SUSTAINABLE AQUACULTURE ALLOCATION AND GOVERNANCE IN RELATION TO MARINE PROTECTED AREAS OF BANGLADESH

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Roll No. 0119/01

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Session: 2019-2020

A thesis submitted in the partial fulfillment of the requirements for the degree of Master of Science in Marine Bioresource Science

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APRIL 2021

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April 2021

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This is to certify that we have examined the above Master's thesis and have found that is complete and satisfactory in all respects, and that all revisions required by the thesis examination committee have been made.

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APRIL 2021

Dedicated

To my

Beloved parents

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The Author

April 2021

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LIST OF ABBREVIATIONS

BMD	Bangladesh Meteorological Department
CBD	Convention on Biological Diversity
DESA	Department of Economic and Social Affairs of United Nations
DoE	Department of Environment
DoF	Department of Fisheries
ECAs	Ecologically Critical Areas
EIA	Environmental Impact Assessment
FAO	Food and Agriculture Organization
GIS	Geographic Information System
ICZM	Integrated Coastal Zone Management
IMTA	Integrated Multi-Trophic Aquaculture
IUCN	International Union for Conservation of Nature
MoFA	Ministry of Foreign Affairs
MoFL	Ministry of Fisheries and Livestock
MPAs	Marine Protected Areas
MSP	Maritime Spatial Planning
NGOs	Non-Governmental Organizations
NRM	Natural Resource Management
PAs	Protected Areas
RS	Remote Sensing
SDGs	Sustainable Development Goals
SME	Small and Medium-Sized Enterprises
SoNG	Swatch of No Ground
TPA	Terrestrial Protected Areas
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
WCMC	World Conservation Monitoring Centre
WCS	Wildlife Conservation Society
WDPA	World Database on Protected Areas
WS	Wildlife Sanctuary

ABSTRACT

To meet the challenges of supplying food products, for the increasing demands of the growing population, the natural resources and biodiversity management need to focus on how and where the protein source can be exploited from. The wild fishery and aquaculture production are enhanced rationally to fulfill the increasing demand of protein and these are becoming the fastest growing food production system throughout the world. Concurrently, sustainable uses of those exploited resources should be assured for the perpetual supply of this important protein source. Convention on Biological Diversity suggested to conserve at least 10% of the total marine area by 2020 to protect the biodiversity and mitigate the ecological damage. Based on this, aquaculture reflects a positive and alternative way to be executed within the Marine Protected Areas (MPAs) to mobilize the coastal community for food production, upgrading socioeconomic condition and most importantly to minimize the extraction of excess natural resources. This study was designed to find out the possible best spatial setup for the sustainable aquaculture within the MPAs in Bangladesh. International Union for Conservation of Nature management classification for protected area was used to determine the suitability of aquaculture within the MPAs without conflicting the other management goals. This study proposes some new MPAs based on the critical environmental status along with current MPAs for Bangladesh. Different aquaculture practices are also suggested within these MPAs as a means of maritime spatial planning. Results are expressed in GIS based processed graphical canvas which found potential synergies between aquaculture and MPAs. Implementation of the result will be one of an important key tool for the growth of the blue economy of Bangladesh.

Keywords: Marine Protected Areas, Sustainable aquaculture, Maritime spatial planning, GIS, Blue economy

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

Bangladesh is a densely populated country with a limited food production facilities. According to the United Nations Development Programme (UNDP), the population of Bangladesh will reach between 230-250 million in 2050. Hence, sustainable management of natural resources and biodiversity have reached in the apex concern to fulfill the food demand of growing human population in Bangladesh. The consumption of animal food products and non-cereal crops will experience increasing trend during the next fewer decades. Bangladesh will have surplus productions of rice and maize by 2030 but will deficit productions of meat, egg and fish (Islam and Talukder, 2017). Thus, the necessity to increase the production of enough food, energy and other required products from sustainable sources emerges to challenge the upcoming demand gap (Searchinger *et al*., 2019).

To continue the increasing food production, attention is steadily being pinched to aquaculture as one option to meet this predicted shortfall. Seafood will have to be produced on more considerable and synchronized scale from oceans, in order to ensure food security (Troell *et al*., 2014). It is projected that aquaculture in 2025 will supply 52% of fish for human food (FAO, 2016a). In the meantime, the requirement for marine conservation turn into more important as the increase of some human activities directly portends ocean biodiversity, ecosystem services and aquatic food security (Laffoley & Baxter, 2016). Furthermore, global changes, including climate change, have been shown to significantly impact marine systems. Therefore, the establishment of marine protected areas (MPA) is a key implement that may assist the various Aichi targets to be met. For example, the Aichi target number 6, 7, 10 and 11 is focused to achieve the sustainable stock of fish and invertebrate and aquatic plants, ensuring conservation of biodiversity, reducing anthropogenic pressures on coral reefs and ensuring 10 percent of coastal and marine areas under conservation measures respectively (CBD, 2010).

UNDP proposed to conserve and sustainably use the oceans, seas and marine resources for sustainable development on their goal number 14 of Sustainable Development Goals (SDGs). This goal indicate targets for managing and protecting life below water. Besides this direct statement linked to maritime sustainability, several more Sustainable Development Goals of UNDP are circuitously indicate the relationship between the

potential aquaculture and the oceans sustainability. Such as, goal number 1 was aimed to end poverty in all its forms everywhere around the world; goal number 2 was aimed to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. The major objective of alleviating poverty and food and nutritional security from goal number 1 and 2 respectively can be able to achieve by aquaculture in the maritime territory (UNDP, 2015).

Most marine aquaculture activities are situated in coastal regions and have a sturdy correspondence with conservation benefits as both MPAs and aquaculture are highly reliant on decent water quality. Consequently, based on the intertwined affiliation between aquaculture, the environment and MPAs (Massa *et al*., 2017), the possible exists for aquaculture activities will be a cautionary systems for the ecological position of coastal ecosystems. Therefore, with suitable site selection and super vision, for instance through the establishment of allocated zones for aquaculture 'AZA' (Sanchez‐Jerez *et al*., 2016), aquaculture benefits could be unswervingly affiliated with MPA objectives. IUCN defines a marine protected area as: "Any area of inter-tidal or sub-tidal terrain, together with its overlying water and associated flora, fauna, historical, or cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment." It is being previously explored the possibility and the prospects and collaborations of aquaculture within the MPAs. Roughly aquaculture can present an affirmative opportunity for MPAs such as restocking of vulnerable species and augmentation of biodiversity (Le Gouvello *et al.*, 2017).

Aquaculture is the administration and/or farming of aquatic floras and faunas for recreation, nutrition and income. As fish is a good source of protein, sustainable aquaculture has become a trendy topic over the recent past decades. There has been considerable dispute and significant discussion about what it is and how it should be done. To a large extent, the discussion has concentrated on global strategy as well as domestic and global regulation. The management and conservation of the natural resource base, and the alignment of scientific and established changes in such a means as to safeguard completion and continued satisfaction of human needs for present and future generations. Environmental sustainable progress protects land, waters, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable, and socially acceptable (FAO, 1991). Sustainability encompasses

the establishment of production systems that can occur, at least theoretically, in perpetuity (Stickney, 2000).

Recent verdicts of international courts ensured the spatial extension of the Bangladesh's EEZ for 118,813 km² (MoFA, 2014). That's why the concept of Blue Economy for Bangladesh has evolved and it triggered this coastal state to explore marine resources sustainably within maritime boundaries. Bangladesh has to be one step advance through the proper maritime spatial planning as its land based resources are very limited in comparison to its huge population. Overfishing, damaging pollution, habitat destruction and other impacts of human activities in the sea are causing damage to the coastal and marine environments. Existing supervision schemes are dwindling to sustain the productivity, biological diversity and marine ecosystems. For that consequences, the marine protected areas have been proposed by the government as a means to preserve the marine habitat. MPAs can be benefitted through the conducting aquaculture in the MPAs sites. The establishment of new MPAs and allocation of aquaculture on MPAs has raised as an issue with a vision to protect the marine biodiversity and to enhance the production by the synergistic correlation between MPAs and aquaculture.

As a first attempt, marine reserve MPA had been declared by the Bangladesh government approaching to marine biodiversity conservation in 2000 (Gazette notification; MoFL, 2000). Later on, The Swatch of No Ground, a submarine canyon in the Bay of Bengal recognized as a hotspot for cetaceans, had been confirmed as "marine protected area" in 2014. The affirmation on the 1,738 square kilometers area, with an average depth of 900 meters and located south of Dublar Char, was made through a circular imposed by the Ministry of Environment and Forestry on October 27 based on the Wildlife (Conservation and Security) Act, 2012 (Gazette notification; MoEF, 2014).

Following that, the Nijhum Dwip Marine Reserve/ Marine Protected Area (MPA) was declared by the Ministry of Fisheries and Livestock, Bangladesh with the combined approvals from ECOFISH, the International Union for the Conservation of Nature (IUCN) and the Wildlife Conservation Society (WCS) in 23 June 2019 based on the provision of clause 28 of Marine Fisheries Ordinance, 1983. This declared protected area covers 3,188 square kilometers of estuarine-marine waters at the mouth of the

world's third largest river system: the Padma- Jamuna Meghna and offshore of the Nijhum Dwip National Park (Gazette notification; MoFL, 2019).

