W D O H earnings. Interestingly, among the agricultural sectors, about half of the export earnings are accrued from the fisheries sector (BER, 2012).

1.5 Aquaculture Industry in Bangladesh

Aquaculture is being considered a recent success story in helping to feed the ever increasing population over the globe. The production of food fish from aquaculture increased at an average annual rate of 8.3% over the globe, while the world population grew at 1.6% per year during 1970 ±2008. The combined result of development in aquaculture worldwide and the expansion in global population is that the average annual per capita supply of food fish from aquaculture for human consumption has increased by ten times, from 0.7 to 7.8 kg, at an average rate of 6.6%. In the last two decades, aquaculture has recorded significant and rapid growth among the food-producing sectors and has developed into a globally robust and vital industry (FAO, 2010).

Aquaculture in Bangladesh has also become a prominent source of fish production and contributes to food and nutritional security. The gift of aquaculture to the total production of fisheries continued to grow, rising from 5% in 1963 to around 53% in 2012 (Table 1.2). Besides, it is a major contributor to the F R X Q W U L H Va¶ d H F R Q R P \ sector with promising export potential. Moreover, aquaculture plays a significant role in providing vital income generation and employment opportunities to the people of Bangladesh. Rahman (2009) noted that out of the total employment in the fisheries sector, 55% are involved in fresh water fisheries. Karim *et al.* (2006) reported that aquaculture has made an important contribution to the income generation and employment of ordinary rural people. This allows rural households to both improve their health standard and supplement their incomes. About 73% of rural households are engaged in some form of fresh water aquaculture (Mazid, 1999). Women participation in aquaculture has provided further momentum on the socioeconomic wellbeing of the households.

Bangladesh is considered one of the most suitable countries in the world for freshwater aquaculture, because of its favorable resources and agro-climatic conditions for fish production. The numerous impounded water areas in the form of ponds and ditches are spread all over the country and fish production has turned from its subsistence nature to commercial pursuit. Following the introduction of technology for inducing carp to spawn in the late 1960s and the subsequent development of fish pond management technologies in the 1970s and 1980s, fish farming became widespread and market driven. Culturing various carp and exotic fish species in ponds and lakes became popular all over the country (Dey *et al.*, 2008). Moreover, a notable structural change in fishery has taken place during the last two decades. During this period, aquaculture expanded significantly with the gradual development of fish culture technology and successful transfer for the same for adaption by the fish farmers. Bangladesh Fisheries Research Institute (BFRI) has played a very big role in this direction by developing 24 different fish culture technologies. Furthermore, International research institutes (e.g. WorldFish Center) as well as government initiatives to promote aquaculture by taking various

development projects are also appreciable in this connection. The dissemination efforts by the Department of Fisheries (DoF) and NGOs are indisputable $ E R Y H D O O I D U P H motivation by adopting technologies at farm level also placed an important role to expand this sector.

Aquaculture in Bangladesh is categorized mainly by *baor*, shrimp/prawn fields and ponds. The fresh water aquaculture comprises farming mostly in ponds/ditches and coastal brackish water is mainly shrimp/prawn farms. Among the total area of culture fisheries, ponds alone constitute 55% (DoF, 2013). Over the last 12 years, there has been a dramatic increase in inland freshwater aquaculture production in Bangladesh. Fish production from aquaculture has increased from about 0.713 mn tons in 2000-01 to 1.72 mn tons in 2011-12, and the annual average growth rate was around 12% (Table 1.5). $ P R Q J W K H V H V R X U F H V S R Q G ¶ V F R Q W U L E X W L R Q L Q W Throughout these years, fish production increased by more than double from pond culture, with an average growth of around 10% which is the highest among all sources of fish catch. Currently, it alone contributes about 41% of total fish production in Bangladesh (DoF, 2013). Asche *et al.* (2006) illustrated that a revolution has taken place in the production technology available for aquaculture in recent decades, as semi-intensive and intensive production technologies have been invented. This has led to a substantial increase in pond fish production. With gradual increase of freshwater fish S U R G X F W L R Q % D Q J O D G H V K L V Q R Z U D Q N H G V H F R Q G L Q O D U J H V W L Q F D S W X U H D Q G U D Q N H G V L [W K L Q D T X D F X O W X U H S U R G X F L Q J F R X Q W U \ D P R Q J W K H W R S W H Q L Q W K H Z R U O G ¶ V second largest in capture and ranked sixth largest aquaculture producing country among top ten in the world (FAO, 2010). Thus, pond aquaculture has become an increasingly important fish food producing industry in Bangladesh and contributing to improve socio-economic status of rural communities.

