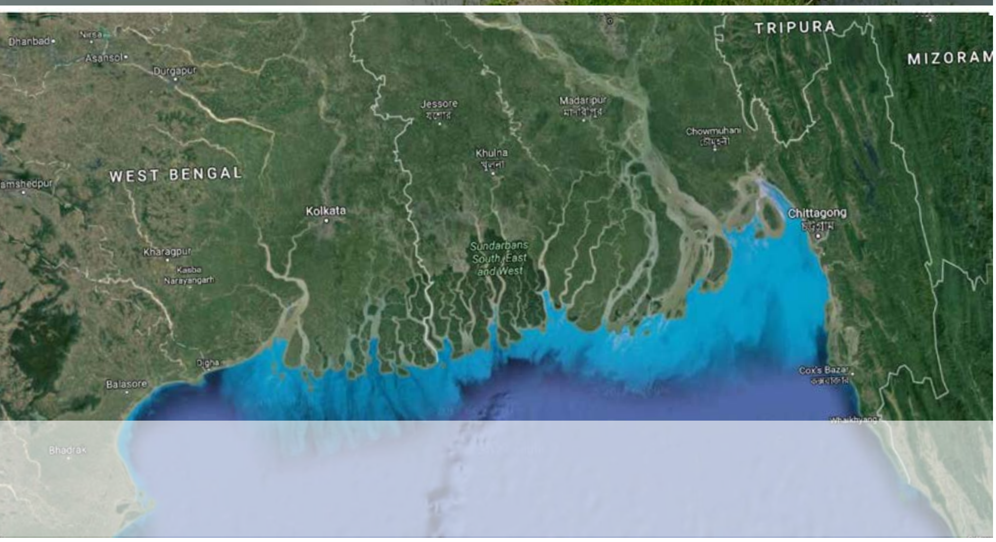
Food and Agriculture Organization of the United Nations

FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER

618

ISSN 2070-7010

An assessment of impacts from shrimp aquaculture in Bangladesh and prospects for improvement



***Cover photographs*:**
Top left: View of extensive/traditional shrimp farms (locally called *gher*) in southwest Bangladesh. Bottom left: Image of Bangladesh coast (source: Google maps). *Top right*: Harvested shrimp from a traditional shrimp farm. *Middle right*: Waterlogging in a village near the shrimp farms in southwest Bangladesh. *Bottom right*: Women in shrimp farming areas coming back home after collecting rice straw to be used as cooking fuel.

***Cover design*:**
Mohammad R. Hasan and José Luis Castilla Civit.

An assessment of impacts from shrimp aquaculture in Bangladesh and prospects for improvement

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by

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2017

ISBN 978-92-5-130007-7

Preparation of this document

This technical paper was prepared under the coordination of Dr Mohammad R. Hasan of the Aquaculture Branch, FAO Fisheries and Aquaculture Department as a part of FAO's Strategic Objective (SO2): Increase and improve provision of goods and services from Agriculture, Forestry and Fisheries. This publication will contribute to the organizational outcome 20101: producers and natural resource managers adopt practices that increase and improve the provision of goods and services in agricultural sector production systems in a sustainable manner.

This study, and the publication of this document, was funded under the auspices of the project "FMM/BGI/ARI under Blue Growth Initiative (BGI) in Support of Food Nutrition Security, Poverty Alleviation and Healthy Oceans [FMM/GLO/112/MUL Baby 4 (Blue Growth)].

Section 3.14 (Life cycle analysis of the main environmental impacts) of this technical paper was prepared by Dr Sk. Ahmad-Al-Nahid. The authors wish to thank Dr Michael MacLeod of Land Economy, Environment and Society Group, SRUC, Edinburgh for kindly reviewing this section. The authors acknowledge the contribution of the staff of the Office of the FAO Representation in Bangladesh, particularly Mr Mike Robson, former FAO Representative and Ms Begum Nurun Naher, National Operations Officer. Department of Fisheries (DoF), Universities, and NGOs working on the shrimp sector of Bangladesh are also acknowledged for their kind assistance throughout the process. They would like to express their sincere thanks to numerous shrimp farmers, coastal fishers and all other stakeholders involved in the broader value chain of this sector who were interviewed/consulted during the study and for their contribution to the qualitative and quantitative data and information.

Dr Richard Anthony Corner edited this technical paper for its linguistic quality and technical content. Most of the photographs in this technical paper were provided by the first author Dr Mostafa A.R. Hossain. Where this is not the case, due acknowledgements are made to the contributors. For consistency and conformity, scientific and English common names of fish species were used from FishBase (www.fishbase.org/search.php) and that of crustaceans and mollusks from SeaLifeBase (www.sealifebase.org).

Ms Marianne Guyonnet and Ms Danielle Rizcallah are acknowledged for their assistance in quality control and FAO house style. Mr José Luis Castilla Civit prepared the layout design for printing. The publishing and distribution of the document were undertaken by FAO, Rome. Finally, Dr Malcolm Beveridge, Head of the Aquaculture Branch of the FAO Fisheries and Aquaculture Department is acknowledged for providing the necessary support, advice and insight to complete this publication.

Abstract

Aquaculture has become one of the fastest-growing economic subsectors of the Bangladesh economy, providing protein-rich food, source of employment and foreign currency earnings. Presently, the sector provides income and livelihood for more than 11 percent people of the country's 160 million people. Total farmed shrimp production in Bangladesh increased from 14 773 tonnes in 1986 to 132 730 tonnes in 2016, an almost 9.0-fold increase over the last 30 years. The land area under shrimp farming has increased from 70 331 ha in 1986 to 275 509 ha by 2016. The contribution of the farmed shrimp to total shrimp production and export has been increasing over the last 15 years at a rate of about 20 percent per year. The country earned foreign currency equating to USD450 million in 2015–16, through the export of 40 726 tonnes of frozen shrimp.

In parallel with the significant contribution of the shrimp sector to the local and national economy, it has caused some negative impacts on local ecosystems. Ecological impacts include some deterioration of soil and water quality, depletion of mangrove forest, decrease in population of native fish and shellfish species, intrusion of saline water, water pollution and changes to local hydrology. There have also been some socio-economic consequences, most acutely on the livelihood patterns of people living in coastal areas and on rural to urban migration, particularly among the poor and unskilled. Other impacts include deterioration of drinking water quality, loss of land for grazing of livestock and changes in agricultural cropping patterns, which has particularly affected the landless agricultural laborers. Social and environmental sustainability may have been overlooked during the expansion of shrimp farming. Losses due to disease, which are still a periodic problem for the sector, are a major indicator of the current unsustainable system of shrimp farming.

At this stage, a paradigm shift is needed away from current shrimp farming practices to a more holistic and integrated approach that accounts for environmental integrity and social cohesion. Some modification and improvements have been made in recent years, and these should be extended. At the same time, incentives are needed for appropriate investment, to improve the physical infrastructure of *ghers* (shrimp ponds), and for adoption of new management methods. In this there is an important role for government in formulating appropriate policy and monitoring. Without a guiding policy on the development of the shrimp sector, private businessmen are likely to move ahead in an unplanned or unregulated way.

To support this process, research is needed to better understand the effects of hydrology on biotic processes and of the biota on hydrology under the altered land-use scenario caused by shrimp farming. Alternative and innovative culture systems must be identified to form pathways to make shrimp aquaculture production more sustainable, including improvement in the hatchery sector, to reduce the environmental impact of wild-caught post-larvae and broodstock. Benefits for poor and marginal shrimp farmers and local stakeholders must be ensured, through improved understanding and identifying right ways to address the practical constraints under which poorer and less organized shrimp producers operate. Access to interest free or credit with minimal interest, through institutional reform, could help transform the shrimp farming sector, particularly for the poor and marginal shrimp famers, and post-larvae harvesters and traders. This will also prevent mal-adaptation, and increase diversification of livelihood strategies, as well as reduce the cost of farming. Institutional reform can also improve the enforcement of existing laws, particularly on the area of post-larvae harvesting, improve feed supply and hatchery provision, and improve fisheries diversity and conservation. Enforcement of regulations, and provision of insurance, would increase the safety of

shrimp farmers. Finally, building shrimp farmer's human capital will underpin the creation of alternative livelihood activities.

To evaluate the overall resource use and environmental impact caused by shrimp farming and to identify the hotspots and improvement options, a life cycle assessment (LCA) was conducted. Among different farming stages (i.e., fertilization, stocking, feeding and harvesting), feeding and fertilization were identified as the major contributors for the environmental impacts associated with the shrimp farming.

This technical paper also assesses the major spatial risks of shrimp farming in southwest Bangladesh in relation to landscape deterioration, waterlogging and salinization of land and water, nutrients and material flow and impact on natural biodiversity. The ongoing measures to improve and streamline environmental performance of shrimp farming in Bangladesh are analyzed and a number of measures proposed, based on this activity and comprehensive stakeholder engagement.

Hossain, M.A.R. & Hasan, M.R. 2017. *An assessment of impacts from shrimp aquaculture in Bangladesh and prospects for improvement*. FAO Fisheries and Aquaculture Technical Paper No. 618. Rome, FAO. 96 pp.

View of water inlet canal in between the shrimp ghers in southwest Bangladesh

COURTESY OF FAO/MOHAMMAD HASAN

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Abbreviations and acronyms

ADB	Asian Development Bank
AP	acidification potential
BDT	Bangladesh Taka
BFRI	Bangladesh Fisheries Research Institute
BGI	blue growth initiative
BMFA	Bangladesh Marine Fisheries Association
BMP	better management practices
BMP (S+F)	better management practice (shrimp + fish)
BOD	biochemical oxygen demand
BWDB	Bangladesh Water Development Board
CCRF	FAO code of conduct for responsible fisheries
CEP	Coastal Embankment Project
CMLCA	chain management by life cycle analysis
CST (T)	closed system technology (shrimp)
DoF	Department of Fisheries
EC	electrical conductivity
EP	eutrophication potential
EXT (S+F)	extensive (shrimp + fish)
FAO	Food and Agriculture Organization of the United Nations
FGD	focus group discussion
GAA	Global Aquaculture Alliance
GDP	gross domestic product
Gher	local name for a shrimp pond/farm in Bangladesh
GHG	greenhouse gas
GoB	Government of Bangladesh
GO	government organization
GWP	global warming potential
ha	hectare
IDA	International Development Agency
IEX (S+P+F)	improved extensive (shrimp + prawn + fish)
INR	Indian Rupee
ISO	International Standards Office
LCA	life cycle assessment/analysis
LCI	life cycle inventory
LCIA	life cycle impact assessment
MOC	mustard oil cake
MoFL	Ministry of Fisheries and Livestock
MTT (S+F)	modified traditional technology (shrimp + fish)
NACA	Network of Aquaculture Centres in Asia-Pacific
NGO	non-governmental organization
ODA	Official Development Assistance of the United Kingdom
PL	post-larvae
ppt	parts per thousand
PRSP	poverty reduction strategy paper
PSF	pond sand filters
SHAB	Shrimp Hatchery Association of Bangladesh
SIS (S)	semi intensive (shrimp)
SRDI	Soil Resource Development Institute
SRF	Sundarbans Reserve Forest
TFP	Third Fisheries Project
TSP	triple superphosphate
UFO	upazila fisheries officer
UNDP	United Nations Development Programme
Upazila	sub-district
WFC	WorldFish Centre
WWF	World Wildlife Fund

1. Introduction

Fisheries and aquaculture are important contributors to global food supply, food security and livelihoods; none more so than in low-income countries, such as Bangladesh. It is estimated that global aquaculture sector provides between 27.7 and 56.7 million full- and part-time jobs (FAO, 2016a). Asia generally, provides a high proportion of production and sector employment, where aquaculture has become an important source of food and nutrition, along with international income through export markets.

Aquatic foods have high nutritional value and are one of the most widely traded and exported food products around the globe. Fish products account for at least 15 percent of the animal protein consumed for more than 4 billion people, most in developing countries (FAO, 2012). For some countries and communities, this number is much higher, accounting for up to 50 percent of animal protein in some regions and Small Island Developing States (SIDS). In recent years, the world *per capita* fish consumption has been increasing from an average of 9.9 kg in the 1960s to 19.2 kg in 2012 (FAO, 2014).

Fisheries and aquaculture in Bangladesh provide the main source of income for millions of people and a large proportion of the animal protein consumed. In Bangladesh, the fishery and aquaculture industry, particularly of shrimp, plays an important economic and social role providing income, employment and contributing significantly to food supply. There is a long history of such activity in Bangladesh, although development of production to any scale has only occurred since the late 1970s. Fishery and aquaculture of shrimp now provides a vital component of the Bangladesh economy, but also has a number of accompanying environmental and social issues, that must be addressed in order to provide an improved and sustainable sector in to the future.

This technical paper outlines some of the history of shrimp and aquaculture production in Bangladesh and provides an assessment of the primary impacts that fishery and aquaculture of shrimp has caused, with particular reference to habitats, landscape, biodiversity and people. The evaluation also includes a life cycle analysis of the main environmental impacts. Having identified the key environmental and social issues this technical paper concludes with a section on potential for improvement in the shrimp sector, with recommendations derived from the review and a consultation exercise with relevant stakeholder groups.

A semi-intensive shrimp farm (with good aquaculture practice compliance) in Paikgachha, Khulna, Bangladesh

2. Fisheries and aquaculture in Bangladesh

2.1 IMPORTANCE OF FISHERIES AND AQUACULTURE

Fisheries and aquaculture have long been an integral part of life for the people of Bangladesh. The sector is second only to agriculture in the overall economy of Bangladesh, and contributes almost 3.65 percent to gross domestic product (GDP), 23.81 percent of gross agriculture products and 1.97 percent of total export earnings. It accounts for approximately 60 percent of animal protein intake in the diet of the people of Bangladesh, who have a higher than average *per capita* fish consumption of at 24.08 kg per annum (DoF, 2017). The people of Bangladesh largely depend on fish to meet their protein needs, in both rural and urban areas.

Bangladesh has an estimated 1.32 million full time fishers, mostly artisanal fisherfolk; and up to 2.00 million full time equivalent people are estimated to be involved in aquaculture (FAO, 2016b), from small owner-operators providing food for the family to large shrimp and fish farmers. The number of people overall gaining income and support from fishery and aquaculture activity on a full and part time basis is significantly larger, however, estimated at 14.7 million people (DoF, 2017), representing approximately 11 percent of the overall population of Bangladesh. The value chain from catch and pond/farm to plate/fork and beyond includes hundreds of stakeholders, whose livelihoods fully depend on fisheries and aquaculture, plus associated and ancillary activity.

In aquaculture the major stakeholders include fish farmers, shrimp farmers, hatchery owners, nursery producers, farm/hatchery technicians/workers, those working on farming supplies (e.g., feed ingredient, fertilizer, hormone, chemical, instruments, and so on), importers/suppliers, industrial feed producers, small- and medium-scale feed producers, fishers, fish processors, fish transporters, wholesalers, exporters, retailers, consumers, scientists and technology providers (government and non-government) and many others. Aquaculture has increasingly played a major role in fish supply, with a total fish production of 3.88 million tonnes of aquatic products in 2016. Presently, more than half of that production (56.8 percent) comes from aquaculture, equating to approximately 2.20 million tonnes (DoF, 2017).

Aquaculture has become one of the fastest-growing economic subsectors of the Bangladesh economy and over the last two decades has provided a protein-rich food source for the local population, a source of personal and national income through exports and generation of foreign currency earnings, and generated employment.

If the available resources are used sustainably with proper technological assistance, farmed fish and shrimp would efficiently meet the protein demand of the growing population in the country, will ensure food and nutritional security, employment and foreign exchange earnings, which together could help shape a Bangladesh free of hunger, malnutrition and poverty.

2.2 BANGLADESH COAST: ENVIRONMENT, VULNERABILITIES AND USE CONFLICTS

The Bangladesh coast (Figure 1) is complex in terms of its physical, hydrological and environmental conditions; with diverse and often conflicting land uses; but provides both economic opportunities, and risks.

FIGURE 1
Image of Bangladesh coast

Source: Google maps.

The coast is characterized by low-lying topography and extends over an area of 47 201 km^2 representing approximately 32 percent of the country's geographical area. Coastal areas include 147 Upazilas (sub-districts) within 19 regional districts, and are inhabited by approximately 35 million people at a population density of nearly 800 people per km^2, representing about 21 percent of Bangladesh's population.

Coastal areas are economically and ecologically very important and contain critical industries, alongside terrestrial and aquatic habitats and ecosystems that provide essential goods and ecosystem services to the people. Mangrove cover is extensive and provides coastal and marine fisheries, shrimp, crab and salt production. Land generated through accretion processes allows new settlement opportunities for the growing coastal population. On-shore and off-shore oil and gas fields exist to provide energy along with other potential energy sources like wind and wave energy. Sea ports located at Chittagong and Mongla maintain industrial infrastructures and tourism opportunities exist at coastal beaches, islands and in the Sundarbans. Added to this is fishing and support to aquaculture development. These activities exist alongside highly environmentally productive and ecologically important mangrove, wetlands, tidal flats and coral reefs, which hold a unique biodiversity.

Coastal natural resource use is based predominantly on subsistence agriculture; mainly the use of paddies to grow vegetables, oil seeds and timbers; and coastal fisheries that provides a major food and income source.

Although vital, the coastal region is subject to a number of vulnerabilities, including periodic cyclones and storm surges, salinity intrusion, coastal erosion, human-derived pollution, plus an overall lack of sound physical infrastructures.

In a sense, this diversity of habitats and ecosystems, multiple use, the services provided and the vulnerabilities identified gives complexity to the planning and management of coastal regions, which requires careful identification of structures, application of use and defined measures for their overall sustainable management.

2.3 SHRIMP FARMING IN BANGLADESH

2.3.1 Phases of development

Shrimp culture is an age-old practice in Bangladesh, taking place in brackish-, saline- and freshwaters of the coastal areas of Khulna, Satkhira, Bagerhat and Cox's Bazar districts. Historically, people trapped tidal water in low-lying intertidal lands by constructing small dykes to trap water, and harvested naturally occurring shrimp and finfish after three to four months. There was no stocking of fry under this system and only wild seeds of shrimp and fish carried in by tidal waters were allowed to grow; and there was no form of any distinct management. Since then production has undergone a major change (Table 1).

During the 1970's, after independence, interest in shrimp production grew with rising prices and demand in international markets. Shrimp farms were established in peripheral lands near the mouths of coastal rivers where inundation of saline water was possible. The success of these early farmers encouraged others to come forward and shrimp *ghers* (local name for a shrimp farm) were established on land inside saline water protection embankments, called Polders, which had been constructed by the Water Development Board in the late seventies. In Bangladesh shrimp production systems were often dispersed and extensive and relatively few shrimps were harvested at any one place and or at one time. Product had to be transported to local markets where it could be aggregated to a scale useful to traders and processors; but where quality control and product tracking was virtually impossible to manage (IIED 2003). The main cultivated species were, and remain, the black tiger shrimp (locally called *bagda*) *Penaeus monodon.* Other farmed shrimp species included brown/speckled shrimp (locally called *harina chingri*) *Metapenaeus monoceros*, Indian white prawn (locally called *chaka* chingri) *Fenneropenaeus indicus*, green tiger prawn *P. semisulcatus* and banana prawn *F. merguiensis* and giant river prawns (locally called *golda*) *Macrobrachium rosenbergii.*

From the late seventies and early eighties, the shrimp culture system expanded steadily. In addition to trapping of natural shrimp seeds, farmers began selective stocking of shrimp post-larvae (PL) caught from the wild. This created a new work opportunity for poorer coastal people who began to collect PL from coastal waters. From the mid-eighties, the Government launched infrastructure development programs together with improved technology dissemination and fiscal incentives for producers and processors. International development partners such as World Bank, Asian Development Bank, Food and Agriculture Organization of the United Nations (FAO of the UN) and Official Development Assistance (ODA) from the United Kingdom supported the industry with credit and technical assistance; most notably through ten projects managed by Department of Fisheries (DoF) between 1979 and 1999.

Government has been very active in stimulating entrepreneurial growth in the shrimp industry. From 1986, for example, it introduced a licensing system for setting

TABLE 1
Progress of shrimp farming in Bangladesh

Development pattern	Time scale	Associated favorable conditions
Traditional subsistence oriented shrimp farming by local farmers	Up to 1985	Construction of polders & sluice gates Good market price
Export oriented commercial shrimp farming by outside entrepreneurs and local elites	1986 to 1997	Licensing system for shrimp farms Leasing of *khas* land from government
Smallholder shrimp farming by local land owners	1998 onwards	Capital loss due to shrimp disease Withdrawal of licensing system Non-renewal of lease deeds by landowners Increased land rent in shrimp areas

Source: Nuruzzaman (2006).
Khas land = Government owned land.

up shrimp farms through Upazila Shrimp Culture Regulation Committees, which attracted many outsider investors. These investors were generally wealthy people who found it easy to obtain licenses from the shrimp committee members. *Khas* land allocation and leasing for shrimp farming encouraged the politically powerful to access new shrimp areas.

The industry grew rapidly to the mid-1990s. There was concomitant growth of other allied activities including the establishment of processing plants, ice production plants and shrimp depots. There were also over-ambitious initiatives to setup semi-intensive shrimp farms with imported PL. Local shrimp hatcheries did not become well established until the late 1990s. In 1994 white spot disease spread throughout the semi-intensive farms, and into extensive farms, with most investors incurring heavy losses over successive years. Coastal outsider investors, in particular, lost interest in the business opportunities.

In 1998, government withdrew the shrimp licensing system and many local landowners refused to renew old lease deeds for outsiders, and others demanded higher rents for their private lands. The capital losses from shrimp disease and growing non-cooperation from local landowners made it difficult for outside shrimp farmers to continue shrimp farming. They began to leave the sector and local landowners began shrimp farming themselves. Landowners split up large farms into smaller units, which they owned and could farm or they tried to operate larger farms under cooperative arrangements with other landowners. Thus, what began as a large-scale commercial shrimp farming activity was gradually replaced by smallholder shrimp farming, managed predominantly by local, small landowner-cum-operators.

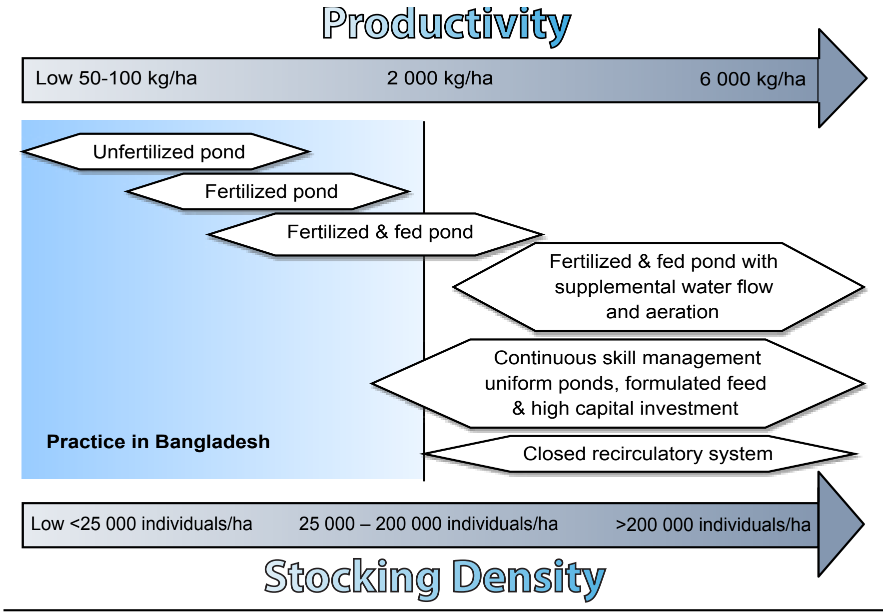
Giant river prawns or golda farming started in the mid-1970s and achieved steady growth during the late 1980s and 1990s. Such farming was subject to less criticism than brackishwater shrimp farming. Freshwater shrimp farms in rice fields are found mainly around the coastal districts with some extension into inland districts where there are perennial water bodies. Such farming has been small-scale, pro-poor and integrated with rice and dyke cropping. The main environmental problems associated with freshwater farming have been the decline of snail populations used as shrimp feed and drainage congestion created by unplanned construction of shrimp farms in wetland areas. More recently farm-made feed using local ingredients and commercial pellet feed has begun to replace snail meat in freshwater shrimp aquaculture.

There are now two main shrimp species cultured in Bangladesh. The most important is *Penaeus monodon* or the black tiger shrimp (locally known as *bagda*), which contributes about 70 percent of all cultured shrimp. *Macrobrachium rosenbergii* or the giant river prawns (locally known as *golda*) contributes about 15 percent of total farmed production. The remaining 15 percent comes from other shrimp species including *Metapenaeus monoceros* or the brown/speckled shrimp (locally known as *harina chingri*), *Fenneropenaeus indicus* or the Indian white prawn (locally known as *chaka chingri*), *Penaeus semisulcatus* or the green tiger prawn, and *F. merguiensis* or the banana prawn.

2.3.2 Sector contribution to Bangladesh economy

Over recent decades the shrimp aquaculture industry has experienced rapid growth and has taken a key position in the economy of Bangladesh, becoming the second largest export industry after garments. Total aquaculture production of shrimp increased from 14 773 tonnes in 1986 to 132 730 tonnes in 2016 (DoF, 2017), to become an increasingly higher proportion of the overall harvest of shrimp. The contribution of the farmed shrimp to the total shrimp production and export has been increasing over the last 15 years at a rate of about 20 percent per year (Table 2). The area under shrimp farming has also subsequently increased, from 52 000 ha in 1983 to a 276 494 ha by 2014, spread across a number of districts (Table 3). The expansion was driven by the high profit

FIGURE 2
Shrimp farming practices in Bangladesh based on intensity of input, use and production per unit area



Source: Clay (1997).

potential of shrimp farming and attracted a wide range of investors, ranging from individual farmers converting paddy fields to multinational companies and corporate business owners investing in large-scale improved extensive and semi-intensive shrimp farming (Figure 3); overall, providing a mix of production modes (Table 4). The country earned approximately USD568 million in 2014–15 through the export of 44 278 tonnes of frozen shrimp overseas. However, the export earning declined to USD450 million in 2015–16 and the frozen shrimp export was 40 726 tonnes during that period. The economic significance of the shrimp sector is large in terms of export earnings, and is currently approximately 1.7 percent of the value of Bangladesh exports, but representing nearly 87 percent of the total fish exported (DoF, 2017).

TABLE 2
Annual production (tonnes) of shrimp between 1986 and 2016 from inland and marine waters through fisheries and aquaculture

	Inland waters			Marine waters				
Year	Open water capture fishery	Aquaculture	Inland total	Trawler fishery	Artisanal fishery	Marine total	Grand total	Aquaculture (%)
86–87	42 882	14 773	**57 655**	4 488	10 666	**15 154**	**72 809**	20.3
87–88	36 386	17 889	**54 275**	3 545	11 535	**15 080**	**69 355**	25.8
88–89	42 824	18 235	**61 059**	4 893	12 211	**17 104**	**78 163**	23.3
89–90	36 284	18 624	**54 908**	3 117	12 751	**15 868**	**70 776**	26.3
90–91	43 262	19 489	**62 751**	3 696	13 937	**17 633**	**80 384**	24.2
91–92	61 042	20 335	**81 377**	2 902	17 140	**20 042**	**101 419**	20.1
92–93	78 226	23 530	**101 756**	4 188	19 787	**23 975**	**125 731**	18.7
93–94	50 721	28 302	**79 023**	3 479	18 040	**21 519**	**100 542**	28.1
94–95	58 973	34 030	**93 003**	2 416	17 947	**20 363**	**113 366**	30.0
95–96	44 079	46 223	**90 302**	3 588	22 765	**26 353**	**116 655**	39.6
96–97	41 868	52 272	**94 140**	3 537	21 281	**24 818**	**118 958**	43.9
97–98	46 635	62 167	**108 802**	2 444	22 346	**24 790**	**133 592**	46.5

TABLE 2 (CONTINUED)

Year	Inland waters			Marine waters				
	Open water capture fishery	Aquaculture	Inland total	Trawler fishery	Artisanal fishery	Marine total	Grand total	Aquaculture (%)
98–99	49 296	63 164	**112 460**	3 765	27 977	**31 742**	**144 202**	43.8
99–00	43 167	64 647	**107 814**	2 915	28 480	**31 395**	**139 209**	46.4
00–01	44 343	64 970	**109 313**	3 172	27 865	**31 037**	**140 350**	46.3
01–02	54 965	65 579	**120 544**	3 168	28 808	**31 976**	**152 520**	43.0
02–03	60 876	66 703	**127 579**	2 486	29 445	**31 931**	**159 510**	41.8
03–04	63 103	75 167	**138 270**	3 075	33 413	**36 488**	**174 758**	43.0
04–05	68 768	82 661	**151 429**	3 311	40 950	**44 261**	**195 690**	42.2
05–06	77 381	85 510	**162 891**	3 444	44 675	**48 119**	**211 010**	40.5
06–07	82 422	86 840	**169 262**	2 175	49 694	**51 869**	**221 131**	39.3
07–08	75 678	94 211	**169 889**	2 620	50 586	**53 206**	**223 095**	42.2
08–09	89 901	102 854	**192 755**	2 932	49 285	**52 217**	**244 972**	42.0
09–10	46 388	87 972	**134 360**	2 496	50 096	**52 592**	**186 952**	47.1
10–11	57 922	124 648	**182 570**	2 785	54 204	**56 989**	**239 559**	52.0
11–12	57 688	137 175	**194 863**	2 212	55 448	**57 660**	**252 523**	54.3
12–13	45 013	140 261	**185 274**	3 083	43 485	**46 568**	**231 842**	60.5
13–14	47 807	128 313	**176 120**	3 799	43 869	**47 668**	**223 788**	57.3
14–15	51 717	132 794	**184 511**	3 443	42 290	**45 733**	**230 244**	58.5
15–16	53 875	132 730	**186 605**	2 583	45 000	**47 583**	**234 188**	56.7

Source: DoF (2017).

TABLE 3
Area of black tiger shrimp (bagda) and giant river prawns (golda) production in Bangladesh in 2014, by district

Districts	Area (ha)		
	Bagda	Golda	Total
Khulna	36 557	13 960	50 518
Satkhira	60 348	7 664	68 012
Bagerhat	47 900	18 556	66 456
Chittagong	2 071	-	2 071
Cox's Bazar	62 907	-	62 907
Others	3 834	22 697	26 531
Total	**213 617**	**62 877**	**276 494**

Source: DoF (2015).

TABLE 4
Modes of shrimp farming in Bangladesh

Species	Mode of culture	Area under culture (ha)	Management	Production (kg/ha)	Production cost (BDT/ha)	Net profit (BDT/ha)
Bagda	Traditional (extensive)	190 080	PL stocking and water exchange (A number of marine fish in the *gher*)	300 (rotational rice and shrimp farming is possible)	82 000	80 000
Bagda	Improved extensive	25 380	Dyke elevation; healthy & virus free PL stocking; Supplemental feeding	600–700 kg	200 000	190 000
Bagda	Semi-intensive	500 (target 20 000)	Proper *gher* preparation pollutant free sufficient water, disease free healthy PL, standard feeding, proper rearing and caring	4 000–5 000 (target 8 000)	1 600 000 – 2 000 000	1 200 000 – 1 400 000
Golda	Integrated With rice, fish, vegetables	Nearly 60 000	Little or no management except PL stocking, occasional feeding	450–550	-	-

Source: DoF (2015).

FIGURE 3
View of extensive (top) and semi-intensive (bottom) shrimp ponds

Due to its potential to improve the economy, the development of the shrimp sector is regarded as an important means of reducing poverty and boosting pro-poor growth, through increased production and exports. As the bulk of shrimp aquaculture is in rural coastal areas, it plays a major role in providing employment, income and food security to the remote coastal people where alternative livelihood options are limited (Nuruzzaman, 2006).