MPA establishment will ensure the habitat restoration, ecological balance, spawning and nursing ground for various species and limiting the ocean over exploitation. On the other hand, potential aquaculture within these MPAs can results a positive vibes in the sustainable food security, nutritional demand fulfillment, poverty alleviation, species restocking, ecological advancement and socio economic development. This will maximize the blue economic growth in context of Bangladesh.

1.1 Significance of the Study

- This study is designed to explore the scope for producing safe sea food by the synergistic aquaculture in MPAs through direct manipulation.
- This study will develop the synergistic aquaculture model within the MPAs to make ultimate sustainability, food security, livelihood of coastal people and gross economy.
- Implementation of this project is supposed to explore the unexplored resources of Bangladesh's maritime boundaries.
- The study is aimed to create the new wings and prospect as an MSP component (i.e. aquaculture in MPA) to aid and boost up the Bangladesh's blue economy.
- To enhance the socio-economic status of the coastal stakeholders.

1.2 Aims and Objectives of the Study

The aim of the study is to propose and make the hypothetical design of the sustainable aquaculture activities within the MPAs with the specific objectives such as:

- ✓ To propose new areas for the creation of new marine protected areas targeting 10% of the total maritime boundary of Bangladesh as protected zone within 2030 through maritime spatial planning.
- ✓ To identify opportunities to develop sustainable aquaculture within the MPAs based on GIS tools.

CHAPTER 2

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

For understanding the basics of sustainable aquaculture in the marine protected areas, synergies between aquaculture and MPAs studies are considered as an important tool. Evaluation of the benefits of MPAs regarding ecological conservation and habitat resilience can give valuable information for this study. Moreover, a close look at the different maritime spatial planning regarding the MPA will provide the significant information and real scenario of the hypothetical sites for aquaculture within the MPAs. This chapter is about the review of aquaculture-MPA synergies, IUCN management types of the MPAs and relevant legislation to conservation. The following information was collected to design the present study and validation of the new findings.

2.1 Aquaculture-MPA Synergies

2.1.1 Global Scenario

Species restocking for fisheries based on aquaculture has been well developed in many countries for decades. Such as in Japan (all fisheries) and in the USA (salmon fisheries). These categories of aquafarming depend on definite national and local traditions, proper governance applications, marketing and depend on appropriate observing tools, in order to circumvent the influences on wild stocks. (Le Gouvello *et al.*, 2017)

Having the higher demand of aqua crops, there have been established aquaculture system within the protected areas maintaining the conservation goal of protected areas. Australian's Great Barrier Reef Marine Park (GBRMP) is the most magnificent marine protected area in the world where authority allows aquaculture in some zones of the Marine Park. There are four pearl oyster culture facilities in the GBRMP (two at Fantome Island and one each at Arlington Reef and Walker Bay). There is also one cage culture facility (managed under Queensland legislation) for the production of barramundi in the Hinchinbrook Channel, which is outside the GBRMP, but in the Great Barrier Reef World Heritage Area (GBRMPA, 2002).

Mayotte MPA is a French Outermost region which created as a large National Marine Park, comprising almost its entire EEZ. Joint creation of multiple-use MPAs with aquaculture operations (IUCN, 2017).

Dempster *et al.* (2006) and Yang *et al.* (2015) analyzed and found that some MPAs were established in order to alleviate the pressure on wild fish stocks and restore population health. Aquaculture cages or farm substructure may assist as probable nurseries/feeding surroundings and accommodations for wild populations under measured conditions.

Radulovich *et al.* (2015) established the tropical seaweed production trials undertaken in Costa Rica showed that cultivated seaweed plots rapidly and significantly enhanced local biodiversity compared with control zones, particularly for a huge number of fish species.

Pomeroy *et al.* (2006) and Todinanahary *et al.* (2017) showed that farming coral reefs appeared an appealing option in tropical MPAs could be a source of material for reef restoration in MPAs and at the same time reduce the pressure on wild populations. More than 80% of exported-imported corals are still captured from the wild-natural stock, culture systems have become reasonable and flexible on a minor-scale for some specific cases, as recently emphasized.

Traditional coastal lagoon management in some particular areas of the Mediterranean Sea (e.g. the vallicoltura in North Italy) is similarly a good instance of aquaculture practice in sensitive ecosystem. Traditional extensive aquaculture (mainly based on restocking and hydrological controlling) and artisanal fisheries are executed in that sensitive ecosystems, and these have remained unaffected for centuries and contribute to the livelihood of coastal populations (Cataudella *et al.* 2015).

Based on IUCN (2017) report direct collaboration with fish farms may lower costs and improve the logistics of MPAs. In a pilot project, a fish farm in Madeira established in the 1990s located near a remote terrestrial protected area (TPA), there was close collaboration between the farm management and the conservation authority. MPA administration officials may also obtain payments from aquafarming as it aids from a definite place and clean environment. This opportunity is, however, dependent on small and medium enterprises (SMEs) and industrial production rather than on community-based small-scale aquaculture.

Farmed bivalves contribute to nutrient regulation in coastal regions (Filgueira *et al*. 2015 and Jiang *et al*. 2015). Bivalve and seaweed aquaculture have the potential to support local ecosystem services through their interactions with such services, though

this issue sometimes leads to conflict. Cultivated seaweeds can usage nitrogen to produce and therefore can mitigate eutrophication incidents (Wu *et al*. 2015). Other authors suggested that cultured shellfish could alleviate coastal eutrophication (Cranford *et al*., 2007; Lindahl, 2011; Petersen *et al*., 2014; Rice, 2001) and equally play a role in benthic refurbishment (Dumbauld *et al.*, 2009).

Whatever the objective of aquaculture production is, compatibility with MPA objectives and conservation targets relies on an integrated and ecosystemic approach. The Ecosystem approach is a powerful tool for the integrated management of human activities and should be used to address site selection and management. This approach, based on the best available scientific, traditional and local knowledge, gives an equal voice to all stakeholders including the aquaculture community. It aims to optimize the use of an ecosystem without damage, through the management of human impacts and activities (IUCN, 2009).

2.1.2 Local Scenario

Sharifuzzaman *et al.* (2019) found that mariculture is restricted to coastal and brackish water farming which was devoted for shrimp culture only in Bangladesh. They also found the reduction trend of some high value fishery stocks (i.e. lakkha/threadfin). In response to the decreasing capture fisheries, growing demand of fish protein by the increasing population and limiting land based resources, an increasing marine food production through expansion of mariculture and management of marine fisheries is unavoidable.

DoF (2017) reported that, Bangladesh has 272,717 ha suitable area for coastal aquaculture where farming is mostly carried out in tide-fed ponds. Black tiger shrimp *(Penaeus monodon)*, locally known as 'bagda', is the only species farmed in the coastal districts of Satkhira, Khulna, Bagerhat and Cox's Bazar. Shrimp farming was extended swiftly between 1970 and 1990, mostly in ghers (i.e. area of land secured from the sea by polders) under extensive culture systems. There are also very small scale farming of mullet *(Mugil sp.)*, seabass *(Lates calcarifer)*, crab *(Scylla spp.)* and seaweeds. Mariculture is significant to our national economy, earning a sizeable foreign exchange for the country, about BDT 44309.94 crore by exporting 68,935.72 ton of shrimp/prawn and other fisheries products in 2017-18 fiscal year (DoF, 2019).

Furthermore Sharifuzzaman *et al*. (2019) added, beside the massive prospect for further progress, coastal aquaculture is facing various challenges associated to disease outbreaks, technological barriers, unscientific use of inputs, bad compliance with value standards, finding of seed etc. by selectively cope up these limitation, the enhancement of coastal and marine aquaculture production can be upgraded significantly.

Marine cage farming, not in practice at present, can be done at artisanal level with simple design and small size. Fish farming cages can be made using locally available materials including bamboo, wooden boards, steel/PVC pipe, and nylon nets. Cages can be inshore coastal, open sea or offshore types, installed either individually or connected together to form floating raft. Probable fish species for cage culture are seabass, mullet, grouper *(Epinephelus sp.)* and seabream *(Acanthopagrus sp.),* (Hossain *et. al.* 2017).

In a different study of Hossain *et al.* (2015) found that aquasilviculture (integrated mangrove based aquaculture) is a low-input farming system. It promotes symphonic co-existence between aquaculture and mangrove forestry that aids income, food security, coastal defense, community resilience, and restoration and/or conservation of the mangroves. Thus, for example, suitable locations for 'integrated' mangrove-shrimp, 'separate' mangrove-shrimp (i.e. mangroves as biofilter for shrimp pond effluents) mangrove-crab, and nipa-shrimp systems include the Chakaria Sunderbans and adjacent Cox's Bazar coasts. Among these silvofishery representations, crab-mangrove culturing in pens or cages grips great possibility for firming up the livelihoods of coastal populations without environmental and conservational harm.

Hossain *et al*. (2017) also proposed integrated multi-trophic aquaculture (IMTA) which is a suitable approach providing environmental sustainability, economic diversification and social acceptability for the aquaculture sector within the broader perspective of responsible coastal zone management. No efforts have been taken to develop and experiment the IMTA method before in Bangladesh, although the Authors found cites such as the Islands of St. Martin's, Sonadia, Moheshkhali and Cox's Bazar-Teknaf coast can be considered appropriate for the IMTA studies.