Table 1.5. Aquaculture Production (Mn tons) by Sources (2000/01-2011/12)

Year	Baor	Shrimp/ prawn farm	Pond	Total	Annual growth (%)
2000-01	0.0038	0.0930	0.6158	0.7126	8.45
2001-02	0.0039	0.0976	0.6851	0.7866	10.38
2002-03	0.0041	0.1008	0.7521	0.8570	8.94
2003-04	0.0043	0.1147	0.7958	0.9148	6.74
2004-05	0.0044	0.1207	0.7570	0.8821	-3.57
2005-06	0.0045	0.1279	0.7596	0.8920	1.13
2006-07	0.0047	0.1292	0.8120	0.9458	6.03
2007-08	0.0048	0.1347	0.8660	1.0055	6.32
2008-09	0.0050	0.1456	0.9122	1.0628	5.69
2009-10	0.0087	0.1559	1.1405	1.3520	27.21
2010-11	0.0049	0.1849	1.2197	1.4608	8.05
2011-12	0.0052	0.1963	1.3423	1.7261	18.16

Source: DoF (2013 and 2000/01-2011/12)

1.6 Pond Culture

Although pond aquaculture in Bangladesh has a long history, semi-subsistence and commercial pond aquaculture started only three decades ago (Dey *et al.*, 2008). Over the period, both area and production under pond culture has increased massively due to its commercial viability. Specially, pond area has increased from 0.24 to 0.371 mn ha during the last decade. Pond fish-culture systems practiced in Bangladesh can be divided into four groups. These are mainly extensive and extended extensive with some semi-intensive and in very few cases intensive systems are practiced by the farmers (FAO, 2005-2012). The most important technology accepted widely is carp poly-culture, *pangas* monoculture, shrimp and giant freshwater prawn culture and Genetically Improved Farmed Tilapia (GIFT). Currently, pond poly-culture of Indian major carps and exotic carps accounts for 80% of the total freshwater aquaculture production (Samina Shirajee *et al.*, 2010 and Alam, 2005).

Fish culture has been increasing both vertically and horizontally as pond fish culture and shrimp farming offer great potential (DoF, 2008-09). Fish production from ponds has shown an annual average growth rate of nearly 10% from 0.616 to 1.34 mn tons during the period from 2000-01 to 2011-12 (Table 1.6). The production of fish from ponds is now higher than all sources of fisheries. Presently, fish culture in ponds alone supplement V W R W K H Q D W L R Q D O L Q O D Q G I L V K H U L H V and around 78% to culture total in the country. Although the pond fishery contributes 50% of inland fish production, it covers only 7.89% of the total inland water bodies, thus playing a vital role in fresh water fish production (Tables1.2, 1.4, 1.5 and 1.6).

