

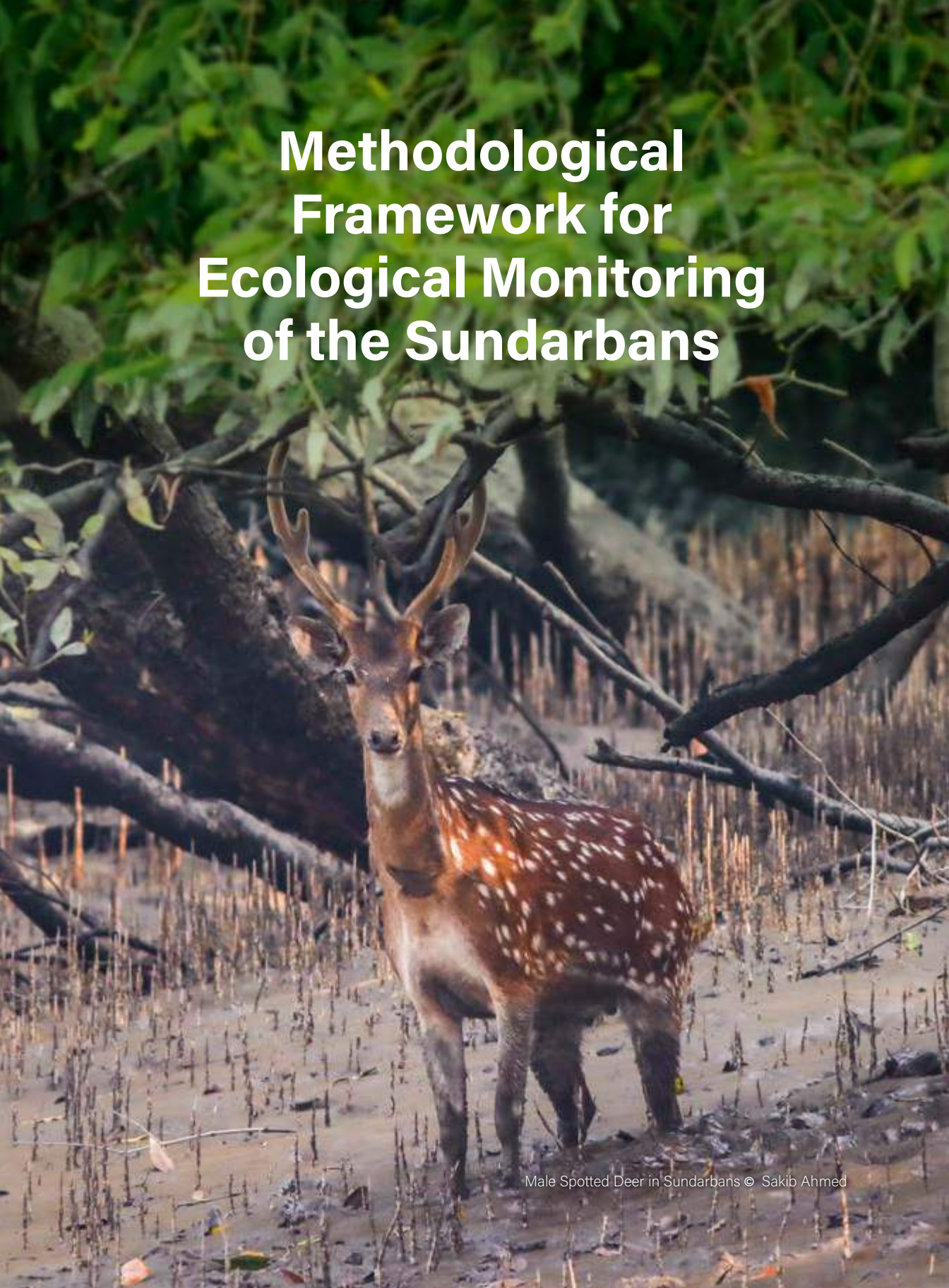


# METHODOLOGICAL FRAMEWORK FOR ECOLOGICAL MONITORING OF THE SUNDARBANS





# Methodological Framework for Ecological Monitoring of the Sundarbans



Male Spotted Deer in Sundarbans © Sakib Ahmed



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This publication is result of a grant agreement with IUCN on 'Ecological Monitoring for the Sundarbans' under the project 'Support to the Management of the Sundarbans Reserved Forest (SMPII)' implemented by the Bangladesh Forest Department, Ministry of Environment, Forest and Climate Change, with support from GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

This publication is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) and supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

### Published by:

Support to the Management of the Sundarbans Reserved Forest project (SMPII), Bangladesh Forest Department

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### Citation:

Bangladesh Forest Department, IUCN, International Union for Conservation of Nature and Natural Resources, and Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. 2023. Methodological Framework for Ecological Monitoring of the Sundarbans. Bangladesh Forest Department, IUCN, International Union for Conservation of Nature and Natural Resources, and Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bangladesh Country Office, pp. v+192

Front Cover: Adnan Azad, Monirul Khan, A B M Sarowar Alam, Mirza Shamim Ahasan Habib, Gazi Mosharof Hossain

Back Cover: A B M Sarowar Alam

### Creative & Production:

Nymphea

([www.nymphea-bd.com](http://www.nymphea-bd.com))

### Available From:

Support to the Management of the Sundarbans Reserved Forest project (SMPII)  
Bangladesh Forest Department  
Bon Bhaban, Agargaon  
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**Dr. Farhina Ahmed**  
Secretary  
Ministry of Environment,  
Forest and Climate Change

## Message

The Ministry of Environment, Forest and Climate Change acknowledges the significance of the Sundarbans – a UNESCO World Heritage Site and Ramsar Site - as a vital ecosystem rich in biodiversity and a crucial source of livelihood for many. The recently published "Methodological Framework for Ecological Monitoring of Sundarbans" is a notable achievement. This framework is a result of the collaborative effort of IUCN in Bangladesh, GIZ, and the Forest Department. This framework addresses the need for systematic long-term ecological monitoring in the Sundarbans, crucial for its sustainability in the face of climate change and human activities. It provides a structure for comprehensive monitoring, enhancing our understanding of the ecosystem's health and aiding conservation efforts.

We express gratitude to all contributors, including government agencies, academic institutions, and individual experts. Special thanks go to Forest Department, IUCN, GIZ and the various stakeholders who played essential roles in formulating the framework.