2.2 IUCN management categories of the MPAs

The IUCN categories are valid to all kinds of protected areas, whether terrestrial or marine. The 2008 *Guidelines for Applying Protected Area Management Categories* (*2008 Guidelines*) deliver significant detail on the usage and application of the

categories, including for marine protected areas (MPAs). The IUCN management classification for protected areas from Dudley (2008) was used in order to identify MPAs where aquaculture will not conflict with their conservation goals. This classification divides Protected Areas within 7 different classes, as shown in the Table below.

Table 1: IUCN management category of Protected Area

Category	Description
Ia	Strict Nature Reserve: Protected area managed mainly for science.
Ib	Wilderness Area: Protected area managed mainly for wilderness protection
II	National Park: Protected area managed mainly for ecosystem protection and recreation.
III	Natural Monument: Protected area managed mainly for conservation of specific natural features.
IV	Habitat/Species Management Area: Protected area managed mainly for conservation through management intervention.
V	Protected Landscape/Seascape: Protected area managed mainly for landscape/seascape conservation and recreation.
VI	Managed Resources Protected Area: Protected area managed mainly for the sustainable use of natural ecosystem.

In view of that the aquaculture can be executed in MPAs within the categories V and VI and also in IV according to Day *et al*. (2012) as long as production model, and aquaculture intensity would be compatible with the MPA's objectives. The aquaculture within MPAs idea was focused by the IUCN study about potential opportunities and synergies between aquaculture and MPAs (IUCN, 2017) and by the study from Le Gouvello *et al*. (2017). In both studies authors equally found the positive correspondence of aquaculture and conservation of marine areas might have parallel benefits.

According to Dudley *et al*. (2008), MPAs that maintain predominantly natural habitats but allow the sustainable collection of particular elements, such as particular food species or small amounts of coral or shells for the tourist trade, could be identified as category VI. The fact where a region is managed for resource exploitation becomes a category VI. MPAs on occasion may be tough to judge and will be determined finally by reference to whether the area fulfill the general meaning of a protected area or not,

and whether the area attains demonstrable ecological sustainability as measured by appropriate metrics.

2.3 Relevant legislation

International legal instruments are the key structural components in a wider international regulatory regime (Karim, 2016). There are a number of international conventions and declarations which either directly or indirectly provide legal stands for MSP (i.e. mariculture). Some of these are as follows:

United Nations Convention on the Law of the Sea (UNCLOS): UNCLOS III, was adopted in 1982 makes all coastal states collectively responsible for the sustainable use of the oceans, and makes accountable to protect their maritime areas. It is one of the most uniform and comprehensive instrument of ocean governance among international treaties. Articles 61-68 expressly provides for conservation of living resources and other species at the Exclusive Economic Zone. Articles 116-120 says about the conservation and management of living resources at the High Sea. Part XII, Articles 192-237 provide for general and specific obligations of member state to protect marine environment. The Convention is legally binding instrument and Bangladesh is state party to the Convention.

UN Fish Stock Agreement, 1995: The FAO Code of Conduct for Responsible Fisheries, 1995 is a non-binding instrument which covers almost all aspects of fisheries for developing and implementing their own national fisheries policies as per the Code. Later on, UN Fish Stock Agreement, 1995 was adopted which came into effect in 2001. This is a legally binding agreement providing the framework for long-term conservation and sustainable management of straddling and highly migratory fishes in the sea. This Code is seen as a groundbreaker to global rule of fisheries management. Bangladesh is a signatory to this treaty (Duck, 2012).

Convention on Biological Diversity, 1992: The Convention on Biological Diversity (CBD) Earth Summit Rio de Jenerio, Brazil, 1992 set up three goals, namely (a) conservation of biological diversity, (b) sustainable use, and (c) fair and equitable sharing of benefits arising from biological resources. Bangladesh has ratified to the convention and therefore mandated to act on the principles and issues of this convention (Duck, 2012).

Environmental protection: There are a number of scattered policy and legislation to deal with environmental aspects in Bangladesh. The legal framework for environmental protection are-

- Bangladesh Environment Conservation Act, 1995
- Bangladesh Environment Conservation Rules, 1997, and subsequent amendments in 2000 and 2001,
- Bangladesh Environment Conservation (Amendment) Act, 2000,
- Bangladesh Environment Conservation (Amendment) Act, 2002,
- National Action Plan for Adaptation (NAPA) to Climate Change,
- Bangladesh National Conservation Strategy 2005.

All of these legal frameworks are focusing to conserve and protect the nature and ecosystem. As MPAs are the one of the major key tools to conserve and protect the marine life, these frameworks will recognize the establishment of MPA within the Bangladesh maritime boundary. Hence, achieving the objective of this study will aid the aim of those legal frameworks as well.

CHAPTER 3

MATERIALS AND METHODS

CHAPTER 3

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This chapter deals with the methods that are followed and materials that are used to achieve the objectives of the study. This study was based on GIS tools to allocate the aquaculture within the marine protected areas (MPAs) and to propose the new areas for the creation of new MPAs.

3.1 Site selection

This study was held in the Bangladesh's marine protected areas, which are already established and managed by the government. Some new sites are also being considered for the aquaculture allocation which have been proposed for the declaration of the new MPAs.

3.1.1 Existing MPAs

There are three MPAs declared and managed by the government which are shown in the map below (Fig. 01). These are The Swatch of No Ground (SoNG) MPA, the Nijhum Dwip MPA and the Marine Reserve MPA.

Shape files for the existing MPAs were taken from World Database on Protected Areas (WDPA) for individual current MPA, though latest MPA data was not updated in the WDPA. Based on the coordinate data from Bangladesh Gazette notification, non-updated recent MPA's (i. e. Nijhum Dwip MPA) shape file was created through GIS. Then all the currently existing MPA's shape file were merged into a single shape file and expressed in the following map (fig. 01).

The Swatch of No Ground (SoNG) MPA spans 1,738 sq. km, covering about 1.5% of Bangladesh total marine area (WCS, 2015). The protected area is shaped as a five-sided polygon with the subsequent turning coordinates: Northwest – E 89° 21' 13" N 21° 37' 35"; Northeast – E 89° 40' 30" N 21° 37' 35"; Southwest E 89° 21' 13" N 21° 19' 57"; Southeast – E 89° 40' 30" N 21° 20 28"; and South E 89° 31' 14" N 21° 06' 25" (WCS, 2015).

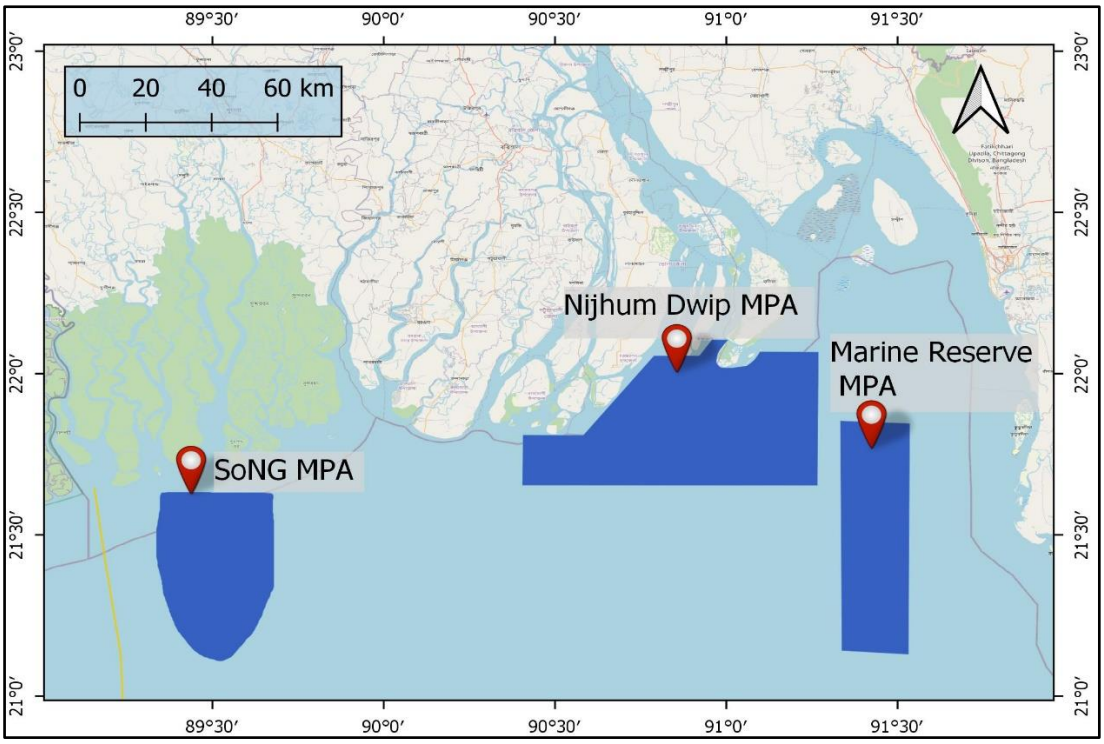

Figure 1: Existing MPAs of Bangladesh (Source: UNEP-WCMC, 2020; modified by Author by using QGIS)

Nijhum Dwip MPA covers 3,188 sq. km of estuarine and marine waters at the gateway of the major river system: the Padma- Jamuna Meghna and offshore of the Nijhum Dwip National Park.

The Marine Reserve covers 698 sq. km area of the Bangladesh Fisheries Waters in the middle ground and south patches areas of the Bay of Bengal (Gazette notification, 2000).