Table 1.6. Total Area (Mn ha) and Catch of Fish (mn tons) under Ponds (2000/01-2011/12)

Year	Total area of ponds	Total production	Annual growth (%)
2000-2001	0.242	0.616	9.76
2001-2002	0.266	0.685	11.22
2002-2003	0.291	0.752	9.77
2003-2004	0.305	0.796	5.82
2004-2005	0.305	0.757	-4.88
2005-2006	0.305	0.760	0.35
2006-2007	0.305	0.812	6.89
2007-2008	0.305	0.866	6.66
2008-2009	0.305	0.912	5.31
2009-2010	0.351	1.140	25.05
2010-2011	0.371	1.220	6.88
2011-2012	0.371	1.342	10.09

Source: DoF (2013 and 2000/01-2011/12)

The gradual shift of effort from self-consumption to market has led to the proliferation of pond aquaculture as a lucrative agribusiness in Bangladesh. Various studies showed that fish culture is a profitable enterprise in Bangladesh (Hasan *et al.*, 2010; Kohinoor *et al.*, 2010 and Dey *et al.*, 2008). Even Karim *et al.* (2006) found that returns from pond fish culture are several times higher than other crop and non-crop enterprises.

Employment intensity of pond culture is also fairly high compared to that of other agricultural enterprises such as rice cultivation. They also reported that the upland rice-fields are being converted into fish ponds. Many research works further mentioned that aquaculture practice has become a promising and gainful enterprise to alleviate poverty, especially, in rural areas of Bangladesh (Ahmed, 2003 and Graaf *et al.*, 2002). Moreover, the involvement of women in aquaculture provides three basic improvements: economic, nutritional and social benefit and those are assumed to be interlinked in order to empower women. They also exhibited that with increased participation in aquaculture, Z R P H Q¶V V R F L R H F R Q R P L F F R Q G L W L R Q V Z L W K L Q W K H K significantly (Sarker, 2011 and Samina Shirajee *et al.*, 2010). The ongoing SFYP of Bangladesh is also recognized to increase wom H Q ¶V S D U W L F L S D W L R.Q L Q I D U P

Fish is an important source of vitamins and micronutrients for the poor people in Bangladesh (Thilsted *et al.*, 1997). Though the country has been blessed with vast water resources and fish production has increased remarkably, still the per capita deficit of fish is 1.5 kg/year (DoF, 2013). Moreover, fish consumption is still below the recommended dietary allowance. FAO recommended daily protein intake of a healthy person is 45 g/capita of which 15 g animal protein is necessary as against the 11 g we are enjoying (Mustafa *et al.*, 2010). It is alarming that the availability of protein intake from fish gradually decreased from 73% in 1991 to 60% in 2012 (DoF, 2013 and Dey *et al.*, 2008). Moreover, studies claimed that the protein intake is not equal among the people in the society. Low-income households consume less fish than rich households. Most of the rural poor just cannot afford to buy fish and as such are severely animal protein deficient (Bose *et al.*, 2007; Islam, 2007; Dey *et al*., 2005b; Hossain *et al.*, 2005 and Chowdhury *et al.*, 2000). As a result, Bangladesh today is characterized by the lack of sufficient protein which causes the problem of malnutrition. Conversely, the demand for fish is continually increasing in the country with nearly three million people being added every year to the population (Chowdhury, 2009). With a huge population and demand for fish, the expansion of fish supply to maintain food security has emerged as a priority concern in Bangladesh.

Productivity is very important to run any enterprise effectively. Though productivity is increasing overtime in pond fishery, but still the per ha productivity is far behind in comparison to other countries. The average yield of pond culture increased from 2,580 kg/ha in 2000 to 3,615 kg/ha in 2012 (DoF, 2013 and 2000/01), which is much lower than other Asian countries (Karim *et al.*, 2006). The average yield of pond culture in China was 6.8 tons/hectare (FAO, 2010) and an average yield of cropped fish per annum was 1,200 kg/m^2 in Nigeria (Ogundari *et al.*, 2010). Even species-wise fish production also varied in the Asian countries and showed that Bangladesh was far behind. Dey *et al.* (2008) showed that output in carp poly-culture in ponds was 3,262 kg/ha for Bangladesh while, it was 12,085 kg and 3,777 kg for China and Thailand, respectively. Dey *et al.*

(2008) further reported that past increases in freshwater pond production in Bangladesh came mainly from expansion of the production area. Karim *et al.* (2006) also revealed that the yield rate of aquaculture in Bangladesh was, one of the lowest in the world, and could be increased several fold through appropriate actions and policies.