Our goal is to safeguard the Sundarbans, ensuring its resilience and long-term sustainability. The ecological monitoring framework will enable evidence-driven decision-making, and empowering effective conservation strategies, that will be instrumental for the Government of Bangladesh to safeguard this vital and fragile ecosystem. There remains a lack of systematic monitoring, which this framework aims to address by facilitating data collection, analysis, and monitoring efforts.

Together, we work towards the conservation of the Sundarbans, preserving its invaluable biodiversity for future generations.

**Dr. Farhina Ahmed**



**Md. Amir Hossain Chowdhury**  
Chief Conservator of Forests  
Bangladesh Forest Department

## Message

The Sundarbans, rich in biodiversity and home to many threatened species of flora and fauna, serves as a crucial source of livelihood for millions, while also fights the adverse effects climate change and protects Bangladesh from deadly cyclones and tropical storms.

The publication of the book "Methodological Framework for Ecological Monitoring of Sundarbans" by International Union for Conservation of Nature (IUCN) Bangladesh, with support from Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH and Bangladesh Forest Department, is a significant achievement for the conservation and management of Sundarbans. It outlines a methodology for monitoring the ecological status of the Sundarbans, the world's largest mangrove forest, and includes capacity building workshops, training, and a roadmap for a central data management platform.

Despite its importance, the Sundarbans face threats from climate change and human activities. The lack of systematic long-term ecological monitoring hampers efforts to evaluate impacts and predict the future of this unique ecosystem. The publication emphasizes the necessity of science-based monitoring for Sundarbans. It aims to gather and analyze data from selected indicators to monitor the ecological status of the Sundarbans for conservation purposes.

I express my gratitude for the support from Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, IUCN in Bangladesh, and Forest Department's commitment to biodiversity conservation of the Sundarbans.

This book will enable the custodians, managers and stakeholders to assess the state of the Sundarbans, detect changes, evaluate ecosystem health, and assess impacts from human or climate changes, thus contributing to the long-term welfare of the populace.

**Md. Amir Hossain Chowdhury**

## Message

The Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), on behalf of the German Government, is Support to the Management of the Sundarbans Reserved Forest project (SMP II) as a follow-on project of the Management of the Sundarbans Mangrove Forest for Biodiversity Conservation and Increased Adaptation to Climate Change Project (SMP). The aim of the project is to strengthen the Bangladesh Forest Department as well as those forest dependent communities and local administration to utilise newly developed instruments for a more sustainable management and long-term planning of the Sundarbans Mangrove Forest. The full implementation of Co-management, Spatial Monitoring and Reporting Tool (SMART), a standardised Ecological Monitoring and a new Resource Management Plan (IRMP) for the decade until 2030 are the key focus areas of SMP II.

Keeping that in mind, GIZ, in collaboration with IUCN Bangladesh, a project called "Ecological Monitoring of Sundarbans" has been initiated with grant support from GIZ. This project aims to establish long-term ecological monitoring in the Sundarbans, allowing managers and stakeholders to assess the forest's condition, identify changes and trends, evaluate ecosystem health, and assess impacts from human and natural factors.

The Sundarbans is the world's largest mangrove forest containing national and international importance, which is highly biodiverse and uniquely remarkable. It has been recognized as a Ramsar Site since 1992 and a UNESCO World Heritage Site since 1997. The Sundarban provides crucial habitat for critically endangered Cetacean species such as the Irrawaddy Dolphin and Ganges River Dolphin. The income and food sources of many local populations come from the forest resources, such as supplying fish and fuel woods. The ecosystem of the Sundarbans benefits 3.5 million people that rely on the Sundarbans' resources for a living, either directly or indirectly.

I am pleased to state that the project was able to determine a precise set of ecological parameters, both biotic and abiotic, for monitoring the ecological status of representative Sundarbans areas. Associated with launching a pilot sample technique, conducting consultative meetings, capacity-building workshops, and training programs focused on Ecological Monitoring (EM) methodology, data collection, data analysis, and other relevant components.

The entire ecological monitoring framework, along with the achievement made during the project period is captured in this book. This book will enhance understanding of the multi-dimensional factors affecting the Sundarbans and contribute to rigorous ecological monitoring that will improve environmental health the forest. Also, it will strengthen capacity, promote social and economic well-being, help in an effective forest management planning, and align with global goals like the SDGs and UNESCO World Heritage Sites, all while contributing to conservation, environmental protection, and resource preservation.

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## Message

I'm pleased to share the culmination of our efforts in formulating the Ecological Monitoring Framework for the Sundarbans, which is detailed in this book. This project marks another chapter in the longstanding history of IUCN Bangladesh, particularly in the Sundarbans region. IUCN has been actively involved in various conservation efforts in the Sundarbans. For instance, IUCN is playing an important role in improving tiger habitat management, reducing human-tiger conflict, and enhancing community resilience. Similarly, IUCN worked in dolphin conservation in Sundarbans as well. Additionally, IUCN developed strategies for the long-term sustainability of the Sundarbans and its ecosystem services, emphasizing community well-being.

The methodological framework for the ecological monitoring of Sundarbans that we've developed will serve as a crucial tool for monitoring the health and integrity of the delicate Sundarbans ecosystem. Its comprehensive nature will enable evidence-based decision-making, empowering effective conservation and management strategies.

Despite earlier efforts, there remains a lack of systematic Long-Term Ecological Monitoring in the Sundarbans, which is crucial for understanding its dynamics and ensuring its long-term sustainability. Our framework addresses this need by facilitating data collection, analysis, and monitoring efforts.

I want to extend my deepest appreciation to the stakeholders, government bodies, academic institutions, and individual experts who played pivotal roles in making this framework a reality. Special thanks go to the Forest Department of the Ministry of Environment, Forest and Climate Change (MoEFCC) for their guidance and support throughout the project.

Together, we are dedicated to safeguarding the Sundarbans, preserving its rich biodiversity and essential ecosystem services.

This book will help consolidate scattered data and aid in monitoring the ecological status of the Sundarbans for the conservation of its valuable biodiversity. May it serve as a valuable guide for those committed to the protection and sustainable management of the Sundarbans.