3.1.2 Visualizing proposed MPAs

To propose any new MPA we need to identify the potential site depending on information, importance for species and habitat and their ecological status. Over exploitation deployed the ecological status of some areas of the adjacent coast of some islands such as, Saint Martin's Island, Moheshkhali, Kutubdia and Swandip (IUCN, 2015).

Focusing on these four major island of Bangladesh's coast, adjacent area of those island has been proposed as the potential area for the establishment of the new MPAs. We used QGIS software (version: 3.10.14) as a GIS tool to visualize those area for the exhibition and marking in the map (Fig. 02).

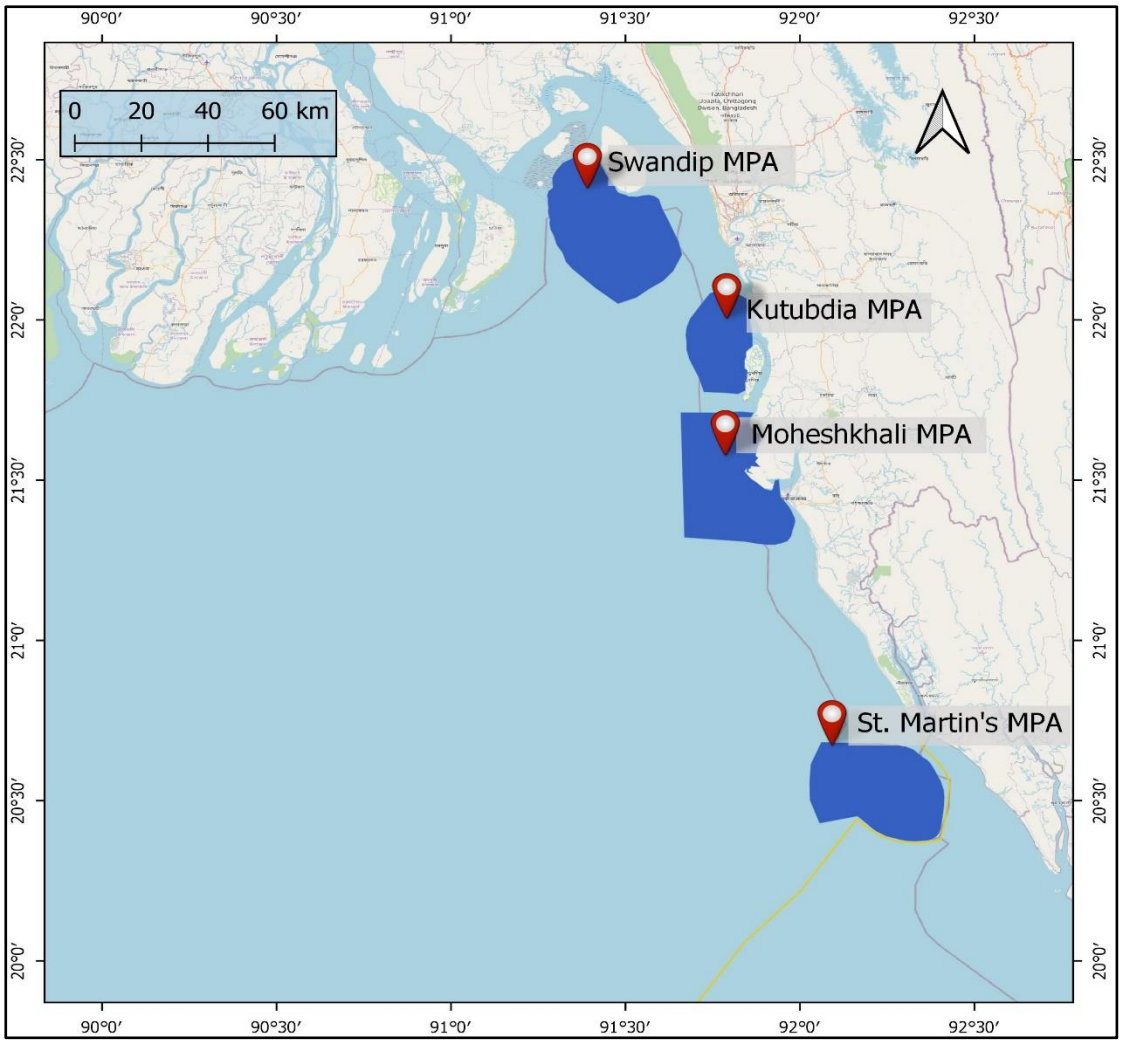

Figure 2: New sites for new MPA establishment within 2030 in the maritime boundary of Bangladesh

3.2 MPA's classification

The IUCN management categories for protected areas from Dudley (2008) was used to identify the MPAs where aquaculture will not conflict with their conservation goals. This classification divides Protected Areas within seven different classes. MPA's category of IUCN are more specified in as shown in the Appendix-A.

IUCN settled a background with potential activities that might match to each different IUCN management category (Table 2) which depicts the potential uses of different IUCN categories. Analyzing this matrix for aquaculture specifcally, aquaculture can be implemented in MPAs within categories V and VI and even IV.

Table 2: Matrix of activities that may be appropriate for each IUCN management category (Day *et al*., 2012).

Activities	Ia	Ib	II	III	IV	V	VI
Research: Nonextractive	Y*	Y	Y	Y	Y	Y	Y
Nonextractive traditional use	Y*	Y	Y	Y	Y	Y	Y
Restoration/enhancement for conservation (e.g. invasive species control, coral reintroduction)	Y*	*	Y	Y	Y	Y	Y
Traditional fishing/collection in accordance with cultural tradition and use	N	Y*	Y	Y	Y	Y	Y
Nonextractive recreation (e.g. diving)	N	*	Y	Y	Y	Y	Y
Largescale high intensity tourism	N	N	Y	Y	Y	Y	Y
Shipping (except as may be unavoidable under international maritime law)	N	N	Y*	Y*	Y	Y	Y
Problem wildlife management (e.g. shark control programmes)	N	N	Y*	Y*	Y*	Y	Y
Research: Extractive	N*	N*	N*	N*	Y	Y	Y
Renewable energy generation	N	N	N	N	Y	Y	Y
Restoration/enhancement for other reasons (e.g. beach replenishment, fish aggregation, artificial reefs)	N	N	N*	N*	Y	Y	Y
Fishing/collection: Recreational	N	N	N	N	*	Y	Y
Fishing/collection: Longterm and sustainable local fishing practices	N	N	N	N	*	Y	Y
Aquaculture	N	N	N	N	*	Y	Y
Works (e.g. harbours, ports, dredging)	N	N	N	N	*	Y	Y
Untreated waste discharge	N	N	N	N	N	Y	Y
Mining (seafloor as well as subseafloor)	N	N	N	N	N	Y*	Y*
Habitation	N	N*	N*	N*	N*	Y	N*

Key:

N = No

N* = Generally no, unless special circumstances apply

Y = Yes

Y* = Yes because no alternative exists, but special approval is essential

*= Variable; depends on whether this activity can be managed in such a way that it is compatible with the MPA's objectives

We also analyzed and considered the risk matrix aquaculture systems in context of MPA categories (Table 3). Here, IUCN classes V and VI were considered as the ones that could have aquaculture can be applied within the MPAs (Le Gouvello *et al*., 2017).

Table 3: Possible example of a risk matrix aquaculture systems and MPA categories (Le Gouvello *et al*., 2017).

Categories	I	II	III	IV	V	VI
Restoration purpose aquaculture						
Medium density invertebrate (e.g. sea cucumber) culture						
Low density shellfish culture						
High density seaweed culture						
Low density pond/lagoon fish culture						
High density shellfish culture (table, longlines)						
Medium density onland circulating system fish pond culture						
High density onland closed system fish culture						
High density fish cage culture						

Key: = No = Yes

= Variable; depends on whether this activity can be managed in such a way that it is compatible with the MPA's objectives

The marine reserve MPA located in mostly in the south patches fishing ground with a vision to protect natural ecosystems and use natural resources sustainably, when conservation and sustainable use can be mutually beneficial. When sustainably exploitation and conservation occur at the same time, it matches to the IUCN category no VI. So, marine reserve MPA belongs to the management category VI.

According to IUCN management categories, the SoNG-MPA lies under the IUCN management category IV as this MPA was proposed with a view to protect the cetacean group along with their habitat. Category IV protected areas target to defend specific species or habitats and management replicates this importance. Many category IV protected areas need regular, active interventions to address the requirements of particular species or to maintain habitats.

On the other hand, ECOFISH formed co-management and community management bodies in 6 Hilsha sanctuaries, and the management plans for improved natural resource management (NRM) were developed and agreed upon by the Department of Fisheries (DoF, 2019). The ECOFISH activity continued its activities in the 6 Hilsha Sanctuaries and facilitated Marine Protected Areas (MPA) in Nijhum Dwip to ensure improved natural resource management. As the Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems, the Nijhum Dwip MPA lies under the IUCN Management category VI.

Newly proposed four sites for MPAs will be in the category VI as these sites are going to be applied as protected areas managed mainly for the sustainable use of natural ecosystem.

3.3 Assessment of suitability for aquaculture

Data from all MPAs were analyzed through the QGIS software (version: 3.10.14), by selecting areas according to what is established as the most suitable conditions. The present study considered marine areas mostly covered by water, area below the mean low tidal level, coast type whether rock or mud and IUCN category V and VI for aquaculture. Remote areas were not considered as appropriate to have aquaculture, and thus not considered in the present analysis. Further analysis, including other criteria as proximity to ports, shipping traffic and distance from the coast for the location of the aquaculture sites inside every MPA were analyzed.