About 20 fish species are cultured in pond fishery and the major cultivated species are: *rui* (*Labeo rohita*), *catla* (*Catla catla*), *silver carp* (*Hypophthalmichthys molotrix*) and *mrigal* (*Cirrhinus cirrhosus*). This top four species enveloped together 80% in 2000-01, but decreased to about 54% in 2011/12 (Table 1.7). This four species practiced in ponds has a long history of fish farming in Bangladesh; however, these species are being replaced by other species including some exotic species like Thai *koi* and Thai *pangas* (*Pangasius hypophthalmus*). The annual average growth rate of the top four fish species is 2.34% as against the average growth rate of Thai *koi* at 49.2% in recent decades (DoF, 2002/03-2011/12). The growth of Thai *koi* is impressive as this strain is a new species as well as a novel technology to the farmers.

Table 1.7. Top Four Fish Species Cultured in Ponds (%) (2000/01-2011/12)

Species	2000 -01	2001 -02	2002 -03	2003 -04	2004 -05	2005 -06	2006 -07	2007 -08	2008- 09	2009- 10	2010 -11*	2011 -12
Rui	21.5	21.8	21.8	20.8	21.6	22.9	22.4	23.3	24.8	22.1	22.0	18.7
Catla	19.9	18.6	18.1	17.6	18.2	19.8	19.0	17.4	19.6	17.1	17.2	14.4
Silver carp	24.5	24.7	23.8	19.6	21.0	22.0	20.6	18.6	18.7	16.6	10.5	11.1
Mrigal	14.5	14.3	14.0	15.0	14.8	15.2	15.1	14.1	14.5	13.0	12.5	9.5
Total	80.4	79.4	77.7	72.9	75.6	79.9	77.1	73.4	77.6	68.8	62.1	53.8

Source: DoF (2000/01-2011/12)

* From 2010/11and onward, Thai *pangas* scored top 4 species and presently the weight is 19%.

1.7 Thai *Koi* Farming in Bangladesh

With the low productivity in aquaculture as well the large deficit of fish intake per capita created a demand for introducing high yielding and quick growing exotic fishes to boost up the domestic fish production. In this arena, an exotic strain of climbing perch (*Aanabas testudineus)* was introduced into Bangladesh from Thailand in 2002 by private entrepreneurs. This fish, popularly (locally) known as ¡Thai *koi* ¶ was henceforth referred to as Thai *koi*. Currently, this strain is getting more popular than the native *koi* strain as the growth rate of Thai *koi* is much higher and attains 80-100 g in size within 90-120 days. Moreover, it can be stocked at higher densities as well as harvested twice a year (Hasan *et al.*, 2010 and Saha *et al.*, 2009). The higher growth rate and larger size of Thai *koi* and tolerance to a wide range of environmental conditions caught the attention of farmers in Bangladesh (Hossain *et al.*, 2012). It is now a prominent freshwater farmed fish species in the country.

The species Thai *koi* is scientifically recognized by Bloch (1792) and termed it *Anabas testudineus* based on its classification under the family Anabantidae, order-Perciformes. Climbing perch possesses a pair of accessory respiratory organ which enable it to breathe from air and survive out of water for prolong periods. This fish is hardy and can tolerate very unfavorable water conditions. This species is naturally distributed in

Bangladesh, Burma, Ceylon, Cochin-China, India, Malaysia, Pakistan, Polynesia, Sri Lanka, southern China, Thailand, Tongking, and The Philippines (Rahman *et al.*, 2010b; Tay *et al.*, 2006; Kohinoor *et al.*, 1994; Patra, 1993; Talwar *et al.*, 1991; Sen, 1985 and Jayaram, 1981). This freshwater fish is found in the *beels, haors, baors*, flooded water bodies, ponds, streams and rivers of Bangladesh (Siddique *et al.*, 2000). It matures earlier than some of the carps and the fishes are marketed mostly in live condition. This fish is very suitable for cultivation in ponds, reservoirs and rice fields. The climate, water and soil conditions have proven to be totally suitable for its culture in Bangladesh.