### **Raquibul Amin**

Country Representative, IUCN Bangladesh Country Office,  
Head, Sub-regional Leader South Asia,  
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Buffy-fish Owl in Sundarbans © Adnan Azad

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# CHAPTER 1

## INTRODUCTION

The Sundarbans is the largest mangrove forest in the world covering about 6,017 square km spanning across Bangladesh and India, and is the host to a plethora of species making it one of the most biodiverse areas. While dominating mangrove tree species in the forest is the Sundri (*Heritiera fomes*), at least three different saline zones can be differentiated in the Sundarbans with more than 528 documented species of higher plants including at least 18 species of orchids, while 165 algae, 43 species of fungi and 16 species of lichen as lower groups of plants. The forest canopy is dense and closed with more than 70% canopy coverage, and tree heights of up to 25 m. One other unique feature of the Sundarbans is the abundance of mega-fauna, although several species are showing decreasing trends in population. The Tiger (*Panthera tigris*) and its main prey, the Spotted Deer (*Axis axis*), are still abundant (114 tigers estimated in 2018 survey). The Irrawaddy Dolphin (*Orcaella brevirostris*) and Ganges River Dolphin (*Platanista gangetica*) are globally threatened Cetacean species which have a large stronghold in the waters of the Sundarbans and adjacent coastal and river areas. For many people around the Sundarbans, the rich fish population provides essential livelihood and food supply. The intact forest not only stores immense amounts of carbon but also protects the densely populated hinterland in the north of the Sundarbans from wave surge and storm damage. Since this forest provides so many natural resources and ecological services, it has great national as well as international importance. In 1992, Sundarbans was declared as Ramsar Site and in 1997 as UNESCO World Heritage Site. Climate change impact (sea level rise as well as storm surges and storm damage) and increasing pressure by more than 3.5 million people living around the Sundarbans as well as the growing industrialization are jeopardizing the conservation of the Sundarbans.





Ariel view of the Sundarbans © Touhid Parvez Biplob

Despite earlier inventories and monitoring programs for the forest resources (since 1960) and regular census of flagship species such as the Tiger and Crocodile, there is a lack of a systematic Long-Term Ecological Monitoring (LT-EM) which would be essential for assessing many different impacts on the Sundarbans and forecasting the future of this unique ecosystem on the basis of reliable data. A science-based modern monitoring is also the pre-condition for UNESCO World Heritage Sites (WHSs) and for an updated Integrated Resources Management Plan (IRMP) for the Sundarbans until 2035 and beyond. Furthermore, an EM is needed to support the strategic environmental assessment (SEA) done for the southwestern region and track the possible impacts of numerous current developments on the Sundarbans.

GIZ, on behalf of the German Government, is Support to the Management of the Sundarbans Reserved Forest project (SMP II) as a follow-on project of the Management of the Sundarbans Mangrove Forest for Biodiversity Conservation and Increased Adaptation to Climate Change Project (SMP), which was implemented by Bangladesh Forest Department. IUCN Bangladesh with the grant support from GIZ has started a project the development of the methodological framework for the ecological monitoring of the Sundarbans to support the 'Management of the Sundarbans Reserved Forest (SMP II)' on November 2021

The overall objective of the study is to identify a set of selected ecological parameters for monitoring the ecological status, pilot methodology (sampling) in representative areas of the Sundarbans and to conduct consultation meeting, capacity building workshop, and training programs focusing EM methodology, data collection, data analysis, etc.





Sundarbans in high tide © IUCN/A B M Sarowar Alam

## 1.1 Physiography of the Sundarbans

### Geography

The Sundarbans, the world's largest single tract mangrove forest, is located in the vast delta formed by the super confluence of the Ganges, Brahmaputra and Meghna (GBM) rivers at the edge of the Bay of Bengal (Hussain et al., 2013; Pramanik et al., 2019; Rahman et al., 2020; Titumir et al., 2020). It lies between latitude 21'39 and 22'30 N and longitudes 89'01 and 89'52 in the southernmost part of the administrative districts of Bagerhat, Khulna and Satkhira (Hussain, 2014). It is a cluster of low-lying islands covering an area of approximately 140,000 ha, divided between Bangladesh (~60%) and India (~40%)

(Mondal, 2019; Sarkar, 2021). This mangrove forest is an impassable saltwater swamp that runs for around 125 kilometers from east to west and extends by an average 80 km inland (maximum 100km) (BFD, 2017; Mahmood et al., 2021; Neogi et al., 2016).

Three wildlife sanctuaries have been established within the Sundarbans; 1. Sundarbans East Sanctuary, located along the Baleshwar River in the east and cover an area of 1,22,921 ha; 2. The Sundarbans South Sanctuary along the Bay of Bengal with an area of 75,310 ha and 3. Sundarbans West Sanctuary in Satkhira district with an area of 1,19,719 ha, along the Bay of Bengal. The Sundarbans is a region of transition, between the freshwater of the Ganges and the saline water of the Bay of Bengal, resulting in the meeting of salt and fresh water.





Morning in Sundarbans © IUCN/Sakib Ahmed



## CLIMATE

The climate in the Sundarbans has a strong seasonality between monsoon, summer and a cool winter. The rainy monsoon season stretches from June to September and provides torrential rainfall under the impacts of South-West trade winds, with 75 percent of the annual precipitation occurring during this period. The dry season extends from November to April and brings intermittent rainfall, under the influences of the north and northeast winds. The temperature in the dry season might soar above 35-degree Celsius during the months of April and May (Hussain, 2014).

During the pre-monsoon season of April-May, the average yearly temperature, as measured in Khulna by FD in 2010, ranges from 20.4 degree to 35.2-degree Celsius, and during monsoon the temperature ranges from 23.6 degree to 33.5 degree Celsius. The monsoon winds bring high rainfall, humidity, and cloud cover, sediment load and water levels of the rivers. The annual average temperature during post- monsoon season at Khulna is 31.7 degree Celsius and the season is marked by southerly winds, high temperatures and evapotranspiration rates, with occasional large thunder storms. The area inundated by tidal water expanded and

the salinity of river water reached a maximum during this season. The post monsoon season is hot and humid, sunny weather with low precipitation (Hussain, 2014).

The average yearly rainfall (as observed at Mongla by JOEC, 2002) is 1887.5 mm while the monthly, average rainfall varies from 1.6 mm in December to 344.1 mm in July. The mean yearly relative humidity varies from 70 percent at Satkhira to 80 percent in Bagerhat. The prevailing breeze comes from South in March to September and North-Northwest in November. The Sundarbans, being positioned at the apex of the Bay of Bengal, places in the immediate route of cyclonic storms originating over the sea. They are accompanied by intense tropical storms, flood and tidal bore, which cause many disasters. Majority of the storms occur during the pre- and post-monsoon months of May and October. Major cyclones have been reported for centuries as the cause of loss to human and animal life. The pre- and post-monsoon months of May and October are noted for strong and brief duration thunderstorms over the land masses and severe cyclonic storms in the Bay of Bengal (Hussain, 2014).