CHAPTER 4

RESULTS

CHAPTER 4

RESULTS

4.1 MPAs of Bangladesh

Present status of MPAs in Bangladesh and other management and uses of marine resources are compiled in a single map and shown in the figure below. The map expresses spatial configuration of the current MPAs, fishing ground, shrimp ground, military exercise port use andr marine traffic and other uses of EEZ.

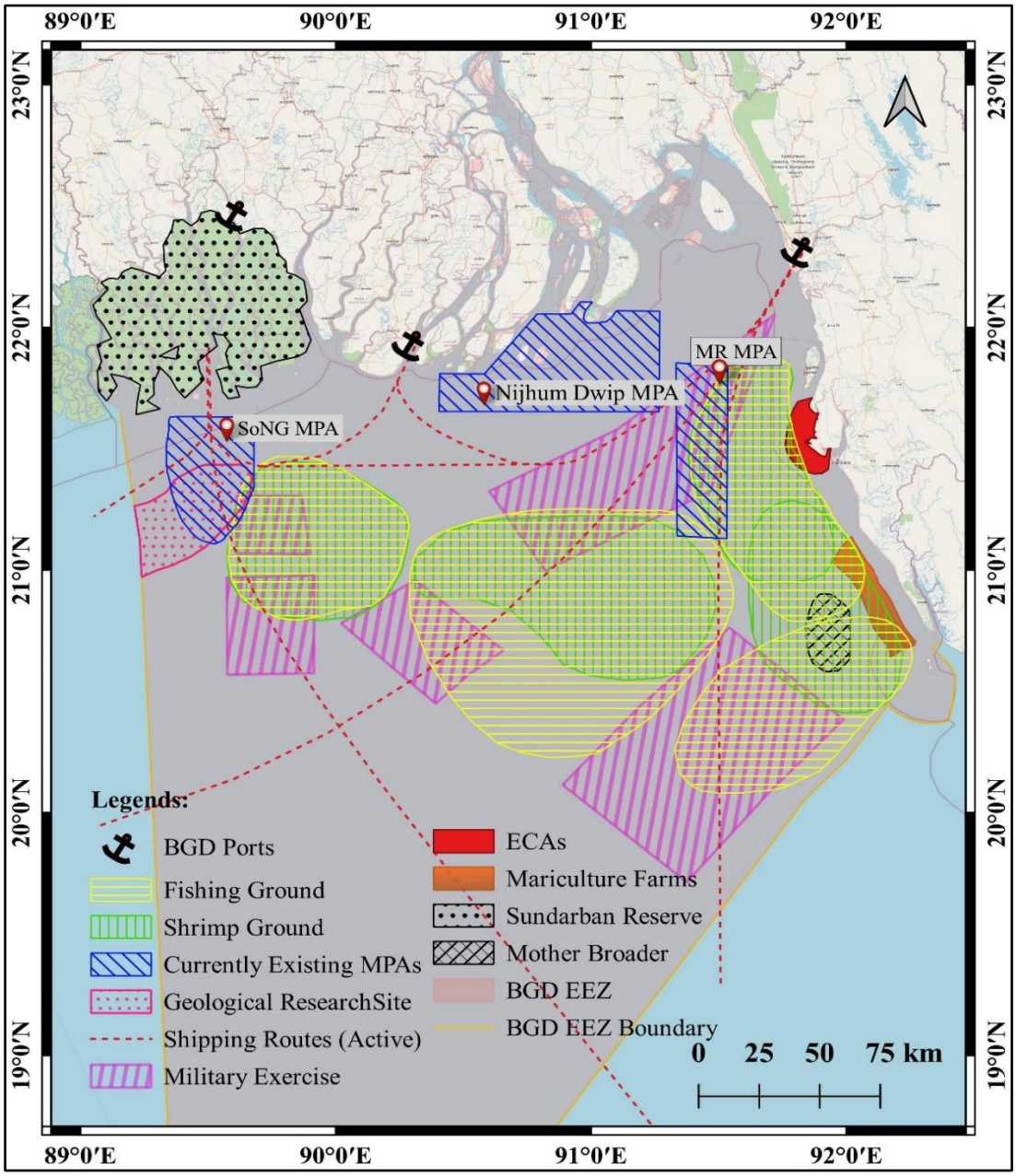

Figure 3: Current MPAs of Bangladesh and other uses of maritime resources

To achieve the sustainable conservation of marine resource, some of newly proposed MPAs are designed to be declared and take action within 2025 and then following to 2030 for further extended target. In 2025, the current MPAs are proposed to be reach at least 7.5% of the total area. Hence, the SoNG MPA has been proposed to expansion its range by merging the adjacent geological research site from 1789 to 2390 sq. km as it is providing significance habitat for cetaceans and marine turtle. Basis on the ecological degredation in the Moheshkhali island and Saint Martin's Island, these two area are also proposed to declare as MPAs. Kutubdia and Swandip Island's adjacent coast is likely to over exploitation and IUU fishing (IUCN, 2015). Therefore these two areas are also proposed to be declared for conservation (Fig. 4).

The figures 4 expresses the spatial scenario of current and proposed new MPAs within 2025.

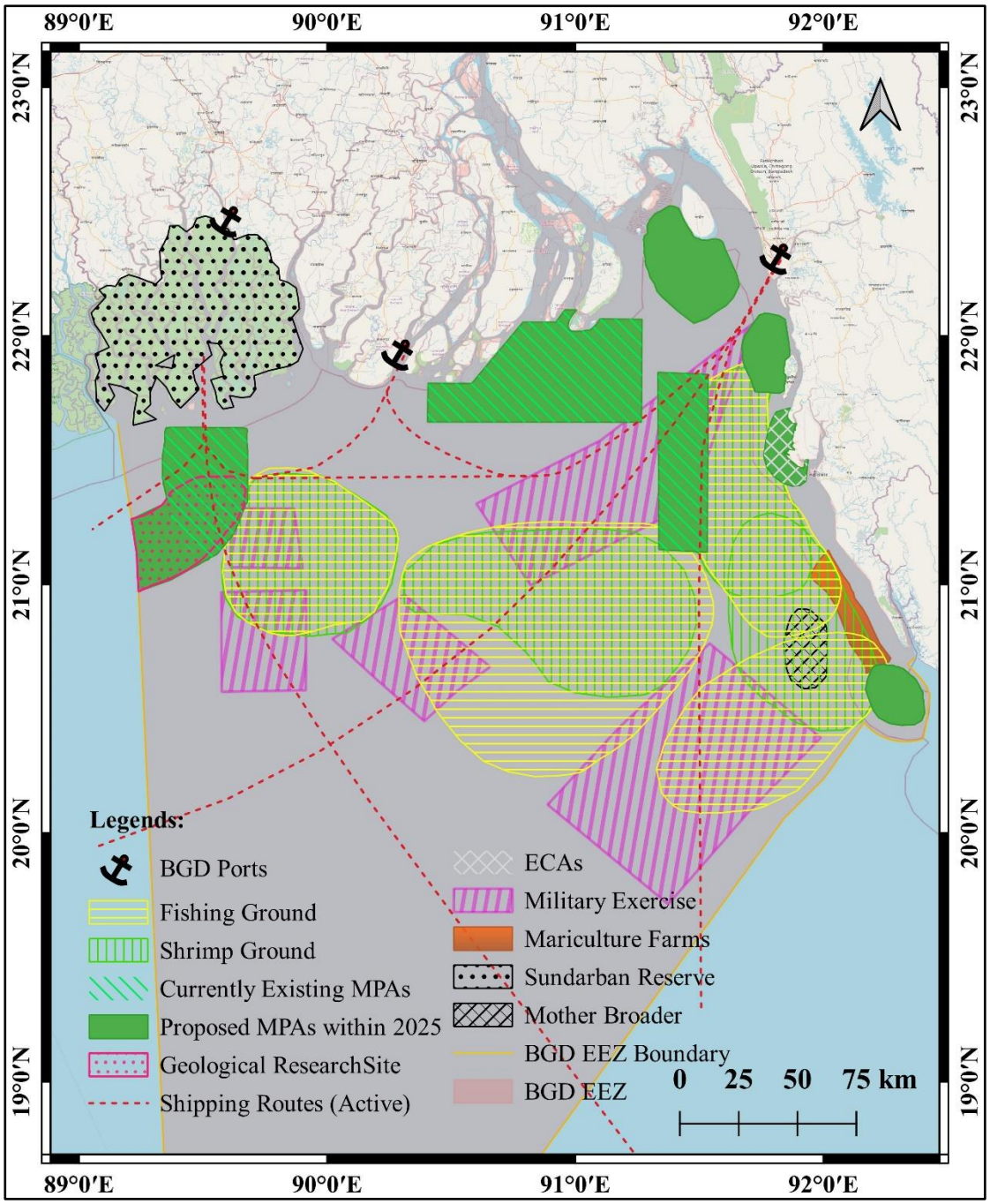

Figure 4: MPAs Proposed to be declared in the maritime boundary of Bangladesh within 2025

Following the trend within 2030, further expansion of the MPAs are aimed to reach at least 10% of total areas. It includes the further expansion of SoNG and Saint Martin's MPAs (Fig. 5).