2.3.3 Areas used for shrimp farming

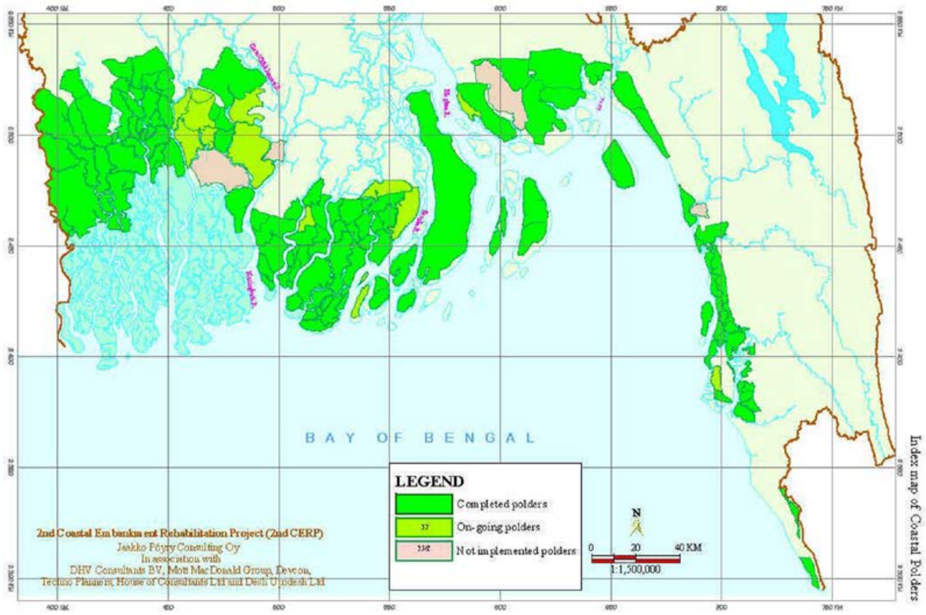
Shrimp are mainly cultivated in coastal areas of Bangladesh, where estuarine rivers and tidal creeks meet the Bay of Bengal. Production of giant river prawns (golda) was made possible by the building of strong embankments that offer protection from tidal waters, referred to locally as “polders” (Figure 4).

A total of 123 polders were constructed in the 1970s by the Bangladesh Water Development Board (BWDB) under the Coastal Embankment Project (CEP). As part of the overall construction some 5 000 km of embankments were built, along with 1 347 regulators, 1 164 flushing inlets and 5 937 km of drainage channels (Nuruzzaman, 2006). The coastal embankments and connected infrastructures were originally designed to protect farm land and increase crop production by preventing flood and saline water intrusion into low lying areas, and to protect human settlements; but it became clear that certain areas were suitable for shrimp production. The total area covered by coastal polders was 1 076 179 ha, out of which 765 333 ha was cropland and 85 745 ha was lowland suitable for shrimp. Moreover, optimum temperature regimes, nutrition-rich water and productive soil conditions inside polders made shrimp farming a viable livelihood option for many coastal people.

Between 1984 and 2003, shrimp farming area grew from 55 312 ha to an estimated 210 000 ha. During the same period, the area under freshwater prawn farming grew from a small 3 500 ha to over 40 000 ha. Since then the area used for shrimp culture has increased greatly, now standing at an area of approximately 2 500 km^2 of coastal floodplains, inundated twice a day from semi-diurnal tidal water with varying degrees of salinity. Given the already large increase since 2003 there is probably little scope for further increases in cultivation area for brackishwater shrimp. There is scope to increase freshwater prawn farming, which to date has expanded at a rate of about 20 percent annually, though future expansion depends on the degree of intensity in the of culture practices used.

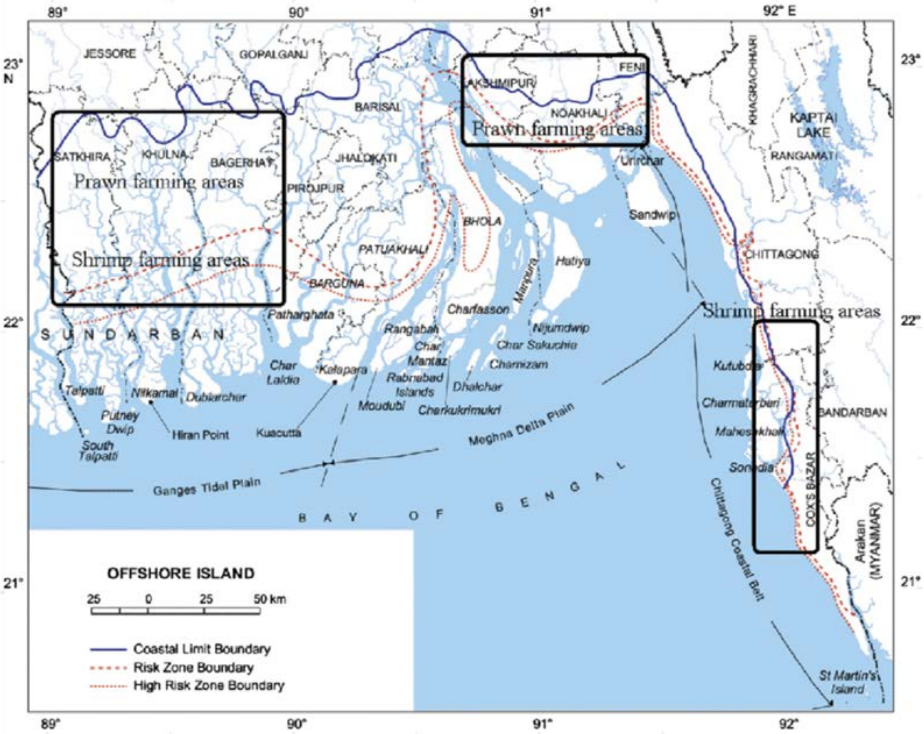
The main areas of black tiger shrimp (bagda) farming are three districts adjacent to the Sundarbans - Khulna, Satkhira and Bagerhat in the southwest; and Cox’s Bazar district on the southeast coast (Figure 5). Giant river prawns (golda) farming areas are distributed across the country but mainly concentrated in Bagerhat, Khulna, Jessore, Narail, Satkhira and Pirojpur districts (Figure 5). Production area for shrimp farming in the main producing districts is shown in Table 3.

FIGURE 4
Map of Bangladesh coast, highlighting polders (see text for explanation)



Source: PDO-ICZMP (2004).

FIGURE 5
Areas used for shrimp farming in Bangladesh



Source: Ahmed (2013).

A woman collecting shrimp post-larvae from Cox's Bazar beach, Cox's Bazar, Bangladesh

3. Impact of shrimp farming

3.1 GLOBAL CONTEXT

The shrimp aquaculture industry is a large international business being farmed in 50 countries globally (Kanduri and Eckhardt, 2008), currently producing 55 percent of the world's shrimp (WWF, 2016), with the vast majority of countries and production located in the developing world. Leading producers (in order of production) are China, Thailand, Indonesia, India, Viet Nam, Brazil, Ecuador and Bangladesh. Growing consumer demand for shrimp is fueling an environmental crisis in some of the world's poorest nations.

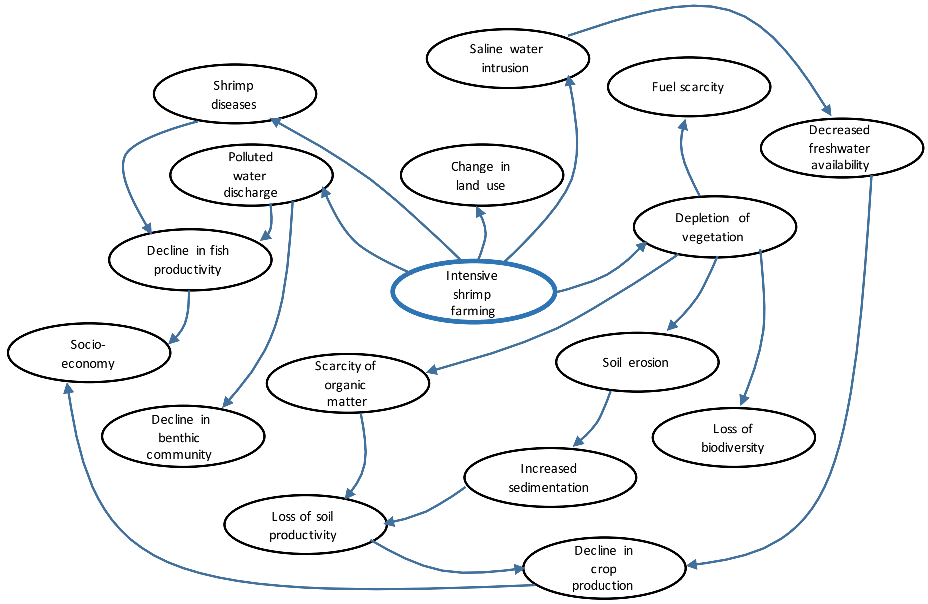
The Environmental Justice Foundation (EJF, 2014) linked shrimp farming with significant environmental damage, including the large-scale conversion of ecologically sensitive and important wetland areas and farmland. Destruction of mangroves for shrimp farming has been publicly condemned by the United Nations Environment Programme (UNEP, 2010), which stated that "Vast tracts of mangroves have been cleared for shrimp aquaculture, allowing fast profits but leaving long-term debts and poverty which are hard to reverse". The unregulated seizure and conversion of traditional farm land to shrimp aquaculture has put food security at risk and left many of the vulnerable people of the coast without alternative livelihoods. Shrimp farming has been dubbed as "good for the rich and bad for the poor", particularly with regard to food and livelihood security (Hensler, 2013). More generally, high global demand for shrimp as a low-priced, low fat, high protein source of food has driven an industry that has often outpaced the development of environmental and labour standards in producer countries (Accenture, 2013).

3.2 SHRIMP FARMING AND ENVIRONMENTAL ISSUES IN BANGLADESH

Shrimp farming in Bangladesh has been recognized as a part of the Blue Revolution (Kabir and Eva, 2014). Since the introduction of commercial farming, shrimp has been the subject of significant international and national debate. The debate in Bangladesh has often been highly political and, at times, a source of conflict in coastal rural communities. The central issues identified are environmental sustainability, pro-poor economic growth, access to resources, and human rights abuses (Khan, 2002). Fisheries in Bangladesh in 2012–13 was one of the major contributors to the agricultural GDP (23.37 percent) and to overall GDP (4.37 percent). Within this sector, shrimp (*Penaeus monodon*) is the dominant contributor (DoF, 2014). However, in parallel with its large contribution to local and national economy, it has been suggested to cause significant damages to local ecosystems (EJF, 2004; Paul and Vogl, 2011). Attracted by prospects of high incomes and economic prosperity, farmers have brought hundreds of acres of lands under shrimp production, most of which have been unplanned leading to haphazard and uncoordinated expansion. The consequences include use and inundation of saline water carried by canals and rivers from the Bay of Bengal, employ traditional and not always efficient systems of farming and processing, and indiscriminate use of chemicals that are likely to be very sensitive to the overall environment. The entire process diversely affected the soil and agriculture yields, ecology, biodiversity (World Bank, 2002) and sustainability in the coastal regions of Bangladesh.

In addition to the ecological costs, Barraclough and Finger-Stich (1996) noted that modern shrimp farming also has socio-economic costs; with a cost benefit analysis study by Khor (1995) revealing that that shrimp farming might have caused more economic harm than good. The reported damage outweighed the

FIGURE 6
Schematic diagram of cause-effect relationship of coastal shrimp farming in Bangladesh



Source: Redrawn from Sohel and Ullah (2012).

benefits by 4 to 1 (63 billion INR[1] vs. 15 billion INR per annum) in Andhra, India, for example, which included loss of mangroves, salinity intrusion and rise of unemployment. In Bangladesh, the causes and effects of shrimp production are also varied (Figure 6) as it in India and other countries.

Shrimp farming, and the associated scale of its impact on the environment depends on a variety of interrelated factors including species farmed, the type and mode of production, scale and intensity of culture practices and physiographic location of the shrimp farm.

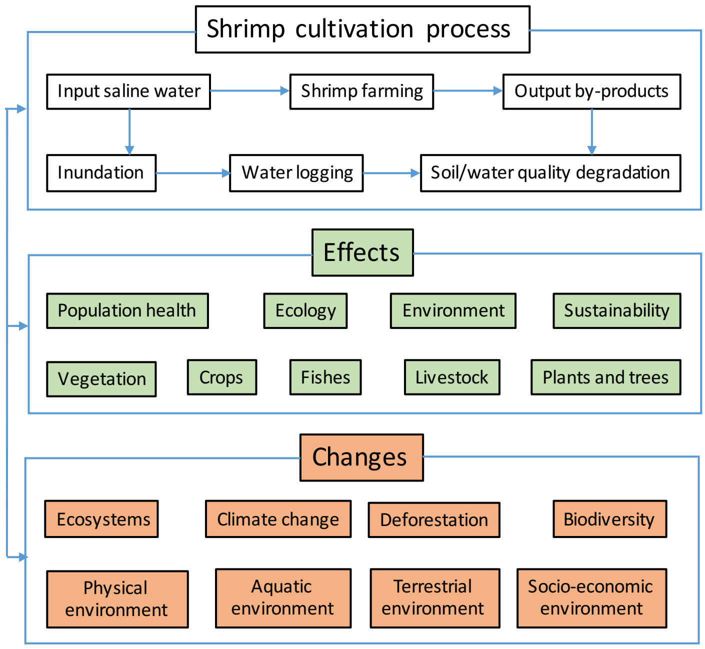
Shrimp farming has long been causing severe threats to ecological systems of Bangladesh (Figure 7), such as deterioration of soil and water quality, depletion of mangrove forest, decrease of local variety of fish and shellfish, saline water intrusion in ground water, local water pollution and change of local hydrology (Kabir and Iva, 2014). Recent expansion of shrimp cultivation has caused severe depletion of forest cover in the Chakaria-Sundarbans and led to a near complete loss of mangrove forest and biodiversity of flora and fauna within (Shahid and Islam, 2003). Ground water salinization and saline water intrusion in surrounding areas have caused a serious ecological and socioeconomic damage in the coastal environment. Salinity has been dubbed as a silent poison to the coastal Bangladesh due to extensive shrimp farming (Kabir and Iva, 2014). The practices of shrimp farming have caused loss of crop production, loss many indigenous flora, drinking water and cooking fuel crisis and so on (Karim, 2003). Gradual increase in toxic elements is contaminating lower level soil and products of the soil also carry these toxic substances and have the potentiality to create health hazards. According to Alauddin and Hamid (1996), conflict associated with control of the large shrimp farms is one of the important causes responsible for social imbalance and deteriorating law and order in the coastal areas in Bangladesh.

More broadly the DeWalt *et al.* (2002) summarized the following major issues as:

- Ecological consequences of conversion and changes in natural habitats such as mangroves, associated with construction of shrimp ponds and related infrastructure.
- Discharge of pond effluent leading to water pollution in farming and coastal areas.

[1] Indian Rupee

FIGURE 7
Diagrammatic model of shrimp cultivation process, concomitant effects and changes due to shrimp farming



Source: Redrawn from Islam and Bhuiyan (2016).

- Seepage and discharge of saline pond water that may cause salinity changes in ground water and surrounding agricultural land.
- Use of fishmeal and fish oil in shrimp diets.
- Improper use of chemicals raising health and environmental concerns.
- Spread of shrimp diseases.
- Transboundary movements concerning the spread of genetic materials, exotic species and diseases.
- Biodiversity issues primarily arising from the collection of wild shrimp/prawn seed.

In Bangladesh, the previous commercial nature of shrimp farming has slowly been turning into smallholder-type production of shrimp; and freshwater prawn farming in rice fields during the rainy season is spreading over increasingly large inland areas of the country. Despite having very good climatic condition for shrimp farming, production efficiencies are low due to high post-larvae (PL) mortality, poor management techniques and poor farm management practices are considered responsible for lower shrimp production (Nuruzzaman *et al.*, 2001; Huntington, 2003), a lack of extension services and poor infrastructure in coastal areas (Nuruzzaman, 2006). Development of shrimp aquaculture in Bangladesh has therefore been questionable and generated considerable national and international debate in recent years on its environmental and social costs and benefits. Among the substantial environmental and social problems in Bangladesh specifically are water pollution; salinization of drinking water wells and paddy fields; destruction of fry of wild fish and crustacean species; various social conflicts related to land conversion and, critically, the conversion of mangroves to shrimp farms; reduced agricultural production due to the reduction of agricultural land and soil fertility, decrease of cattle production as a result of a decline in grazing land, human health hazards and diseases and reduction in mangrove forest (UNEP, 1999). Rice farming is also said to have suffered from prolonged water logging from extended shrimp seasons (Bhattacharya *et al.*, 1999; FFP, 1999). Destructive methods of shrimp PL collection from the wild have also had significant impacts on coastal biodiversity (FFP, 1999; World Bank *et al.*, 2002).

3.3 IMPACT ON PHYSICAL RESOURCES

3.3.1 Habitat and landscape deterioration

The introduction of shrimp farming to the Bangladesh coast has undoubtedly increased the income of the people in coastal regions, but it has also gradually changed the land use pattern of the area, from agricultural and mangrove into shrimp farms. Figure 8 shows how the land area under shrimp farming has changed between 1976 and 2010 in three divisions of Bangladesh.

The loss of land previously used for agricultural crops was estimated 352 ha (0.03 percent) per year between 1976 and 2000 in Khulna division, rising to losses of 8 781 ha (0.66 percent) per annum between 2000 and 2010. Also in Khulna, the area under forest was estimated at 617 ha in 1976, and this has declined by almost 100 percent up to 2000 and no further changes observed between 2000 and 2010. The area under mangrove forest decreased annually by 0.36 percent during 2000–2010. The area under aquaculture increases during 1976 to 2010, which was almost from zero ha in 1976 and reached to 45 596 ha in 2000 and further, increased to 96 283 ha in 2010 (Hasan *et al.*, 2013).

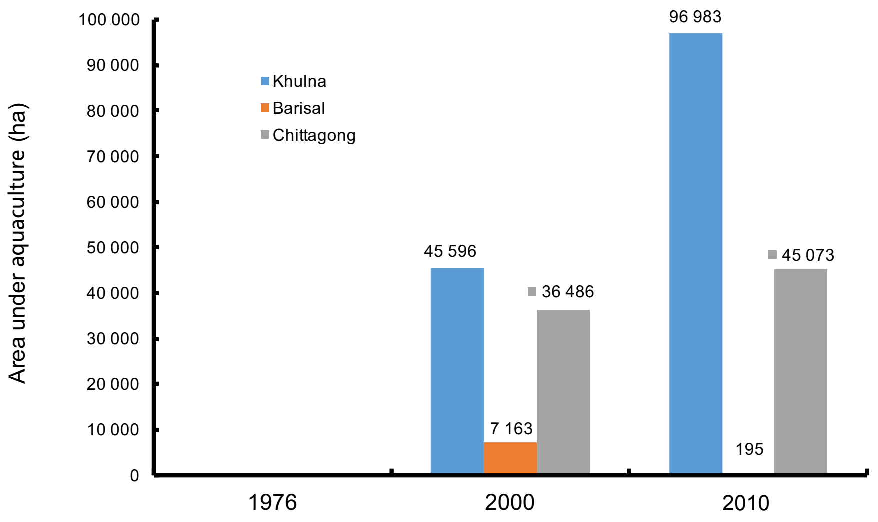
In Barisal division, the loss of agricultural cropland is estimated at 978 ha (0.12 percent) per year during 1976 to 2000, reducing slightly to 666 ha (0.08 percent) between 2000 and 2010, to give an overall loss rate of approximately 886 ha (0.10 percent) during the period 1976 to 2010. The area under mangrove forest decreased annually by 4.27 percent during 2000 to 2010. In Barisal, the area under aquaculture increased between 1976 and 2000, from almost from zero ha to 7 163 ha but it declined by 195 ha in 2010.

In Chittagong division, the area under aquaculture increased from almost zero ha in 1976 to 36 486 ha in 2000 and further, increased to 45 073 ha by 2010. In this division, the area under mangrove forest decreased annually by 4.18 percent during over the period 2000 to 2010 (Hasan *et al.*, 2013).

Overall during this period approximately 50 percent of coastal lands face different degrees of inundation, thus limiting their effective use for anything else except aquaculture, and 70 percent of land in the Barisal and Khulna divisions is affected by different degrees of salinity, which reduces agricultural productivity (Mia, 2004).

FIGURE 8

Changes in area under aquaculture (ha) in three coastal divisions between 1976 and 2010



Source: Data from Hasan *et al.* (2013).

3.3.2 Greenhouse gas contribution

Shrimp farming contribute to global greenhouse gas (GHG) emissions through various processes including fishing of shrimp broodstock, farming activity, growth, processing, transportation and storage. There are many different activities in the wider value chain from farm to fork with many different energy requirements. The predominant contributor is transportation with products typically transported via freight on ships or plane, especially if they are being exported from developing countries to developed-country markets (Shelton, 2014). High-value species like shrimp are more likely to be shipped via ships or airfreight, meaning their transport emissions are quite high. In addition, small low-power single engines to larger vessels to fish factory ships need to travel farther or to deeper waters and spend more time than they have in the past to catch the same amount of brood-stock shrimp.

3.3.3 Water impacts

Good quality water is the most vital factor in shrimp farming and production of shrimp in ghers is often limited by water quality degradation and inappropriate water depth. Water quality problems are increasing in shrimp farming areas because of excessive feeding, presence of high biomass due to high stocking density and application of drugs, antibiotics and chemicals, effluents etc. Higher amounts of particulate substances also exist as suspension in the water of shrimp ponds. Poor water qualities are causing diseases, higher mortality and low production and in some locations; it has become impossible to continue shrimp farming any more, due to these poor water quality conditions. Added to this the level of soil electrical conductivity (EC) has remarkably increased to lower depth of soil of shrimp farms affecting soil productivity. Insoluble materials from food inputs in the shrimp ponds have been prevalent causing high levels of water contamination. This has been exacerbated by the current changes in shrimp *gher* ownership happening all over the coast with large *ghers* are being converted into small *ghers* but without any excavation or renovation of canals and sluice gates. Stagnation of saline water in the shrimp ponds allows toxic substances to settle in the *gher* soil.

3.3.4 River impacts

Once highly abundant fish and shellfish that were present in the estuarine river systems of Bangladesh are becoming increasingly scarce. Many important, popular and common fish and shrimp species once abundantly available in the rivers throughout the year are now disappeared altogether or found only occasionally. The biodiversity of estuarine fishes in particular might have decreased considerably due to harvesting of shrimp post-larvae and the associated indiscriminate killing of hundreds of bycatch, shellfish, mollusks and other aquatic fauna. Biodiversity is also affected by heavy siltation that has occurred, which along with river erosion has resulted in ever-decreasing river water depth. Both are concerns for locals and for fishers as the catch per unit effort has been reported to be substantially decreased. In the focus group discussion (FGD) with riverine fishers of Dumuria, Khulna, it was revealed that just five years ago it was relatively easy to catch 2 to 3 kg of fish per hour with a cast net (khepla jal), pull net (thela jal) or triangular net (tinkona jal). Now a fisher is more likely to spend 3 to 4 hours to catch less than one kilogram of fish. Both full-time and part-time fishers have complained about the diminishing catch from rivers, are having problems in maintaining income and fulfilling the needs of their families, and though difficult many are nonetheless switching from fishing to other livelihood strategies.

3.3.5 Floodplain impacts

At the Bangladesh coast, much of the floodplain land has been under polders since the 1970s, for crop farming and flood protection and can no longer be considered as natural wetland areas. Many coastal floodplains are also now converted into shrimp farms. In addition, there are large areas of both tidally inundated and freshwater wetland areas in, and out of the polder belt that are lucrative to the shrimp farming industry for a number of reasons, including land being often water-logged and not suitable for agro-farming; polders now have almost no available land for new investors; and conflict of sharing water with other shrimp and paddy farmers. Thus, in terms of potential biodiversity loss, it is this growing trend that is more concern than the historic utilization of the polder areas. This, allied with the major expansion of freshwater prawn in very low salinity areas, shows the importance of limiting aquaculture expansion to appropriate areas that do not conflict with agricultural or biodiversity conservation needs.

In Bangladesh, *beels* are generally open access resources used by the local communities for fishing, grazing livestock and collection of wild plants for food, fodder and medicinal purposes during times of hardship. During the shrimp farming revolution, the low-lying land in the *beels* were highly sought after because it was land most easily converted into rain fed shrimp farms that could retain water throughout the year. Shrimp farms in higher areas required more irrigation to ensure a year-round supply of water. Most of the seasonal and perennial *beels* have now been converted into shrimp farms.

Shrimp farming has had a dramatic effect on the rural landscape and with vast areas of low lying floodplain having been converted into shrimp farms, there is concern that the adverse environmental effects of shrimp farming on wetland systems are making it unsustainable. Unplanned expansion of shrimp farms has reduced the *beel* area and blocked fish migration routes, caused drainage problems and reduced the grazing areas to support fewer livestock.

The *beels* are the natural breeding grounds for native/wild fish and support a wide range of wetland flora and fauna. The expansion of shrimp farming has had a dramatic effect on the floodplain landscape; with most of the *beel* area and many of the *khals* (canals), being the "lifelines" through which fish migrate to and from Bangladesh's main river systems, are now congested with shrimp farms. The poor drainage and reduced flow has caused many *khals* to completely silted. This has also been made worse by the underlying deterioration in drainage caused by building of embankments and most notably the Farakka Dam. The blockage of migration routes and destruction of their natural feeding and breeding grounds has led to sharp declines in native fish populations and some species have become extinct. Islam (2001) reported decreased fish yields and diversity in four *beels* in Bagerhat at a time when fishing pressure also remained high.

Fishers, who would naturally use the *beels* are having problems accessing the *beel* areas due to shrimp farm owners blocking access routes through their shrimp farms. Such blocking of routes is due to concerns of shrimp theft. Despite this lack of access and the declines highlighted, many fishers have actually seen their standard of living improved since shrimp farming started in this area resulted in increased employment opportunities. Wage rises associated with the "shrimp revolution" means that traditional fishers can earn more as a daily-paid laborer on the shrimp farms than from fishing directly. That said the likely decline in fish yields from the *beels* remains worrying, since it is the main source of protein for the majority of people in Bangladesh.

3.3.6 Drainage impacts

All sluice gates constructed by Bangladesh Water Development Board (BWDB) and those under the Third Fisheries Project (TFP) are now under the management of local large shrimp farm owners. Third Fisheries Project gates are technically faulty and heavy siltation has taken place at the mouth of sluice gates, creating problems with water flow through the system. One problem with lack of flows is that a shrimp pond situated in the middle of other ponds has to depend on adjacent pond owners for their water supply and will sometimes pay money for gaining access to water. Other pond owners get water only by natural seepage from adjacent ponds, limiting water depth of an individual pond, depending on depth of these adjacent ponds.

The canals and canal system inside almost all of the polders have been encroached by local power elites; or some of them have taken a lease from the government and, ultimately, have been using this as their private property (CEGIS, 2015). Shrimp farm owners in the middle of the polders therefore suffer water shortage for their shrimp culture. When the water level of the individual pond is not uniform in all areas of the farm it creates problem for the cultured shrimp, especially in the extremely hot summer months, when evaporation is high, and shrimp can become stressed leading to disease and high mortality occurs at that time.

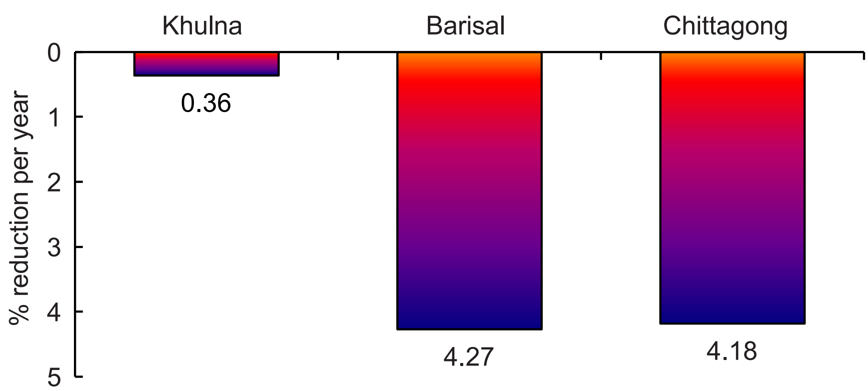
3.3.7 Impacts on mangrove

The Sundarbans delta extends over the southwest coastal area of Bangladesh, and West Bengal, and contains one of the largest contiguous mangrove forests in the world. As in many parts of the world, mangroves play a vital role in the coastal environment as a cyclone protection belt (in Bangladesh it provides a safety barrier for three greater districts – namely Satkhira, Khulna and Bagerhat), as a habitat for juvenile fish and crustacean species and through the supply of a variety of products (e.g. shellfish and wood) to the local population. Considerable areas of mangroves have been reduced in Bangladesh since the beginning of the initial expansion of shrimp farming in the early 1980s (Figure 9). Causes for the degradation of mangroves include land conversion for aquaculture and other uses, timber and fuel wood collection, and grazing, along with natural causes such as cyclone damage.

Mangroves are salt tolerant forest ecosystem of tropical and subtropical intertidal regions of the world and are important resources in coastal ecosystems that contribute multiple ecosystem services. Mangrove forests offer both tangible and intangible benefit to coastal peoples. With coastal geo-morphological changes, mangroves are facing rapid change brought about by social requirements, where population pressure for food production and urban development has changed mangrove habitat into ecologically undesirable states along coastlines globally.

The Bangladesh coast supports approximately 503 000 ha of natural mangrove forest and plantation, which represents approximately 3.9 percent of the total land mass and 15 percent of the total land canopy cover of the country (Potapov *et al.*, 2017); the great majority of which lies in the Sundarbans Reserve Forest (SRF) in the southwest region. Due to population pressure, the mangrove forest has been gradually shrinking due to conversion of forestland to human settlement, agricultural land and to aquaculture development (Alam *et al.*, 2014). According to EJF (2004) as much as 38 percent of

FIGURE 9
Mean annual reduction (%) in Mangrove over the period 2000 to 2010 in different districts of Bangladesh



Source: Hasan *et al.* (2013).

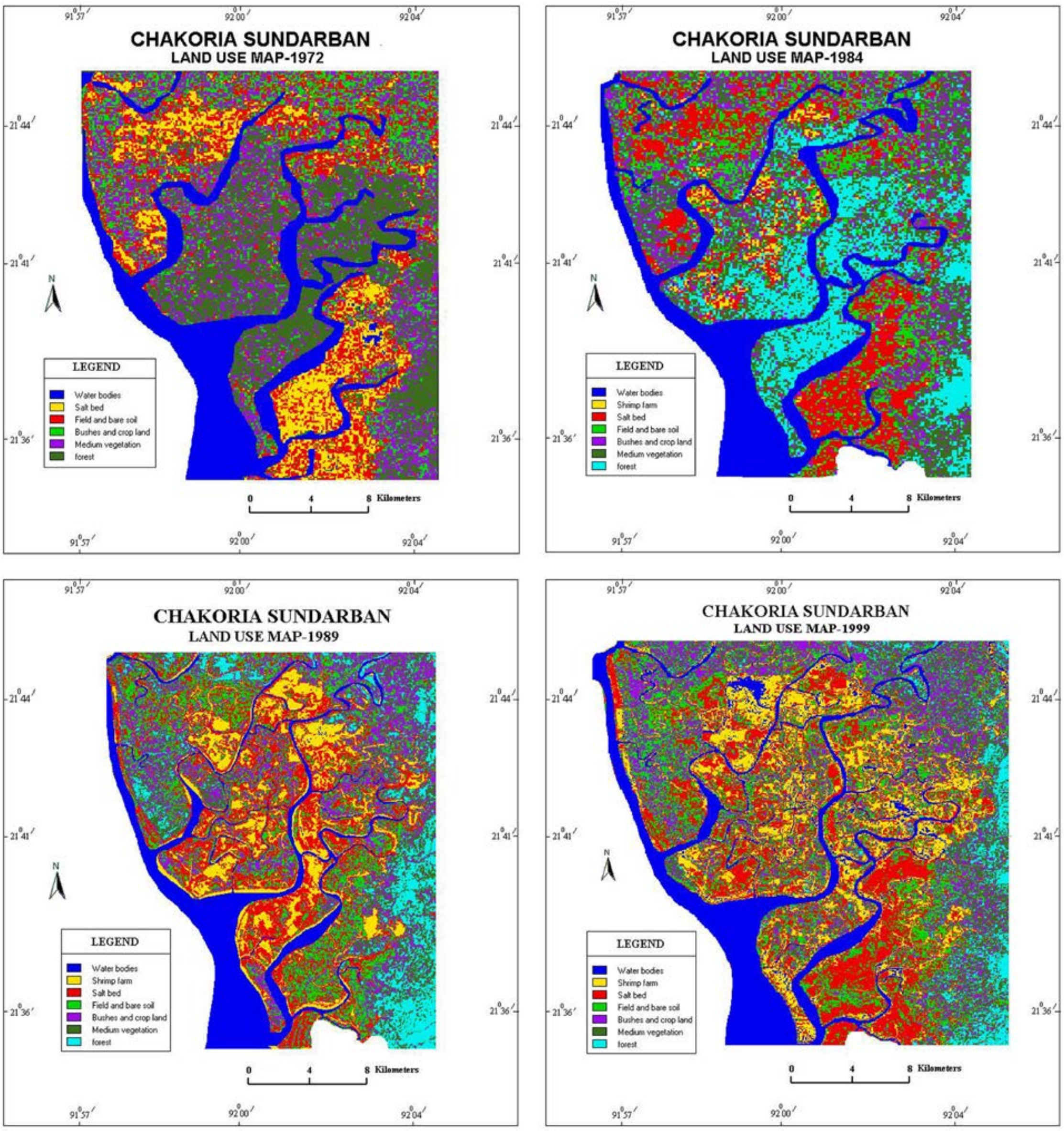
global mangrove destruction is linked to shrimp farm development; such that global mangrove deforestation rates now exceed those of tropical rain forests.