Figure 1.4. Thai *Koi* (Climbing perch): *Anabas testudineus* (Bloch, 1792)

Climbing perch is one of the most popular fishes in Bangladesh because of its taste and high market demand both at home and abroad. It is very much esteemed for its highly nourishing quality and prolonged freshness. The medicinal as well as nutritional value of this fish has been documented from time immemorial (Chandi, 1970). It contains very soaring amounts of physiologically available iron and copper fundamentally needed for hemoglobin synthesis; besides, it possesses easily digestible fats of very low melting point and good many essential amino acids (Kohinoor *et al.*, 1991). Therefore, climbing perch is considered as a precious item in the diet for the sick and convalescent (BFRI, 2006). Table 1.8 below displays the nutritional values of Thai *koi* fish.

Table1.8. Nutritional Status of Climbing Perch

Nutrients	Percentage
Protein	14.80
Fat	8.8
Carbohydrate	4.4
Mineral (Kcal)	156
Iron (mg)	1.4
Calcium	410

Source: Sarker (2011)

In the past native *koi* was plentifully available in almost all freshwater systems of Bangladesh, but the recent trend shows a continuous dilapidated tendency. Due to ecological changes and increased fishing pressure, the abundance of indigenous fish is declining gradually. DoF (1992) reported that one decade ago, climbing perch contributed 2.8% of the total pond catch of Bangladesh, but off late its share to total pond catch was down to 0.85% (DoF, 1999). This has created a demand for introducing exotic fishes (Rahman, 2005).

The productivity of Thai *koi* is fairly high than the native *koi*. Its productivity is much higher than other fish species cultured in Bangladesh. The productivity of Thai *koi* varied from 6,480 to 9,880 kg/ha in different studies as opposed to 1,916 kg/ha of native *koi* (Khatune-Jannat *et al.,* 2012; DoF, 2010; Kohinoor *et al.* 2007 and 2009). Therefore, farmers are very much interested to culture it due to its higher growth rate and better returns compared to other species (Hasan *et al.*, 2010). Recently, in the Mymensingh region, many farmers are involved in Thai *koi* culture resulting in high demand for fry. Under these circumstances, artificial propagation technique of Thai *koi* has been developed for mass seed production (Saha *et al.*, 2009 and BFRI, 2006).

Thai *koi* culture in ponds is a new intervention of the aquaculture industry in the country. Table 1.9 illustrates the Thai *koi* catch from ponds over the past 13 years. The table shows that the production of *koi* in 1999-2000 was 3,871 tons, while the production increased to 31,143 tons in 2011-12. The overall fish catch accounts 8 times higher and most of the growth took place after introducing Thai *koi* culture in ponds. The annual average growth rate of production was 54% during these periods. Though over the period, the growth performance is impressive, however, growth fluctuates widely from year to year. The highest production was recorded in 2011-12 with the annual growth rate of 132%, while the lowest production was recorded in 2008-09, with a growth rate of -72% (Table 1.9). The share of *koi* fish in total pond culture has also increased from 0.69% in 1999/2000 to 2.32% in 2011/12. Figure 1.5 portrays the

Table 1.9. Thai *Koi* Production (tons) (1999/00-2011/12)

Year	Total production	Percentage of pond total
1999-2000	3,871.25	0.69
2000-2001	4,495.52	0.73
2001-2002	4,864.26	0.71
2002-2003	5,264.38	0.70
2003-2004	6,127.74	0.77
2004-2005	1,892.48	0.25
2005-2006	8,887.65	1.17
2006-2007	2,354.67	0.29
2007-2008	6,495.37	0.75
2008-2009	1,824.00	0.20
2009-2010	7,056.00	0.62
2010-2011	13,406.00	1.10
2011-2012	31,143.00	2.32

Source: DoF (1999/2000-2011/2012)

production trend of this fish strain. Though the production has increased steadily over the years; however, the ups and downs in overall production of this species indicates that there might be some problems in Thai *koi* culture in the study area causing fluctuations in production.