## Geology

The Sundarbans was raised by the deposition of sediments as a result of soil erosion in the Himalayas. The process of sedimentation was accelerated by the tidal system of the sea. The substratum consists mainly of Quaternary Era sediments, sand and silt mixed with marine salt deposits and clay. In the Bangladesh portion of the Sundarbans, formation of the pro-gradational sequence began prior to 4,000 years BC and ended about 1800 Cal years BC. Although they are most likely subsiding at the rates of 1-4 mm/year, rapid shoreline decay is not present because of the continued supra-tidal sediment delivery to the lower delta plain surface (Hussain, 2014).

## Topography

The Sundarbans have a complicated drainage pattern comprised of interconnected rivers, cross channels, and estuaries that are influenced by seasonal rainfall, fresh water inflow, and sediment intake. The alluvial formations form a saucer-shaped basin by surrounding a core low-lying area toward which the ground surface slopes. Thus, the micro-topographical types conducive to mangrove formation are the result of stream deposition and fluvial processes. Due to the huge number of interconnected streams inside the Sundarbans, the process of accretion and erosion is extremely complex. Both river and tidal sediments are dispersed across forest

floors. While net erosion occurs along the sea face, new islands are forming in some locations. The Sundarbans have a topographical range of 0.5 to 4.0 meters. Within the Sundarbans, the tidal fluctuation is between 1.5 and 2.5 meters. Around 70% of the land is between 1.5 and 3.0 meters above sea level, which is submerged twice daily by tidal flooding. However, about 85% of the land is submerged at the monsoon's high tides (Hussain, 2014).

## 1.2 Hydrology of the Sundarbans

### River System

The Sundarbans receives water from the distributaries of the Padma and Jamuna. Large tidal rivers together with the innumerable small channels and creeks flow from the forest into the Bay of Bengal. The total length of the rivers within the forest is about 12,000 km, which reflects the density of the river network. There is a seasonal variation in the level of salinity, which is inversely proportional to fresh water supply. The major river systems are quite deep compared to the smaller rivers. The rivers and canals in the northern and southern parts are less deep compared to the central part of the Sundarbans. Important rivers that pass through the Sundarbans are Baleshwar, Passur, Shibsa, Kobadak, Kholpetua and Kandi. These river systems create four estuaries in the Sundarbans



Ganges River Dolphin in Sundarbans. © IUCN/A B M Sarowar Alam

knowns as Bangra, Kunga, Malancha and Raimangal. The Raimangal River separated the district of the 24 Parganas of India from that of Satkhira and divides the protected forests from the reserved forests (Hussain, 2014).

The eastern portion of the Sundarbans is flushed with water from the Ganges and its distributions. However, the water courses in the western Sundarbans within Bangladesh territory resemble long arms of the sea rather than river as they are subject to tidal influences throughout their course. There also have a higher level of salinity compared to the waterbodies in the central and eastern Sundarbans. The freshwater flow from Madhumati-Baleshwar system keeps salinity level low in the eastern Sundarbans (Hussain, 2014).

## Tidal Flow

Tide in the Bay of Bengal are predominantly semi-diurnal with a tidal period of about 12 hours and 25 minutes. It takes approximately 2.5 hours for the tide to traverse in the Raimangal, Jamuna, Malancha, Passur, Sibsa and Baleshwar Rivers. The tidal variation is about 3m on an average between low and high tides. The tidal regime is larger at Mongla than the Hiron Point. The lowest tide at Mongla is 0.03 m in March while it is 1.37m in August (Hussain, 2014).



## Salinity

The freshwater that flows from the rivers and the tidal ingress in the forest result in a gradient of salinity that varies both spatially and temporally. In general, the salinity is higher nearer to the coast, while the water is much fresher on the inland side of the forest. Similarly, the salinity decreases from west to east, and the eastern part of the Sundarbans is oligohaline (<5‰ salinity). During the past few decades, however, the sources of all rivers in the western part of the Sundarbans have progressively been silted up, thereby disconnecting sources of fresh water from the mangrove delta. The freshwater flows are much larger from the Brahmaputra and Meghna rivers, particularly, through the Baleshwar River on the eastern side of the Sundarbans. The reduced freshwater flows in the western parts of the Sundarbans have resulted in an increased salinity of the river water, and have made the rivers shallow over the years (Hussain, 2014).

Salinity in the Sundarbans is highly dependent on the salinity on the coast and the volumes of fresh water flowing from the upstream. The arrival of high tide water at the coast generally coincides with the peak in daily salinity. The tidal

amplitudes during spring tides are 2.5 to 3 times higher than that during the neap tides. The higher water levels tend to cause greater volumes of saline water to enter the forest than during the neap tides. The dilution effect of any fresh water flow is consequently weaker during the spring tides. As a result, salinity concentrations during the spring tides are generally higher. The salinity levels on the coast are also affected by the volume of freshwater discharges through the lower Meghna estuary (Hussain, 2014).

## 1.3 Flora and Fauna

### Flora

Mangrove plants dominate the Sundarbans' flora. The Sundarbans alone are home to 35 of the world's 50 true mangrove plant species (Neogi et al., 2016; Rahman and Asaduzzaman, 2013). A total of 528 vascular plant species have been recorded from the Sundarbans regions, including 24 ferns, 131 monocotyledons, 373 dicotyledons, of which 42 legumes, 41 grasses, 39 sedges, 29 euphorbias and 18 orchids (Hossain et al., 2022; Habib et al., 2019; Rahman et al., 2015). The Sundarbans supports 22 families of mangrove tree species, including six



species from *Rhizophoraceae*, three each from *Acanthaceae* and *Meliaceae*, two each from *Combretaceae* and *Lythraceae* (Rahman et al., 2015; Hossain, 2013).