The following figures expresses the spatial scenario of current and proposed new MPAs within 2030.

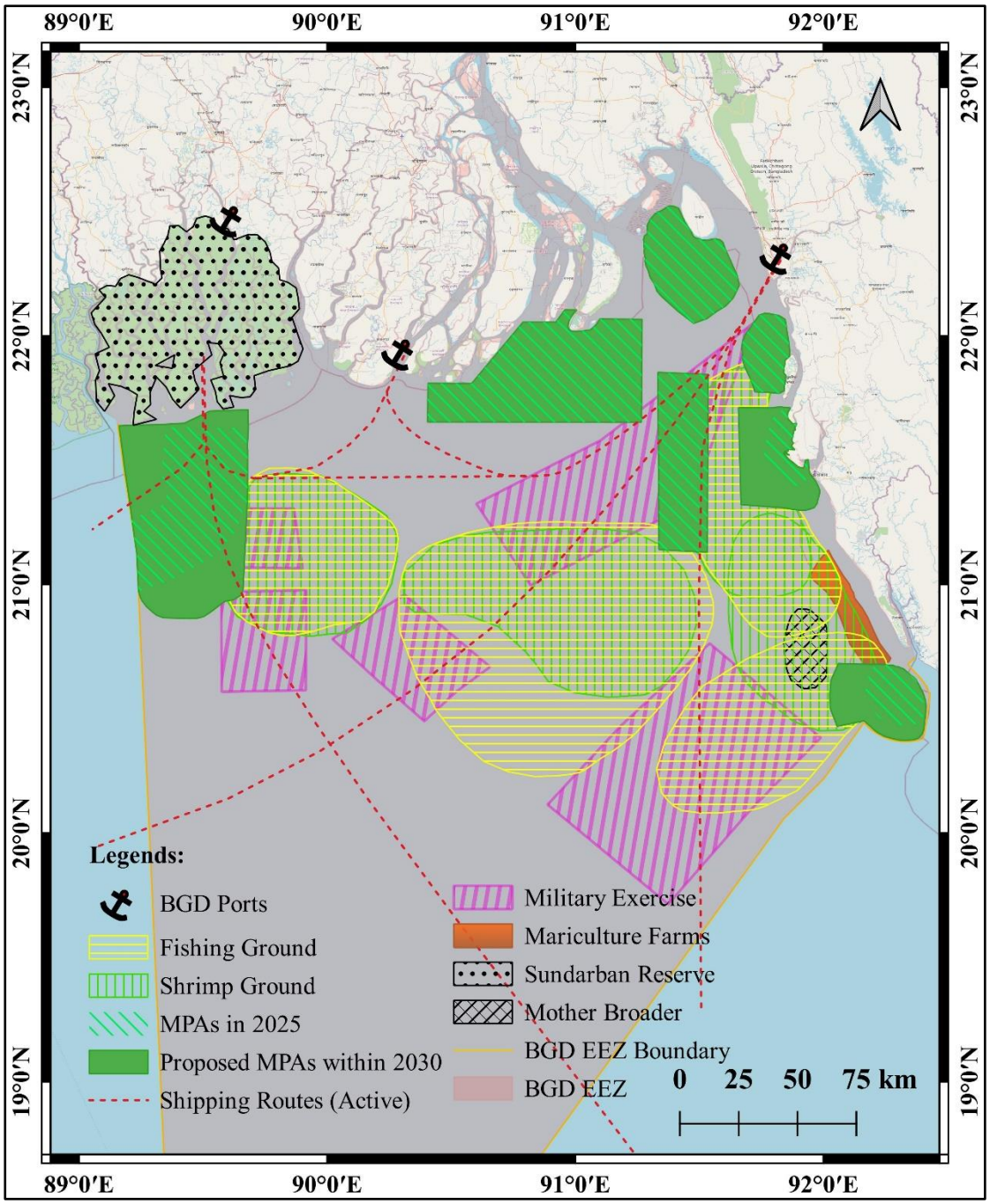

Figure 5: MPAs Proposed to be declared in the maritime boundary of Bangladesh within 2030

These vision on MPA creation and expansion will lead to reach the global target of Nagoya protocol of CBD (Aichi target 11).

The table below is expressing all the MPAs extends and detailed information.

Table 4: Different MPA and their status

Status of the MPAs	Names of the MPAs	Area of the MPAs
Currently existing MPAs	1. The marine reserve MPA (designated in 2000)	698 sq. km
	2. Swatch-of-No-Ground MPA (designated in 2014)	1738 sq. km
	3.Nijhum Dwip MPA (designated in 2019)	3,188 sq. km
	Sub-total = 5,624 sq. km	
Proposed new MPAs within 2025	1. Saint Martin's Island MPA	518 sq. km
	2. Moheshkhali Island MPA	354 sq. km
	3. Kutubdia Island MPA	552 sq. km
	4. Swandip MPA	1292 sq. km
	5. Expanded SoNG MPA	2390 sq. km
	Cumulative subtotal (including previous MPA) = 8,992 sq. km	
Proposed new MPAs within 2030	1. Expanded Saint Martin's Island MPA	1096 sq. km
	2. Expanded Moheshkhali Island MPA	1142 sq. km
	3. Further expansion of SoNG MPA	4124 sq. km
	Cumulative subtotal (including previous MPA) = 12,092 sq. km	

Currently Bangladesh have 5624 sq. km MPAs which is covering 4.73% of total area. In 2025, the total conserved area is proposed up to 8,992 sq. km which will reach the 7.54% of total marine area. Accordingly, within 2030, MPAs will reach more than 10% (10.17%) covering up to 12,092 sq. km area (Table 4). Current MPAs will be then reach the at least 10% of total maritime territory as of the Aichi biodiversity target-11.

4.2 Compatible site for aquaculture within MPAs

Having the solid shoreline and muddy-sandy beach of the Nijhum Dwip Island, the Nijhum Dwip MPA can be a potential site for different aquaculture. The inter-tidal zone will provide the spatial and infrastructural support for the bivalves mollusk and seaweed culture. The shallow depth sub merged zone will be the strong potential site for the finfish and even shrimp cage culture, IMTA site, set bag and hanging rope mollusk

culture and seaweed culture. Besides these, the hydro physio-chemical interaction and the tidal fluctuation will play the key role for aquaculture installation in this area.

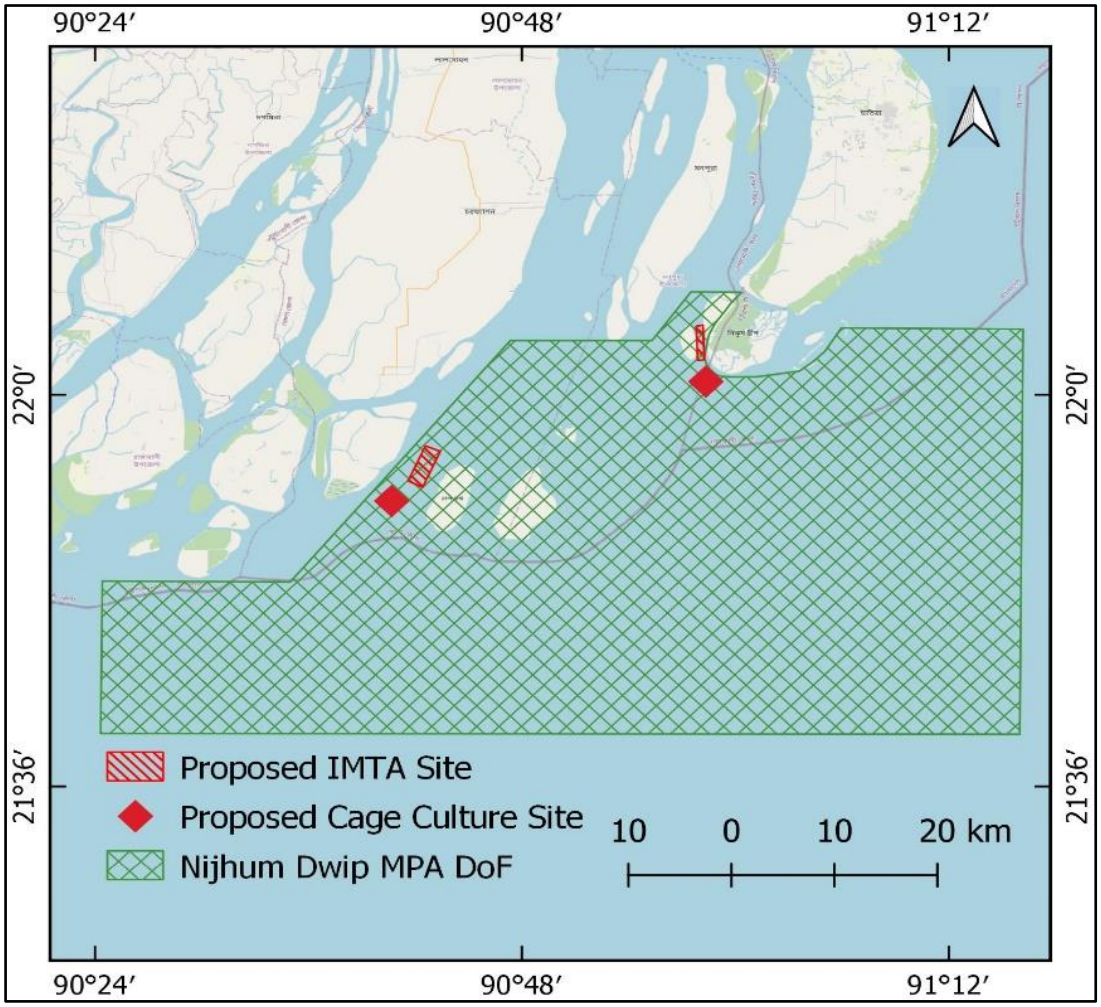

Figure 6: Compatible site for aquaculture in Nijhum Dwip MPA

Newly proposed MPAs sites are the potential aquaculture site for cage and IMTA culture model. The figure below is showing the potential site for aquaculture site within the MPAs.