Thai *koi* is a fast growing fish species which has great potential for expansion and export earnings in Bangladesh. Its productivity and growth is also higher compared to other fish species cultured in the country (Khan, 2012 and Sarker, 2011). However, the production trend displays a high range of variability in *koi* farming. Farmers are practicing intensive production technology in Thai *koi* culture which is new in Bangladesh. Basically, farmers usually practice extensive to extended extensive production technologies. Thai *koi* is a feed intensive species and therefore can, cause high or low growth and survival that is likely to cause production variability (risk) and inefficiency in the production process. Output variability is observed from farm to farm, location to location and also year to year; and this indicates that there may be some risk element in Thai *koi* farming. It was learnt during the survey that despite its notable growth at the early stage, farmers are now experiencing a high degree of uncertainty due to large cross-sectional variations in production and profitability which results in a large number of Thai *koi* farmers quitting from this agri-business.

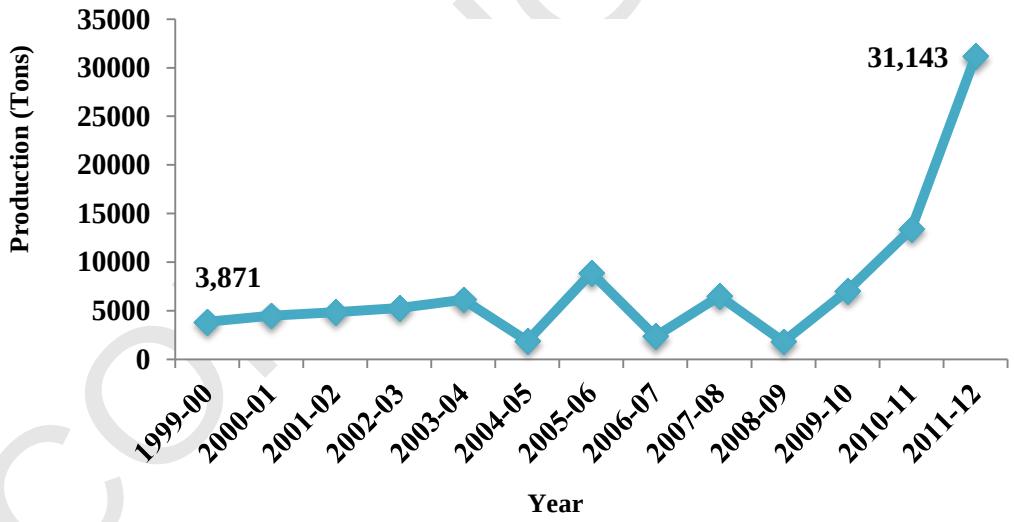

Figure 1.5. Production Trend of Thai *Koi* (tons) (1999/00-2011/12)
(Adapted from Table 1.9)

Thai *koi* farming is a young industry as well as new technology to the farmers. The private sector is the major player in Thai *koi* culture, and with well-considered strategies, good management practices and proper handling technology, the outlook for the aquaculture can be very positive. However, there is a need to carry out detailed studies to develop and grow this farming system in an economically viable and sustainable fashion.