Most shrimp farm development has occurred in the inter-tidal non-forest coastal wetlands of Khulna region. A satellite image analyses study revealed that there was no loss of mangrove areas in the SRF from 1975 to date coinciding with the period when the expansion of commercial shrimp farming took place (Shahid *et al.*, 1992; *personal observation*). However, more than 80 percent of shrimp farms lie along lands adjacent to the SRF.

There are, however, mangrove areas that have been directly affected and the Chakaria Sundarban is one of such degraded mangrove forest in Bangladesh (Hossain *et al.*, 2001), which has seen a gradual change in land use since 1972 (Figure 10). According to Alam *et al.* (2014) when considering the loss due to shrimp farming and salt production, particularly of mangrove forest in terms of the value of mangrove products, economic

FIGURE 10

Changes in land use of Chakaria Sundarbans over the period 1972 (top left), 1984 (top right), 1989 (bottom left) and 1999 (bottom right)



Source: Alam (2013).

implications of increased coastal erosion, loss of livelihood for coastal communities, reduction of natural fish and shellfish production and environmental degradation, shrimp farming and salt production is not more profitable at a national level given the losses incurred. Damage is caused by pollution and by clearing of the vegetation to make way for new farms. Chemical pollutants used in the process include antibiotics, fertilizers, disinfectants and pesticides, which could be harmful for human health as well as for the environment. There is no specific advantage for people to build shrimp farms in mangrove areas compared to other areas; but it is done because it is common land that people can get hold of cheaply (BBC, 2004).

The Chakaria Sundarban is located in Chakaria upazilla of Cox's Bazar District in Bangladesh. The area is the extended plain landmass located between 21°35′ N to 21°48′N latitude and 91°57′E to 92°05′E longitude. Chakaria is bordered by the Matamuhuri-Harbang *khals* is the north, the confluence made *khal* at the south, the Cox's Bazar-Chittagong highway in the east and the Maheskhali Chanels in the west.

The Chakaria Sundarban area at the mouth of the Matamuhuri river has been almost completely destroyed by shrimp culture, and salt farming, leaving only some patches and bushes, totaling approximately 411 acres[2] (Alam, 2013), by 1999 (Table 5). In the pre-independence period of Bangladesh, prior to 1971, the Chakaria Sundarbans was a forest reserve of 18 200 ha (Cowan, 1926). Between 1977 and 1985 a total of 3 077 ha of state-owned land were leased to private shrimp farmers by the Ministry of Fisheries and Livestock, before the Ministry of Land took over leasing arrangements. In 1985, the Ministry of Land issued an instruction (No. 8-400/85/1232 (2) dated 8 December 1985) as a means to bring back land suitable for shrimp farming under this ministry. In effect all khas lands, and lands suitable for shrimp culture but under the administrative control of other ministries, were deemed to be reverted to the Ministry of Land that then allowed them to lease the land for shrimp farming. The lease term was initially 10 years with a provision for further extension. However, no attempts have ever been made for a technical evaluation of these lands, as to their suitability and environmental compatibility for shrimp farming prior to initial leasing or subsequent development (FAO, 1997).

By 1999, about 8 540 ha of mangrove forest of Chakaria Sundarbans in southeast coastal region of the country was under shrimp farming (Braaten, 2002). Approximately 2 250 ha and 900 ha were developed into shrimp farms by development projects funded by International Development Agency (IDA) and the Asian Development Bank (ADB) respectively. Within the overall total, it is estimated that 8 540 ha (Table 5) was mangrove forest reclaimed specifically for shrimp aquaculture use (Shahid and Islam 2003), although, part of the initial destruction of the forest resulted may result from clearance by timber traders and agricultural settlers before shrimp farming started.

TABLE 5
Loss of mangrove forest between 1975 and 1999 in southwest and southeast regions of Bangladesh

Area	Location	Total area of mangrove (ha)			Loss of mangrove (ha)
		1975	1983	1999	
Southwest	Sundarban reserve forest	600 386	600 386	600 386	0
Southeast	Chakaria	8 512	4 758	411	8 540
	Maheshkhali island	1 645	-	2 773	290
	Matharbari island	125	-	315	104
	Jaldia island	140	146	13	133
	Naaf River	667	-	0	667
Total					**9 734**

Source: Shahid and Islam (2003).

[2] hectare = 2.47 acres

According to Shahid and Islam (2003) a total of 9 734 ha of mangrove, being approximately 1.6 percent of total mangrove forest in Bangladesh, has been converted to shrimp farms since 1975 (Table 5). The authors also reported that other areas where mangrove loss due to shrimp farming activity include Moheskhali Island, Matharbari Island, Anjumanpara near the Naaf River and Jaldia Island. In Jaliardwip mangrove (known locally as Kewra containing *Sonneratia apetala* forest) along the Naf River, about 133 ha has been cleared for shrimp farming, representing most of the inland area of this small coastal island and till that point an important habitat for crab-eating monkeys. In summary, approximately 9 734 ha of mangrove loss, in various locations along the Bangladesh coast, has been directly attributed to shrimp farming since 1975. Figure 11 showing an example of farms developed within the Chakaria Sundarban.

It is notable that the shrimp farms within the Chakaria and other areas are often converted to salt beds in the winter season, followed by increasing use for shrimp farming in the rainy season, and is becoming increasingly common. In 1972, salt bed cover was 5 115 acres; whereas by 1984, 1989 and 1999 salt bed cover was increased to 8 827 acres, 12 231 acres and 12 596 acres respectively.

At Chakaria, there have been a number of effects of the loss of mangrove forest. The local population traditionally collected fuel from the forest and they are now facing a tremendous crisis providing wood for fuel. Local fishers undertook fishing using traditional techniques, but have lost their jobs and many of them have become either day laborers, or have been forced to migrate elsewhere, including further seaward to

FIGURE 11
Extensive shrimp farms in Chakaria Sundarban in 2015

Source: Google maps.

offshore islands. It should be noted that a new young group has been evolved, who collect shrimp fry from the wild to supply to shrimp farms. Traditional peasant families have also been affected and many small farmers have changed their occupation towards salt production, day laborers or other small business development. According to Khan and Hossain (1996) shrimp farming in Chakaria did not bring good to the local poor, with rich, mainly outsiders living in cities and having the capacity to invest money, getting benefit out of shrimp cultivation.

3.4 PRODUCTIVITY AND DISEASE IN SHRIMP FARMING SYSTEM

3.4.1 Shrimp *ghers*

Productivity of shrimp *ghers* (ponds) decreased heavily following the impacts of Cyclone Aila, which happened in 2009, but since then productivity has gradually increased again, at a time when the individual size of the farms has also gradually decreased, over a number of years. Overall species composition in shrimp *ghers* has remained similar since 2009, however, since 2003–2004, some of the farmers started mixed cultivation (shrimp along with different types of finfish) to reduce the uncertainty in income from production from the main crop – shrimp (Islam, 2003). This has been done to compensate for ever-fluctuating profit and loss from shrimp production and sales. The majority of the farmers now follow a mixed culture system, with mixture of shrimp and brackishwater finfish such as mullet (*Chelon parsia*) and barramubdi (*Lates calcarifer*) and catfish (*Mystus gulio*) (Paul, 2013; Akber *et al.*, 2017). Now many of the shrimp PL providers also supply the fry and fingerlings of these brackishwater fish to the shrimp farmers, which also provides additional income for the PL providers (*personal observation*). Input costs of production is also gradually increasing, and in particular farmers are concerned with rising price of quality shrimp PL, feed and other input costs (Morf, 2014). Many farmers, who operate at marginal profitability, do want to stock good quality PL and to provide quality feed to the shrimp, but have been prevented from doing so because of the lack of necessary capital. Thus, although *gher* productivity has been increasing, overall profitability has been decreasing gradually due to higher production costs. Low profitability also results from frequent outbreaks of a number of diseases, where often the farmers lose all the shrimp in their *ghers* within a very short period of time.

3.4.2 Shrimp disease issues

Many of the diseases that occurs in shrimp farms are directly caused by environmental degradation, while a number of other diseases are triggered by the stress induced by poor environmental quality. Since 1994, shrimp farming has been afflicted by outbreaks of bacterial and viral diseases, that have greatly undermined both profitability and sustainability of shrimp farming operations (FAO, 1997; Mazid and Banu, 2002; DoF, 2007). Occurrence is closely related to shrimp pond management and other parameters such as water depth, salinity, pH, water level, water quality management, soil acidity and so on. Bangladesh has experienced disease outbreak in both semi-intensive and extensive shrimp farms which were associated with physico-chemical factors such as *gher* pH, water temperature and dissolved oxygen concentration which fluctuate abruptly, particularly after heavy rain downpours or after long spells of drought. Under these circumstances shrimp become vulnerable to stress, leading to disease (Paez-Osuna *et al.,* 2003), such as red colour, soft shell, tail rot and black gill diseases (Alam *et al.,* 2007). Generally, high stocking density and excessive use of feed are the main reasons leading to degraded water quality, which contributes to stress and diseases among shrimp in semi-intensive farming systems, for example (Paez-Osuna *et al.,* 2003). It is environmentally damaging when uneaten feed and other waste are discharged directly in to the culture system, which reduces the overall water quality and renders the shrimp being extremely susceptible to disease vectors present in the water. The movement of water between neighboring farms, particularly if the water is polluted and of poor quality, enables the spread of water-borne diseases from farm to farm (Paez-Osuna, 2001). Poor water quality, associated with unplanned and uncontrolled farming, has increased the incidence of disease and reduced production and productivity accordingly (Deb, 1998).

Disease outbreaks have been recognized as one of the largest problems limiting development of shrimp aquaculture in Bangladesh. Red disease and white spot disease (locally called virus) are most prevalent. Among other common diseases, black gill, tail rot, shrinkage of muscle, blue diseases, change of body color and some behavioral changes are also reported by the shrimp farmers. To complicate matters, most shrimp farmers use the term ‘virus’ to mean any diseases or health problems that cause mass mortality, irrespective of its source or diagnosis. This lack of understanding is due to a lack of training and technical knowledge, and lack of diagnosis facilities within the farmer community.

3.5 WATER IMPACTS BROUGHT ABOUT BY SHRIMP FARMING

3.5.1 Waterlogging and saline intrusion

The Bangladesh coast is an extremely vulnerable part of one of the most flood-prone countries in the world. Waterlogging and saline intrusion are identified as major problems in most of the shrimp farming areas of Bangladesh. Prior to 1960 people used tidal water for aquaculture, where waterlogging for long periods and salt intrusion in soils was not a problem. With the building of polders in the 1960s, and particularly through the 1970s, plus strong international market demand and high prices encouraged farmers to enhance shrimp farming in polders. More recently rice cultivation is no longer financially viable due to salt water intrusion, and the combination of factors (i.e., strong market demand and high price of shrimp) acted as a catalyst to accelerate shrimp farming development thus increasing the likelihood of further waterlogging incidence.

Communities in southwest Bangladesh experience prolonged flooding that does not recede easily, and results in pools of stagnant water in their fields. Estimates of the number of people affected by waterlogging over time varies, but government data from 2011 indicates that more than 800 000 people were affected that year in Satkhira District alone after heavy monsoon rains. An October 2013 report by Shushilan, an NGO reported that more than 21 000 families in Sathkira District are regularly affected by waterlogging. While a variety of factors lead to waterlogging, it is most pronounced in areas where the land is divided by raised earthen embankments or polders (IRIN, 2013), which reduce the opportunity for waters to recede. Research shows that the construction of embankments often results in increased river sedimentation, where silt and debris build up in riverbeds instead of being deposited on flat land during floods (UNESCO, 2011). This results in the riverbed levels rising and water depth falling. When embankments are in place and water spills over the edge during a high tide or heavy rain, trapped water cannot recede, leading to waterlogging (Figure 12), which has affected some areas for more than a decade. Many people have had to move their homesteads a number of times and people have had to leave their family land or farming plots because those were turned to ponds. While some migrate, others have adjusted to the protracted waterlogging by cultivating fish, prawns, or shrimp. However, using waterlogged land for commercial cultivation of shrimp leads to increased water salinity, which causes soil to become infertile for any other forms of cultivation (e.g. rice, crops etc.). Many argue that shrimp farms also mask the broader issue of waterlogging, instead of catalyzing communities to demand long-term solutions to the problems that waterlogging and salt intrusion cause (Rahman *et al.*, 2013). Even in the best case, shrimp farming can last for an absolute maximum of 10 years (Nijera Kori, 1996; Hagler, 1997) - and by

FIGURE 12
Impacts of waterlogging in the villages near the shrimp farms

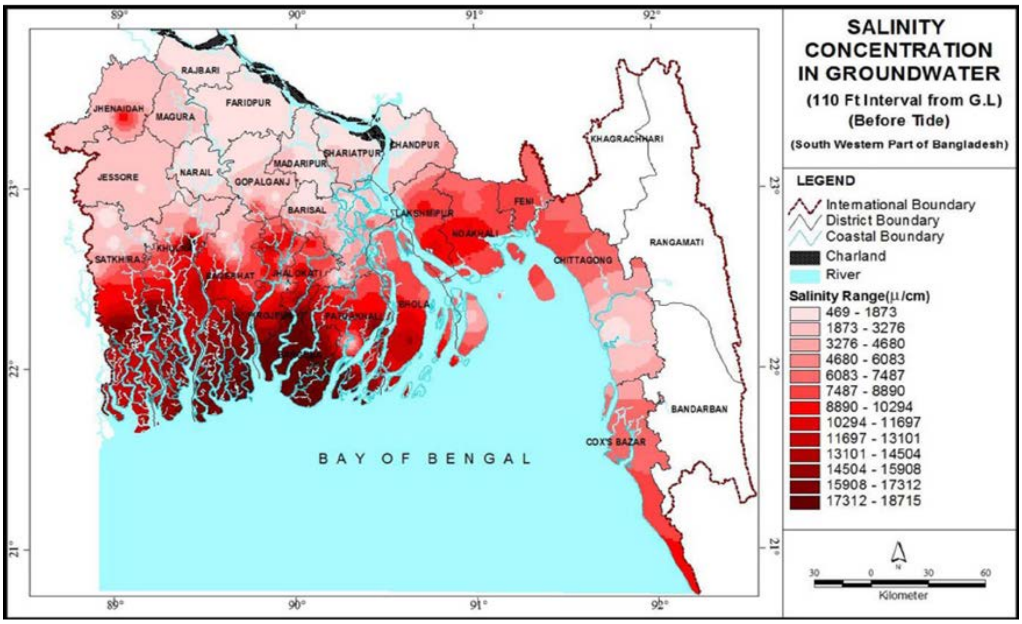
the time farmers learn how to cultivate shrimp, the environment is so badly damaged they cannot turn back to crop or other farming when shrimp farming fail.

3.5.2 Salinization of land and water

Prolonged shrimp farming increases the soil salinity, acidity, and depletes soil calcium, potassium, magnesium and organic carbon content which leads to soil degradation (Ali, 2006). Before the shrimp farming started, rice was cultivated on 80 percent of the cultivable land and harvested twice a year, in February–March and July–August. Rice yield was supplemented by growing a number of pulses, vegetables and fruits. The increased salinity due to shrimp cultivation brought about declined rice and other crops production (Swapan and Gavin, 2011), because shrimp farming causes salinization in the adjacent rice and other agricultural lands. Land inundation by saline water for long periods leads to its percolation into the surrounding soils, resulting in altered soil chemistry (Islam, 2003). A study conducted by Ali (2006) in the village of Damarpota in Satkhira district of Bangladesh showed that expanded shrimp farming in the area resulted to a loss of 1 049 tonnes of rice production during the period of 1985 to 2003. Moreover, salinity intrusion affects freshwater supplies for irrigation and people needed to install deep tube well to gain the needed freshwater, which directly affected groundwater aquifers (Deb, 1998, Chowdhury *et al.*, 2006). Shrimp farming increases soil salinity levels up to five times in non-saline areas, with a proven effect on crop cultivation (Islam *et al.*, 1998). Freshwater bodies were also found to be contaminated with high salinity (up to 22 ppt), which alters the habitat condition of most of the freshwater organisms (Sohel and Ullah, 2012). Glass (2013) showed that groundwater in large areas of Bangladesh has a high salinity (Figure 13).

The farming practices of shrimp are either extensive, improved-extensive or semi-intensive. Extensive shrimp farming rapidly depletes soil organic matter content.

FIGURE 13
Salinity concentration in ground water of Bangladesh



Source: Glass (2013).

Improved-extensive and semi-intensive shrimp farming deliver high volumes of organic matter (e.g. uneaten feed), inorganic effluents and toxic chemicals to the ecosystem that result in hyper-nitrification and eutrophication with high soil toxicity (Kabir and Iva, 2014). Soil fertility is decreased by 92 percent in shrimp farming areas. The major reasons of decreasing soil fertility are use of chemical fertilizer and pesticide, waterlogging and saline intrusion (Williams and Islam, 1999). As a result of lower land fertility, farmers are not getting proper rice yield during the paddy season. Trees near to shrimp cultivation are dying, including date, palm and coconut trees. Those trees that remain alive, do not give any fruit. Whereas previously agro-farmers could cultivate some jute and sugarcane that has now ended; and vegetables and fruit that used to grow in the peoples' yards are not growing well. Thus, saline waterlogging into fresh land degrades soil quality that adversely affects local vegetation, plants and trees, crops, fishes and livestock, changes the environment, ecology, and impacts population health and disease patterns. These effects ultimately accelerate the process of changes in the physical, aquatic and terrestrial environment, including deforestation, changes in biodiversity and ecosystem health, all of which change the condition of the environment of Bangladesh (Rahman *et al.,* 2013), and have serious implications for long-term sustainability of food production.

The main obstacle to activities that could intensify agro-crop production is seasonally high content of salts in the root zone of the soil. Salts enter inland through rivers and channels, especially in dry season when farmers cultivate their lands for shrimp production, and the increased water salinity causes impacts on groundwater that makes it unsuitable for irrigation, for example. This occurs particularly in southern coastal regions. The severity of salinity problem increases with the aridness of the soil (Rahman *et al.,* 2013). The organic matter content of the soils is also reduced to 1.0–1.5 percent; and nutrient deficiencies in nitrogen and phosphorus are prevalent in saline soils. Micronutrient deficiencies such as copper and zinc are widespread also (Anwar, 2003).

The overall quality of soil and water has significantly reduced. Homestead lands once used for production of vegetables, including bitter gourd (korola), beetroot, ash gourd (chal kumra), kidney beans (sheem), pumpkin (kumra), long beans (barboti), pointed gourd (potol), bottle gourd (lau), carrot, yam, tomato, turnip (olkopi), turnip greens (shalgam), sweet potato, ceylon Indian spinach (pui shaakh), drumstick (sajner data), snake gourd (chichinga), spongy gourd (jhinga), potato, radish, mustard, brinjal (begun), elephant foot yam (ol), cucumber, red amaranth (lal shaak), and others, are of no use today. Previously, people would be generally self-sufficient in vegetable needs but now most people in the shrimp farming areas have to buy these vegetables from the markets, and they find the price increasingly expensive. Moreover, a survey of local people, showed that many of the local varieties of large fruit trees like mango, guava, sapodilla (sofeda), palm, shegun, mahogany, berry, rose apple (jamrul), jujube (kul/boroi), kadbel, wood apple, coconut and so on have markedly declined over time (Kabir and Iva, 2014).

3.5.3 Soil salinity

There is evidence that the salinity regime of the entire southwest region of Bangladesh has been changing as a result of reduced freshwater flow from upstream towards the sea. This reduced flow is said to be associated with increased compartmentalization of waterbodies and by excessive groundwater extraction; and withdrawal of upstream flow by the Farakka Barrage in India. The effect is a shorter period of lower river salinity in the region, and conversely longer periods with more saline waters present.

Data has showed that saline water has penetrated inland to a distance of approximately 100 km from the sea through the coastal river system. Thus, the total area in Bangladesh, affected by saline water, has increased by 3.5 percent over 10 years, from 1.02 million ha in 2000 to 1.06 million ha in 2009 (Ahsan, 2010; Ullah and Rahman, 2014).

There has been much speculation about the impact of soil salinization on coastal agriculture. Various authors have attributed degradation of soil fertility, reduction in standing tree stocks and contamination of ground water to salinization from shrimp farming (e.g. Huntington, 2003). The Soil Resource Development Institute (SRDI, 2003) under the Ministry of Agriculture has tested soil composition and prepared soil maps for most upazilas, which show the extent of change in soil salinization between 1973 and 2000 (SRDI, 2003) and has reported the extent of inherent soil salinity in the coastal areas.

SRDI (2003) report that approximately 14 percent (equivalent to 203 720 ha) of the cultivated land on the coast is affected by what are classified as strongly saline (S4) and very strongly saline (S5) categories. According to SRDI (2003) and the Department of Agriculture Extension, soil category S2 (slightly saline) extends to approximately 71 percent of cultivatable land but at this time remain suitable for most agricultural crops. The maximum tolerance level for common varieties of rice is 6 mmoh/cm, while salt resistant rice varieties such as BR 40 and BR 41 have higher tolerance levels and can be grown in moderately saline soil.

Studies in 1999 to 2003 suggested that there had been good rice production within shrimp areas inside coastal polders over that period (Nuruzzaman, 2006; Toung and Hoanh, 2009; Paprocki and Cons, 2014; Kabir and Eva, 2014; and references cited therein). At that time, approximately 80 percent of shrimp farms in the southwest region used to rotate rice and shrimp annually. Shrimp farmers were encouraged by Department of Fisheries extension workers and shrimp experts to change their farming system to avoid shrimp diseases and during this period began to shift from ‘shrimp only’ to ‘shrimp and rice’ systems. Traditionally, local varieties of *aman* rice were grown in shrimp areas, but following the recent shift in soil salinity, farmers increasingly grow HYV rice varieties, including BR 11, BR 23, BR 40 and BR 41 in polder areas. The shift from traditional to HYV varieties resulted in a lower incidence of shrimp disease and better rice production on shrimp farms, and had the added effect of significantly reducing conflicts between shrimp operators and rice farmers. In recent years, the industry has achieved significant progress in understanding the complex interactions among people, environment and economy and in realizing coping strategies to reduce negative impacts.

The major shifts included the exodus of rich entrepreneur outsiders to production by small *gher* owners, splitting of large shrimp *gher* in to smaller units, gradually increasing reliance on hatchery produced PL for stocking, nursing of PL before stocking in *ghers*, integrating rice and finfish with shrimp and no further conversion of mangrove forest into shrimp farms. Initiatives, such as extension and support services, demonstration of alternative farming systems, and the development of saline resistant varieties of rice all contributed to enabling growth of rice within the increased salinity soil, reducing the spread of soil salinization, reduced shrimp disease outbreaks and maintained rice yields, which reduced the fears noted by earlier observers (Nuruzzaman, 2006; Sen, 2008; DoF, 2014; Jannat *et al*., 2017).

Soil salinity levels decreased with increased distance from shrimp farms (Table 6). Huntington (2003) also noted that those areas with clay soils rich in Calcium (Ca+) and Magnesium (Mg+) ions are better at resisting saline intrusion. Moreover, rainfall and frequent tidal flushing by freshwater during the monsoon period tends to act to remove whatever salinity intrusion occurred during dry season when shrimp aquaculture takes place. Although various studies in the 1980s and 1990s (Rahman *et al.,* 1994; Caritas, 1996) showed a reduction in the number of trees in shrimp production areas, large-scale tree planting and increased local awareness have substantially reversed the trend in more recent years (Rahman *et al*., 2009).

What continues to concern people is that rather than limiting development of shrimp aquaculture to areas already affected by increased salinity, new shrimp farms are sometimes created by flooding uncompromised farmland with saltwater. This has the potential to exacerbate the problem of soil salinization (Figure 14). Research has shown that without proper water management, shrimp farming can increase soil salinity and undermine the fertility of nearby rice farms, and this remains a challenge for rice production, an important food production system (Glass, 2013).

TABLE 6
Results of land salinization study around shrimp ponds in Polder 23, Piakgacha, Khulna district, Bangladesh in 1997

Location		Electrical conductivity (mmhos/cm)		
	Month	Shrimp farm dyke	50 m distance	100 m distance
Polder 23	Dec 2002	9.8	5.1	2.0
	Jan 2003	8.5	6.0	2.4
	Feb 2003	8.7	6.1	2.6
	Mar 2003	9.7	6.2	4.1
	Apr 2003	12.9	7.6	4.7
	May 2003	15.2	8.2	5.1
	Jun 2003	11.4	7.5	5.3

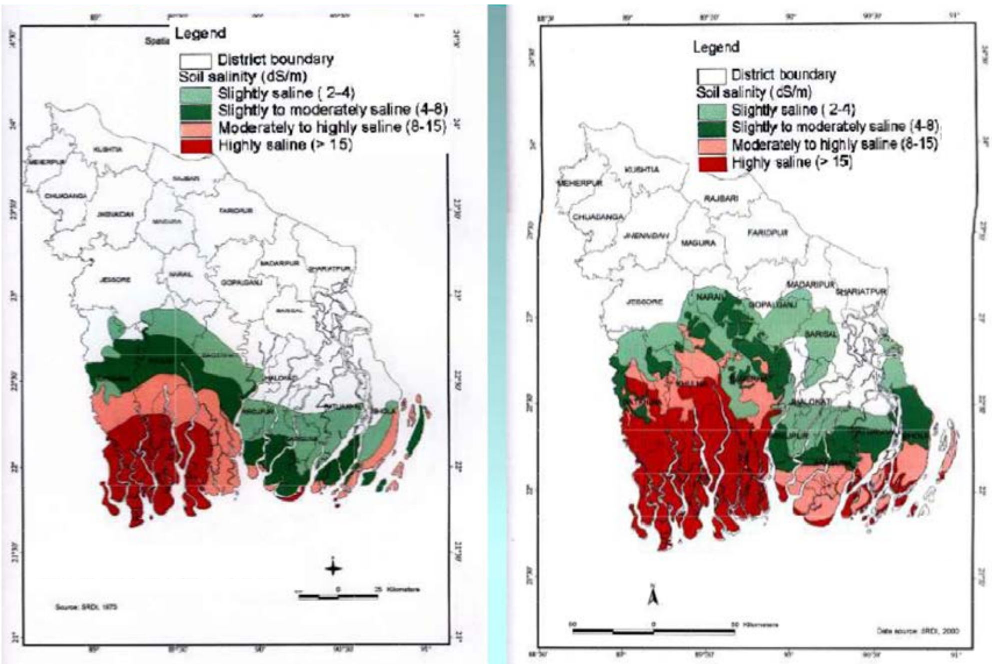
Source: SRDI (1997).

3.5.4 Soil texture

Soil texture is an important soil characteristic, affecting salt holding capacity and appropriateness for different crop types. Generally, sandy soils tend to be less saline because sands particles are not bound tightly, and therefore are less coherent and salts leach easily. Peat soils also support leaching of saline water due to their associated surface drainage network. However, salts tend to attach to clay particles and clay soils tend to be more saline for longer, but clay soils are vital for shrimp farming areas as a means to retain sufficient water because of clays high water holding capacity, very slow drainage rate and poor aeration system.

As part of soil texture, organic matter content is complex, naturally being a mixture of a number of organic substances, including living organisms and carbonaceous remains of organisms, the amount of organic matter depending on the decomposition

FIGURE 14
Maps showing change in maximum soil salinity between 1973 (left) and 2000 (right) in southwest coastal Bangladesh



Source: SRDI (2003).

capacity of the soil. Shrimp cultivation patterns in Bangladesh is mainly extensive to improved-extensive, and relies heavily on the application of mustard cakes and cow dung, as well as a number of farm-made and commercially available pelleted feeds, all of which increase the soil organic matter content. Often this has to be removed from shrimp farms in order to avoid the organic breakdown processes in soils lowering the dissolved oxygen concentration in the shallow pond water column. Although potentially valuable soil with a higher organic content, it remains almost unusable because of the salt content.

3.5.5 Water salinity

Salinity plays a pivotal role in the farming of brackishwater shrimp, with movement of tidal water from the Bay of Bengal to the coast increasing overall water salinity within the polders. Salinity concentration decreases in the upland areas and increases towards the sea, with mixing of freshwater during the onset of the monsoon, with rainfall and increased upland river flows having a dilution effect further inland.

The optimum salinity range for bagda growth is between 15 and 25 ppt (Kungvankij *et al.*, 1986). Salinity is found to be highest in Shyamnager Upazila of Satkhira (24 ppt recorded in May 1999) and medium to low in Khulna, Bagerhat and Kaligoj Upazila of Satkhira. Over the year, the salinity regime varies (Table 7) from 0 to 24 ppt around Khulna, Satkhira and Bagerhat. Levels are lowest during the monsoon and highest during the dry season. The monthly salinity range varies, however, depending on the amount of rainfall and quantity of upland flow. Shrimp farm salinity levels sometimes increases gradually during the summer due to high evaporation rates.

Water needs to be changed within the *ghers,* which is typically done during the new moon and full moon when the tidal height is at its highest, locally termed as *goin*. Shrimp *gher* owners replenish their *gher* water directly, where access is possible, or indirectly though other *ghers*. Shrimp *gher* owners who cannot change water directly or simply cannot change water will struggle to maintain desired water levels and

TABLE 7
Water salinity of four coastal rivers of Khulna and Satkhira districts, 1995–2000

Location	Year	Monthly average salinity (ppt)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Shibsha river (adjacent to polder 23), Paikgacha, Khulna	1995	4	7	8	12	15	11	7	3	0	0	0	1
	2000	2	5	16	13	15	10	2	1	0	0	0	0
Passur river (adjacent to polder 31 and 32), Dacop, Khulna	1999	1	4	7	15	20	7	1	0	0	0	0	0
	2000	2	4	8	10	6	2	0	0	0	0	0	0
Passur river (adjacent to polder 35), Mongla, Bagerhat	1995	5	9	11	12	16	15	15	12	7	2	0	2
Kakshiali river (adjacent to polder 3 and 5), Kaligonj, Satkhira	1995	4	9	11	14	16	14	14	8	4	1	0	0
Malancha river (adjacent to polder 5 and 15), Shyamnager, Satkhira	1999	16	17	19	23	24	21	17	13	9	6	7	10
	2000	11	15	18	22	21	22	17	14	11	4	2	5

Source: Upazila Fisheries Officers (UFOs) of Khulna and Satkhira districts.

under these circumstances *gher* owners can face an adverse situation, if water quality deteriorates, leading to increased incidence of disease, for example.

3.5.6 Sedimentation

Water runoff during the rainy season carries sediments from upstream through river tributaries to coastal areas where it settles when the flow rates reduce. When water from estuaries or river channels is stored in shrimp *ghers*, any sediment quickly settles on the bottom of the *gher* as water velocity slows down (Dewalt *et al.*, 1996). Added to this is organic and inorganic matter that derives from the surrounding *gher* walls and organic sludge from uneaten feed and faceal material that accumulates on the pond bottom during each production cycle (Briggs and Funge-Smith, 1994). Management practices, including high stocking density, excessive feed application, aerator use, liming and addition of fertilizers also contribute to both suspended particulates and to overall sediment accumulation (Funge-Smith and Briggs, 1998).