The floral diversity of Sundarbans is characterized by the abundance of Sundri (*Heritiera fomes*), which accounts for approximately 73 percent of total landmass, followed by Gewa (*Excoecaria agallocha*), which accounts for approximately 16 percent of total forest area, Goran (*Ceriops decandra*), and Keora (*Sonneratia apetala*), which all occur prominently throughout the area (Ghosh et al., 2016; Iftekhhar and Saenger, 2007). Baen (*Avicennia officinalis*), Dhundul (*Xylocarpus granatum*), Passur (*Xylocarpus moluccensis*), Kankra (*Bruguiera gymnorhiza*, *B. sexangula*) and Jhana (*Rhizophora apiculata*, *R. mucronata*) are some of the other common mangrove tree species. Hental (*Phoenix paludosa*) are well-represented among palms, while Dhanshi (*Oryza coarctata*), Baliaghas (*Myriostachya wightiana*), Sun grass (*Imperata cylindrica*) and Khagra (*Phragmites karka*) are well-represented among grasses (Roy et al., 2016; Triverdi et al., 2016; Rahman et al., 2015).

Other plant species of the Sundarbans include 64 species of climbers like *Derris scandens*, - *D. trifoliata*, *Dalbergia candenatensis*,

25 epiphytes like *Psilotum nudum*, *Haplopteris elongata*, *Microsorium punctatum* *Hoya parasitica*, *Dischidia numularia* and seven species of parasites like *Cassytha filiformis*, *Cuscuta reflexa*, *Dendrophthoe falcata* are commonly found (Rahman et al., 2015; Hossain et al., 2015; Hossain et al., 2022). Although there are many records on the species diversity of major vascular flora in the Sundarbans but the records on the non-vascular flora is limited. However, 165 species of algae have been recorded in the Sundarbans, which include varieties of *Vaucheria*, *Cladophorella* and *Boodleopsis* (Hussain, 2014). Only one species of moss, 16 species of lichens, five species of cyanobacteria, and 43 species of wood decay fungi and mushroom in the Sundarbans. However, the details about these are still unknown (Hussain, 2014).

The floristic elements of Sundarbans are usually divided into mangroves and mangrove associates. The members of the families *Rhizophoraceae* and *Acanthaceae* (*Avicenniaceae*) generally dominate most of the mangrove in the world, while the Sundarbans has the greatest abundance of the members of the families *Malvaceae* (*Sterculiaceae*) and *Euphorbiaceae* (Hussain, 2014).

## Fauna

The Sundarbans is home to an estimated 505 species of wildlife, including 355 birds, 49 mammals, 87 reptiles, 14 amphibians. Nearly 50% of all species in Bangladesh can be found in the Sundarbans, barring the amphibians (Dipu et al., 2013). This Ramsar Site is home to a variety of aquatic wildlife as well, including the Estuarine Crocodile (*Crocodylus porosus*), Olive Ridley Turtles (*Lepidochelys olivacea*), dolphins (*Platanista gangetica* and *Peponocephala electra*), and mollusks such as the Giant Oyster (*Crassostrea gigas*) (Titumir et al., 2020).

From a terrestrial point of view, the Sundarbans is the critical habitat for the Tiger (*Pantera tigris*) (Khan, 2004). The Tiger is the largest terrestrial predator in the Indo-Pacific region, depending on prey such as Spotted Deer (*Axis axis*), Indian Muntjac (*Muntiacus muntjak*), Eurasian Wild Boar (*Sus scrofa*), and Rhesus Macaque (*Macaca mulatta*) in the Sundarbans. The forest also provides a habitat for small wild cats such as Jungle Cat (*Felis chaus*), Fishing Cat (*Prionailurus viverrinus*) and Leopard Cat (*P. bengalensis*) (Khan, 2004). Along with it

we have the largest concentration of Rhesus Macaque and the Wild Boar in this forest (Dipu et al., 2013).

Sundarbans supports a large variety of resident and overwintering migrant birds including the globally critically endangered Masked Finfoot (*Heliopais personata*) as well as Asian Giant Softshell Turtle (*Pelochelys cantorii*), Northern River Terrapin (*Batagur baska*), Fishing Cat (*Prionailurus viverrinus*), White-bellied Sea Eagle (*Haliaeetus leucogaster*), Pallas's Fish-eagle (*Haliaeetus leucoryphus*), Lesser Adjutant (*Leptoptilos javanicus*), Ruddy Kingfisher (*Halcyon coromandra*), Mangrove Whistler, (*Pachycephala grisola*), Red Junglefowl (*Gallus gallus*), as well as certain migratory waders, gulls and terns.

Some of the Critically Endangered species found in the aquatic environments of the Sundarbans include the Knifetooth Sawfish (*Anoxypristis cuspidate*), Northern River Terrapin (*Batagur baska*) and the Ganges River Shark (*Glyphis gangeticus*). Other significant faunal components include Barking Deer (*Muntiacus muntjak*), Ganges River Dolphin (*Platanista gangetica*) and Irrawaddy Dolphin (*Orcaella*



Saltwater Crocodile in Sundarbans. © IUCN/A B M Sarowar Alam

*brevirostris*), Olive Ridley Turtle (*Lepidochelys olivacea*), Estuarine Crocodiles (*Crocodylus porosus*), King Cobra (*Ophiophagus hannah*), Green Frog (*Euphlyctis hexadactylus*), etc (Dipu et al., 2013).

Among invertebrates the most dominant are the crabs and gastropods and bivalves on mud banks and intertidal zones, when some gastropods could be found on mangrove plants such the Baen, Genwa, Golpata, Bola, and Sundari trees. Butterflies, moths, dragonflies, honeybees, wasps, beetles, bumblebee, bugs, spiders, flies, midges, mosquitoes, damselflies, spiders, cicadas, scorpions and centipedes dominate the terrestrial habitats. Zooplankton provides a lifeline for the fishes and other animals living in aquatic environment. This generally comprises the larvae of shrimps, crabs and other crustaceans, mollusks and echinoderms as well as fish fries. Among invertebrates the most important commercial species are the shrimps and prawns and lobsters. Major prawn and shrimp species used in commerce are *Macrobrachium rosenbergii*, *M. malcolmsonii*, *M. rude*; *Penaeus monodon*, *P. semisulcatus*, *P. indicus*, *P. japonicas*, *P. merguiensis*, *P. penicillatus*, *P. orientalis* and *Metapenaeus monoceros*. The commercially trawled lobsters include *Panulirus polyphagus*, *P. versicolor*, *P. homarus*, *P. ornatus*, and *Thenus orientalis* (Anon, 2006, Prawns and Lobsters). Among insects the most important commercial ones are the honeybees. Non-commercial crabs that decorate the mudflats, mud banks, sandflats, overland, tree trunks and in the water of the Sundarbans includes Red fiddler crab *Gelasimus annulipus*, Fiddler Crabs of *Uca* and *Gelasimus* species, *Metopograpsus* species, *Portunus pelagicus* (Dipu et al., 2013).