1.8 Statement of Problem

Bangladesh's inland capture and marine fisheries display a gloomy scenario in terms of fisheries production despite the existence of an excellent aquaculture potential. The current production is not adequate enough to meet the demand by the growing population. Moreover, the demand for fish is continually increasing in the country with nearly three million people being added every year to the population. While overall fish production keeps on increasing, per capita fish consumption is still in deficit at 1.5 kg/year compared to the optimal requirement. This shortage in fish consumption results in declining daily animal protein intake. The fish intake declined from 73 to 60 g during 1991 to 2012. Studies also showed that fish intake is not equitable between poor and rich households in the country. Among the two major sources of animal protein, the growth of livestock remained stagnant (SFYP, 2011-15) and hence the only way to fill-up this gap is to boost up domestic fish production. A country like Bangladesh with a huge population (139 million, BBS, 2011) cannot afford to depend on imports perpetually by spending huge foreign currency. Since increasing fish production through horizontal expansion (i.e. increase in area) of fish culture is bleak, there is no alternative other than to increase per unit production. The productivity of fish per hectare from pond farming in Bangladesh lags behind than other Asian countries. Thus steps need to be taken to increase the productivity of pond fishery in the country.

The growing demand for fish have motivated farmers to introduce high yielding and quick growing exotic Thai *koi* farming in Bangladesh. Thai *koi* can be harvested two times a year and thus can, play a significant role to meet the increasing protein requirement. However, despite its impressive growth during the initial years, the industry is now experiencing volatility in production. The fluctuating Thai *koi* production poses a serious concern among the fisheries extension personnel as well.

Chakraborty *et al.* (2014) carried out an on-station experiment under three treatments and found the productivity of *koi* fish were 22,063 kg, 19,852 kg and 16,381.2 kg/ha, respectively. Another experiment was conducted in nine experimental ponds (on station) by Rahman *et al.* (2013) and they found per ha productivity to have varied from 4,800 kg to 5,582 kg. On the contrary, Sarker (2011) conducted an economic study on small-scale *koi* farming and found per hectare productivity of Thai *koi* was 22,179 kg, while in a more recent study it was found to be 16,551 kg/ha. Therefore, causes of Thai *koi* production variability attracts due investigation.

Thai *koi* production is relatively a newly introduced technology in the aquaculture practices of Bangladesh, farmers know less about its culture practices, food and feeding habit, health and disease incidence. Many have no training about Thai *koi* technology and learnt the same from neighboring farmers. Good number of farmers may not have any idea about the optimum allocation of feed, fingerlings, cultural length, stocking density and use of other inputs. Production variability might be due to all these. Moreover, many of the farmers may be technically inefficient. Thus, input-out relationship, production variability and extent of technical inefficiency for a new technology warrant in-depth investigation. A study like this is deemed very timely. It would provide answers related to i) nature of inputs contribution to Thai *koi* production,

ii) whether the inputs are risk-neutral, risk-increasing and risk-deceasing to the production variability and iii) extent of average and farmer specific inefficiency. This information is new as this is the first investigation in Bangladesh on Thai *koi* fish production. This information would add a new insight to Thai *koi* production and help improve the current level of production. The research findings of this study will also be helpful for the government to formulate policy actions and support to encourage output JURZWK DW WKH IDUPHUV¶ OHYHO ,W LV ZLWK WKHVH E have been developed:

i) What affects Thai *koi* productivity in Bangladesh?
ii) Is production variability in Thai *koi* farming linked with intensity of input use?
iii) Are Thai *koi* farmers in Bangladesh capable of achieving production at the frontier level?
iv) Do types of feed used constitute a concern to production of Thai *koi* farming?

1.9 Objectives of the Study

The overall objective of this research is to explore the production risk and technical efficiency of Thai *koi* production in selected areas of Bangladesh. The specific objectives are:

i) To identify the nature and extent of risk associated with the use of variable inputs in Thai *koi* production;
ii) To estimate the levels of farm-specific and mean technical efficiency associated with *koi* farming;
iii) To identify the factors affecting technical inefficiency in *koi* farming;
iv) To determine the farm profitability and insight farming practices of Thai *koi* production; and
v) To assess how types of feed affect Thai *koi* productivity.