Shrimp farming increases suspended solids, or colloids, that increase turbidity in the water column, and reduces sunlight penetration, which, in turn, significantly reduces primary productivity in the *ghers* and affects the trophic structure of the shrimp farming system (Dewalt *et al.*, 1996). Bergheim *et al.* (2003) report turbidity as high as 23 percent for extensive farm systems and up to 39 percent at semi-intensive farms in Bangladesh. Such sediment loads have a detrimental impact on other water users, as well as on the local fauna and flora (Dewalt *et al.*, 1996). The excessive organic material that accumulates on the shrimp pond bottom, including nitrogen and phosphorus, ammonia in the water column, and development of hydrogen sulfide as the water and sediment quality deteriorates also creates an unpleasant odor and increases eutrophication (Funge-Smith and Briggs, 1998).

3.6 IMPACT ON BIODIVERSITY

Ecosystems within the coastal zone are highly diverse and include aquatic encompassing saline water, brackishwater and freshwater systems, and terrestrial ecosystems containing mud flats, sandy beach and sand dunes, flatlands and undulating terrain that houses different ecosystems with a diverse and wide range of habitats. This large ecosystems' diversity also supports a wide range of flora and fauna including genetically rich varieties. Thus, when considering all level of biodiversity (genetic, species and ecosystem) these are very high in the coastal zone.

The coastal zone of Bangladesh is inhabited by a large population and with diverse livelihood activities, and interaction between human systems and natural systems is very high. Human actions on and with natural ecosystems are sometimes sympathetic and sometimes destructive. The destructive nature often results from poverty, a profit-making motivation, lack of awareness, poor and scant knowledge of the natural system functionality and poor commitment on maintaining the natural systems for future generations. The high level of exploitation and destruction of the habitats in Bangladesh disrupts the integrity of ecosystems in the coastal zone and fosters natural degradation, to levels often far below the threshold where it is able to recover, and thus resulting in irreversible damage. Protection of ecosystems therefore becomes an essential component in any integrated management of the coastal zone.

The coastal region of Bangladesh has a very complex situation regarding freshwater and saline water interaction. Changes in tide and freshwater flows result in the advance and retreat of the salinity limit. Under this process, during the wet season, local rainfall associated with flood flows from upland regions keeps the salinity limit near the coastline. Salinity starts increasing further inland from the beginning of November with cessation of the rains and consequent reduction of river flows (Pramanik, 1986).

Gain *et al.* (2008) observed reduced fish diversity in coastal areas with increased salinity. The reduced fish diversity eventually decreased the fish production of native species, and created extinction of several species. These consequences eventually created instability in the socio-economic sector of coastal Bangladesh, in terms of increased poverty of local fishers. Gain *et al.* (2008) also noted that reduction of salinity in the south west region of Bangladesh could be accomplished by increasing freshwater flow from the Ganges through the Gorai-Madhumati channel. As nothing has been done since then, the flow of the channel further decreased. Using annual trend analysis (1990–2015), Esha and Khan (2016) found that maximum and minimum water level and maximum water level of monsoon period shows a decreasing trend.

Shrimp farming can adversely affect wild fish stocks through pollution and destruction of wetlands, through removal of unsustainable levels of by catch during shrimp PL collection from the sea and through the introduction of disease. Along with the decline in finfish populations and diversity noted by Gain *et al.* (2008), many other aquatic species of flora and fauna have disappeared from the coastal wetland areas. Additionally, livestock population share also decreased due to loss of common resources for grazing and fodder collection. Low lying land where people used to grow only one crop a year was also previously used as common grazing land for much of the year. *Beels* were also used for duck rearing. Now these resources either no longer exist or access has become more restricted as people prevent others crossing their shrimp farm to the remaining *beel* area. As a result, the number of livestock (cattle, goats, and ducks) has fallen sharply.

Fishers in Bangladesh are particularly interested to catch the shrimp post-larvae to supply the shrimp production market, but as a consequence can destroy fry of non-target species as ‘bycatch’ when fishing in the river. In studies during collection of shrimp PL, Toufique (2002) noted that an average of 1 341 fries of non-target fish and shellfish species were destroyed in 1998, 2 038 fries in 1999, and 1 611 fries in 2000. Removal of this level of non-target species has resulted in the natural catch of fish in coastal rivers being decreased 90 percent over last 20 years (Rahman *et al*., 2013) and a declining catch of wild shrimp PL has long been reported (Islam, 1999) because of over-fishing of post-larvae.

The coastal wetlands are the natural breeding grounds for indigenous wild fish and support a wide range of wetland organisms. At the beginning of the shrimp revolution, the low-lying land in the wetlands was highly sought after as it was easily converted into rain fed ponds that could retain water throughout the year. Most of the wetlands and many of the canals that act as “lifelines” through which fish migrate to and from Bangladesh’s main river systems are now congested with shrimp ponds. The generally poor drainage and reduced water flow have caused many canals to completely silted and this along with destruction of natural feeding and breeding grounds have led to a sharp decline of native fishes. Due to the increased salinity, many freshwater fish species like Indian major carps (rohu *Labeo rohita* and catla *Catla catla*), striped snakehead (*Channa striatus*), giant freshwater catfish (*Wallago attu*), small catfish (*Mystus* sp.), climbing perch (*Anabas testudineus*) and stinging catfish (*Heteropneustes fossilis*) have disappeared or are about to disappear in many localities. Along with the decline in fish populations and diversity, many other species of flora and fauna have disappeared from wetland areas in coastal regions (Datta, 2001b). For example, many shrimp farmers often kill mammals and reptiles present, considering them harmful to the shrimp and reducing food availability by competing for resources. Many of these animals are almost extinct from shrimp producing localities (Manju, 1996).

In a study conducted by Hossain (2013), participants from different stakeholder groups of men and women in a number of field group discussions (FGD) in Shyamnagar, Satkhira were asked to rank important fishes and shellfishes, by considering overall impact on their livelihood, based on availability, productivity, price, accessibility, frequency of consumption and overall impact on the livelihood. Results are shown in Table 8.

TABLE 8
Rank order of important fish/shellfishes and reasons for importance in the southwest coast of Bangladesh

Local name	Common English name	Scientific name	Reason	Trend
Tilapia Nilotica	Mozambique tilapia Nile tilapia	*Oreochromis mossambicus* *Oreochromis nilotiocus*	Available, cheap, and easy to access	Increasing
Bagda	Black tiger shrimp	*Penaeus monodon*	High price, cash crop	Decreasing
Harina chingri	Brown shrimp/speckled shrimp	*Metapenaeus monoceros*	Available, medium price	Decreasing
Bhetki	Barramundi	*Lates calcarifer*	High price, cash crop	Decreasing
Bata/parse	Goldspot mullet	*Chelon parsia*	Available, eaten, sold	Decreasing
Bishtara/paira	Spotted scat	*Scatophagus argus*	Available, eaten, sold	Decreasing
Chaka chingri	Indian white prawn	*Fenneropenaeus indicus*	Good price	Decreasing
Baila	Tank goby	*Glossogobius giuris*	Good price	Decreasing
Bhangon bata	Flathead grey mullet	*Mugil cephalus*	Available	Decreasing
Rekha	Four-banded tiger perch	*Datnioides polota*	Available	Decreasing

Source: Modified after Hossain (2013).

Villagers said that more than 40 percent of the fish they consume is tilapia, an exotic species that is cultured, introduced to the then East Pakistan in 1954 from Thailand. The fish is relatively cheap (BDT 50–120/kg based on the size; the bigger the size, the higher the price) and therefore affordable, and it can be grown even in their semi-saline and saline ponds and survives even when no other freshwater fish can be grown. Villagers noted that they can also use small sized cheap tilapia as crab feed. Bagda chingri, harina chingri and bhetki stood 2nd, 3rd, and 4th position respectively, primarily because of their commercial value. Villagers never eat these but sell them in the market as a cash crop. Parse (5th), paira (6th) and chaka chingri (7th) are used mainly as a cash crop but sometimes villagers eat or indeed offer these to their guests. Baila (8th), Bhangon (9th) and Rekha (10th) are also used for both purposes depending on the size. Generally, the larger sizes of the three species are for sold, and smaller sizes used for home consumption. The FGD participants also listed fishes that would have previously been found but now are rare (Table 9).

TABLE 9
List of fish species that have not been found in surveys over recent years

Local name	Common English name	Scientific name	Habitat	Not found for the number of years
Koi	Climbing perch	*Anabas testudineus*	Freshwater pond	> 2 years
Shol	Striped snakehead	*Channa striatus*	Freshwater pond	> 2 years
Magur	Asian catfish	*Clarias batrachus*	Freshwater pond	> 2 years
Shing	Stinging catfish	*Heteropneustes fossilis*	Freshwater pond	> 2 years
Baim	Freshwater eel	*Mastacembelus armatus/ Macrognathus aculeatus*	Freshwater pond	> 2 years
Kholse	Gourami	*Colisa/Trichogaster sp.*	Freshwater pond	> 2 years
Chanda	Glassy perchlet	*Amabassis sp.*	Freshwater pond	> 2 years
Pholee	Bronze featherback	*Notopterus notopterus*	Freshwater pond	> 2 years
Kankshol	Freshwater garfish	*Xenentodon cancila*	Freshwater pond	> 2 years
Punti	Barb	*Puntius sp.*	Freshwater pond	> 2 years
Mola	Mola carplet	*Amblypharyngodon mola*	Freshwater pond	> 2 years
Boal	Wallao	*Wallago attu*	Freshwater pond	> 2 years
Mad/shapla pata	Sting ray	*Dasyatis sp.*	River	1–2 years
Jouke	Medicinal leach	*Hirudo medicinalis*	Freshwater pond	> 2 years

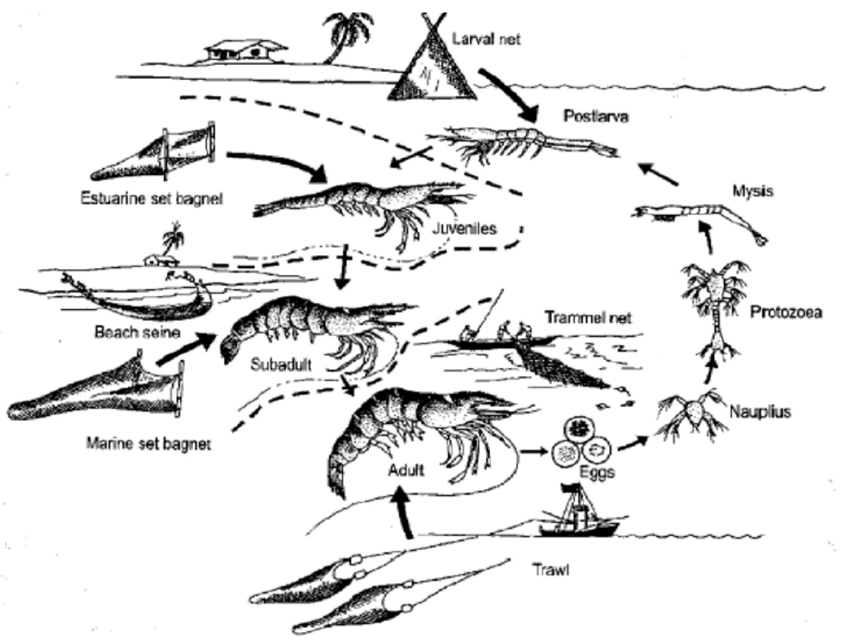
3.7 WILD POST-LARVAE (PL) COLLECTION

3.7.1 Collection process

In Bangladesh, the shrimp hatchery sector is not well developed, with a continuing dependence on wild seed collection, which supports substantial employment (IIED, 2003). Shrimp PL collection from the wild is a destructive fishing method associated with high bycatch. Concerns over the effect of this fishing on the biodiversity and abundance of various fish and shrimp species in coastal and marine waters prompted the Government of Bangladesh to place a ban on fry collection in September 2000. However, this ban has been mostly ineffective due to lack of proper enforcement.

There are generally three types of fishing gears used for shrimp fry collection in the coastal belt of Bangladesh (Figure 15). The three types are: push net (the first type

FIGURE 15
Use of various gears to catch black tiger shrimp (*P. monodon*) at different level of life stages



Source: Khan *et al.* (1994).

introduced), drag net and fixed bag net (the most recent and widely used PL collecting gear). The push net (locally called thela jal) is the traditional method but is now the least used of the three main gear types, largely restricted to Chittagong and Noakhali. Drag net (tana jal) is used on the rivers and estuaries of Barisal and Khulna, although they are almost absent from Cox's Bazar and Chittagong. Bag nets (behundi jal) are used along the sea coasts of Cox's Bazar and Chittagong as well as the rivers of Khulna and Satkhira. Table 10 shows use in other areas of Bangladesh.

The three main gears used to catch fry vary in levels of destructiveness. The most damaging of these is the *behundi* net which is associated with high bycatch mortality. The other two gears (push nets and pull nets) are operated from the riverbanks or in the shallow beach areas and are less destructive, and generally used mostly by poorer fry collectors.

TABLE 10
Main areas of Bangladesh used for wild harvest of shrimp post-larvae (PL) and type of fishing gear used

Station	Site	Main PL collection areas	Gear used to catch PL
Cox's Bazar	Teknaf sea coast	Teknaf, Naf River, Shapari Island, Ukhia, Sonarpora, Cox's Bazar, Bakhali River, Matamuhuri River, Moheskhali channel, Chakaria, Napithkhali, Chofuldandi, Moheskhali and Sonadia islands	Push net and Fixed bag net
	Sonar Para sea coast		Push net and Fixed bag net
	Cox's Bazar sea coast		Push net and Fixed bag net
	Mathamuhuri River		Push net and Fixed bag net
Chittagong	Perki sea beach	Patenga, Sitakunda, Mirsharai, Anowara	Push net, Fixed bag net and Drag net
	South Kattoli sea coast		Push net, Fixed bag net and Drag net
	Muradpur launch ghat		Push net, Fixed bag net and Drag net
	Satal Khal		Push net, Fixed bag net and Drag net
Noakhali	Char Khondakar	Downstream of the Meghna River	Push net and Fixed bag net
	Char Bata		Fixed bag net and Drag net
	Char Elahi		Fixed bag net and Drag net
	Kazirbazar		Fixed bag net and Drag net
Barisal	Bhola	Downstream of Meghna River, Bishkhali River, Baleshar River, Mohipur, Galachipa, Charkajal, Andharmanik River, Kuakata sea beach	Push net and Fixed bag net
	Patuakahali		Fixed bag net and Drag net
	Quakata		Push net, Fixed bag net and Drag net
	Barguna		Drag net
	Pirozpur		Fixed bag net and Drag net
	Andhermanik River		Push net and Fixed bag net
Khulna	Kapatakshi River	Pashur River, Panguchi River, Sibsha River, Bhadra River, Kapotakshi River, Koira, Ichamati River, Kaksheali River, Kalindi River, Kholpetua River, Madar River	Push net, Fixed bag net and Drag net
	Shibsha River		Push net, Fixed bag net and Drag net
	Mixing place of Coxali, Kalindi and Ichamati rivers		Fixed bag net and Drag net
	Mother River		Push net, Fixed bag net and Drag net
	Mongla River		Fixed bag net and Drag net
	Pasur River		Push net and Fixed bag net

Sources: Khan (2002); Gain *et al.* (2005); Azad *et al.* (2007); Hussain and Hoq (2010); Torikul and Mollah (2013); Mahmood and Ansary (2013).

3.7.2 Seasonality of PL collection

The main fishing season for bagda post-larvae (PL) is between November and June, peaking in March and April. For golda PL, the season lasts from April to July, peaking from April to June. There are slight seasonal variations from one area to another. Satkhira shows the highest PL gear use, particularly over January and March. Collection in Cox's Bazar starts later on February and peaks in April although it continues through to October at much lower levels.

Some of the existing practices that reduce survival rates of fry and bycatch include: prolonged fishing periods with *behundi* nets leading to mortalities in the cod end, sorting the PL in direct sunlight, dumping the bycatch on the river banks or beach, and storing in unclean, un-aerated water at high densities. Moreover, extended storage periods at buying and selling stations, poor transport conditions, lack of acclimation of PL to local temperature and salinity conditions and a lack of nursing of PL prior to stocking in shrimp *ghers* also reduces the survival rates.

In the focus group discussions (FGD) PL harvesters noted that "We are concerned with biodiversity loss in coastal rivers due to PL collection activity and accordingly we return the non-target catch back to the water during collection". The reality, however, observed by the authors, was that PL collectors were seen to throw non-target catches on to the land, where they die within minutes, and are not back in to the water as stated. This involved hundreds of eggs, spawns and fry of a variety of coastal fish, shrimps, crabs and mollusks. Even where non-target catches are returned by a few of the PL collectors (although this seemed very low in number), other factors also affect non-target species survival. 30–45 minutes is required for hauling, which is exhausting for species and lethal for many of the organisms, particularly for those trapped at the beginning of the haul. When asked about the present biodiversity status of the river they catch the PL from, the FGD participants stated that biodiversity is in a dire situation and many of the once abundantly available and valuable fishes, shrimps and crabs have now become rare or even locally extinct. The PL collectors, however, said that PL collection is not only to blame, citing the increasing number of fishers, destructive gears (fine meshed nets) and other factors also being responsible for biodiversity loss in the river. Although many of the PL collectors were aware of the harmful impact of PL collection, most were unable to find an alternative means of livelihood, and thus hundreds of coastal poor, including men, women and children, continue to be involved in PL collection. At present it was also observed that *gher* owners tend to prefer wild PL to hatchery produced ones, as they believe the wild PL are stronger than hatchery-produced PL, survive longer and grow better. This high demand for wild-caught PL by shrimp farmers also increases the temptation in poor people to continue catching PL from the wild.

3.7.3 Bycatch from post-larvae collection

There is a large 'bycatch' associated with intensive fishing for PL (Figure 16). In a study of the collection process in the Pasur river, for every PL caught the 'bycatch' is minimum 1 341 fries of other species (Toufique, 2002). The bycatch consisted of many different species of fry and post-larvae including small cyprinids, eels, anchovies, crabs, snails, mussels, bivalves, Bombay duck, marine and coastal catfish, gobies, eel gobies plus many other unidentified species (Figure 16).

The fisherman in the upstream village observed that fish availability is decreasing due to over fishing of PL. The current levels of fishing for PL to supply the shrimp/prawn farms could therefore have negative effects on the recruitment of many other riverine and coastal species across Bangladesh. The practice could have further implications for the nutritional status of many people living upstream, considering that fish is the major source of protein for most of the population, and particularly the poor (Islam *et al.*, 2001). Hossain *et al.* (2015b) summarized the impact of PL harvest on aquatic biodiversity on the coast as;

- The diversity of marine and freshwater fish/shellfish is considerably decreased with much lower individual size in the coastal rivers and estuary due to the shrimp PL collection.
- Catch per unit effort heavily decreased. Even five years ago, it was very easy to catch 2–3 kg fish with a cast net in one hour. Now a person can only catch less than one kg fish in 4–6 hours.

- Fifteen, mostly freshwater fish, have become locally extinct with many more at verge of extinction.

FIGURE 16
Shrimp post-larvae collection, sorting, and sale, including examples of bycatch from PL collection process, which affects overall biodiversity of local waters

3.7.4 Seed and broodstock

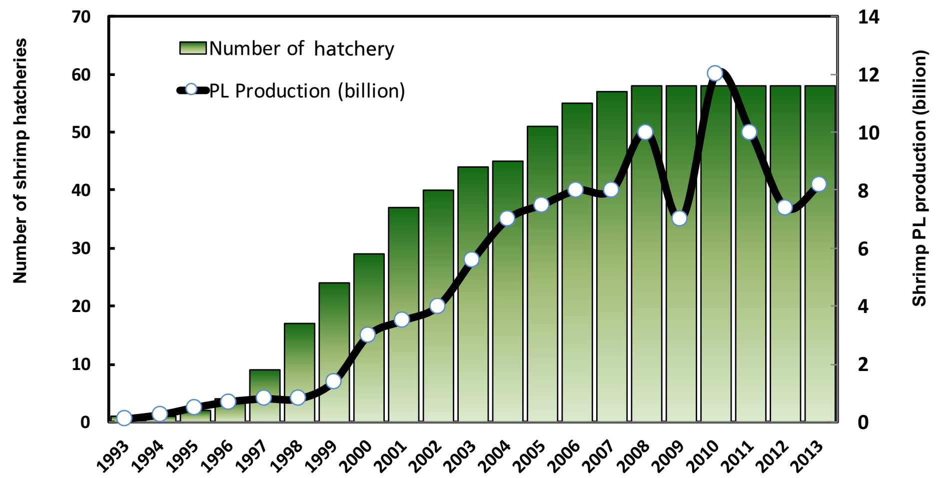
With the rapid growth of shrimp farming during the 1980s, farmers in the southwest coast started selective stocking of wild post-larvae (PL) in their farms. Before that farmers practiced traditional methods of trapping shrimp PL and fish seeds flowing in naturally to their farms with the tidal water. The switch to selective stocking made shrimp farming more profitable and there was rapid growth and expansion of shrimp farming accompanied by a sharp increase in the demand for wild PL. This led to the development of a large wild PL harvesting venture along the southwest coast of Bangladesh. Temporal and spatial variation in abundance and distribution of wild PL, however, meant that as the industry grew the supply of PL remained uncertain from season to season and year to year. During the late 1980s there was a severe shortage of PL in the Khulna-Satkhira region, for example, prompting expansion of the wild fry collecting areas to southeast coast of Cox's Bazar. This resulted in PL being transported long distances, from Cox's Bazar to the main shrimp producing areas in Satkhira, Khulna and Bagerhat in southwest Bangladesh.

3.7.5 Shrimp hatcheries

Given the longevity of production of shrimp in coastal Bangladesh, commercial operation of shrimp hatcheries is a relatively new development. According to available data, there were approximately 57 operational bagda shrimp hatcheries in Bangladesh in 2013 (Figure 17) producing just over 8 billion PL, from a peak production of just over 12 billion PL in 2010. Up to 1996 a few hatcheries were struggling to produce bagda PL commercially, but from 1997, when exports increased and the industry took off with overseas technical assistance, there was a rapid growth in number of new hatcheries and quantity of PL production. There is current over-capacity in bagda production (see section 3.7.7).

Unlike bagda hatcheries, freshwater prawn hatcheries have lagged behind in meeting the growing demand for golda PL. There are currently 35 golda hatcheries, of which 12 are operated by the Department of Fisheries (DoF), and the remainders are operated by the private sector and NGOs. Most of these hatcheries are small-scale, with an average production capacity of 0.5 – 1.0 million PL per year, which is only sufficient to meet 10 to15 percent of the current demand for golda PL. Problems of supply have been exacerbated during the last five to six year, as almost all the golda hatcheries struggled to produce any PL because of problem with uncontrollable water quality, particularly high levels of ammonium being present, along with high alkalinity, pH, and temperature, coupled with some undetermined factors.

FIGURE 17
Changes in the number of shrimp hatcheries and post-larvae production in hatcheries between 1993 and 2013

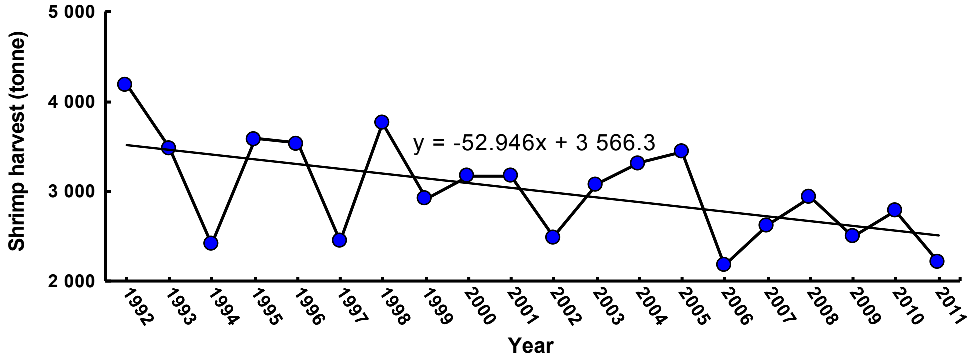


3.7.6 Brood shrimp collection

Currently, all shrimp hatcheries in Bangladesh rely on the collection of broodstock from the wild, collected from the Bay of Bengal and adjacent coast. There are three modes for targeting wild shrimp stocks, namely: fry collection (see above), fishing for juveniles by a large artisanal fleet and shrimp trawling.

P. monodon breed almost throughout the year, but mid-February to mid-March is thought to be the peak spawning period. There are thirty-seven shrimp trawlers exclusively engaged in shrimp fishing (DoF, 2016). The total annual harvest from the Bay of Bengal has been dwindling for some time (Figure 18) and a seasonal ban has never been enforced properly. Since 1994 the Bangladesh government has imposed a seasonal ban on shrimp fishing by trawlers between 15 January and 15 February. However, it could not enforce the ban due to an injunction from the High Court in 1995 following a writ petition filed by the Bangladesh Marine Fisheries Association (BMFA), which mean fishing year-round has continued. Similarly, fishing using set bag nets with a mesh size less than 45 mm at the cod end was also made illegal under the Fish Act, but this is not enforced due to a lack of alternative livelihood options for poor fishers.

FIGURE 18
Annual harvest of shrimp (tonnes) from the Bay of Bengal by shrimp trawlers between 1992 and 2011



Source: DoF (2013).

Marine shrimp trawling is thought to be very destructive and harmful for wild broodstock (Nuruzzaman, 2002). In Bangladesh, brood shrimps are collected using trawl nets rather than trammel netting. Using trawl netting mean many other fish are caught as bycatch and large quantities of mud and sediments are also collected. The system is not efficient and gravid female shrimp are exposed to high stress levels from compression, and by the time they are brought to hatcheries many of them are dead, and those that survive can have premature abortions providing only a small quantity of poor quality eggs.

In Bangladesh to date, no attempts are taken to keep brood shrimp in quarantine after collection. Quarantine is an inexpensive operation, is simple and short-lived and is known to reduce stress levels in berried females (Nuruzzaman, 2002). Although the quarantine of female brood shrimp is a standard and commonly used procedure in most shrimp producing countries, the perception in Bangladesh is that as broodstock may be gravid at the point of collection there is a reluctance by hatchery technicians to undertake any quarantine as a standard procedure.

3.7.7 Post-larvae production and trading

The development of new bagda hatcheries, and increasing production capacities by existing hatcheries in the Cox's Bazar region have meant that there is over-production of bagda PL, exceeding demand. Hatcheries (through SHAB, Shrimp Hatchery Association of Bangladesh) responded to this overcapacity by introducing quotas but the system worked for two years only, in 2001 and 2002, and broke down due to the lack of unity among the hatchery owners with SHAB failing to mediate a quota distribution, acceptable to all the hatchery owners (Nuruzzaman, 2002). The solution lies in rationalization of the hatchery sector and better coordination and dissemination of market information. Moreover, excess capacity should be diverted into golda PL production where possible, using the existing expertise with the assistance of Department of Fisheries.

Conversely, there is an acute shortage of golda PL, with supply not able to keep up with expanding culture activities, so more than 90 percent of the demand derives from wild sources. Out of 35 hatcheries producing golda only a handful are operating, and overall at approximately 13 percent of capacity. Part of the problem is that hatcheries have to compete economically for a share of the market with cheaper supplies coming from wild fry collection. PL production costs in hatcheries are high, ranging from BDT 100–270 per 1 000 PL; due to the employment of expensive foreign technicians, high feed costs and use of expensive antibiotics. However, poor management practices and a lack of quality control are the main constrains in the production of PL in hatcheries. Disease problems in the shrimp industry began with imported PL and since then shrimp farmers regard hatchery produced PL as the main source of disease infection in their farms, which means trust in hatchery production is not there. Quality assurance of hatchery produced PL, through a certification scheme, is urgently needed.

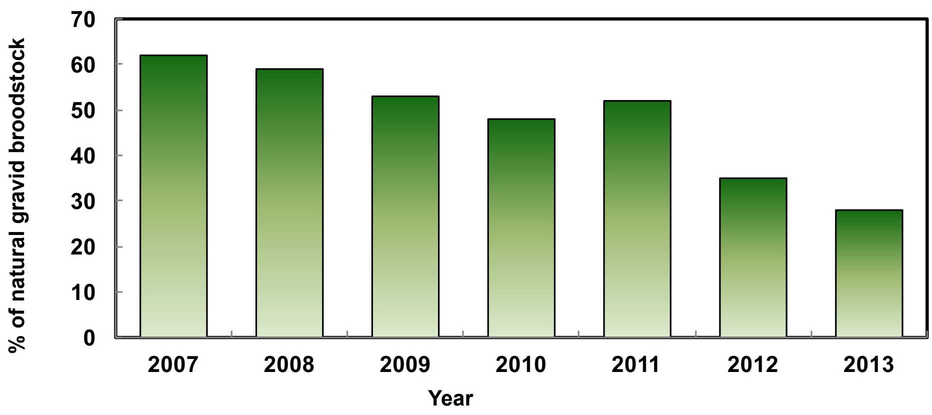
Hatchery produced PL is usually flown from Cox's Bazar to Jessore and then transported and distributed by truck to the main shrimp producing areas. The transport costs vary from BDT 30 per 1000 PL for road transport to BDT 50 per 1 000 PL for airfreight. Higher mortalities occur during road transport (20–30 percent) compared to air (5–10 percent). It has been known for some hatcheries sending PL by road transport, to send stock in mixed batches with wild PL, to secure higher prices to offset the higher mortality using this transport means.

There are also too many intermediaries operating in the PL supply chain, with prices increasing after each handling. Agents, for example receive 10–15 percent commission and intermediaries mark up 20–30 percent before PL reach farmers, which also increases the overall costs. Governance is extremely weak within the hatchery sector and there is absence of tractability, which in particular, encourages bad practices such as lack of disease prevention and control, poor care of broodstock, sale of underage PL, poor acclimatization and mixed packaging with wild fry. Shrimp farmers lack the necessary information on the condition of PL at the point of sale due to an absence of labelling. To date, very little research work has been undertaken in this area of trading, through the supply chain for PL and for traceability. Extension support for shrimp farmers also remains very weak due to the limited number of extension workers in the field.

The main shrimp farming season in the Khulna region is from February to July but continues in high saline areas up until November. Wild PL are also found in Khulna, Satkhira, Bagerhat, Patuakahali, Bhola, Noakhali and Lakshimpur. An estimated 1 500–2 000 million PL is collected from these areas. However, recent indications are that the average PL collected per person is falling drastically, along with changes in natural gravidity of broodstock (Figure 19) and changes in the success of gravid management of stock and mortality before spawning (Figure 20).

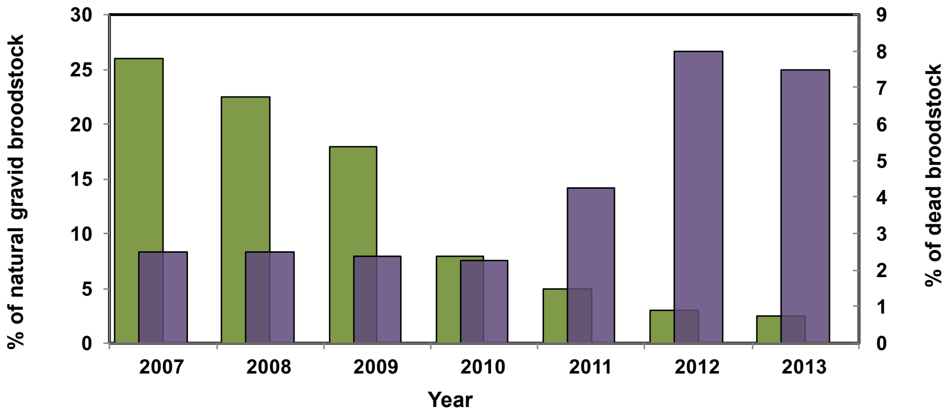
Wild PL has historically been preferred by farmers because it is perceived to have a lower mortality, it is locally available and it is available on demand throughout the year. If this changes then demand will have to increasingly be filled by hatchery production.