The Sundarbans is heaven for butterflies. Most spectacular, colorful, immense varieties in colors define the hordes of species that we encounter regularly in the Sundarbans, irrespective of seasons. Wasps, beetles, bugs, hornets, cicadas, crickets, midges, flies, grasshoppers, leafhoppers, aphids, ants and spiders are countless.

Sundarbans is also the home not only for the largest diversity of snake species but also supports the highest density of most snakes in Bangladesh. Notable among these are the King Cobra, Green Pit Vipers, Vine Snakes, Tree Snakes *Dendrelaphis* species etc. (Dipu et al., 2013).

## 1.4 Socio-ecological Importance

The Sundarbans is critical to the national and regional economies as it provides numerous direct and indirect benefits (e.g., ecosystem services, such as fuelwood collecting, fishing and so on) to the communities that surround them. It is estimated that each hectare (ha) of Sundarbans will generate \$ 302.16 million (Hussain 2014), for the next 22 years. The valuation of economic services per ha ranges from \$105.7 to \$840.59 per year. The upper values include important ecosystem services that are provided by mangroves, including waste management, water regulation among others. It was also estimated that \$ 229.45 is the value per ha per year, the mangrove ecosystem provides in terms of coastal protection.

To summarize, it is estimated that the Sundarbans ecosystem produces a service worth between 456.32 to \$1,191.84 per ha per year, which equates to \$273 to \$714 million per year (Hussain 2014). These services benefit the 2.5 million people that rely on the Sundarbans resources for a living, either directly or indirectly (BFD/ SEA 2021).

It is estimated that for every cyclone, the Sundarbans saves human lives worth \$ 11 billion (Hasnat and Hussain, 2017). Other protection services derived from the Sundarbans contribute US\$ 456.6 million annually, whilst tourism contributes US\$ 48.7 million and livelihood services US\$ 136.6 million (BFD/ SEA 2021).

The Carbon stock of the Sundarbans was estimated to be 136 million tonnes of carbon in 2019 (BFD/ SEA 2021, Bangladesh National Forest Inventory Report, 2021) which is equivalent to 499.12 million tonnes of carbon dioxide.





## 1.5 Threats to Biodiversity

The Bangladesh Sundarbans delta, comprising the mangrove woodland and neighboring panorama, helps the vastest array of lifestyles bureaucracy amongst ecosystems of a similar kind. However, over the past twenty-five years, the high fee of the human front into the mangrove, followed by the mushrooming increase of shrimp farming at the periphery, has induced extreme harm to the entire environment. Besides, the weather trade has an enormous influence on Sundarbans. The expected elevation of the Sundarbans is lower than one meter above sea degree, which means that this area is particularly susceptible to flooding. Due to this, any ocean water swelling will affect the place dramatically. Many areas of the sector are affected by climate change; however, Sundarbans is one of the highest affected areas due to high salinity, sedimentation, and land erosion stages. The salinity grows daily due to frequent cyclones, sedimentation, and brackish tiger shrimp cultivation. The elevated

salinity jeopardizes Sundarbans' ecosystems and poses extra hazards than other stressors (Rahman et al., 2021).

Climate alternate is affecting the Sundarbans in numerous approaches. It is because global warming is expected to cause an annual temperature upward push of 0.4 degree celsius in Bangladesh, and the ensuing sea degree is predicted to rise by 4 millimeters yearly (Sunny, 2017; Sunny, 2017b; Giri, 2014; Payo et al., 2016; Lönnqvist, 2010). These phenomena will increase salinity, and subsequently damage primary wooded area sources (Allison, 2005; Haq, 2009; Chowdhury et al., 2007). Firstly, rising sea ranges are posing sizeable threats to these delicate ecosystems. The volume of water in the oceans is increasing because of thermal enlargement and the addition of extensive amounts of water because of the melting of polar ice caps and glaciers. it's been estimated that a 28-cm sea-level upward push above levels of the year 2000 could result in a 96 percent decline of the Bengal Tiger's habitat in Bangladesh. These threats are increasingly



Fishing boats in the periphery of Sundarbans. © IUCN/A B M Sarowar Alam

worrying because the rise in sea level is currently 3.2 mm per year.

Apart from the risks of climate change, there are several others, more immediate threats that are present for Sundarbans, as per the SEA Report published in 2021 (BFD/SEA 2021).

*Industrial Growth:* Rapidly growing industries around Sundarbans will result in increased air and water pollution and an increased footprint of industrial infrastructure. This increase in pollution will likely cause increase in diseases, impaired breeding and mortalities amongst aquatic and terrestrial animal species. There are 9 jute companies and 48 associated spinning mills remaining in the region. In addition, there are more than 70 rice mills and 80 food processing operations within the ECA boundaries. LPG bottling plants have been increased in recent times, along with storing facilities and refineries, as well as countless brick kilns in the periphery of the Sundarbans.

*Power and Energy Generation:* It will cause an increase in air pollution especially emissions of SO<sub>2</sub> and NO<sub>2</sub> and particulate matter (ash and fly ash), as well as heavy metals like mercury, lead, cadmium, arsenic, and other toxic elements and compounds, which might lead to pollution of surface water, fish habitats (depleting fish diversity), decrease of aquatic species. Constructions of coal-fired power plant(s) will lead to large emissions of CO<sub>2</sub>. Current, most of the power plants in the periphery of Sundarbans are operating on either heavy fuel oil (HFO) or high speed diesel (HSD). Furthermore, construction of four new fossil fuel-fired power plants are underway, which will generate a total capacity 2550 MW.

*Decreased freshwater flow:* Decreasing freshwater flow through the river system will cause salinity in the lower reaches of the distributary rivers in the Sundarbans to increase and may result in loss of floral and faunal habitats and hamper growth of important plant species (e.g. *Heritiera fomes*)



Lichens inside a Sundarbans creek © Sayam U. Chowdhury

*Anthropogenic Activities:* Around 2.5 million people in the areas surrounding the Sundarbans and ECAs are highly dependent on the ecosystem services provided by Sundarbans. This will increase the pressure on the protected areas.