1.10 Hypotheses of the study

The following hypotheses require testing with respect to the gratification of the research objectives:

i) Inputs used in Thai *koi* farming does not significantly influence production;
ii) Thai *koi* farming scores no production risk;
iii) Thai *koi* farmers are not technically efficient;
iv) There is no existence of technical inefficiency in *koi* production and
v) Types of feed used have no influence on Thai *koi* farming and its productivity.

1.11 Significance of the study

As an agro-based country, pond aquaculture plays a very crucial role in the Q D W L R Q ¶ V W R W fish supply. Thai *koi* is a newly introduced production technology in the aquaculture industry. It is high yielding as well as a quick growing fish species that attains marketable size within a very short period. Moreover, it can be cultured twice in a year.

It is now one of the high commercially valued farm fishes of Bangladesh and plays a significant role to meet the increasing protein requirement of the ever growing population. Thai *koi* farming is a totally feed intensive technology which is also new to the farmers. Though over the period, the growth performance is impressive, however, production of this strain varies widely. Unfortunately, no detailed empirical investigations have been made to find out the causes of production variability in Thai *koi* farming in the economic arena.

In practice, risk plays a vital role in aquaculture both in input use decisions as well as production of outputs. A number of stochastic biophysical and socioeconomic factors may differentiate production practices and intensity of input use among producers and it may create substantial risks among the growers. Many things may happen under water that sometimes may be beyond control. Hence, production techniques and managerial value judgment is important. Therefore, improvement of farm level efficiency is also a crucial factor in fish production. The efficiency variables are related to socioeconomic characteristics that may lead to input use variations in the production process and can create production variability. Thus, examining production risk and TE is very pertinent in aquaculture.

A number of studies have utilized the stochastic frontier approach in assessing TE in aquaculture and most recent studies include: Alam *et al*. (2012), Islam *et al*. (2011), Onumah *et al*. (2010), Rahman *et al*. (2010c), Singh *et al*. (2009), Kareem *et al*. (2008), Den *et al*. (2007), Islam *et al*. (2007), Sesabo *et al*. (2007), Dey *et al*. (2005c), Chiang *et al*. (2004), Dey *et al*. (2000) and Sharma *et al*. (2000a and 2000b). There are limited studies in the literature that have analyzed production risks in aquaculture and these include: Khan (2012), Kumbhakar *et al*. (2003), Asche *et al*. (1999), Tveteras *et al*. (2000) and Tveteras (1999). However, the literature so far has paid little attention on production risks and TE in a single framework in the broad agricultural sector and there are only two such studies in aquaculture, i.e. Ogundari *et al*. (2010) and Kumbhakar (2002).

Most of the stochastic frontier analysis was concentrated on some species such as carp, prawn, tilapia and salmon. These empirical studies have provided evidence of output risk and technical inefficiency in the aquaculture sector. However, none has focused on risk or efficiency and, or simultaneously on production risk and TE at farm level covering Thai *koi* or any species in Bangladesh. This is the first research initiative of input use on production risk and TE in Thai *koi* farming in Bangladesh. This research is expected to open a new window for policy makers in understanding the dynamics of this industry and hence to make better informed decision making.

1.12 Organization of the Study

This thesis is divided into five chapters. General introduction of Bangladesh agriculture, fisheries resources, aquaculture, significance of the study and objectives are discussed in Chapter 1. A critical review of the literature on production risk in inputs and TE is described in Chapter 2. This chapter also reviews the theoretical background of the

models related to this research. Chapter 3 contains the research methodology used for this study. It also looks at the empirical estimations of the models, data collection procedure and descriptive statistics of variables. Chapter 4 reports the empirical results and their interpretation. The concluding chapter provides the summary, conclusion, recommendations and limitations of the study.

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