FIGURE 19
Change in mean percentage of naturally gravid broodstock between 2007 and 2013



Source: Debnath *et al.* (2015).

FIGURE 20
Change in mean percentage of gravid broodstock achieved through eye ablation (green) and change in percentage of dead broodstock before spawning (purple) between 2007 and 2013



3.8 EXOTIC SPECIES

The scarcity of wild shrimp PL has led to opportunist traders to import PL from neighboring countries. The practice of transporting shrimp PL between facilities and different geographic regions, with a lack of appropriate control, has resulted in the introduction of five of the six known penaeid shrimp viruses to regions where they had previously not existed. Importing of shrimp PL without quarantine has also spread several viral and fungal diseases throughout Bangladesh (Deb, 1998). In addition, various other diseases have been widely disseminated through the introduction of fishes to the natural environment, as shrimp farmers draw on tidal water. Moreover, non-endemic pathogens and disease, and introductions of non-endemic aquatic species can lead to habitat changes, disruption of host communities by competition and predation, and genetic drift with indigenous stock. The indigenous diversity of both wild and farm stocks has been affected due to the introduction of invasive species and modified genotypes (Diana, 2009). All across the shrimp farming areas of the Bangladeshi coast, salt tolerant aliens of tilapia have also become highly abundant. Tilapia can easily out-compete native species and adversely affect biodiversity and ecosystem health.

3.9 DECLINE IN POPULATIONS OF THE APPLE SNAIL

Farmers have traditionally used the meat from apple snail (*Pila globosa*) as a feed for prawn. As prawn farming became more popular, the demand for snail meat grew and harvest of snails intensified, so much so that they have disappeared from many local wetlands.

Collection areas extended to distant districts and snails had to be transported long distances by boat and truck to satisfy the demand. Between July and October when the main snail harvest takes place, tonnes of snail are transported into the *gher* farming areas every day. The estimated annual harvest of apple snail from various *beel,* canals, and rice fields in 1999 was 365 849 tonnes (Chowdhury, 1999). Dependency on snail meat as a prawn feed has caused a widespread decline in snail populations in this region compounded also by a loss of wetland habitat due to *gher* expansion.

P. globosa plays an important role in the wetland ecosystem occupying an intermediate role in the food chain, consuming phytoplankton, algae, aquatic plants and insects. Snail eggs are a potential feed for fish, snakes, ducks, rats and birds. The recycling of alkaline elements found in shell of the snail could also be important in maintaining water and soil chemistry (Datta, 2001a). The long-term effects of removal of this species, on the ecological balance of the wetlands, has not been well studied.

3.10 NUTRIENT INPUTS AND OUTPUTS

Most shrimp farms are generally enriched in suspended solids, added chemicals and fertilizers, and nutrients such as ammonia, nitrate, nitrite, and chlorophyll-a. As a result, the water of most shrimp farms have a high biochemical oxygen demand (BOD) (Paez-Osuna *et al.*, 2003; Hall, 2004). Untreated effluents from shrimp farms are moved between farms and are discharged into local waterways, and pollute surrounding water and soil (Deb, 1998). Moreover, this causes eutrophication in water bodies and alters the structure of bottom dwelling organisms (Dewalt *et al.*, 1996), that may eventually lead to substantial decline in aquatic biodiversity and capture fisheries in neighboring rivers and floodplains (Islam, 2003).

Using poor quality feed is one of the main sources of environmental loading in shrimp farms and adjacent waters (Yang *et al*., 1999). Unused feed, which can be as high as 40 percent of the total feed used, interacts with many elements affecting pH, osmotic pressure and chemical parameters, as it swells and breaks up, and increases oxygen demand by bacteria that break the feed down, leading to low oxygen conditions and poor water quality. Added feed dissolves readily, such that 24 percent of nutrients are leached with 2–3 hours, and soluble matter dissolves rapidly and completely in water (Chen *et al*., 1995). Intensive shrimp farming demands a daily water exchange of approximately 5–10 percent of the total farm volume during the early stages of stocking, and between 30 and 40 percent exchange during late stages of shrimp growth cycle (Flaherty and Karnjanakesorn, 1995). In extensive shrimp farming, water is exchanged over a period of 4–6 days during full and new moon when the tide is highest, farmers exchanging 0–10 percent of the total farm volume every fortnight (Wahab *et al.,* 2003). The discharged effluents can easily and rapidly reduce the dissolved oxygen content of the receiving water, create hyper nutrification leading to eutrophication, raises sedimentation load, and can cause changes in all kind of aquatic organisms, particularly those living in the water column and in and on the sediment (Flaherty *et al.,* 2000).

3.11 USE OF INDISCRIMINATE CHEMICALS AND DRUGS

Shrimp farmers apply different types of agrochemicals, antibiotics and disinfectants as a means to reduce disease, and to stabilize their farms from fluctuating water quality parameters, without specific recourse to how effective they are being. Farmers are also not aware of the impact of the use of these chemicals on the farm and wider environment. Overuse of antibiotics often results in antibiotics residues being present in the system and results in increased resistance, decreased efficacy and reduced immunity of the shrimp to disease.

Poor water quality, brought about by the negative impact of high stocking density and excessive use of artificial feed, leads to stress and diseases among shrimp in intensive and semi-intensive farming systems. Alam and Phillips (2004) reported that poor management of shrimp farm environments results in large-scale disease outbreaks and hence mass production losses. Among poor farm management practices, shallow *gher* depth, poor water quality, lack of quality food, presence of thick submerged weeds and vegetation were considered to be major factors to overall poor environmental condition, which then drive bacterial diseases and stress symptoms and recurrent mortality (FAO, 1997). Effluents discharged into nearby environments, that are then used to exchange water, are also likely to act in this disease transfer. Unplanned and uncontrolled farming was also identified as the cause for incidence of diseases and reduced production (Deb, 1998). In 1996, Bangladesh lost 44.4 percent of its total shrimp production due to a sudden outbreak of disease (Mazid and Banu, 2002). Such losses resulted largely from poor management practices.

It has been reported that a range of chemicals, other than antibiotics, were found be used in aquaculture including shrimp farming (*personal observation*; Ali *et al*., 2016; Shipton and Ali, 2017). Commonly found chemicals used in heath management included lime, salt, potassium permanganate, sumithion, melathion, formalin, bleaching powder and malachite green. Thirteen branded probiotics were also found in the market, primarily for use by the coastal shrimp farmers, against vibriosis and other luminescent bacteria, and to improve water and soil quality. A number of new products with various trade names were also found available in local markets, including new products based on zeolite, geotox, green zeolite, and others. These new products often contained more or less similar ingredients to existing products, and are used mainly for pond preparation as well as practical management during production. Bangladeshi markets also contained products produced by overseas companies from overseas countries including India, United Sates of America, Thailand, Taiwan Province of China, Indonesia, Malaysia and Spain. Often these were similar products, sold under different trade names (Shamsuzzaman and Biswas, 2012; Ali *et al*., 2016; Shipton and Ali, 2017).

3.12 SOCIAL IMPACTS ON HUMAN RESOURCES

In Bangladesh, it is estimated that more than 0.8 million people work in the farming of black tiger shrimp, *Penaeus monodon* and giant river prawns, *Macrobrachium rosenbergii* (DoF, 2016). In this section a number of different social components and impacts are summarized.

3.12.1 Gender impacts

Shrimp farming has resulted in substantial changes to the role women play in rural livelihoods in coastal Bangladesh. There is an increasing involvement of women in economically productive activities and as a result women are increasing their involvement in decision-making at family level. In middle class shrimp farming households, women are generally involved with feed preparation for shrimp, post-harvest activities during the rice season and vegetable production over the last few years.

An increase in external technical support for shrimp farming communities, from both the NGOs and the Government with a commitment to create a strong gender balance, has increased women's knowledge, mobility and leadership qualities. Husbands recognize the economic value of involving their wives in shrimp farming and women are having gradually increasing influence over household expenditure, particularly when the income has been derived from their own labor. Undoubtedly their workload has increased with the advent of shrimp farming but many women happily trade this off against their enhanced status in the household and community. Beyond working in the shrimp farms, demand for women's involvement as net makers in fishing communities has also seen a sharp increase, especially during the harvesting season between November and February (Williams and Khan, 2001).

3.12.2 Migration impacts

There are also strong evidence that shrimp farming in many coastal areas brought about social displacement and marginalization of farmers. The most unanticipated outcome of the conversion of traditional agriculture into shrimp cultivation is rural-urban labour migration. Shrimp farming reduces on-farm work opportunities considerably for marginal and landless farmers living in and around the shrimp farming areas. As a result of the shift from agriculture to shrimp farming, a section of rural people have lost employment opportunity, and are unable to maintain themselves and these rural unemployed laborers typically migrate to cities to seek work (Hagler *et al*., 2009). Dispossessed farmers are also forced to seek work elsewhere. Overall, migrating to cities swells the ranks of the urban unemployed (Alauddin and Hamid, 1996) and leaves wives and children alone for long periods (Barraclough and Finger-Stich, 1996).

3.12.3 Social interactions

There are grave socioeconomic impacts for many people in coastal zone including displacement of traditional livelihoods, loss of land security, food insecurity, marginalization, rural unemployment, social unrest and conflicts in the wake of shrimp culture development in Bangladesh (Hossain *et al.*, 2015a). Shrimp farming affects soil and water quality in the cultivated areas that increases soil salinity levels (up to five times) in non-saline area, that hampers crop cultivation (Islam *et al.*, 1998). Peasant households therefore lose income due to a decline in rice productivity, loss of poultry and livestock, and erosion of homestead vegetation and social forestry (Manju 1996). Prior to the advent of shrimp culture, people of coastal regions depended mostly upon the cultivation of food grains, whereby influence and status were achieved through the possession of land and crops. Shrimp cultivation produced another affluent class; where influence and social power gradually transferred away from previous landowners, to others; and thus the basic social hierarchy broke down. This initially created a precarious situation in some areas, as the inhabitants became hostages to the whims of the new shrimp producing landowners (Rahman *et al*., 2013). The key social issues are the marginalization of the rural poor, their increasing landlessness, breakdown of traditional livelihood support systems, increasing poverty, diminishing food security, and the transfer of land and wealth to local and national elites.

The provision of low cost credit and flexible terms and conditions for shrimp farmers and non-farmers by a few NGOs is a promising sign but many people still do not have access to this credit. Savings groups within the community have shown that it is possible to save within the community but this is not yet widespread. Some banks have provided bank accounts for these groups but the application process for opening a bank account remains difficult.

The high value of shrimp and income potential has not been shared equally among farmers and there are questions of social equity within the industry, which has led to conflict. Large and powerful shrimp farm owners do not necessarily generate employment locally. Instead, the poor are left with deteriorating soil quality, hunger, and rising tempers, which has resulted in violent clashes between locals and farm owners (Glass, 2013).

The shrimp farming system has had defined impacts on land holding patterns and on the land ownership system in southwest coastal Bangladesh. The politically and financially strong large farmers have exploited marginal and small farmers. Often this has resulted in marginal and small farmers having to sell their small agricultural farmland at relatively cheap price. Sometimes the stronger farmers “capture” nearby farmer’s small plots without any payments or perhaps pay only a very small amount of money as land rent. When investors either get access to an area for shrimp farm by purchasing land or by forcibly taking it, land prices increase substantially and in Bangladesh, land prices rose 18-fold between 1994 and 2000 (Ito, 2002). This change in land ownership, along with migration to urban environments, changes to access (e.g., to fishing) and joblessness, and the conversion and salinization of rice and other agricultural lands has led to the marginalization of coastal rural communities.

3.12.4 Poor health and family nutrition

People living in and around the shrimp farming areas are under severe health risks as a result of extensive shrimp farming. The need to increasingly sell more of the decreasing number of fish caught by fishers and lower availability of fish for family consumption has resulted in poor nutritional security in fisher households. There is a perceived decline in nutritional diversity, as consumption of fish, poultry, fruits, and vegetables has declined due to decreasing survival rates of different species of plants and animals, resulting from increased salinity. Such realities adversely impact population health, nutrition, workload, and livelihood strategies (Rahman *et al.*, 2013). There is also a lack of cooking fuel and in many households' fishers tend to cook just one meal a day and live on it throughout the day, which is leading to reduced consumption. Prolonged limited consumption of a small quantity, and poor quality of food, has led to deterioration in nutrition of children, as well as pregnant and lactating women.

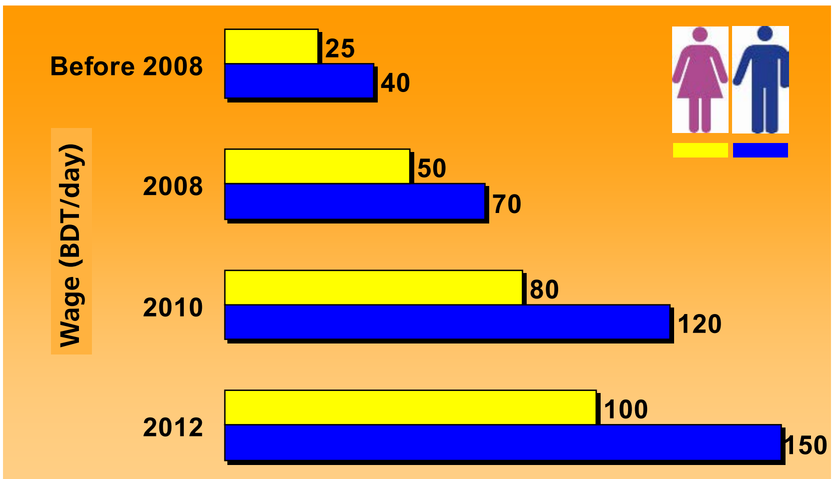
Waterborne diseases like jaundice and diarrhoea are very common among the villagers, including women and children in *gher* farming areas (Masum, 2008; Khan and Azad, 2014). The poor also spend much of the day in rivers and creeks to collect shrimp fry, often standing in waist-deep water for very long periods, which increases health problems, including skin diseases (Ghafur *et al.,* 1999).

3.12.5 Gender biased wages in shrimp farming areas

In the shrimp farming areas of southwest Bangladesh, women do the same laborious work as the men do (Figure 21). This is different from most other parts of the country where women generally do not do laborious work, like working in *ghers* or fishing. In shrimp farming areas work includes earth cutting to construct gher and ponds; undertaking dyke repairs; collection of shrimp PL for long hours; fishing using push nets, cast nets, and pulling of seine netting and angling; working in crop fields for transplanting rice, weeding and harvesting; in addition to activity that tends to be female specific activity including growing and nursing of vegetables. Despite undertaking similar work, however, when it comes to the wages paid, particularly for earth work and working in crop fields, women always receive lower wages than men (Figure 22). According to available information women's income per day was BDT 100, a four-fold increase on pre-2008 values, compared to a 3.75-times increase for men over the same period. However, the initial difference has resulted in larger differences in terms of income, despite the same work being undertaken.

FIGURE 21
Men and women in shrimp farming areas do the same job but with different pay

FIGURE 22
Change in wages in the southwest coast of Bangladesh, for men and women in shrimp farming areas showing the increased gender pay gap



3.12.6 People's stories: Rokeya Begum, aged 65 and Md. Kausar Gazi, aged 61

The village of Sotokupot under the Atulia Union, part of the Upazila called Shyamnagar in the district of Satkhira has long been surrounded by lowland *beel*. This large area of lowland is owned by rich people living in the city of Shyamnagar and Satkhira. The people of the villages also have small land holding in this lowland and have long been cultivating paddy on their own land, but also sharecropping the land owned by rich city people.

FIGURE 23
Picture of Rokeya Begum (aged 65) who lives in Uttar Sotokupot, Atulia Union in Upazila Shyamnagar in the district of Satkhira

During rice harvesting many of the poor women of the village used to collect rice straw for free and often collected 20–40 kg of paddy each, just by picking from the beel. Rokeya Begum, now 65 (Figure 23), was interviewed during the FGD in Sotokupot and described that she used to collect about 100kg of paddy each year during the harvesting season, along with rice straw, which provided approximately 4 months cooking fuel. Villagers also used to take their cattle, goats and other livestock to graze on the lowland. Everyone could fish in the *beel* during monsoon.

After cyclone Aila, however, most of the lowland became salinized, resulting in a very poor rice harvest in this beel. After Aila, the rich landowners transformed the lowland *beel* to shrimp *gher* by bringing in saline river water through a canal. Now the small landholders cannot use their lands as efficiently due to the increased salinization. All fruit and timber trees, which were replanted after Aila are dying again. Md. Kausar Gazi (61) complained that the salt tolerant mangrove plants Golpata and Keora are now growing in his land and as a result all kind of previous activities have stopped; there is no rice production, no straw available, no grazing of domestic animals and villagers have been told they are not allowed to enter newly set up *ghers*. Added to which, the small landholders are not in a position to fight or argue against these actions with the *gher* owners of Sotokupot, which has led to a desperate situation. When asked to compare the positive and negative impact of *gher* farming on their livelihood, Rokeya Begum noted that it is very difficult to compare. Regarding positive impact – now the women have employment opportunity, they can work in the *gher* and they can sell the PL to the *gher* owners. However, they are having problem of salinization due to the expansion of *gher*. They have problems of cooking fuel and drinking water. As she told, "We are now drinking poor quality water. In the past, we used to have best quality fresh vegetables in our backyard. Quality of drinking water was wonderful. Now the old ways of long traditional life are apparently over."

3.13 LIVESTOCK, COOKING FUEL AND DRINKING WATER IMPACTS

3.13.1 Livestock

Livestock are decreasing in shrimp farming areas due to the unavailability of grazing land and of fodder crops. Availability of grazing land has long been decreasing, but this has occurred more rapidly in shrimp farming areas than in non-shrimp farming areas. Shrimp cultivation means the needed green grasses and straws are not available like they had been previously and fodder for livestock falls short and people are unable to suitably take care of the domestic animals. As a result, the number of cows has fallen and cows production of milk has fallen significantly, which is also impacting human health.

FIGURE 24
Women in shrimp farming areas coming back home after collecting rice straw to be used as cooking fuel

The unavailability of livestock has had knock on effects on shrimp culture, whereby the availability of cow dung, used as a fertilizer, is decreasing; which in turn increases the reliance on artificial fertilizers.

3.13.2 Cooking fuel

People in the shrimp farming areas have been suffering from an acute shortage of cooking fuel for a long time. Almost 70 percent of the households cook just once in a day and have continuous suffering over managing fuel for cooking. Typically, the men in households almost ignore the problem and finding fuel is, therefore, the job of women only (Figure 24). As most of the paddy fields have now been converted to *gher*, the rice straw the women used to collect for free has now been stopped. Cyclone Aila killed almost all timber trees and bamboos, and due to shrimp farming people are unable to maintain domestic animals like cows that previously would have supplemented cooking fuel, as dry cow dung.

The women in households typically spend more than an hour every day seeking cooking fuel in and around the villages. Slightly better off households are able to purchase rice straw after the rice harvest, at a cost of BDT 800/bigha (note: a "bigha" is a traditional unit of land area, generally equivalent to 33 decimals but varies in size with location), which is sufficient for 2–3 months for a normal size family. Poorer households cannot afford even that. Buying cooking wood (lakri or khari) from the market is beyond most households' capacity. Thus, much of the time, women along with their young children, walk 2 to 3 km in search of something they can burn to be able to cook their one meal a day.

3.13.3 Drinking water

The extent and range of salinity in groundwater has long been increasing, in part because of continued expansion of shrimp cultivation in to fresh agricultural land (Rahman *et al.,* 2013). People rely on pond water or rainwater in the monsoon season for drinking. In dry season, it is difficult to obtain potable water and people in many areas need to walk considerable distances to get water from freshwater ponds (Hagler *et al.*, 2009). Use of tube wells in coastal areas is not very common. Broadly, there is therefore an overall difficulty in gaining sufficient drinking water. Some coastal families are fortunate enough to have potable water wells, pond-side aquifer wells or rainwater harvest facilities with the help of different charitable/voluntary organizations. Generally, however, water concerns are differentiated by social class in coastal areas with richer households able to create and maintain freshwater ponds for consumption. Poorer people, by contrast, may have to walk for about 2 to 5 km to get drinking water, or provide free labor in return for access to closer water sources from freshwater ponds owned by the rich people. Even then this does not ensure a year-round supply of drinking water. Similar to cooking fuel collection, the collection of drinking water is the duty of female members of the household.

3.14 LIFE CYCLE ANALYSIS OF THE MAIN ENVIRONMENTAL IMPACTS[3]

In order to evaluate the challenge associated with environmental issues, a useful tool is life cycle assessment (LCA), by which better practices can be identified, and future eco-labeling, certification and production may be assured. An LCA study was completed which addressed what are the environmental impacts of different inputs used in Bangladesh shrimp farming systems and what options exist to reduce the environmental impacts.

The objectives of the study were:

- To identify the environmental interventions of nutrients and material flows in the shrimp farming systems of Bangladesh; and
- To provide information and recommendations to policymakers for improving the sustainability of the Bangladeshi shrimp aquaculture industry.

3.14.1 Approach

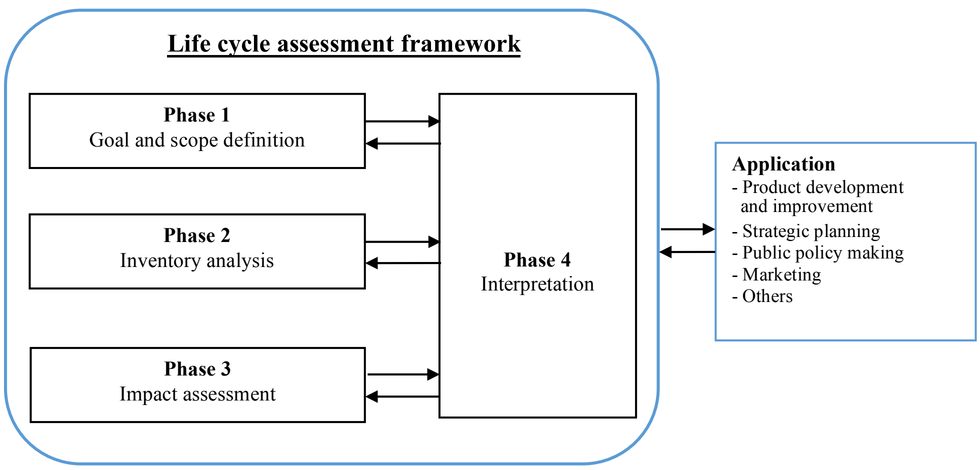
This study has been structured in accordance to all four phases of LCA, as described by ISO (ISO, 2006a; ISO, 2006b) defined in Figure 25, including defining the goal and scope, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA) and interpretation of results.

The environmental comparison among different shrimp farming systems and relative contribution of different environmental loads in these systems were established on the basis of area (one hectare), weight (one tonne) and calorie content (one kCal).

The analysis was undertaken with the system boundaries from "cradle to farm-gate", which started from shrimp broodstock collection and ended at the farm-gate, before selling the products (Figure 26). At each step the economic inflows and environmental resources are considered as inputs while the economic outflows and environmental emissions as outputs. The flowchart of commonly used shrimp feed resources and system boundaries is that defined by Nahid (2014), outlined in Figure 27, based upon the flowchart of the complete shrimp production chain up to the farm-gate. Figure 28 shows the relationships between products (e.g., shrimp) and their co-products (e.g., shrimp PL, feed, and fertilizer).

Primary data were collected over the period August to November 2015, at different locations in southwest Bangladesh, from a total of twenty-one farmers using six different shrimp farming systems (see below). Secondary data was mainly obtained from Nahid (2014). Initial primary data collection helped categorize the necessary secondary data needed to identify the environmental and economic inputs and outputs.

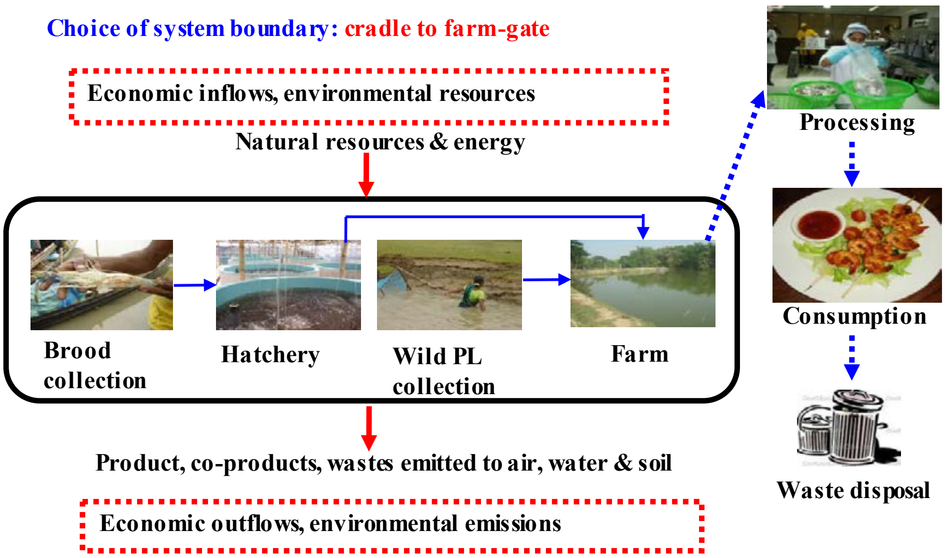
FIGURE 25
General framework and phases for life cycle assessment (LCA) based on ISO 14044 format



[3] This section has been prepared by Dr Sk. Ahmad-Al-Nahid, FAO Consultant, Chittagong, Bangladesh.

FIGURE 26

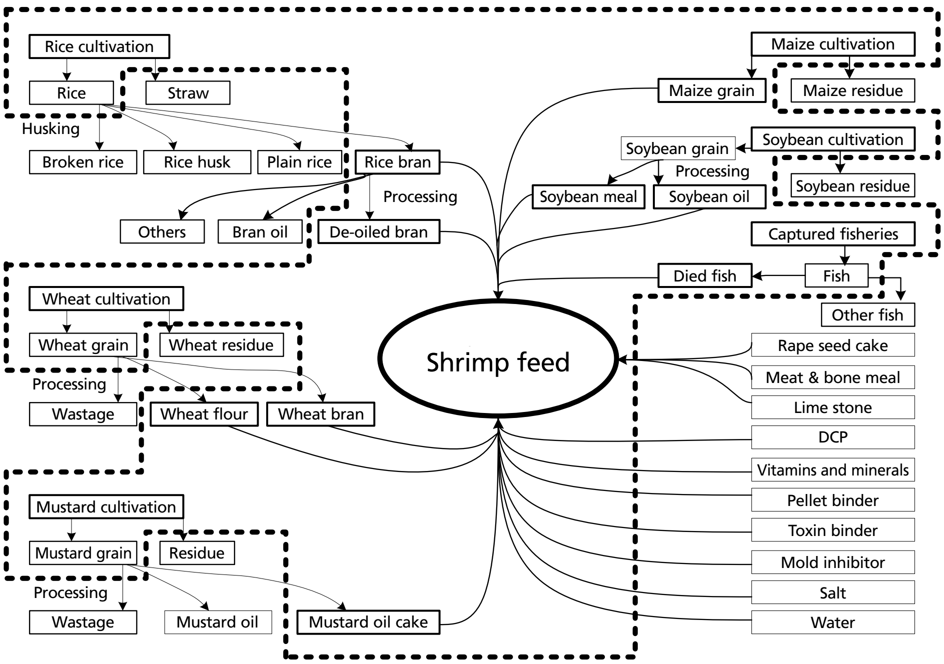
Overall potential life cycle analysis system with study boundary defined by the black line



Source: Revised from Nahid (2014).

FIGURE 27

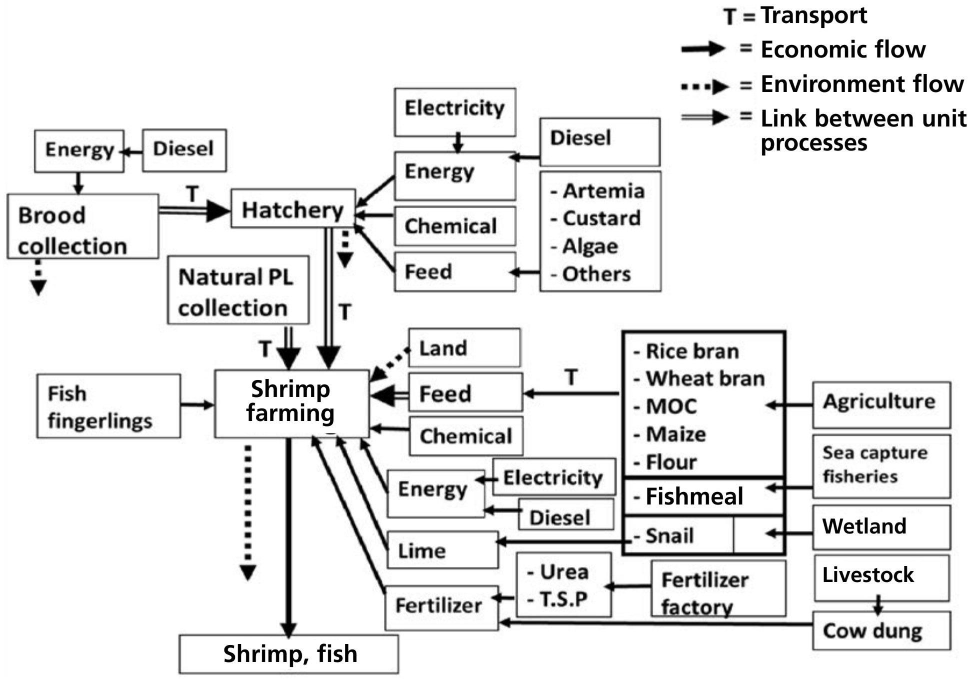
Flowchart of shrimp feed resources in Bangladesh, boundary defined by the dashed bold line



Source: Revised from Nahid (2014).

Beyond primary data specific to the study, secondary data was often consulted when modelling the supply of upstream processes in line with general practice (IPCC, 2008; Nemecek and Schnetzer, 2011; Henriksson *et al.*, 2012). For the foreground secondary data, such as that associated with electricity supply and transportation, peer-reviewed literature and official reports were consulted, and where several sources were available, weighted means were calculated (Baidya and Borken-Kleefeld, 2009; IEA, 2009; Zhou and McNeil, 2010; BPDB, 2011; DFID, 2011). For processes with an assumed lesser importance (based upon previous experiences and the literature review), or processes of

FIGURE 28
Flow chart of shrimp farming in Bangladesh



Source: Revised from Nahid (2014).

high complexity (such as oil refining or lorry production), the ecoinvent v.2.2 database was consulted for appropriate values. In cases where substantial emissions were related to ecoinvent processes, these processes were revisited, and when necessary modified to better suit the relevant scenario under investigation. Thus, the LCI included a wide array of data of diverging quality and robustness. LCI and LCIA results were finally calculated using CMLCA software (Version 5.2: http://cmlca.eu/). In this study, for one unit process, it has several background unit process linkages, which are calculated using LCA software. As for example, while calculating the emission for rice bran, raw data was collected from paddy field for rice production, where the emissions from seed, fertilizer, tilling, diesel combustion, were calculated. Production for each fertilizer (urea, TSP, etc.) was also calculated separately. From IPCC (Intergovernmental Panel on Climate Change) data (IPCC, 2008), CH_4, NO_2 emission was also calculated from paddy field based on Bangladeshi soil. After harvesting of paddy, data was collected from threshing than milling at mill, where electricity and diesel were also used. Thus, to get emission from rice bran, it had several unit process linkages, each of which has environmental emission. Finally, only the emission from the final product (e.g., shrimp) and major unit processes (fertilization, stocking, feeding and power supply at shrimp farming stage) linked with this product were shown in this document.

In this study six shrimp farming systems were identified and evaluated, three within each of two groupings, being those farmers supported by WorldFish Centre, and other farmers; as follows:

a) WFC (WorldFish Centre) supported farmers:
   i) Closed system technology (shrimp): **CST (S)**
   ii) Modified traditional technology (shrimp + fish): **MTT (S+F)**
   iii) Better management practice (shrimp + fish): **BMP (S+F)**
b) Other farmers
   i) Semi-intensive (shrimp): **SIS (S)**
   ii) Extensive (shrimp + fish): **EXT (S+F)**
   iii) Improved extensive (shrimp + prawn + fish): **IEX (S+P+F)**

3.14.2 Results

The inputs and outputs per hectare of the different shrimp farming systems, collected during the field survey are shown in Table 11. For comparative analysis, the inputs and outputs of the shrimp farming systems were categorized in four stages: a) power supply (e.g., diesel used for shrimp production); b) fertilization (application of urea, triple superphosphate, etc.); c) stocking (shrimp, prawn, fish, etc.); and d) feeding (commercial pellet feed, farm-made feed, etc.).