*Water Vehicular Movement:* This will lead to increased disturbance inside Sundarbans, to wild animals and aquatic fauna due to noise and light as a result from the expansion of Mongla port, as well from transporting raw materials to the port and industries, and from tourism boats and other vessels. This also increases the risk of pollution from fuel and oil leaks/spills from lowly maintained boats, accidents and discarded materials (e.g. polythene bags and bottles).

*Illegal/unsustainable fishing practices:* Unsustainable harvesting of shrimp fry and wild fish larvae, with illegal fishing gear, poison fishing and fishing during the 'ban' period, will adversely affect wild fish populations, harm breeding grounds and threaten fish and shrimp cultivation. There is a risk of continued, or even increased, poison fishing using pesticides around the Sundarbans.

*Pollution from Solid Waste:* Solid waste is generated from many sources surrounding the Sundarbans, including urban areas as well as wastes from industrial complexes. The waste composition may contain organic matter, heavy metal, and plastics, metals, glass, oil and grease, and inerts (e.g. soil and ash). One of the major solid waste threats comes from plastic pollution.

Some other threats include Invasive Alien Species, and sedimentation of waterways are also considerable.

## 1.6 Management and Conservation Status

The Sundarbans mangrove forest has been managed by the government with technical and financial support from the national and international environmental and development

agencies. The entire forest has been divided into two forest divisions and four administrative ranges for better management: Chandpai, Sarankhola, Khulna, and Satkhira, each with 16 forest stations. It is subdivided further into 55 compartments and 9 blocks. In 1875, the Sundarbans was designated as a Reserve Forest. In 1997, UNESCO designated 139699.49 hectares of the Sundarbans as a World Heritage Site demonstrating the significance of the area's unique ecosystem (Siddiqi, 2001).

The Forest Department's establishment and forest management activities began in 1862. The Forest Act was enacted in 1865. Protected forests, known as Mini Head Water Catchment Forests, were established in 1875. Forest development activities commenced in 1871. The first working plan for scientific forest management was prepared for the Sundarbans in 1892. Forest policy was formulated in 1894. The first forest inventory was conducted in the Chittagong Hill Tracts in 1961. The first afforestation program started in 1963. Social forestry began in Chittagong in 1979. Wildlife sanctuary was established in the Sundarbans in 1960 and co-management system began in 2004.

The current forest management systems in Bangladesh have evolved to meet changing needs and objectives. Forests are no longer valued solely for timber, but also for providing clean air, clean water, quality wildlife habitat, biodiversity, and serving as a major source of nature-based tourism. The contemporary concept of forest management emphasizes involving people in the process, enabling them to feel a sense of ownership over forest lands and improving the living standards of those residing nearby. Practices such as agroforestry, homestead plantation, strip plantation, participatory forestry on encroached forest, mangrove afforestation in coastal areas, and REDD+ initiatives require adaptive management strategies. Bangladesh's forest management aims at enhancing environmental preservation and conservation, increasing public participation and benefits from forests, strengthening

institutional arrangements, improving management practices, and addressing climate change concerns.

The Sundarbans Reserved Forest Area falls under the jurisdiction of the Khulna region of the Bangladesh Forest Department. Within its territory, two forest divisions exist: the Sundarbans West Forest Division, with its headquarters in Khulna, and the Sundarbans East Forest Division, with its headquarters in

Bagherhat. The Sundarbans East Forest Division encompasses two ranges (Chandpai and Sarankhola), seven stations, and thirty-six toll stations. Similarly, the Sundarbans West Forest Division comprises two ranges (Khulna and Satkhira), nine stations, and twenty-eight toll stations. Additionally, the Wildlife Management and Nature Conservation Division, Khulna, and the Planning and Management Division, Khulna, provide coordinates for the management of wildlife and forest resources in the Sundarbans.



White-collared Kingfisher © IUCN/Sakib Ahmed

# CHAPTER 2

## ECOLOGICAL MONITORING: PROPOSED INDICATORS AND MONITORING FRAMEWORK

### **A framework for biotic and abiotic indicators**

#### Previous work related to the study

**E**cological monitoring incorporates retrospective and ongoing recordings of physical, chemical and biological parameters on a regional scale (Reise 1989). The aim of long-term ecological monitoring (EM) is to record changes in critical properties of biological communities, abiotic parameters and identifying to ecosystem health.

IUCN has been involved in developing EM plans in different habitats. Since mangrove ecosystems are dynamic both in space and time, indicators for EM has been chosen very carefully for the purpose of this framework. Relevant example is the toolkit for EM of Huraa Mangrove Nature Reserve, Maldives, to monitor the ecosystem health and conservation issues (Sriskanthan et al. 2008). Details can be found in: <https://portals.iucn.org/library/sites/library/files/documents/2008-097.pdf>





Spotted Deer is one of the primary prey of Tigers in Sundarbans. © IUCN/A B M Sarowar Alam

## 2.1 Ecological Monitoring

Although ecosystem varies greatly, all ecosystem have five inherent properties: composition, structure, function, complexity, and temporal change.

Ecological monitoring is the process of gathering data regarding the state and conditions of ecosystems structure, functions and services, at different points in time and space, in order to understand the causes of changes in ecosystem state variables (Yoccoz et al., 2001; Jones, 2011).

Ecological monitoring is usually done using a set of indicators (biotic and abiotic) to understand the current conditions of the ecosystem. It is difficult to measure everything of potential interest within an ecosystem, hence the selection of indicators to measure the changes is critical.

Important indicators may have some or all of the following characteristics:

- 1 Indicators that points to early warning of natural responses to environmental impacts (Noss, 1990a; Marshall et al., 1993; Munn, 1993; Woodley, 1996b)
- 2 The indicators that directly help understand the cause of change (Herricks and Schaeffer, 1985)
- 3 Provide a scope of continuous assessment over a wide range and intensity of stresses (Woodley, 1996a; O'Connell et al., 1998), which allows the detection of the impacts on the ecosystem (Noss, 1990a; Woodley, 1993; Gibbs et al., 1999)
- 4 Indicators that are cost-effective to measure and can be accurately estimated by all personnel (even non-specialists with training) involved in the monitoring (Kriesel, 1984; Davis, 1989; di Castri et al., 1992).