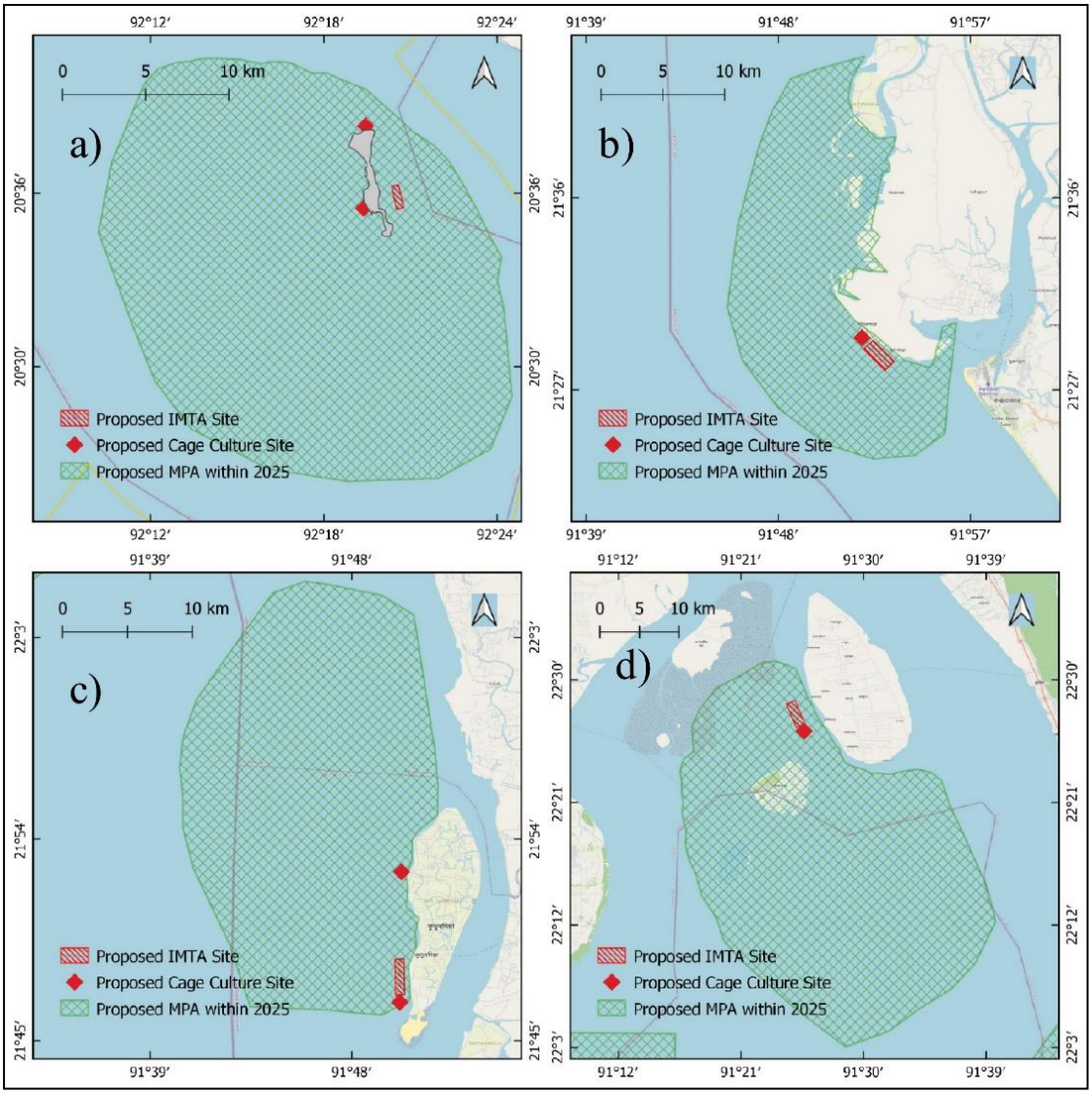

Figure 7: Proposed aquaculture within proposed MPA

a) St. Martin's b) Moheshkhali c) Kutubdia d) Swandip

CHAPTER 5

DISCUSSION

CHAPTER-5

DISCUSSION

This study was designed to describe the potentiality of aquaculture within the MPAs and to develop aquaculture models. This chapter described the overall results comparison, achievement of the study and problems associated to the study on the farming aspects within the protected area. The objectives of the study were achieved by the revision of related information and facts. However, information on the MPA-aquaculture synergies in Bangladesh does not exist. Information of previous studies from other areas by different authors around the world was taken into consideration for this study.

Aquaculture is frequently restricted to food production tenacities but some aquaculture can also present an affirmative opportunity for MPAs such as replacing of vulnerable and threatened species and augmentation of biodiversity for preservation purposes started in Italian MPAs, Donadelli *et al.* (2015) which is similar to this study in context of aquaculture within MPAs.

Pomeroy *et al.* (2006) found farming coral reefs appeared an appealing option in tropical MPAs. Furthermore reported that in Kenya's coastal areas, small scale aquaculture of extractive species was being developed to provide alternative livelihoods and diminish fishery pressure in coral reefs (FAO, 2016b). Proposed Saint Martin's MPA in this study is likely to provide alternative livelihoods and diminish fishery pressure in coral reefs.

Some regulation on aquaculture and MPAs for the Natura 2000 sites has been developed within the European country and can be an example of attention for other countries as it clarifies a step-by-step method for a full impact assessment. In the approaching time MPA administrators and their shareholders should come parallel for more to better comprehend the aquafarming sector, its constrictions for production, and its requirements for ecosystem and water quality. MPA authority should always effort to diminish conflicts, and should also discover optimizing benefits, especially in the extent of associate conservation efforts, restocking, and environmental impression lowering and strength of production arrangements (Le Gouvello et al., 2017).

Beside the traditional assessment of MPAs, more possibilities for collaboration may exposed in the upcoming year through new direction IUCN will develop for the Convention on Biological Diversity to further elaborate achieving Aichi Target 11- "by 2020, at least 17 per cent of terrestrial and inland water, and 10 per cent of coastal and marine areas, especially areas of particular importance for biodiversity and ecosystem services, are conserved through effectively and equitably managed, ecologically representative and well connected systems of protected areas and other effective area-based conservation measures, and integrated into the wider landscapes and seascapes." This will focus on 'other effective area-based conservation measures' as they are becoming known (IUCN, 2017).

An investigation to identify opportunities can be established, based on socio economic and environmental criteria related to the present MPAs or the local habitats and ecosystem. The indigenous circumstances are reliant on the local environments. So, Environmental Impact Assessment (EIA) can be prerequisite by the authorities. Impact assessment tools such as Life Cycle Analysis (LCA) or Ecological Footprint (EF) are being adapted for aquaculture activities (Hall et al., 2011).

The Farm Aquaculture Resource Management (FARM) model outcomes found for carbon and nitrogen mass balance presented the positive environmental impacts produced at the appropriate sites by the high net nitrogen removal from the water through filtration of algae and detritus by shellfish. The net removal of carbon and nitrogen has a direct significance to integrated coastal zone management (Ferreira et al., 2007). Shellfish culture can aid to decrease eutrophication by eliminating chlorophyll, enhance water transparency, which endorses growth of submerged aquatic vegetation and sea weed and reduces the breakdown of organic material, which in turn reduces secondary eutrophication (Bricker et al., 2003). The implementation of a nutrient credit trading in ICZM for aquaculture site selection are central to this approach.

Other suggestions would promote more sustainable aquaculture systems as Integrated Multi-Trophic Aquaculture (IMTA), which tend to be more balanced for the environment. Also, avoid many activities in areas and seasons of breeding, spawning, nursery and migration of priority species.

The expenses and complications of finding the essential scientific data are also limiting. This monitoring activity should be developed with aquaculture specialists to keep it operational and adapted to the realities of fish farm operations.

The development and application of Marine Spatial Planning (MSP) together with Integrated Coastal Zone Management (ICZM) constitute dynamic processes facilitating site selection with the correct water quality and siting measures for aquaculture applications.

5.2 Aquaculture site compatibility

Among the three declared MPAs, the Nijhum Dwip MPA has been found suitable in several areas for aquaculture. The Marine Reserve MPA and the SoNG MPA are the non-feasible area for aquaculture as both the MPAs possess no coast or island. However, marine reserve MPA is supporting as extensive fishing zone. Thus no aquaculture is practical there. SoNG MPA's management category IV support only extensive aquaculture but the sub marine canyon forming the bottom topography and not having any shore, beach or island, makes the SoNG MPA as a non practical aquaculture site. Besides these, even floating cage or bag culture installation would not be possible due to the too much depth (>900m) of the bottom surface. This area is also a hard to reach site from the adjacent main coast.