TABLE 11
Input and outputs per hectare per year of six farming systems

Aquaculture inputs (per ha)		WFC prescribed			Others		
		CST (S)	MTT (S+F)	BMP (S+F)	SIS (S)	EXT (S+F)	IEX (S+P+F)
Power supply (kg)	Diesel	146	117	146	208	0.3	32
Fertilizer (kg)	Urea	49	235	371	-	46	-
	TSP	49	210	309	-	43	-
	Mustard oil cake (MOC)	222	321	259	-	9	-
	Lime	1 050	519	395	500	63	184
	Molasses	124	173	12	250	-	-
	Yeast	11	16	0.5	-	-	-
	Rice bran	124	173	12	50	26	-
Stocking (number)	Shrimp PL	74 100	37 050	49 400	148 200	109 837	20 686
	Prawn PL	-	-	-	-	-	19 882
	Fish fry	-	9 880	9 880	-	9 152	767
Feed (kg)	Pellet feed	2 964.00	1 235	247	7 250	-	1 209
	Dry fish	-	-	-	-	-	86
	Wheat bran	-	-	-	-	10	51
	Rice bran	-	-	-	-	6	51
	Cooked broken rice	-	-	-	-	2	16
	Boiled mixed pulses	-	-	-	-	-	132
	Boiled peas pulses	-	-	-	-	-	72
	Boiled Maize	-	-	-	-	-	58
	Cooked rice	-	-	-	-	-	150
	MOC	-	-	-	-	5	-
	Wheat flour made vermicelli	-	-	-	-	-	0.6
	Snail meat	-	-	-	-	-	449
Outputs							
Kg/ha	Shrimp	2 100	618	309	3 750	433	110
	Prawn	-	-	-	-	-	457
	Fish	-	618	1 235	-	154	193
Total kg/ha (shrimp+prawn+fish)		2 099	1 235	1 544	3 750	587	759
Million kCal/ha		1.69	1.22	1.70	3.02	0.54	0.72

Notes: Please see text for explanation.

Among the studied farming systems, semi-intensive SIS (S) showed the highest and extensive EXT (S+F) showed the lowest yield, in respect of shrimp (kg), total output (kg) and total energy (kCal) production (Table 11).

Among the WFC supported farmers, closed system technology (CST (S)) farmers stocked PCR tested shrimp PL. They stocked 240–320 individual PLs per decimal (1 decimal[4] = 40 square metre) where aeration facilities are not available and

[4] 1 ha = 2 470 decimal

400–600 PLs where aeration facilities were available. Survival rates of stocked PL was 75–85 percent and average production was 1 200–1 800 kg per hectare. Average farm area at CST (S) farms was 1–3 acres. In modified traditional technology: MTT (S+F) farms the average farm area was 5–7 acres. Farmers undertook nursing of PCR tested PLs and then stocked at the lowest density of 40–50 juvenile per decimal. Survival rates were 60–70 percent and average production was 400–500 kg per hectare. In better management practices BMP (S+F) sites, farmers did not nurse shrimp PLs. They stocked 50–60 PLs per decimal, although this may have been enhanced through PLs that came in through tidal water exchange through the farm. Survival rates were 30–50 percent and average production was 250–300 kg per hectare. Average farm area for BMP (S+F) sites was the largest at 8–15 acres per farm.

Among the “other farmers” the semi intensive: SIS (S) farms were few numbers and data for this study was collected from a single farm, Gazi Fisheries, located at Mongla, Khulna. They stocked 600 PLs per decimal and achieved survival rates between 80 and 85 percent, giving a yield of 3 000–4 000 kg per hectare of shrimp production. The Gazi Fisheries site was large at 180 acres with an average of 1.5 acres per pond. In Extensive EXT (S+F) systems, farmers stock 400–500 PLs per decimal. Survival rate was the lowest of those sites assessed at 25–30 percent, giving a production of 400–450 kg shrimp per hectare. These farmers rely on natural food sources, not on pelleted feed, and to achieve the needed primary productivity they apply fertilizers into the ponds. Extensive farms were big, having over 10 acres. For the improved extensive: IEX (S+P+F) systems, stocking density was 70–100 PLs per decimal and survival rate was 30–40 percent with 100–120 kg shrimp produced per hectare. The average farm size was less than 1 acre of those that were assessed.

Among different systems, CST (S) and SIS (S) farmers produced only shrimp, whereas IEX (S+P+F) produced prawn (*Macrobrachium rosenbergii)* and fish (rohu, catla, tilapia, etc.) alongside shrimp; and other farms produced fish with shrimp. Though CST (S) and SIS (S) farmers were more financially benefited by producing only shrimp, they were also always at higher risk of large financial losses due to disease outbreak potential in shrimp farms. Such farmers were able, generally, to take this risk due to their better financial and technological position. Other farmers, who were comparatively poor, generally took less risks and stocked different fish species to shelter themselves from overall losses, if disease outbreaks did occur in shrimp. All WorldFish supported farmers applied fertilizers (to produce natural food) along with supplemental pellet feed in varied ratios. SIS (S) farmers relied fully on pelleted feed and conversely EXT (S+F) farmers were dependent on natural food produced through fertilization, although could supplement to a small extent using on-farm feed ingredients. IEX (S+P+F) farmers used both pellet feed and on-farm feeds due given that prawn was their main production type. The economical feed conversion ratio (eFCR) is the weight of feed required to produce one kilogram of live fish at harvest, including mortalities and was highest (1.93) in SIS (S) due to their dependence on supplemental feeds; and lowest (0.04) in EXT (S+F) due to their reliance on natural primary production.

Table 12 shows major emissions from the different farming systems assessed through life cycle inventory analysis. The inventory analysis was based upon the inputs supply as shown in Table 10. Biological productivity like plankton production was not assessed due to the limitation of this LCA study. System SIS (S) was responsible for highest CO_2, N_2O, NH_3, NO_x, SO_2, N and PO_4^{3-} emissions (bold), system BMP (S+F) was highest for P emission and IEX (S+P+F) was for highest CH_4 and NO_3 emissions.

The impact assessment results for the different shrimp farming systems are shown in Tables 13, 14 and 15 scaled to one ha of farming, one kCal of total farming output, and one tonne of shrimp production respectively, giving equal weighting (21) to each impact category, where the lower the score the lower the overall impact.

TABLE 12
Major emissions (kg/hectare of production) from different shrimp farming systems

	Global warming			Acidification			Eutrophication			
	CO_2	CH_4	N_2O	NH_3	NO_X	SO_2	NO_3	P	N	PO_4^{3-}
MTT (S+F)	2 669	5.70	4.52	5.98	35.10	7.29	187.00	124.00	160.00	1.60
CST (S)	3 344	6.75	8.39	10.40	59.80	7.29	342.00	55.30	123.00	1.48
BMP (S+F)	2 624	4.38	1.80	2.70	20.60	7.66	69.60	**148.00**	157.00	1.81
SIS (S)	**5 357**	12.27	**18.10**	**22.40**	**124.00**	**13.40**	733.01	77.00	**253.00**	**2.43**
EXT (S+F)	412	0.75	0.14	0.23	2.60	1.16	5.08	32.60	33.70	0.23
IEX (S+P+F)	1 910	**18.15**	14.00	16.70	78.10	5.29	**810.00**	1.27	0.02	1.10

Based upon outputs per ha of farming (Table 13), global warming and acidification were higher when using the SIS (S) production system and eutrophication was higher in the BMP (S+F) system. All impacts were lowest when using the EXT (S+F) production system.

When considering environmental impacts per kCal of total farming output (Table 14), global warming and acidification were higher in IEX (S+P+F) and eutrophication was higher in MTT (S+F) system. EXT (S+F) showed lower impact for global warming and acidification; and SIS (S) showed lower impact for eutrophication.

TABLE 13
Environmental impacts of shrimp farming per ha of production

System	GWP (kg CO_2 eq.)	Rank GWP	AP (kg SO_2 eq.)	Rank AP	EP (kg PO_4^{3-} eq.)	Rank EP	Total score	Impact position
MTT (S+F)	4 160	4	43.1	3	473	5	12	4th
CST (S)	6 010	5	68.8	5	267	3	13	5th
BMP (S+F)	3 270	2	27.2	2	532	6	10	3rd
SIS (S)	11 100	6	142.0	6	438	4	16	Highest
EXT (S+F)	472	1	3.4	1	115	1	3	Lowest
IEX (S+P+F)	3 820	3	47.3	4	120	2	9	2nd

Notes: GWP = global warming potential, AP = acidification potential and EP = eutrophication potential. For system descriptions see text.

TABLE 14
Environmental impacts of shrimp farming per kCal of total production (shrimp, fish and prawn)

System	GWP (kg CO_2 eq.)	Rank GWP	AP (kg SO_2 eq.)	Rank AP	EP (kg PO_4^{3-} eq.)	Rank EP	Total score	Impact position
MTT (S+F)	0.0034	3	0.000035	3	0.00039	6	12	5th
CST (S)	0.0036	4	0.000041	4	0.00016	2	10	3rd
BMP (S+F)	0.0019	2	0.000016	2	0.00031	5	9	2nd
SIS (S)	0.0037	5	0.000047	5	0.00015	1	11	4th
EXT (S+F)	0.0009	1	0.000006	1	0.00021	4	6	Lowest
IEX (S+P+F)	0.0053	6	0.000066	6	0.00017	3	15	Highest

Notes: GWP = global warming potential, AP = acidification potential and EP = eutrophication potential. For system descriptions see text.

TABLE 15
Environmental impacts of shrimp farming per tonne of shrimp production only

System	GWP (kg CO_2 eq.)	Rank GWP	AP (kg SO_2 eq.)	Rank AP	EP (kg PO_4^{3-} eq.)	Rank EP	Total score	Impact position
MTT (S+F)	5 770	5	59.9	6	656	5	16	Highest
CST (S)	2 860	2	32.8	2	127	2	6	Lowest
BMP (S+F)	6 350	6	52.9	4	1 030	6	16	Highest
SIS (S)	2 950	3	37.9	3	117	1	7	2
EXT (S+F)	1 030	1	7.43	1	250	4	6	Lowest
IEX (S+P+F)	4 710	4	58.2	5	147	3	12	3

Notes: GWP = global warming potential, AP = acidification potential and EP = eutrophication potential. For system descriptions see text.

Global warming and eutrophication results were higher in BMP (S+F) systems and acidification was higher in the MTT (S+F) system of production when evaluating per tonne of shrimp production (Table 15). EXT (S+F) showed lower impact for global warming and acidification; and SIS (S) showed lower impact for eutrophication.

Based on total score of the studied system categories, EXT (S+F) had the lowest impact per ha, per kCal and per tonne of shrimp production, whereas SIS (S) was responsible for highest impact per hectare of shrimp production; IEX (S+P+F) for per kCal production; and BMP (S+F) and MTT (S+F) had a higher impact for per tonne of shrimp production.

The contribution of the different farming stages (viz. fertilization, stocking, feeding and power supply) to global warming potential, acidification potential and eutrophication potential are shown in Tables 16, 17, and 18 respectively.

TABLE 16
Contribution (%) of different farming stages for GWP per ha production

Farming practices	GWP (kg CO_2 eq.) per ha	% contribution at farming stages			
		Fertilization	Stocking	Feeding	Power supply
MTT (S+F)	4 160	**43.74**	1.78	*37.73*	16.75
CST (S)	6 010	*20.63*	2.40	**62.54**	14.44
BMP (S+F)	3 270	**60.88**	3.00	9.57	*26.55*
SIS (S)	11 100	3.13	2.61	**83.05**	*11.21*
EXT (S+F)	472	**47.14**	*45.66*	6.83	0.36
IEX (S+P+F)	3 820	2.75	*10.35*	**81.95**	4.95

Note: Bold values indicate highest contributions and italic values indicate 2nd highest contributions.

TABLE 17
Contribution (%) of different shrimp farming stages for AP per ha of production

Farming practices	AP (kg SO2 eq.) per ha	% contribution at farming stages			
		Fertilization	Stocking	Feeding	Power supply
MTT (S+F)	43.1	*35.9*	1.1	**51.7**	11.3
CST (S)	68.8	*12.2*	1.4	**77.7**	8.8
BMP (S+F)	27.2	**58.9**	2.3	16.4	*22.4*
SIS (S)	142.0	0.6	1.3	**92.0**	*6.1*
EXT (S+F)	3.41	**44.3**	*40.8*	14.63	0.4
IEX (S+P+F)	47.3	0.3	*4.1*	**92.9**	2.8

Note: Bold values indicate highest contributions and italic values indicate 2nd highest contributions.

TABLE 18
Contribution (%) of different shrimp farming stages for EP (per ha production)

Farming practices	EP (kg PO_4^{3-} eq.) per ha	% contribution at farming stages			
		Fertilization	Stocking	Feeding	Power supply
MTT (S+F)	473	**81.51**	1.85	*16.39*	0.25
CST (S)	267	*37.50*	0.07	**61.88**	0.55
BMP (S+F)	532	**95.2**	1.65	*2.88*	0.27
SIS (S)	438	*8.65*	0.08	**90.79**	0.48
EXT (S+F)	115	**93.62**	*5.68*	0.70	0.00
IEX (S+P+F)	120	0.03	*6.99*	**92.72**	0.27

Note: Bold values indicate highest contributions and italic values indicate 2nd highest contributions.

Overall, feeding and fertilization were identified as the major contributors for the environmental impacts associated with the different shrimp farming systems. Feeding was the largest contributor for global warming in CST (S), SIS (S) and IEX (S+P+F) production systems; acidification in the MTT (S+F), CST (S), SIS (S) and IEX (S+P+F) production systems; and eutrophication in CST (S), SIS (S) and IEX (S+P+F) systems.

Fertilization had the highest contribution for global warming in the MTT (S+F), BMP (S+F) and EXT (S+P) production systems; as well as the highest contribution to acidification in BMP (S+F), EXT (S+P) systems and eutrophication in MTT (S+F), BMP (S+F) and EXT (S+P) systems.

3.14.3 Conclusions

Six farming systems under two categories of farmers, one group supported by WorldFish and the other without specific support, were investigated to establish the present status of environmental impact based on three impact categories – namely global warming, acidification and eutrophication potentials. Farming practices varied significantly between systems and indeed between farmers, depending on farm location, area of waterbody, the economic status and technological knowledge of farmers, ownership of farm and whether or not they received additional support.

IEX (S+P+F) had the highest CH_4 and NO_3emissions, due to the use of more rice, wheat and pulse based ingredients as feed (Nahid, 2014). BMP (S+F) had highest phosphorus emissions due to their higher use of TSP fertilizers. SIS (S) had a higher contribution for other emissions, mainly due to the effect of having higher inputs combined. Based on the outputs per ha of farming, global warming and acidification potential were highest in semi-intensive shrimp only (SIS (S)) systems due to the combined effects of using more diesel than other farmers, the application of commercial pellet feed and the addition of lime. Eutrophication potential was highest in BMP (S+F) systems due to the increased use of fertilization ingredients, including urea, TSP and MOC. All impacts were lowest under the EXT (S+F) system, due to the comparatively lesser amount of different ingredients used.

If impacts per kCal of total farming output are considered, the IEX (S+P+F) system had the highest global warming and acidification impact. Although this farming system produced prawn and fish along with shrimp, using various feed ingredients, the total output in kCal was very low (0.74) compare to other systems. Only the EXT (S+F) system had lower kCal output than IEX (S+P+F), but is explained by the use very lesser amount of inputs compare to other systems and explains why it had lowest global warming and acidification impact, for example. Regarding eutrophication, MTT (S+F) had the highest impact; which was due to more fertilization ingredients used per kCal production than in other systems. SIS (S) showed the lowest eutrophication impact; because these systems produce the highest kCal (3.02) output and use little in terms of fertilization ingredients.

Global warming impact and eutrophication impact results were higher in BMP (S+F) when considering outputs per tonne of shrimp production. This result is due to BMP (S+F) systems using comparatively higher amount of different inputs (especially diesel and fertilizers) to produce fewer shrimp than other systems. Acidification potential was higher in MTT (S+F) systems, and may be due to the low production achieved whilst at the same time using higher feeding input. Similarly, per kCal production in EXT (S+F) systems showed the lowest global warming and acidification impact, and SIS (S) showed lowest eutrophication impact due to same reasons.

EXT (S+F) had the lowest overall impact due to very low inputs. These farmers stock shrimp PLs from hatcheries and supplement through tidal water exchange, then apply fertilizers to enhance the primary production to provide natural food sources, and wait for growth to occur before harvesting. Though this system had lowest overall environmental impact and profit percentage was highest (Table 11), land utilization and efficiency was very poor due to lowest production per hectare. Thus, reliance on this system of production in a country like Bangladesh which has limited land resources, means it is losing total aquaculture production potential, and therefore limiting national income and food security potential. Conversely the SIS (S) production system had highest overall environmental impact in respect of per hectare production, had 4th lowest impact per kCal and 2nd lowest impact per tonne of shrimp production, which indicates that if production is more efficient and is higher per unit area, then the overall impact is reduced per unit (e.g. per kCal, per tonne) production. In the context of resource utilization this system utilized land more efficiently and achieves the highest yield per unit area than other systems, though it has only a moderate profit percentage and requires a large investment. All farming systems except SIS (S) and CST (S) additionally produced fish besides shrimp, and although shrimp is mainly produced for export market, the additional fish production supported local food security.

Although it is recommended that comparing values of impact results amongst different LCA studies should really be avoided, as they all are based upon their own methodological choices and assumptions there are a couple of useful comparisons to be made. According to Cao *et al.* (2011), one tonne live-weight of shrimp production in China generated 3100 kg of CO_2 eq. and 23.1 kg of SO_2 eq., which were similar to the per tonne of shrimp production in Bangladesh (Table 15). Chinese shrimp production uses only intensive and semi-intensive systems and the impact was very close to the semi-intensive system – SIS (S) - practices in Bangladesh. Chinese production system, however, has a lower eutrophication impact (36.9 kg PO_4^{3-} eq.) than the Bangladeshi systems in this study, which is probably due to more efficient utilization of supplied nutrients (N and P), and having a higher yield in China.

It is obvious that each production system will have some form of environmental impact, as no aquaculture can be zero impact; but the question is how we can best reduce this environmental impact. If we evaluate the different stages of farming systems included in this study, then feeding (in some cases fertilization, where feed inputs were lower) was the major contributor to overall environmental impact. This is similar to other previous LCA studies in aquaculture (Naylor *et al.*, 2000; Henriksson *et al.*, 2011; Nahid, 2014) and supports the notion that increasing feed efficiency and FCR is an appropriate course of action to reduce the overall environmental impact. For the long-term sustainability of the shrimp sector in Bangladesh, production should be economically viable, socially acceptable and environmental friendly. To achieve this goal, there is no alternative but to improve the efficiency by increasing the production per unit area using modern technology and using more environmental friendly ingredients. Thus recommendations are that Bangladesh shrimp production:

- Should emphasize the use of natural food (produced naturally in the pond and through fertilization) based shrimp farming, along with balanced supplementary feed prepared using environmental friendly ingredients.
- Should follow a proper feeding schedule and use delivery techniques (e.g. feeding tray) to improve this resource use.
- Should ensure that measure of nutrient content (especially N and P) is done regularly in pond waterbodies to ensure correct fertilization is applied.
- Should integrate different species to utilize supplied inputs properly.

A woman harvesting shrimp and fish using cast net from her gher in Shyamnagar, Satkhira, Bangladesh.

4. Improving and streamlining the impact of shrimp farming

4.1 INTRODUCTION

Shrimp farming is now widely spread across almost all of the coastal regions of Bangladesh. Shrimps are cultivated generally in low lying areas called beels, on land that is barely one meter above mean sea level and below high tide level. These are areas where nutritious and rich organic foods are available for all types of aquatic lives. The people who live in and around the shrimp farmlands have not been able to control its rapid expansion, stop or reduce farms, and protect against the aftermath of unplanned and unorganized cultivation. Shrimp farming has apparently emerged as a threat to agriculture production, livestock rearing, biodiversity and ecology of local environments, public health, and overall environmental and social sustainability of coastal regions in Bangladesh. Besides the direct economic losses for many people who are living in shrimp farming areas, long-term environmental degradation is also creating damage that is likely to be irreversible and irrecoverable. Yet, in spite of the negative impacts, the economic importance of shrimp culture cannot be overlooked for a developing country like Bangladesh.

New ways of developing and expanding this sector need to be found. It is therefore important that an economically viable, socially acceptable and environmentally sustainable shrimp farming need to be identified. In this respect, among many other factors, increasing the efficiency of resource use in shrimp production at the farm level stands as an attractive option because it has the potential to generate output growth without increasing quantities of inputs that generate the negative environmental externalities. Proper management can ensure a sustainable growth and wider benefit of shrimp cultivation. Protection and restoration of the aquatic environment, from the pollution caused by shrimp cultivation, can be considered as one of most realistic options within environmental management.

The degree of interaction between shrimp farming and the environment depends on a wide variety of interrelated factors; such as species being farmed, and the mode, scale and intensity of culture practices used. There has been substantial interest in coastal shrimp farming over the last decades, and to date a significant progress has been made, in both understanding these interactions and providing mitigation measures to reduce the impacts (Huntington, 2003). The most effective approaches can be summarized as below:

1. Introduction, adoption and implementation of codes of practice by the industry.
2. Use of environmental impact assessment techniques, both at site-specific and cumulative levels.
3. Increasing use of certification to standardize sustainable farming methods and products.
4. National management strategies for controlling the import and use of exotic organisms.
5. Integration of shrimp farm planning into overall coastal land use zoning and management.

Ullah and Rahman (2014) identified the major vulnerability issues in the shrimp sector of Bangladesh, the reasons behind these vulnerabilities and proposed a number of adaptation measures that could be implemented (Table 19).

TABLE 19
The major vulnerabilities, causes and adaptive measures in the shrimp sector of Bangladesh

Vulnerability	Causes of vulnerability	Adaptation
Safe drinking water	Salinity in pond water and in other surface and sub-surface water sources. Lack of deep tube well for provision of freshwater.	Supplying safe portable water through water vending, raising of the pond dyke, digging saline free new ponds, rain water harvesting during monsoon, construction of sub-surface water supply system, drilling deep tube wells and construction of desalination plants. Construction and repairing of pond sand filters (PSFs).
Saline water intrusion	Sea level rise due to global warming, and occurrence of periodic cyclones.	Cultivation of saline tolerant crops and crop varieties, construction of embankment considering long-term planning, and afforestation.
Crop production	Saline water intrusion to pond, surface, and ground water by natural disaster and sea level rise.	Cultivation of saline tolerant fodders and crops, dredging and desalination of rivers, repairing the roads, culturing giant river prawns (golda), awareness raising of farmers through training, encourage farmers to cultivate saline tolerant crops, and re-excavation of canals.
Freshwater fish culture	Saline water intrusion by natural disasters and sea level rise.	Culturing saline tolerant fish, releasing fry in ponds observing natural disaster, construction of saline free ponds with elevated pond dyke, and cancellation of the lease system of canal by the government.
Saline water shrimp farming	Virus diseases, importation of shrimp fry without appropriate quarantine, lack of capital and saline water supply, natural disaster and saline water shortage due to canal controlled by rich, lack of shrimp fry in rivers, and use of fragile fry in shrimp farming.	Arrange training for shrimp farmers, provide proper dose of limes and fertilizers, test pH and salinity of water, establishment of resource centre in the locality, awareness raising of people, arrangement of proper drainage system, changing water of farms in optimum time, use local fry instead of imported fry, release fry in farms observing cyclone, repairing the boundary of shrimp farms, and culture of freshwater fish.
Livestock and poultry rearing	Drinking saline water, shortage of fodder with grazing field and shortage of rearing space.	Desalinization of land and cultivation of saline tolerant rice and fodder.
Embankment	Breaking of embankment due to low height, thin and fragile construction, lack of overhauling and plantation.	Construction of wide and raised embankment following new and improved design, revetment of open embankment, preparation of long term planning, repairing the embankment, and enormous plantation along with embankment and foreshore.
Sanitary latrine	Destroying latrines by natural disasters.	Construction of elevated sanitary latrines.
Housing	Damaging houses by natural disasters	Construction of strong and raised houses including homestead.
Communication	Damaged road by natural disasters and due to the shrimp farming.	Repairing the damaged roads and construction of new roads with brick soling, and increase surveillance during construction of roads.
Employment opportunity	No land based production, lack of industry, and frequent natural disasters.	Cultivation of saline tolerant crop, development of grocery, small business, craftsmanship, fish culture and livestock rearing, and enhancement of other local employment opportunities.
Agriculture equipment	Lack of fund to purchase agricultural equipment.	Provision of low interest loan to purchase agricultural equipment.
Migration	Destitution because of natural disaster.	Construction of cyclone resistant housing, and creation of employment opportunity in the locality.

Source: Modied after Ullah and Rahman (2014).

But the question that remains are to what extent the adaptations identified in **Table 19** have been or can be implemented.

4.2 INITIATIVES UNDERTAKEN BY THE GOVERNMENT OF BANGLADESH

The Government of Bangladesh (GoB) has introduced a number of initiatives aimed at streamlining and reducing the impacts of shrimp farming. Some initiatives that have been undertaken include:

- The GoB delineated the zoning of shrimp areas, to provide effective support and control of shrimp farm expansion, is to be conducted in a planned way, as part of its strategic development activities.
- The collection of wild shrimp fry from nature is banned officially by the government, and PL transport from the hatchery located in Cox's Bazar and other locations is regulated by government, to increase shrimp farmers' awareness about

the PL quality. In practice, as has been outlined above, the ban has been ineffective and not enforced and skepticism remains in farmers on the quality of hatchery produced stocks of post-larvae.

- Government has initiated preparation of a comprehensive plan, encompassing relevant resources under a Coastal Zone Management Project. This is mostly focused on increasing production of shrimp and has less focus on socio-economic and environmental impacts and consequences. More careful considerations should be given on environmental aspects, lessons learnt from pilot initiatives, sustainable livelihood and economic aspects. Synergies between Poverty Reduction Strategy Paper (PRSP) and Coastal Zone Management Project need to be considered carefully.
- Emphasis has been given on infrastructural development in shrimp farming areas, including socio-economic development of coastal fishers, and development associated with modern technology to improve quality control of final products. Under a BDT 300 million donor funded collaborative project (DoF, FAO and WorldFish), DoF has been developing shrimp farming infrastructure – mainly through the re-excavation of silted-up canals (the water inlet to the shrimp farms) to increase availability of saline water in shrimp ghers and by increasing the depth of *ghers*. Some 40 clusters, involving more than a thousand farmers, were selected under the project.
- Initiatives have been undertaken for the construction of water management infrastructures particularly sluice gates, canals, and dikes, on public and private land; development of hatcheries for shrimp seed production; establishing demonstration farms and training centers for technology demonstration and farmer training; and landing and service centers to provide post-harvest facilities. In a national workshop on *Comprehensive support measures for development of an inclusive and sustainable aquaculture industry in Bangladesh* held in Dhaka on February 20, 2017, the Director General of Department of Fisheries (DoF), Bangladesh noted that the DoF has been implementing comprehensive programs for the development of the shrimp sector for which support from all concerned is needed along with a major investment in infrastructure, institutional capacity buildup and sustained resource flow to the sector.
- Quality certification system (along with recently introduced e-traceability system on pilot scale) of the shrimp industry has already been introduced, with more emphasis, however, on ensuring food safety, traceability and environmental sustainability and less on social responsibility. The biosecurity compliance measures at all levels of shrimp/prawn hatchery operations has already been implemented.
- Government has taken farmer training programs, aimed at increasing the technical knowledge of farmers, in areas such as disease prevention and improvement of management; and has prepared and disseminated a good number of printed extension and training materials about shrimp culture. Many farmers already increased their skill level substantially and were able to increase the production both qualitatively and quantitatively.
- The GoB, together with FAO and Network of Aquaculture Centres in Asia Pacific (NACA) have developed a regional network to address fish health and disease information systems, in a package of training modules and other dissemination materials that address culture practices, to shrimp farmers, to increase the quality of production and sustainability.

4.3 APPROACHES AND INITIATIVES PROPOSED

Environmental impacts such as mangrove degradation, loss of biodiversity, sedimentation, saltwater intrusion, and pollution and disease outbreaks are the main impacts from the development of sustainable shrimp farming. Inappropriate management practices and inadequate plans regarding water quality, seed supply, irrigation facilities and management of fishery resources are the main reasons for these impacts from shrimp farming. Effective management measures to mitigate the adverse environmental impact of shrimp farming development are urgently requirement.

Respondents to questionnaires within study areas and the field group discussions noted a number of negative consequences, such as decline of paddy yields, physical destruction of common property resources, and loss of fertile agricultural land. The majority of the poor and marginal shrimp producers, however, are still in favor of shrimp farming because of its economic potential. Economic wellbeing is the driving force behind shrimp farming and shrimp business development. The positive livelihood effects of shrimp farming are seen to outweigh the negative livelihood effects. It is therefore necessary to develop environmentally friendly and appropriately sustainable shrimp culture practices and Hossain *et al.* (2013) provided a framework by which such implementation could be carried out (Figure 29).

Water quality management in shrimp *ghers* is a prime area of concern due to the complicated management system of existing canals and sluice gates. With provision of proper sluice gates and canals, availability of saline water to all the shrimp farms can be improved. To achieve shrimp production in a sustainable way, more initiatives from private sector, NGOs, Government and research organizations is required. Lack of capacity, adequate tools to address the impacts of shrimp farming, political-institutional barriers for mainstreaming the adaptation measures, the weak position of government line ministries, establishing a linkage between mitigation and adaptation, effective costing of adaptation measures in the national action plan including multi-sectors and multiple stakeholders, and funding problems including utilization with accountability and transparency are the major challenges. Most programs are short-term and are focused only in limited areas or specific farms and require a larger transformation towards long-term planning over wider area.

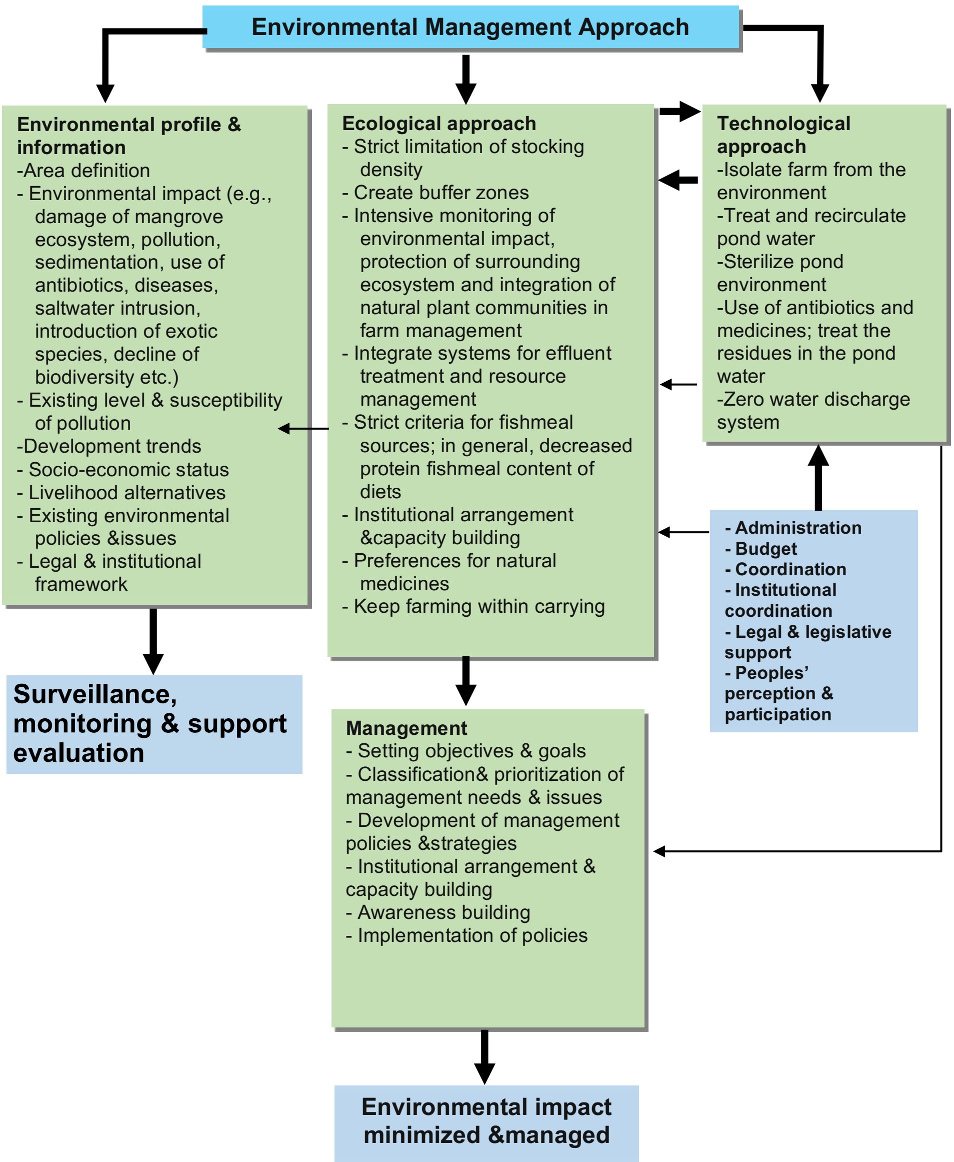
There are need for higher-level research in innovation of new technologies, improvement and promotion of the existing technologies/options for the sectors and the ecosystems. This will also entail maintenance with community participation on regular basis. Government, in collaboration and partnership with community actors and other stakeholders should play the key role in advancing its program of implementation, which should be based on selection of priority areas conducted with transparency and accountability.

4.4 DEALING WITH THE MAJOR ISSUES

4.4.1 Mangrove protection

As a matter of policy, GoB decided that shrimp farming should not be extended if it causes any further mangrove destruction and this practice has been adhered to so far (*personal communication, DoF, Bangladesh*). In 1997, Global Aquaculture Alliance (GAA) commissioned a global study, which resulted in the recommendation of six management practices, forming the GAA's Codes of Practice for Responsible Shrimp Farming. The GAA's Responsible Aquaculture Program is based on quantitative and qualitative standards and third-party certification, which includes not damaging local ecosystem services, such as mangroves. FAO developed a Code of Conduct for Responsible Fisheries (CCRF) including aquaculture (FAO, 1995). In the environmental arena, the codes developed or being developed call for a total ban on shrimp farming in mangrove areas. Producers and the processors who distribute aquaculture products in compliance with these standards are eligible to receive a Seal of Quality endorsement that considerably enhances the attractiveness of their products to world markets. As these codes come into being, international buyers will only purchase shrimp from countries and companies that meet these international certifications standards.

FIGURE 29
Conceptual model for environment impact management of shrimp cultivation



Source: Hossain *et al.* (2013).

Department of Fisheries (DoF) under Ministry of Fisheries and Livestock (MoFL), Government of Bangladesh should continue its leasing policy that the land near mangroves should not be leased for the purpose of shrimp farming. Inland shrimp farming on privately owned land should be encouraged. Investors are generally more willing to invest into improving land they have complete control over rather than being subjected to short-term leasing conditions. Such a policy would also eliminate the lack of transparency that challenges the government's leasing program.

4.4.2 Shrimp broodstock and PL

Brood shrimps (berried female) collected from the wild and the resulting PL produced from hatcheries are not screened properly for disease and genetic quality. Procedures for ensuring the quarantine of brood shrimps and screening for disease and genetic quality in PL and brood shrimp (using PCR techniques) should be made mandatory. Improved methods for harvesting wild brood shrimp should be developed and introduced; and using trammel net instead of trawl nets, for example, should be introduced to increase survival rates and to reduce the impact of trawling, on bycatch for example. Improved post-harvest handling and proper quarantine procedures are also required for each of the berried females used by hatcheries.

Enforcement of the current ban on shrimp trawling between the 15 January and 15 February is considered to be important to conserve wild stocks and to ensure the supply of broodstock. Legislation, which implements this ban, is currently in abeyance following an injunction from the High Court in 1995 after the writ petition filed by the BMFA. Wild stocks are also under pressure from the collection of wild fry and the use of set bag nets (with mesh sizes smaller than 45 mm at the cod end prohibited under Fish Act) in the juvenile fishery. Both laws should be reactivated and enforced to ensure the sustainable management of wild shrimp broodstock.

Currently the only source of shrimp broodstock for hatcheries is from the wild. Shrimp broodstock should be maintained in the hatchery and a broodstock management programme should be developed through government and private initiatives, that could provide certified disease-free broodstock of known genetic makeup, through a process that ensures genetic diversity is not undermined, by being produced in captivity.

4.4.3 PL and its trading

A reduction in the number of intermediaries acting within the shrimp industry would facilitate greater linkages and contact between hatcheries and farmers, and ultimately lead to lower prices paid by the farmers. A number of smaller hatcheries, in Cox's Bazar and Khulna and a few of the larger hatcheries do transport shrimp PL directly to the farmers and this should be encouraged. Use of field agents in the farming zones and the establishment of transit nurseries by hatcheries are positive developments, for example. These agents are able to determine the demand for PL from farmers well ahead of time and enable adjustment of PL production to match demand. All the hatcheries should follow these pathways, should plan production cycles based on field demand, and make sure that the products that reach the farmers are of high quality and maintain the appropriate qualitative properties of PL.

PL bags should be labelled with batch number, quantity, age, time of packing, water salinity, pH, hardness and other such information. It should also contain clear instructions about handling and acclimation procedures for the range of salinities and temperatures found in farmers' ponds throughout the production zones in Bangladesh. The expected survival rate under standard conditions should also be stated and hatcheries should encourage buyers to provide feedback to the company about the survival of PL following stocking. All of this will act to increase traceability within the system and will encourage information sharing, particularly on disease issues and outbreaks.

4.4.4 Establishment of PL nurseries

There is good potential to establish PL nurseries in shrimp producing areas, particularly in Khulna, Satkhira and Bagerhat districts. PL reared in nurseries generally have higher survival rates and increase production efficiencies for farmers. Therefore, nursing should be made mandatory before stocking juvenile shrimp in the *ghers*. Nurseries can be operated within the *gher* under ambient water conditions with natural food. Existing nurseries in Satkhira are highly profitable and are low risk ventures. The key requirements are access to land and water and to markets, expertise (technical, marketing and enterprise management), and capital, along with organizational support. High levels of competence from GOs/NGOs would be required to successfully chart the route away from fry collectors' dependence on the *dadondars* and soliciting support from the local elites. In addition, farmers need to be encouraged to develop their own nursery areas within their ghers to reduce production loss.

4.4.5 Increasing farming efficiency through interconnected ponds

Interconnected shrimp ponds (Figure 30) could be very effective for the future development of shrimp farming, as the infrastructural technique substantially improves the eco-efficiency of the system (Barraza-Guardado *et al.*, 2015). By interconnecting ponds, nutrient recycling is favored by promoting primary production of microalgae containing chlorophyll-a, which then act as food, a means to produce oxygen and removal of nutrients including ammonia and other nitrogenous compounds and phosphorus. Based on a mass balance and flow of nutrients, a culture system with interconnected ponds reduces the flow of solids, particulate organic matter, and nitrogen compounds to the environment and significantly increases the water efficiency, when compared with traditional culture systems. With this culture system, it is possible to recover up to 34 percent of total nitrogen entering system (Barraza-Guardado *et al.*, 2015), with substantial increases in production per unit area. A system with interconnected shrimp ponds is technically feasible and improves the overall eco-efficiency of shrimp farming.

4.4.6 Training for PL harvesters

Post-larvae harvesters, traders and other stakeholders in the PL value chain should be trained in PL handling, sorting and returning viable bycatch, PL storage, packing and transport, control of conditions (temperature, salinity and water quality) and acclimatization and nursing of PL. This should be done along with an environmental awareness programme and promotion of the transition of harvesters and traders into alternative livelihoods, to reduce pressure on wild stocks. Training modules would include:

- Environmental awareness (ecological role of PL, importance of nursery and recruitment grounds, migratory routes, and the impact of river bank erosion).
- Legislation awareness (the need for regulation, the details of the regulations, areas, gears and seasons affected by the legislation).
- Tips for checking the viability and health of PL for buyers (to encourage market assessment for high quality PL).
- Transition to alternative livelihoods like fishing for market-sized finfish, poultry and livestock rearing, homestead vegetable and crop farming, floriculture, sewing, van pulling, net making and so on. These could also include the proposed legislation, timeframe for implementation and alternative support mechanisms available to assist PL collectors transition to alternative livelihoods.

There is scope to link this work to ongoing education programmes including the total literacy movement and community education programmes. A number of extension materials (leaflets, posters, radio and television broadcast) could easily be developed or updated if they already exit, and could be rapidly disseminated to PL collectors and traders. The established marketing structure for wild PL would be a useful avenue for the delivery of training and extension messages.

Existing methods of PL harvest and post-harvest handling could be improved through such training and adoption of improvements in such methods could reduce losses substantially.

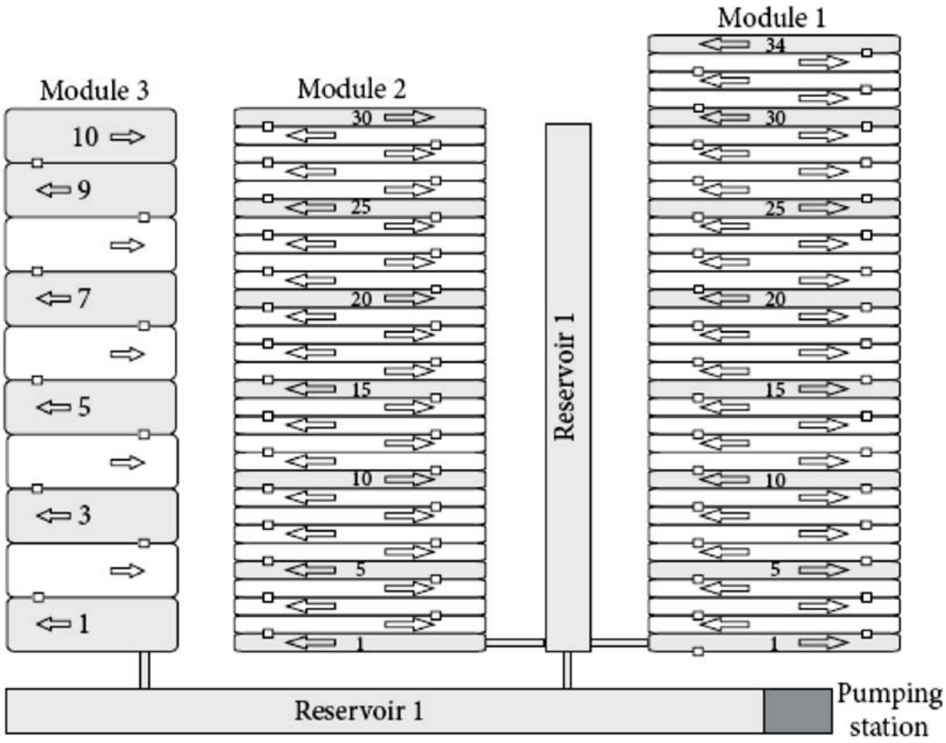
4.4.7 Research and extension

The hatchery sector needs practical research and studies on suitable techniques for shrimp breeding and rearing of PL up to the pre-growout stage. The development of farm raised broodstocks and handling of wild broodstock is critical to the seed supply system. The Bangladesh Fisheries Research Institute (BFRI), research organizations and universities need to be more closely involved in addressing the research needs of the industry. Extension of better management practices (BMPs) on selecting and testing for good PL, PL acclimation, stocking density requirements, and post-stocking monitoring of growth and survival are required to increase shrimp production in extensive systems.

A team of experts should be formed, including researchers and development workers who have expertise on corporate responsibility, value chain analysis, marketing, and institutional management. The team will play a significant role in ensuring that sector

FIGURE 30

Design of interconnected ponds that allow water movement between ponds. Arrows show direction of flow between ponds



Source: After Barraza-Guardado *et al*. (2015).

analysis and conclusions are realistic and appropriate to the real in-field situation in Bangladesh, and ensure that it leads to delivery of practical outputs. Effective and detailed analysis will be carried out by the team of experts, to plan the possible steps the donor community and multilateral institutions could support.

A concise and unbiased appraisal of the social, human rights and environmental issues facing the Bangladesh shrimp sector, including environmental management and ecological degradation, pollution controls, resource use, agrichemicals/nutrient issues, labor issues, community relations, and pro-poor business and sustainable livelihoods should be developed. In addition, the team would work in preparing a concise and relevant summary of the market structure of the shrimp sector in Bangladesh at different levels to understand fully the key players, producer structure, marketing procedures, and organizational issues; along with the key differentiating lines for the purposes of evaluating environmental and social measures in trade (e.g., cooperative versus multinational, large as distinct from small producers/exporters, and so on.). The team needs to develop a plan for a series of targeted field research with the following objectives:

- To explore practical opportunities for leveraging improved social and environmental management at all stages on the production and marketing chain, including the potential to pass on higher prices to producers where standards are met.
- To explore approaches to demonstrating accountability and compliance on the

part of producers and value chain actors.
- To clarify the nature of the chain of custody and the extent to which product certification could be achieved and sourcing guaranteed (e.g. traceability issues).
- To identify and explore key organizational and institutional opportunities and constraints, with particular emphasis on poor marginal producers.
- To examine the opportunities for extending and building on current product quality initiatives, and extending them to cover wider production practices.
- To assess the potential of alternative (i.e., non-market) mechanisms to fund socially and environmentally responsible shrimp culture.
- To begin to explore options for new or revised combinations of packages to promote responsible shrimp culture in Bangladesh.

4.4.8 Measures proposed based on focus group discussion during field visits

During field visits to the southwest coast in this study, a number of focus group discussions (FGDs) were conducted at different stakeholder levels. Shrimp farmers and other stakeholders emphasized the need to improve:

a. *Gher* renovation and increase pond water depth.
b. Provision of water inlet and outlet system, so that during drought season when the salinity in *ghers* increases, freshwater can be added from freshwater ponds, and when after heavy downpour during the monsoon, when salinity decreases in *ghers*, higher saline river water can be introduced.
c. Supply of good quality PL.
d. *Gher* and pond preparation with lime, cow dung, urea and TSP.
e. Feeding of shrimp with oilcake and feed pellet.
f. Construction of compatible dyke structure to canals, so that saline water does not seep to surrounding freshwater ponds and rice fields.

After a thorough discussion with shrimp farmers, input suppliers, traders, extension agents, local leaders and research organizations, the following twenty-three measures are recommended for improved management and mitigation actions:

1. Presently, the major problem in shrimp ponds is water depth. Water depth sometimes drops to less than 30 cm. In most cases, very low water depth and the resulting higher water temperature, is particularly damaging when the change is sudden and related reduced oxygen concentration, and fluctuation in salinity, particularly after a downpour (from high salinity to low) or after a few days of intense sun (from low to high salinity); where shrimp start to die and mortalities can be high. Confusion is enhanced when farmers believe this is all due, incorrectly, to what they call "virus". Therefore, shrimp ponds must be ***excavated and depth must be increased to a minimum of 1 meter.***
2. Locally made low-cost aerators should be introduced in to *ghers*. Following the design of some of the low-cost aerators made overseas, similar aerators can be manufactured in the country. For example, aerators generally cost USD50–100 when imported from China, but equally effective versions can be made in the country with relatively cheaper prices, around BDT2 000–3 000 (USD25–40). In shrimp farming areas, ***use of both electrical and mechanical aerators should be encouraged***. The aerators should be used at night and early in the morning when oxygen levels are at their lowest. This will substantially reduce shrimp mortality in *ghers*.

3. Maintaining biosecurity minimizes disease transmission between broodstock, hatchery and growout systems and stops shrimp diseases spreading within and between farms. Introducing and maintaining ***biosecurity measures on a large scale*** should be strongly encouraged and eventually to be mandatory.

4. Farmers should be encouraged to incorporate settlement and sedimentation ponds into the water inlet and outlet, wherever possible. Proper drainage system is obligatory for good shrimp farming. Farmers should be encouraged to maintain proper ***inlet, outlet and drainage systems*** in their *ghers* which will reduce the quantity of solids entering river systems, which causes siltation and blocking.

5. For use as a piscicide, many farmers now apply tea seed oilcake instead of rotenone. Tea seed oilcake is not only effective as a piscicide but also equally effective for gher fertilization and to increase gher productivity. Farmers should be ***encouraged to apply tea seed oilcake***.

6. Nursing is a must for PL before stocking in ghers. ***Direct stocking should be strictly prohibited and proper nursing should be emphasized***.

7. Some farmers use a tablet called Fumitox (aluminum phosphide) as piscicide; generally used to keep insects out from stored paddy/rice. A slightly higher dose of this Fumitox proved lethal to shrimp and stocking shrimp PL within 15 days of the application of this chemical resulted in complete mortality of stocked PL. ***Farmers should be discouraged from using Fumitox or any such other chemicals***.

8. Farmers should be ***encouraged to stock specific pathogen free (SPF) PL***.

9. Despite training, some farmers continue to stock PL in excessively high density which may result in outbreak of disease and can lead to higher losses. Farmers should be ***strongly discouraged from stocking PL at a high stocking density***. They should receive training and be motivated to stock at a lower level, which combined with improved water quality appears to be the best defense against all diseases. When pathogen populations are low, shrimp's natural defenses are normally capable of preventing disease, but when stressed by deteriorated water quality brought about by high stocking density, shrimp fall prey to "shell-loving" bacteria, fungi and viruses.

10. Farmers should be ***encouraged to stock low salinity tolerant coastal fish*** like parse (*Chelon parsia*), khorsula (*Rhinomugil corsula*), bhangon bata (*Mugil cephalus*), and nuna tengra (*Mystus gulio*) rather than freshwater fish species. These should be added to *ghers* with a low density.

11. Farmers should be ***encouraged to protect and conserve indigenous biodiversity*** in their ghers, as much as possible, to improve overall diversity and ecosystem integrity.

12. Farmers were found to use many known chemicals and many chemicals of unknown origin and content; reportedly to treat disease and increase *gher* productivity, to enhance the growth rate of shrimp and increase production. These include vitamins, antibiotics, and probiotics with dfferent trade names (e.g. Virax, Super pH, A soil, Blumix, Aqua 2 and many others) and other without known trade names. Representatives of many famous, and little known, companies are very active in providing motivation to farmers to use their products, to increase their sales. Most of the time they supply such chemicals on credit, leaving farm owner with a debt. Farmers should be ***strongly encouraged to only use chemicals that are necessary within their ghers and encouraged to consult with extension agents*** (e.g., UFO, well-known NGOs working in shrimp farming etc.) before applying any new unknown chemicals. Farmers should also be encouraged to use less of known

carcinogenic chemicals, such as malachite green.

13. Farmers should be encouraged to implement ***health management practices that reduce shrimp stress and focus on disease prevention rather than treatment***.

14. Shrimp viruses are known to be more prevalent and outbreaks are more frequent after periods of heavy rain. This is a stressful period for shrimp, when temperatures, salinities and water quality variables fluctuate wildly. ***Training and extension activity should ensure that farmers are aware of this*** so they can take extra care of their shrimp during this stressful period, for example by keeping handling to a minimum.

15. Farmers should be ***encouraged to implement measures for sanitary harvest, handling and transport of shrimp***.

16. Farmers should be encouraged to take measures to ensure ***shrimp farming benefits for the communities in the local area,*** and farm owners should ***ensure shrimp farm worker welfare and fair working conditions***.

17. Instead of using chemicals as a means to remove aquatic weed from ponds, ***physical removal should be encouraged***. In extension materials, it should be clearly noted that, ***for weed removal no chemical should be applied*** in the shrimp ponds.

18. In vegetable farming on the dyke of shrimp ponds, ***use of sex pheromones, poison traps and organic pesticide should be encouraged*** as a means to reduce insect infestation. These should be included in any training manual.

19. Farmers should be ***made aware of and encouraged to comply with the Fish Hatchery and Feed Acts and Rules***.

20. Feed is the most expensive component in fish and shrimp farming. The aim always should be to reduce feed costs and thus increase profits, and is particularly encouraged in shrimp and tilapia farming. One means of doing this is ***to introduce biofloc technologies***. In biofloc systems, as the shrimp/tilapia graze on the flocs, so the protein levels in the feeds can be substantially reduced. Bacteria in bioflocs eat shrimp waste and keep the water clean with the main principle of the biofloc system being "the bacteria eat the shrimp waste and the shrimp eat the bacteria when they have reached a certain size/density, and makes production of shrimp a lot cheaper". This will also result in reduced pellet feed requirement and overall feed costs will be much lower.

21. There is an increasing trend to improve water stability for floating feed. Concomitant with increasing pellet stability, ***attractants should be added in the feeds*** so they are consumed within 20–30 minutes.

22. The use of feeding tray in shrimp production has proved to substantially reduce feed wastage. In particular, feeding trays are shown to result in less solid deposition and cleaner pond bottoms. This practice would help to reduce stress with less disease problem and faster growth. The use of feeding tray also helps the farmers to compute the amount of feed that shrimp will eat at the time of feeding and thus the farmers can use more or less exact amount of feed enabling them to reduce feed conversion ratio. ***Therefore use of feeding tray in ghers should be strongly encouraged***.

23. ***Alfalfa (Medicago sativa) farming should be introduced in Bangladesh***. Alfalfa meal is one of the best plant sources of protein, calcium and other minerals, and vitamins (B, C, D, E and K), and can be very effectively used to prepare shrimp feed at a much lower cost. Alfalfa has been farmed in many countries and can be easily farmed in Bangladesh, if farmers are encouraged to grow it on pond and *gher* dykes, for example.

5. Conclusions

The economic benefits of shrimp farming, particularly foreign exchange earnings and provision of employment, are highly important to the Bangladesh economy. There is, however, a need to minimize further its social and environmental costs, which can be achieved in particular through more effective enforcement of current regulations.

Many studies indicate that shrimp aquaculture has contributed to the overall degradation of mangroves in Bangladesh's coast, particularly in southeast coastal areas, where shrimp farm expansion has been responsible for substantial removal of mangrove from the Chakaria Sundarbans. It is critical that remaining mangrove in this area and all other areas across Bangladesh is not damaged as a result of further expansion of shrimp farming. Indeed, conservation and re-expansion of mangrove should be encouraged where possible.

Saline water is destructive to freshwater systems in coastal areas and there has been a large increase in salinity intrusion inland. Whilst the level of salinity has to be maintained in shrimp farms, to ensure good production, this must be done without affecting additional agricultural land and freshwater systems and compromising environmental sustainability. Proper and effective drainage systems need to be introduced to maintain water quality and discharge effluents from shrimp farms and dyke systems need to be improved to ensure agricultural land is not salinized further. Saline tolerant rice and other crops need to be introduced in shrimp cultivation areas to boost these local economies and improve livelihoods further.

The current wild harvest of shrimp post-larvae is unsustainable and hatchery supplies need to replace wild-caught PL as the main sources of both bagda and golda. This will require an improvement in the quality of hatchery produced stocks and traceability systems that enable the source to be identified and would increase marketing of hatchery-produced PL to skeptical farmers. Golda PL producers, in particular, need to improve supply and be able to satisfy increasing demand. Golda hatcheries will need technical support to achieve this. Introduction of a better system of hatchery production that strives for a quality product and thus its transportation to farmers in good condition would drastically reduce the reliance on wild bagda and golda PL, particularly golda, which is currently in undersupply from hatchery stocks.

The depletion of floodplain (*beel*) area has reduced fish stocks and livestock numbers dramatically, and lack of access across shrimp farms has affected livelihoods of fishers in particular. Unplanned polders and dams resulted in increased siltation of canals and rivers and waterlogging of land with salt water. Waterlogging affects crop production, tree plantation and availability of pasture for livestock. Waterlogging is also caused by poor flood control drainage and irrigation structures, uncontrolled land grabbing, road construction, prevention of drainage, and extreme events like cyclones Aila and Sidr. Saline water from the sea finds its way into wetland ecosystem including swamps, canals and rivers during the diurnal tidal cycle and hence, intrudes further inland, in part as consequence of sea level rise because of climate change. The result is that migratory fishes are not getting access to these needed areas and are unable to breed, and consequently the capture fishery production has been drastically reduced. It reduces the availability of fuel for people, and vegetation for livestock. The longer-term and wide-ranging effects of unplanned polders and shrimp farming on drainage, fish migration and wetland ecosystems require further research.

Chemicals and pesticide use in aquaculture have substantially been reduced due to the initiatives of various Government and development partners and by greater compliance to good aquaculture practices. However, residues often remain present from run-off of increased agricultural pesticides used in vegetable and crop fields and poultry, which are damaging the aquatic environment. Measures to control the use of drugs and chemicals have to be adopted across the spectrum of food production. Through the life cycle analysis work undertaken, it is implicit that various aquaculture activities contribute to greenhouse gas emissions and global warming potential. There remains a need to fully quantify and reduce the contribution from different activities of different aquaculture systems. The inefficiencies in material flows, such as the use of fuel in water exchange, use of antibiotics, fertilizers, pesticides and other chemicals, poor feed conversion ratios, hatchery activity, transportation, processing and others needs to be properly analyzed and made more efficient.

In recent years, the shrimp farming communities in coastal Bangladesh have established themselves as an important part of the national economy. Attempts have been made to avoid many of the negative effects that were associated with shrimp farming in the early days, and shown that it can be a sustainable method of farming; accessible not only to rich elites, but also to middle and poorer classes. Despite early and continued issues, shrimp farming and broader aquaculture interventions have improved child nutrition, health, socio-economic condition and livelihoods of the coastal people compared against rice only farming in the past. There is, however, more work to be done, especially in improvement of poorer farmers and for example to stop rural migration to urban areas. Department of Fisheries of the Government of Bangladesh along with other relevant ministries, International NGOs such as FAO, UNDP and WorldFish and other NGOs, policy makers and all other stakeholders need to continue to work together to ensure improvement in quality of production, and equitable distribution of the benefits of shrimp farming across the community as a whole, which will result in better standards of living for the majority of the coastal population.

Women are already playing an important role in shrimp farming, undertaking many of the same activities as the men. As a result, women are becoming more empowered, more mobile, and more involved in family decision making on economic and other issues. They are recognized within their communities as key players in the shrimp revolution. Gender balance is a long way off, but the future holds promise on gender issues in aquaculture communities, but there are many challenges ahead.

The major recommendation of the LCA study (section 3.14) was to emphasize shrimp farming based on natural food by optimizing primary productivity along with the provision of supplementary feed prepared by environmental friendly feed ingredients to ensure both economic and environmental sustainability

In section 4, a number of recommendations have been made that will improve production and the steps necessary to stop the further degradation of coastal ecosystems and the environment. A number of policy measures are recommended to increase enforcement and to decrease the environmental and social costs of shrimp farming in Bangladesh. These measures have primarily focused on environmental protection, with some additional measures on biological (species and genetic diversity, quality of different habitats) and social (peoples' right, food and nutritional security, gender issue and communal harmony) issues. Further measures will need to be undertaken to improve the overall environmental, biological and social sustainability of shrimp aquaculture in Bangladesh. Access to interest free or minimal interest credit through institutional reform could help transform the shrimp farming sector, particularly for the poor or marginal shrimp famers and PL harvesters and traders. This will also prevent maladaptation and diversify livelihood strategies as well as reduce the cost of farming. Institutional reform can also improve enforcement of laws and regulations on PL and broodstock harvesting, fish preservation, fish feed and hatchery requirement, for example. Enforcement of regulations, and provision of insurance, would increase security of livelihoods for shrimp farmers. Building upon shrimp farmer's human capital and the creation of alternative activities to improve income would help diversify livelihoods.

Both internal and external factors pose obstacles to adaptation and some barriers are reinforced by others. To overcome these barriers, adaptations should be planned in multiple scales. Modernization of shrimp farming techniques and technologies and improvement of overall management at all level of the value chain could reduce risk and improve responses to adverse situation. Above all, scientific research, outreach and extension initiatives have to be undertaken in order to identify better solutions to overcome environmental and other issues imparted by shrimp cultivation. Implementation of this endeavor needs the support of government and other partners to ensure implementation is done in a consistent and coordinated way, for the benefit of all relevant peoples and the environment.

6. References

Accenture. 2013. *Exploitative Labour Practices in the Global Shrimp Industry*. (available at http://humanityunited.org/pdfs/Accenture_Shrimp_Report.pdf).

Ahmed, N. 2013. Linking prawn and shrimp farming towards a green economy in Bangladesh: confronting climate change. *Ocean and Coastal Management*, 75: 33–42.

Ahsan, M. 2010. *Saline Soils of Bangladesh*. SRMAF Project, Soil Resource Development Institute (SRDI), Ministry of Agriculture, Government of the People's Republic of Bangladesh. 62 pp. (available at http://srdi.portal.gov.bd/sites/default/files/files/srdi.portal.gov.bd/publications/bc598e7a_df21_49ee_882e_0302c974015f/Soil%20salinity%20report-Nov%202010.pdf).

Akber, M.A., Islam, M.A., Ahmed, M., Rahman, M.M. & Rahman, M.R. 2017. Changes of shrimp farming in southwest coastal Bangladesh. *Aquaculture International,* DOI 10.1007/s10499-017-0159-5.

Alam, M.S., Shamsuddin, S.D. & Sikder, S. 1990. Application of remote sensing for monitoring shrimp culture development in a coastal mangrove ecosystem in Bangladesh. *In Proceedings of the Twenty Third International Symposium on Remote Sensing of Environment*, 18–25 April 1990, Bangkok, Thailand, pp. 109–119.

Alam, S. 2013. Conversion of mangrove forest to saline desert: a case study of Chakaria Sundarban area. *Development Compilation,* 8: 55–66.

Alam, S., Hossain, M.L., Foysal, M.A. & Misbahuzzaman, K. 2014. Growth performance of mangrove species in Chakaria Sundarban. *International Journal of Ecosystems*, 4: 233–238.

Alam, S., Pokrant, B., Yakupitiyage, A. & Phillips, M. 2007. Economic Returns of Disease Affected Extensive Shrimp Farming in Southwest Bangladesh. *Aquaculture International*, 15(5): 363–370.

Alam, S.M.N. & Phillips, M.J. 2004. Coastal shrimp aquaculture systems in Southwestern Bangladesh. *Asian Fisheries Science*, 17: 175–189.

Alauddin, M. & Hamid M.A. 1996. *Shrimp Culture in Bangladesh, Sustainable and Research Issues.* NACA and ACIAR Workshop on Key Researchable Issues in Sustainable Shrimp Aquaculture, Songkhla, Thailand, 28-31 October 1996.

Ali, A.M.S. 2006. Rice to shrimp: land use/land cover changes and soil degradation in Southwestern Bangladesh. *Land Use Policy*, 23: 421–435.

Ali, H., Rico, A., Murshed-e-Jahan, K. & Belton, B. 2016. An assessment of chemical and biological product use in aquaculture in Bangladesh. *Aquaculture,* 454: 199–209.

Anwar, S.M. 2003. *Effect of Shrimp Culture on Ecology in the Coastal Areas of Bangladesh*. Human Landscape Ecology (MNFEL 330). 18 pp. (available at www.scribd.com/document/53695320/Effect-of-Shrimp-Culture).

Azad, A.K., Lin, C.K. & Jensen, K.R. 2007. Wild Shrimp Larvae Harvesting in the Coastal Zone of Bangladesh: Socio-economic Perspectives. *Asian Fisheries Science,* 20: 339–357.

Baidya, **S. & Borken-Kleefeld J.** 2009. Atmospheric emissions from road transportation in India. *Energy Policy,* 37: 3812–3822.

Barraclough, S. & Finger-Stich A. 1996. *Some ecological and social implications of commercial shrimp farming in Asia*. UNRISD Discussion Paper 74. United Nations Research Institute for Social Development. 62 pp. (available at http://unrisd.org/UNRISD/website/document.nsf/ab82a6805797760f80256b4f005da1ab/a90a3147dd72acc480256b67005b6935/$FILE/dp74.pdf).