5.2 Priority aquaculture techniques in the MPAs

Aquaculture species which culture technique is widely feasible and has the high market value should get priority for farming. In case of finfish, the Seabass and the Threadfins can be cultured in the cage. Mussels, Oyster and other Mollusks and seaweed will easily be compatible for farming within the tidal fluctuation.

5.2.1 Cage culture model

Cage culture utilizes little physical facilities and space. A floating cage consists of a floating unit from which a single cage or a battery of net-cages is suspended. A stationary cage is fastened to fixed bamboo or wooden poles at their corners. Floating cages are popularly used for fish rearing in both fresh and coastal waters.

According to FAO, The main species of finfish cultured in marine cages include the salmonids, the carrangids, the breams, the lutjanids (*Lutjanus argenticulatus*, *Lutjanus*

spp.), the sea perch (*Lates calcarifer*), the serranids, the flatfish, the filefish, the puffer fish, the horse mackerel (*Trachurus japonicus*), the threadfins (*Polydactylus sexfilis, Eleutheronema tetradactylum*) and the siganids. However, large-scale commercial cage farming seems to concentrate on seabass *(Lates calcarifer)* in Bangladesh.

5.2.2 IMTA model

A modern mariculture technique which can grow together different species in such a way that the invertebrates and/or plants can recycle the nutrients that are lost from the culture of the other species is the Integrated Multi Trophic Aquaculture (IMTA). A new concept for Bangladesh in the mariculture field which is currently in piloting that can vastly applied in future.

5.2.3 Mussel and Oyster culture model

Mollusk are mostly found wildly in the bottom of high and shallow water depth and littoral zone, attached in clusters on various substrates. Being filter-feeder of phytoplankton and detritus, it is considered the most efficient converter of nutrients and organic matter, produced by marine organisms in the aquatic environment, into palatable and nutritious animal protein. Mollusk culture is the most productive form of saltwater aquaculture and its prospects is significantly good. The common practices are rack culture, hanging culture, raft culture, vertical rope long line culture etc.

5.2.4 Seaweed culture model

As Bangladesh lies between the sub-tropical climatic zones, the ample opportunity of seaweed culturing along the coastline and especially in the dedicated protected island has the great prospects. The following common and popular culture methods can be followed in the designated area. Such as Line method: The use of loop or knotted monofilament line or polyethylene rope or any twine tied end to end of two mangrove stakes into which seaweed will grow. Net method: The use of monofilament or polyethylene net to allow the growth of seaweed in the knot of the net mesh. Besides these floating bamboo method, bottom mono-line method etc. will bring a good outcome.

CHAPTER 6

CONCLUSIONS

CHAPTER 6

CONCLUSIONS

For the sustainable sea food production, this study was designed to find the possibility to protect the marine habitat and ecosystem. Marine Protected Areas are critically important if we are to meet the needs of the increasing world population and demands for a reasonable quality of life. It is vital that we reverse the decline in marine ecosystems. This is essential to maintain, and ideally to increase, the sustainable supply of high quality protein from the sea and to realize the potential of other uses and values.

It is potential to run the aquaculture activities and marine conservation within marine protected areas simultaneously associated with the local conservation management goal and plan. This study develops the synergistic aquaculture model in MPAs and found the prospect to enhance the socio-economic status of the coastal stakeholders by farming the different valuable marine species. Aquaculture within MPAs is an opportunity in the Nijhum Dwip MPA and other proposed MPAs for the nutritional demand, earning money and poverty alleviation, employment and socioeconomic development. However, implementation of this study will supposed to explore the unexplored resources of Bangladesh's maritime boundaries. This is aimed to boost up the Bangladesh's blue economy. This study is concluded with the statement that, production of safe sea food by the synergistic aquaculture within the MPAs through direct manipulation has the significant prospect in context of Bangladesh.

However the benefits and limits to the different MPAs and aquaculture types have to be further explored and investigated. Closing these gaps would have considerable benefits - creating a better understanding all around, a better vision of the real impacts of aquaculture, a richer understanding of the role and importance of MPAs, and above all the opportunity to develop new innovative projects and perspectives for the future.

CHAPTER 7

RECOMMENDATIONS AND FUTURE PERSPECTIVES

CHAPTER 7

RECOMMENDATIONS AND FUTURE PERSPECTIVES

The aim of this study was to find out the potentiality of aquaculture within the MPAs of Bangladesh. This study will be helpful for the fisheries management authority to set the governance tools to maintain a sustainable stock. Although a qualitative approach was followed to explore the objective of this study, there are some limitations regarding this study which can be minimized by following the recommendations:

- ✓ Authority should declare and take the immediate action to establish of new MPAs for the conservation of biodiversity.
- ✓ The goal for achieving at least 10% protected area should be set up as early as possible for the sustainable environmental resilience.
- ✓ Local community should be trained up with the involvement of different aquaculture techniques directly within the MPA.
- ✓ Different aquaculture models should be applied in the MPAs in massive context in order to enhance the production.
- ✓ Furthermore research at this relevant issue at multi-dimensional approach will be the helpful for developing new knowledge.

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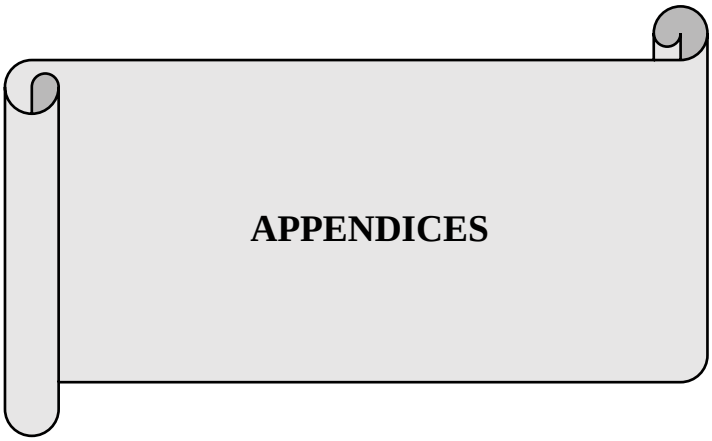
APPENDICES

APPENDICES

Appendix A: Definition and primary objectives of IUCN protected area categories (Dudley, 2008)

IUCN Category	Definition	Primary Objective
Ia	Category Ia are strictly protected areas set aside to protect biodiversity and also possibly geological/ geomorphological features, where human visitation, use and impacts are strictly controlled and limited to ensure protection of the conservation values. Such protected areas can serve as indispensable reference areas for scientific research and monitoring.	To conserve regionally, nationally or globally outstanding ecosystems, species (occurrences or aggregations) and/ or geodiversity features: these attributes will have been formed mostly or entirely by non-human forces and will be degraded or destroyed when subjected to all but very light human impact.
Ib	Category Ib protected areas are usually large unmodified or slightly modified areas, retaining their natural character and influence, without permanent or significant human habitation, which are protected and managed so as to preserve their natural condition.	To protect the long-term ecological integrity of natural areas that are undisturbed by significant human activity, free of modern infrastructure and where natural forces and processes predominate, so that current and future generations have the opportunity to experience such areas.
II	Category II protected areas are large natural or near natural areas set aside to protect large-scale ecological processes, along with the complement of species and ecosystems characteristic of the area, which also provide a foundation for environmentally and culturally compatible spiritual, scientific, educational, recreational and visitor opportunities.	To protect natural biodiversity along with its underlying ecological structure and supporting environmental processes, and to promote education and recreation

III	Category III protected areas are set aside to protect a specific natural monument, which can be a landform, sea mount, submarine caverns, geological feature such as caves or even a living feature such as an ancient grove. They are generally quite small protected areas and often have high visitor value.	To protect specific outstanding natural features and their associated biodiversity and habitats.
IV	Category IV protected areas aim to protect particular species or habitats and management reflects this priority. Many category IV protected areas will need regular, active interventions to address the requirements of particular species or to maintain habitats, but this is not a requirement of the category.	To maintain, conserve and restore species and habitats.
V	Category V protected areas are where the interaction of people and nature over time has produced an area of distinct character with significant ecological, biological, cultural and scenic value: and where safeguarding the integrity of this interaction is vital to protecting and sustaining the area and its associated nature conservation and other values.	To protect and sustain important landscapes/ seascapes and the associated nature conservation and other values created by interactions with humans through traditional management practices.
VI	Category VI protected areas conserve ecosystems and habitats together with associated cultural values and traditional natural resource management systems. They are generally large, with most of the area in natural condition, where a proportion is under sustainable natural resource management and where low-level non-industrial use of natural resources compatible with nature conservation is seen as one of the main aims of the area.	To protect natural ecosystems and use natural resources sustainably, when conservation and sustainable use can be mutually beneficial.

Biography of Author

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Abdulla Al Fahad completed B.Sc. in Fisheries (Hon's) from the Faculty of Fisheries of Chattogram Veterinary and Animal Sciences University (CVASU), Chattogram, Bangladesh with CGPA 3.52 out of 4.00. He has strong passionate in research of marine fisheries field and his specific research interests are on maritime spatial planning, marine survey and research, marine biodiversity conservation, development of mariculture and so on. Now, he is a candidate for the degree of MS in Marine Bioresource Science under the Department of Marine Bioresource Science, Faculty of Fisheries, Chattogram Veterinary and Animal Sciences University (CVASU).