Barraza-Guardado, R.H., Arreola-Lizárraga, J.A., Miranda-Baeza, A., Juárez-García, M., Juvera-Hoyos, A. & Casillas-Hernández, R. 2015. Enhancing Ecoefficiency in Shrimp Farming through Interconnected Ponds. *BioMed Research International*, 1: 1–10.

BBC. 2004. *Shrimp farms 'harm poor nations'*. Science/Nature. Story from BBC NEWS: (available at http://news.bbc.co.uk/1/hi/sci/tech/3728019.stm). Published: 19.05.04 15:43:20 GMT. © BBC 2015.

Bergheim, A., Wahab, M.A. & Braaten, B. 2003. Mass budget of nutrients in extensive shrimp culture, GherSoladana in Khulna region, Bangladesh. *In* M.A.Wahab, ed. *Environmental and Socioeconomic Impacts of Shrimp Farming in Bangladesh*, pp. 33–38. Technical Proceedings of the BAU-NORAD Workshop, Bangladesh, Dhaka. 101 pp.

Bhattacharya, D., Rahman, M. & Khatun, F.A. 1999. *Environmental Consequences of Structural Adjustment: Towards Sustainable Shrimp Culture in Bangladesh*. Centre for Policy Dialogue, Bangladesh. CDP Occasional Paper Series No. 2, 37 pp. (available at http://scribd.com/document/23441069/Sustainable-Shrimp-Productivity-in-Bangladesh).

BPDB. 2011. *Annual Report 2009-2010*, Bangladesh Power Development Board, Dhaka, Bangladesh. 98 pp.

Braaten, B. 2002. *Environmental and socio-economic impacts of shrimp farming in Bangladesh*. Status Report - March 2002 (2nd Phase). Norwegian Institute of Water Research (NIVA) & Norwegian Agency for Development Cooperation (NORAD). 55 pp. (available at https://brage.bibsys.no/xmlui/bitstream/handle/11250/211708/4534_200dpi.pdf?sequence=2&isAllowed=y)

Briggs, M.R.P. & Funge-Smith, S.J. 1994. A nutrient budget of some intensive marine shrimp ponds in Thailand. *Aquaculture and Fisheries Management*, 10: 789-811.

Cao, L, Diana J.S., Keoleian, G. & Lai, Q. 2011. Life Cycle Assessment of Chinese Shrimp Farming Systems Targeted for Export and Domestic Sales. *Environmental Science & Technology,* 45: 6531–6538.

Caritas. 1996. *Ownership and Participation in shrimp culture under the Third Fisheries Project (shrimp component).* 2-Outer Circular Road, Shantibagh, Dhaka, Bangladesh. 42 pp.

CEGIS. 2015. *Final Report on Environmental Impact Assessment (EIA) on Rehabilitation of Polder 30*. (available at http://bluegoldbd.org/wordpress/wp-content/uploads/2016/06/EIA-Report-of-Polder-30-CEGIS.pdf). Dhaka, Bangladesh, 256 pp.

Chen, S.Q., Li, X.Q., Li, Z.X. & Zhai, Y.X. 1995. The loss of nutrients of shrimp formulated diet soaked in water and its effects on the water environment. *Journal of Fisheries Science China*, 2: 40–47.

Chowdhury, M.A., Shivakoti, G.P. & Salequzzaman, M. 2006. A conceptual framework for the sustainability assessment procedures of the shrimp aquaculture industry in coastal Bangladesh. *International Journal of Agriculture Resources, Governance & Ecology,* 5: 162–184.

Chowdhury, M.H. 1999. *Study on Thana level Snail Trading System*. A study report of GOLDA Project, CARE Bangladesh, Dhaka, Bangladesh.

Clay, J.W. 1997. Towards sustainable shrimp culture. *World Aquaculture,* 23(2): 32–37.

Cowan, J.M. 1926. Flora of Chakaria Sundarbans. *Records of the Botanical Survey of India*, pp. 197–226.

Datta. D.K. 2001a. *Ecological role of freshwater apple snail Pila globosa and the consequences of its over harvesting from the beel ecosystem of Bagerhat and Gopalgonj district.* A study report, Khulna University and GOLDA Project, CARE Bangladesh, Dhaka, Bangladesh.

Datta, A. 2001b. Who Benefits and at What Costs? Expanded Shrimp Culture in Bangladesh, Grassroots Voice. *Journal of Indigenous Knowledge and Development*, 3: 12–18.

Deb, A.K. 1998. Fake blue revolution: environmental and socio-economic impacts of shrimp culture in the coastal areas of Bangladesh. *Oceans & Coastal Management*, 41: 63–88.

Debnath, P., Khan, S.H., Karim, M., Belton, B., Mohan, C.V. & Phillips, M. 2015. Review of the history, status and prospects of the black tiger shrimp (*Penaeus monodon*) hatchery sector in Bangladesh. *Reviews in Aquaculture*, 8: 301–313.

Dewalt, B.R., Vergne, P. & Hardin, M. 1996. Shrimp aquaculture development and the environment: people, mangroves and fisheries on the Gulf of Fonseca, Honduras. *World Development*, 24: 1193–1208.

DeWalt, B.R., Ramírez Zavala, J.R., Noriega, L. & González, R.E. 2002. Shrimp Aquaculture, the People and the Environment in Coastal Mexico. Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Published by the Consortium. 73 pp.

DFID. 2011. *Energy Efficient Inland Water Transport in Bangladesh*, The International Bank for Reconstruction and Development/The World Bank 1818 H Street NW Washington DC 20433. 115 pp.

Diana, J.S. 2009. Aquaculture production and biodiversity conservation. *Bioscience*, 59: 27–38.

DoF. 2007. *Annual Report (2005–2006)*, Department of Fisheries, Dhaka, Bangladesh.

DoF. 2013. *National Fish Week 2013 Compendium* (in Bengali). Department of Fisheries, Dhaka, Bangladesh. 144 pp.

DoF. 2014. *Annual Report 2013*. Department of Fisheries, Dhaka, Bangladesh. 70 pp.

DoF. 2014. *National Fish Week Compendium*. Annual Report, Department of Fisheries, Dhaka, Bangladesh. 144 pp.

DoF. 2015. *National Fish Week 2015 Compendium* (in Bengali). Department of Fisheries, Dhaka, Bangladesh. 148 pp.

DoF. 2016. *National Fish Week 2016 Compendium* (in Bengali). Department of Fisheries, Dhaka, Bangladesh. 148 pp.

DoF. 2017. *National Fish Week 2017 Compendium* (in Bengali). Department of Fisheries, Ministry of Fisheries and Livestock, Bangladesh. 160 pp.

DoF-DFID. 2001. *Shrimp Producers' Livelihood Study*. Feasibility Study for the Shrimp Component of the Fourth Fisheries Project. Department of Fisheries, Dhaka, Bangladesh. 59 pp.

EJF. 2004. *Farming the Sea, Costing the Earth: Why We Must Green the Blue Revolution*. Environmental Justice Foundation Series Report, London, UK. 11 pp.

EJF. 2014. *Impossibly Cheap: Abuse and Injustice in Bangladesh's Shrimp Industry*. (https://ejfoundation.org/report/impossibly-cheap-abuse-and-injustice-bangladesh%e2%80%99s-shrimp-industry, accessed May 2017).

Esha, R.I. & Khan, M.S.M. 2016. *Characterization of open channel flow parameters of the river Gorai*. Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development (ICCESD 2016), 12-14 February 2016, KUET, Khulna, Bangladesh.

FAO. 1995. *Code of Conduct for Responsible Fisheries*. Rome. 41 pp.

FAO. 1997. *Disease Prevention and Health Management of Coastal Shrimp Culture.* TCP/BGD/6714, Field document 1. Bangkok.

FAO. 2012. *The State of World Fisheries and Aquaculture 2012*. Rome. 209 pp.

FAO. 2014. *The State of World Fisheries and Aquaculture 2014*. Rome. 223 pp.

FAO. 2016a. *Aquaculture Big Numbers*, by M. Phillips, R.P. Subasinghe, N. Tran, L. Kassam & C.Y. Chan. FAO Fisheries and Aquaculture Technical Paper No. 601. Rome. 60 pp.

FAO. 2016b. *Fisheries Statistics in Bangladesh: Issues, Challenges and Plans*. APCAS/16/6.3.2. Asia and Pacific Commission on Agricultural Statistics. 12 pp. (http://www.fao.org/fileadmin/templates/ess/documents/apcas26/presentations/APCAS-16-6.3.2_-_Bangladesh_-_Fisheries_Statistics_in_Bangladesh.pdf accessed at 25 September, 2017).

FFP (Fourth Fisheries Project). 1999. *Fourth Fisheries Project, Project Proforma*. Department of Fisheries, Bangladesh, 203 pp.

Flaherty, M. & Karnjanakesorn, C. 1995. Marine shrimp aquaculture and natural resource degradation in Thailand. *Environmental Management*, 19: 27–37.

Flaherty, M., Szuster, B. & Miller, P. 2000. Low salinity inland shrimp farming in Thailand. *Ambio*, 29: 174–179.

Funge-Smith, S.J. & Briggs, M.R.P. 1998. Nutrient budgets in intensive shrimp ponds: implications for sustainability. *Aquaculture*, 164: 117–133.

Gain, A.K., Uddin, M.N. & Sana, P. 2008. Impact of river salinity on fish diversity in the south-west coastal region of Bangladesh. *International Journal of Ecology & Environmental Science*, 34: 49–54.

Gain, P., Sircar, L., Moral, S., Malik, A., Kofel, P. & Kamruzzaman, M. 2005. *Shrimp fry collection and its trade.* Society for environment and human development (SEHD) 1/1 Pallabi (5th floor), Mirpur, Dhaka-1216, Bangladesh. 57 pp.

Ghafur, A., Kamal, M., Dhaly, M.R. & Khatun S. 1999. *Socio-Economic and Environmental Impact of Shrimp Culture in South-western Bangladesh: An Integrated Approach*. Proshika, Dhaka, Bangladesh.

Glass, J. 2013. *Amid Perfect Storm of Climate Challenges, Can Aquaculture Net Food Security Gains in Bangladesh?* New Security Beat. The blog of the Wilson Center's Environmental Change and Security Program. (available at www.newsecuritybeat.org/2013/10/perfect-storm-climate-challenges-aquaculture-net-food-security-gains-bangladesh/)

Hagler, M . 1997. *Shrimp: The Devastating Delicacy: the explosion of shrimp farming and the negative impacts on people and the environment.* Green Peace Report, Greenpeace USA, 28 pp.

Hagler, M., Gianni, M. & Lorenzo, C. 2009. *Shrimp: The Devastating Delicacy: The Explosion of Shrimp Farming and the Negative Impacts on People and the Environment*. Greenpeace report, Greenpeace and University of California, USA.

Hall, D. 2004. Explaining the diversity of Southeast Asian shrimp aquaculture. *Journal of Agrarian Change*, 4: 315–335.

Hasan, M.N., Hossain, M.S., Bari, M.A. & Islam, M.R. 2013. *Agricultural land availability in Bangladesh*. SRDI, Dhaka, Bangladesh, 42 pp. (available at http://www.academia.edu/27165446/Agricultural_land_availability_in_Bangladesh).

Henriksson, P., Pelletier, N., Troell, M. & Tyedmers, P.H. 2011. Life Cycle Assessment and Its Application to Aquaculture Production Systems. *In* R.A. Meyers, ed. *Encyclopedia of Sustainability Science and Technology*: 5893–5909.

Henriksson, P.J.G., Guinée J.B., Kleijn R. & de Snoo, G.R. 2012. Life cycle assessment of aquaculture systems-a review of methodologies. *International Journal of Life Cycle Assessment,* 17(3): 304–313.

Hensler, L. 2013. *A sustainable future for shrimp production in Bangladesh?* SEAT - Sustaining Ethical Aquaculture Trade. 19 pp. (available at http://seatglobal.eu/wp-content/uploads/2013/04/A-Sustainable-Future-for-Bangladeshi-Shrimp.pdf).

Hossain, M.A.R. 2013. *Changes in aquatic animal farming and natural aquatic animal abundance over last 10 years in selected parts of South-western coast of Bangladesh*. Practical Action –Bangladesh. House # 12/B Road # 4, Dhanmondi R/A, Dhaka – 1209, Bangladesh. 54 pp.

Hossain, M.A.R., Kabir, H., Faruque, A.M.O. and Hossain, M. 2015a. *Assessment of Agro-ecological zone specific risks, vulnerabilities of disaster and climate change and Climate Change Adaptation (CCA) in fisheries sector of Bangladesh*. Report on Disaster and Climate Risks Management in Fisheries Project, Department of Fisheries/CDMP-II, Matshya Bhaban, Ramna, Dhaka 1000, Bangladesh.

Hossain, M.A.R., Kabir, H., Faruque, A.M.O. & Hossain, M. 2015b. Livelihood security: implications from aquaculture sectors. *In* U. Habiba, M.A. Abedin, A.W.R. Hassan & R. Shaw, eds. *Food security and risk reduction in Bangladesh*. Springer Publication Tokyo-Heidelberg- New York- Dordrecht- London, pp. 83–109. (researchgate.net/publication/275553418_Livelihood_Security_Implications_from_Aquaculture_Sectors).

Hossain, M.S., Kwei, C. & Hussain, M.Z., 2001. Goodbye Chakaria Sunderban: The Oldest Mangrove Forest. *Society of Wetland Scientists Bulletin*, pp. 19–22.

Hossain, M.S., Uddin, M.J. & Fakhruddin, A.N.M. 2013. Impacts of shrimp farming on the coastal environment of Bangladesh and approach for management. *Reviews in Environmental Science and Bio/Technology*, 12: 313–332.

Huntington, T.C. 2003. *Environmental Issues in Shrimp Farming in Bangladesh*. ARDMCS, Dhaka, Bangladesh. 24 pp.

Hussain, M.G. & Hoq, M.E., eds. 2010. *Sustainable Management of Fisheries Resources of the Bay of Bengal- Compilation of national and regional workshop reports*. Support to Sustainable Management of the BOBLME Project, Bangladesh Fisheries Research Institute. SBOBLMEP Pub./Rep. 2. 122 pp.

IEA. 2009. *Bangladesh: Electricity and Heat for 2009, Statistical data*. (available at http://www.iea.org/statistics/statisticssearch/report/?country=BANGLADESH&product=electricityandheat&year=2009).

IIED. 2003. *Investment mechanisms for socially and environmentally responsible shrimp culture.* Nautilus Consultants Ltd. in association with the International Institute for Environment and Development. 160 pp.

IPCC (Intergovernmental Panel on Climate Change). 2008. *2006 IPCC Guidelines for National Greenhouse Gas Inventories*. *In* H.S. Eggleston, K. Miwa, N. Srivastava & K. Tanabe, eds. Institute for Global Environmental Strategies (IGES), Japan, Kanagawa. 20 pp.

IRIN. 2013. *Rethinking how to help water-logged communities in Bangladesh*. Integrated Regional Information Networks, Khulna, October 17, 2013.

Islam, M.A., Sattar, M.A. & Alam, M.S. 1998. *Impact of Shrimp Farming on Soil and Water Quality of Some Selected Areas in the Greater Khulna District*. Research and Development Collective, Dhaka, Bangladesh.

Islam, M.S. 2003. Perspectives of the coastal andmarine fisheries of the Bay of Bengal, Bangladesh. *Ocean & Coastal Management,* 46: 763–796.

Islam, S. 1999. *Impact of Gher Farming on Agriculture and Livestock: a study report.* Golda Project, CARE Bangladesh, Dhaka, Bangladesh.

Islam, S. 2001. *Study on beel fisheries in gher farming areas under Bagerhat district*. Golda Project, CARE Bangladesh, Dhaka, Bangladesh.

Islam, S., Dutta, G.C., Chowdhury, M.H. 2001. *Environmental impact of catching PL (Post Larvae) of prawn and shrimp from coastal areas*. Golda Project, CARE Bangladesh, Dhaka, Bangladesh. 9 pp.

Islam, S.M.D. & Bhuiyan, M.A.H. 2016. Impact scenarios of shrimp farming in coastal region of Bangladesh: An approach of an ecological model for sustainable management. *Aquaculture International,* 24(4): 1163-1190.

ISO. 2006a. *Environmental management-Life cycle assessment-Principles and framework* (ISO 14040:2006). International Organization for Standardization, Geneva, Switzerland. 32 pp.

ISO. 2006b. *Environmental management-Life cycle assessment-Requirements and guidelines* (ISO 14044:2006). International Organization for Standardization, Geneva, Switzerland. 58 pp.

Ito, S. 2002. From rice to prawns: economic transformation and agrarian structure in rural Bangladesh. *The Journal of Peasant Studies*, 29: 47–70.

Jannat, M., Ahmed, M.K., Kundu, G.K., Islam, M.M. & Kamruzzaman, M. 2017. Shrimp Post-Larvae Nursing in Earthen Ponds, Bangladesh. *Journal of Scientific Research,* 9(1): 97–107.

Kabir, M.H. & Eva, I.J. 2014. Ecological Consequences of Shrimp Farming In Southwestern Satkhira District of Bangladesh. *Austin Journal of Earth Science*, 1: 1–7.

Kanduri, L. & Eckhardt, R.A. 2008. *Food Safety in Shrimp Processing: A Handbook for Shrimp Processors, Importers, Exporters and Retailers*. John Wiley & Sons, United Kingdom. 184 pp.

Karim, M.R. 2003. Present status and strategy for future development of shrimp farming in Bangladesh. *In* M.A. Wahab, ed. *Environmental and Socioeconomic Impacts of Shrimp Farming in Bangladesh*, pp. 1-8. Technical Proceedings of the BAU-NORAD Workshop, Dhaka, Bangladesh, Dhaka. 101 pp.

Khan, G., Islam, M.S., Mustafa, M.G. Sada, M.N. & Chowdhury, Z.A. 1994. *Biosocioeconomic assessment of the effect of estuarine set bagnet on the marine fisheries of Bangladesh*. Bay of Bengal Programme (BOBP/WP/94), Madras, India 28 pp. (Summary available at http://fao.org/docrep/007/ae473e/ae473e00.htm).

Khan, M.M. & Azad, M.A. 2014. The nexus between local politics and salinity intrusion in coastal area of Bangladesh: Unveiling the development myth. *Global Journal of Sociology*, 4(2), 29–40.

Khan, Y.S.A. & Hossain, M.S. 1996. Impact of shrimp culture on the coastal environment of Bangladesh. *International Journal of Ecology and Environmental Sciences,* 22: 145–158.

Khor, M. 1995. Protests over shrimp farms spread throughout India. *Third World Resurgence,* 59: 8–10.

Kungvankij, P., Chua, T.E., Pudadera Jr, B.J., Corre, G., Borlongan, E., Alava, Tiro Jr, L.B., Potestas, I.O., Taleon, G.A. & Paw, J.N. 1986. *NACA Training Manual Series No. 2: Shrimp culture: Pond design, Operation and Management.* Food and Agriculture Organisation of the United Nations, Rome and Regional Lead Centre in the Philippines of the Network of Aquaculture Centres in Asia (NACA). 68 pp. (available at www.fao.org/docrep/field/003/AC210E/AC210E00.htm).

Mahmood, S.M. S. & Ansary, B.S. 2013. Shrimp Fry Collection as Alternative Livelihood: A Case Study on the Southwest Coastal Region of Bangladesh. *ASA University Review,* 7(2): 139–149.

Manju, T. 1996. *Political Economy of Shrimp Culture in Bangladesh*. Poverty Research Report 13, Grameen Trust, Grameen Bank, Dhaka.

Masum, S.J.A. 2008. *Working Together for Responsible & Eco-friendly Shrimp Farming in Bangladesh - Exploring Corporate Environmental Responsibility (CER) & Corporate Social Responsibility (CSR) in the context of Commercial Shrimp Sector in Bangladesh*. Coastal Development Partnership (CDP) With assistance from the EGP (Ecosystem Grants Program) of IUCN NL (the Netherlands Committee of the IUCN). 29 pp.

Mazid, M.A., & Banu, A.N.H. 2002. An overview of the social and economic impact and management of fish and shrimp disease in Bangladesh, with an emphasis on small-scale aquaculture. p. 21-25. *In:* J.R. Arthur, M.J. Phillips, R.P. Subasinghe, M.B. Reantaso and I.H. MacRae. (eds.) *Primary Aquatic Animal Health Care in Rural, Small-scale, Aquaculture Development*. FAO Fisheries Technical Paper No. 406. Rome, FAO. 382 pp.

Mia, A.H. 2004. *Proceeding of Technical Discussion on Coastal Land Zoning*. Integrated Coastal Zone Management Plan Project. Working Paper WP031. PDO-ICZMP, Dhaka, Bangladesh. 78 pp.

Morf, S. 2014. *Impacts of Shrimp Farming in Southwest Bangladesh: Challenges for Poverty Alleviation*. Essay on Development Policy, Dhaka, Bangladesh. 16 pp. (available at www.ethz.ch/content/dam/ethz/special-interest/gess/nadel-dam/documents/mas/mas-essays/MAS_2012_Morf_Silvia.pdf)

Nahid, S.A.A. 2014. *Life Cycle Assessment of Freshwater Prawn Farming in Bangladesh for Sustainable Trade*. PhD dissertation, Bangladesh Agricultural University, Mymensingh, Bangladesh. 152 pp.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folke, C., Lubchenco, J., Mooney, H. & Troell, M. 2000. Effect of aquaculture on world fish supplies. *Nature,* 405: 1017–1024.

Nemecek, T. & Schnetzer, J. 2011. *Methods of assessment of direct field emissions for LCIs of agricultural production systems*. Data Quality guideline for Ecoinvent version 3. Zurich. 34 pp.

Nijera Kori. 1996. *The Impact of Shrimp Cultivation on Soils and Environment in Paikgacha Region*. Nijera Kori, Khulna, Bangladesh..

Nuruzzaman, M. 2002. *Status of shrimp hatchery and nursery operations in Bangladesh*. Output of the Shrimp Action Plan, DFIDB and Fourth Fisheries Project, 19 pp.

Nuruzzaman, M. 2006. Dynamics and Diversity of Shrimp Farming in Bangladesh: Technical Aspects. *In* A. Atiq Rahman, A.H.G. Quddus, B. Pokrant and M. Liaquat Ali, eds. *Shrimp Farming and Industry: Sustainability, Trade and Livelihoods*, pp. 431–460. Bangladesh Centre for Advanced Studies (BCAS) and University Press Ltd., Dhaka, Bangladesh. 552 pp.

Nuruzzaman, M., Anwary, B., Shahjahan, M. & Maniruzzaman, M. 2001. *The Dynamics and Diversity of Shrimp Farming in Bangladesh*. Shrimp Sector Technical Review under the Fourth Fisheries Project (FFP), Dhaka, Bangladesh.

Paez-Osuna, F. 2001. The environmental impact of shrimp aquaculture: causes, effects, and mitigating alternatives. *Environmental Management*, 28: 131-140.

Paez-Osuna, F., Gracia, A., Flores-Verdugo, F., Lyle-Fritch, L.P., Alonso-Rodraguez, R., Roque, A. & Ruiz-Fernandez, A.C. 2003. Shrimp aquaculture development and the environment in the Gulf of California ecoregion. *Marine Pollution Bulletin,* 46: 806–815.

Paprocki, K. & Cons, J. 2014. Life in a shrimp zone: aqua- and other cultures of Bangladesh's coastal landscape. *The Journal of Peasant Studies,* 41(6): 1109–1130.

Paul, B.G. 2013. *Pathways towards organic aquaculture (shrimp): Challenges, potentials and risks under a livelihood perspective*. Doctoral Thesis, Division of Organic Farming Department of Sustainable Agricultural Systems. University of Natural Resources and Life Sciences, Vienna. Austria. 141 pp.

Paul B.G. & Vogl, C.R. 2011. Impacts of shrimp farming in Bangladesh: Challenges and alternatives. *Ocean and Coastal Management*, 54: 201–211.

PDO-ICZMP. 2004. *Where Land Meets the Sea: A Profile of the Coastal Zone of Bangladesh*. Program Development Office for Integrated Coastal Zone Management Plan. The University Press Limited, Dhaka, Bangladesh, 317 pp.

Potapov, P.V., Siddiqui, B.N., Iqbal, Z., Aziz, T., Zzaman, B., Islam, A., Pickens, A., Talero, Y., Tyukavina, A., Turubanova1 S. & Hansen, M.C. 2017. Comprehensive monitoring of Bangladesh tree cover inside and outside of forests, 2000–2014. *Environmental Research Letters*. (available at http://iopscience.iop.org/article/10.1088/1748-9326/aa84bb/pdf).

Pramanik, MAH. 1986. *The dynamics of coastal processes and land use changes*. Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Dhaka, Bangladesh.

Rahman, A., Islam, M.A., Roy, I., Azad, L. & Islam, K.S. 1994. *Shrimp culture and the environment in the coastal region*. Bangladesh Institute of Development Studies. E-17, Agargaon, Sher-e-Bangla Nagar, GPO Box 3854, Dhaka, Bangladesh. 124 pp.

Rahman, M.M., Flitner, M. & Krause, G. 2009. Environmental assessment of shrimp farming in relation to livelihoods in the south-west coastal Bangladesh. *Bangladesh Journal of Fisheries Research,* 13(1): 47–54.

Rahman, M.M., Giedraitis, V.R., Lieberman, L.S., Akhtar, T.M. & Taminskienė, V. 2013. Shrimp Cultivation with Water Salinity in Bangladesh: The Implications of an Ecological Model. *Universal Journal of Public Health,* 1: (3): 131–142.

Sen, J. 2008. *Resent status of biosecurity maintenance in Penaeus monodon hatcheries of Cox's Bazar, Bangladesh*. MS Dissertation, Institute of Marine Sciences & Fisheries, University of Chittagong, Chittagong-4331, Bangladesh.

Shahid, M.A. & Islam, J. 2003. Impact of denudation of mangrove forest due to shrimp farming on coastal environment in Bangladesh. *In* M.A.Wahab, ed. *Environmental and Socioeconomic Impacts of Shrimp Farming in Bangladesh*, pp. 49–60. Technical Proceedings of the BAU-NORAD Workshop, Bangladesh, Dhaka. 101 pp.

Shahid, M.A, Pramanik, M.A.H, Jabbar, M.A. & Ali, S. 1992. Remote sensing application to study the coastal shrimp farming area in Bangladesh. *Geocarto International,* 7: 5–13.

Shamsuzzaman, M.M. & Biswas T.K. 2012. Aqua chemicals in shrimp farm: A study from south-west coast of Bangladesh. *Egyptian Journal of Aquatic Research*, 38: 275–285.

Shelton, C. 2014. *Climate change adaptation in fisheries and aquaculture – compilation of initial examples*. FAO Fisheries and Aquaculture Circular No. 1088. Rome, FAO. 34 pp.

Shipton, T.A. & Ali, Z. 2017. *Current status of chemical and feed additive use in the aquaculture industry in Bangladesh*. Unpublished Report of TCP/BGD/3501. Dhaka, FAO. 116 pp.

Sohel, M.S.I. & Ullah, M.H. 2012. Ecohydrology: a framework for overcoming the environmental impacts of shrimp aquaculture on the coastal zone of Bangladesh. *Ocean & Coastal Management,* 63: 67–78.

SRDI. 1997. *Land and Soil Resources Utilization Guide* (*Thana Nirdesika*). Soil Resources Development Institute, Dhaka, Bangladesh.

SRDI. 2003. *Soil Salinity in Bangladesh 2000*. Soil Resources Development Institute, Dhaka, Bangladesh. 114 pp.

Swapan, M.S.H., & Gavin, M. 2011. A desert in the delta: participatory assessment of changing livelihoods induced by commercial shrimp farming in Southwest Bangladesh. *Ocean & Coastal Management,* 54: 45–54.

Torikul, H. & Molla, J.U. 2013. *The plight of the shrimp post-larvae collectors*. The Financial Express. 22 Nov. 2013. Dhaka, Bangladesh.

Toufique, K.A. 2002. *Impact of Structural Adjustment Policies on the Environment in Bangladesh*. Bangladesh Institute of Development Studies (BIDS), Dhaka.

Tuong, T.P. & Hoanh, C.T. 2009. *Final report of the Coastal Lands Challenge Program Project No 10 Managing Water and Land Resources for Sustainable Livelihoods at the Freshwater/Saline Interface in Vietnam and Bangladesh*. CGIAR Challenge Programme on Water and Food. 93 pp.

Ullah, M.B. & Rahman, M.H. 2014. Assessing Vulnerability and Adaptation to Climate Change by Farming Communities in Southwestern Coastal Bangladesh. *Journal of Environmental Science and Natural Resources*, 7(2): 31–35.

UNEP. 1999. *Environmental Impacts of Trade Liberalization and Policies for the Sustainable Management of Natural Resources: A Case Study on Bangladesh's Shrimp Farming Industry*. UNEP, New York. 45 pp. (available at http://unep.ch/etb/publications/intAssessment/bangladesh.pdf).

UNEP. 2010. *Press Release: Mangroves among world's most valuable ecosystems- 'World Mangrove Atlas' highlights the importance of and threats to mangroves.* 14 July, 2010. 2 p. (available at http://inweh.unu.edu/wp-content/uploads/2013/05/Atlaspressrelease_20101.pdf).

UNESCO. 2011. *Sediment issues & sediment management in large river basins interim case study synthesis report*. International Sediment Initiative Technical Documents in Hydrology (CN/2011/SC/IHP/PI/2), UNESCO Office in Beijing & IRTCES. 82 pp. (available at http://unesdoc.unesco.org/images/0021/002128/212891e.pdf).

Wahab, M.A., Bergheim, A. & Braaten, B. 2003. Water quality and partial mass budget in extensive shrimp ponds in Bangladesh. *Aquaculture*, 218: 413-423.

Williams, D. & Islam. S. 1999. *Study report on impacts of gher farming on agriculture and livestock*. A study report of GOLDA Project, CARE Bangladesh, Dhaka, Bangladesh. 49 pp.

Williams, D. & Khan, N. 2001. *Freshwater prawn gher farming Systems: Indigenous technology developed in southwest*. A study report of GOLDA Project, CARE Bangladesh, Dhaka, Bangladesh. 17 pp.

World Bank. 2002. *Review of the current knowledge on coastal shrimp fry collection and its impact on biodiversity*. Fourth Fisheries Project. Department of Fisheries, Dhaka, Bangladesh. 85 pp.

World Bank, NACA, WWF and FAO. 2002. *Shrimp Farming and the Environment*. A World Bank, NACA, WWF and FAO Consortium Program 'To analyze and share experiences on the better management of shrimp aquaculture in coastal areas'. Synthesis report. Work in Progress for Public Discussion. Published by the Consortium. 119 pp.

WWF. 2016. *Farmed shrimp – Overview.* World Wildlife Fund, 1250, 24th Street, N.W. Washington, DC 20037, USA. (available at www.worldwildlife.org/industries/farmed-shrimp).

Yang, Q.X., Jiang, Y.W., Zhang, X.Y. & Yang, Y. 1999. Study on the effects of decomposition of the bait in a shrimp pond on the maricultural environment. *Marine Environmental Science*, 18: 11–15.

Zhou, N. & McNeil, M.A. 2010. *Assessment of Historic Trend in Mobility and Energy Use in India Transportation Sector Using Bottom-up Approach*. Lawrence Berkeley National Laboratory, USA. LBNL Paper LBNL-2415E. 24 pp.

Total farmed shrimp production in Bangladesh increased from 14 773 tonnes in 1986 to 132 730 tonnes in 2016. In parallel with contribution of the shrimp sector to the local and national economy of the country, it has caused some negative impacts on local ecosystems. This includes deterioration of soil and water quality, depletion of mangrove forest, decrease in population of native fish and shellfish species among others. There have also been some socio-economic consequences on the livelihood patterns of people living in coastal areas. At this stage, a paradigm shift is needed away from current shrimp farming practices to a more holistic and integrated approach that accounts for environmental integrity and social cohesion. In this paper, the ongoing measures to improve and streamline environmental performance of shrimp farming in Bangladesh are analyzed and a number of measures are proposed.

ISBN 978-92-5-130007-7 ISSN 2070-7010

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I8064EN/1/11.17