Fishing inside Sundarbans during monsoon season © IUCN/Sakib Ahmed

Indicators for ecological monitoring can be of different types, including species, environment, landscape, and ecosystem. At the species level, a wide variety of potential indicators can be selected:

- Keystone species: species that interacts with other species and cause effects that are large relative to their abundance (Mackey et al., 1994; Paine, 1995)
- Area-limited 'umbrella' species: Species that need vast areas of suitable habitat in order to maintain viable populations, due to which other associated species are also covered. These species usually have very large home ranges.
- Dispersal-limited species: Species that are confined to a small area, and their ability to

move from patch to patch is limited or that face a high mortality risk in trying to do so

- Resource-limited species: Species that need specific resources which may be in critically short supply, temporally or spatially
- Process-limited species: Species sensitive to the level, rate, spatial characteristics or timing of some ecological processes such as fire, flood, grazing, competition with exotic species, or predation
- Flagship species: Species that can easily attract public support for conservation. Species strongly associated with particular habitat features could also be useful indicators.



Bengal Tiger – the apex predator of Sundarbans © Monirul Khan

Indicator species which possess several of the above-mentioned characteristics are more desirable for monitoring purposes since the conservation of the processes, resources, and habitat features associated with them will probably coincide with the protection of the requirements of other ecologically-similar species.

As for the ecosystem level, the indicators might be a bit different. Abiotic and biotic parameters such as parameter to understand soil health, chemical parameters, and water quality parameters are

used. Other potential indicators may be events such as fires, nutrient cycling (Nitrogen, Potassium etc), insect outbreaks, primary productivity, and hydrological regimes etc.

Parameters like changes in land cover, or habitat loss, diameter and age class distributions of trees left standing after cutting versus trees removed (Noss, 1999), soil nutrient levels, and stand growth efficiency (Riitters et al., 1992) can be indicators for ecological monitoring.

A comprehensive conservation plan should include measures of indicators at several scales (White and Bratton, 1980; Woodley and Theberge, 1992) and, incorporate indicator species from all major functional guilds (producers, herbivores, carnivores, decomposers, etc.), so as to ensure that integrity is preserved at every level.

## Objectives of Ecological Monitoring

The overall objective of EM is to enable managers and relevant stakeholders to assess the state of the reserved forest, to detect changes and trends, to evaluate ecosystem health and to assess impacts by human or natural sources. The main objectives of this ecological monitoring framework are to systematically observe and assess the biodiversity, habitat conditions, and population dynamics of Sundarbans. Additionally, the framework aims to evaluate ecosystem functioning, monitor the impact of climate change and human activities. It also focuses on tracking key indicators of environmental change, assessing the effectiveness of conservation measures, and establishing an early warning system. Overall, the framework provides valuable data for informed decision-making, adaptive management, and effective conservation practices.

The aim of long-term ecological monitoring (EM) is to record changes in critical properties of biological communities. Since mangrove ecosystems are dynamic both in space and time, indicators for EM were chosen very carefully for the purpose of this assessment.

## 2.2 History of Ecological Monitoring

An essential part of management of forests, including the protected areas management, is the need for comprehensive monitoring framework. This framework should provide guidance and oversight for the effective management of the surrounding resources, the preservation of terrestrial and aquatic biodiversity, sustainable land-use practices, the establishment of

necessary facilities, administrative support, and sufficient budgetary resources.

There have been some management and monitoring programs in the Sundarbans, including the Integrated Resource Management Plan (IRMP), management plans for the wildlife sanctuaries inside Sundarbans, SMART Patrolling etc.

In spite of previous inventories and monitoring programs dating back to 1960, as well as regular censuses of flagship species like the Tiger, there was a notable absence of a systematic Long-Term Ecological Monitoring (LT-EM) initiative. This absence hinders the comprehensive assessment of various impacts on the Sundarbans and the ability to forecast the future of this unique ecosystem based on reliable data. Moreover, an Ecological Monitoring (EM) framework is imperative for conducting a strategic environmental assessment (SEA) to anticipate potential impacts arising from numerous ongoing developments in the Sundarbans and the broader south-western region of Bangladesh, including references to the Delta plan 2100.

Under the IRMP of Sundarbans, it is mentioned that field monitoring will serve as a strategic tool for enhancing protection efforts through the utilization of specific indicators and corrective measures. Within the monitoring aspect, the primary interventions will concentrate on: i) enhancing the monitoring of field staff patrolling activities to control unauthorized logging, fishing, and poaching of both predators (tigers) and prey (deer); and ii) establishing monitoring units in designated canals within selected compartments.

The Forest Department is also implementing the SMART (Spatial Monitoring and Reporting Tool) patrol management system to enhance its patrol efforts. SMART integrates data from various sources, including boat and foot patrols, intelligence sources, tour operators, and fishing communities, offering a comprehensive approach to monitor and combat threats to wildlife, fisheries, and forests. SMART patrolling

combines user-friendly software, training materials, and implementation standards. The initiative aims to address specific needs of patrolling in the Sundarbans, ensuring effective monitoring of illegal activities, and regular monitoring of important wildlife species.

The UNESCO World Heritage Commission first requested Bangladesh Forest Department to develop a program on ecological monitoring in 2009. Again in 2011, the World Heritage Commission reiterated the need of a robust ecological monitoring program. Thereafter, the committee urged Bangladesh to initiate ecological monitoring of the Sundarbans in 2014 and 2015, as mentioned in the Report on the mission to the Sundarbans World Heritage Site, Bangladesh, in 2016. Again in 2021, UNESCO urged Bangladesh to persist in and enhance ecological monitoring endeavors and the inventorying of large fauna by reinforcing the synergy and consistency of methodological approaches. This is essential to affirm the sustained positive trends in the populations of crucial species. Afterwards, Bangladesh Forest Department supported GIZ and in collaboration with IUCN Bangladesh, initiated the development of the ecological monitoring framework for the Sundarbans.

## 2.3 Ecological Monitoring Global Context

This toolkit brings together a simple range of methodologies to carry out regular socioeconomic and ecological monitoring in the reserve. By selecting some key ecological indicators (fish, birds, crabs, mangrove health and regeneration, garbage dumping, sedimentation, death of mangrove vegetation, clearing of natural vegetation, encroachment, invasive alien species, and erosion), ecosystem health and conservation issues of the reserve would be monitored effectively. This toolkit outlines the techniques that can be used to collect data and provides a framework for monitoring and analysis that can be used by individuals with no prior training in the field

of ecological monitoring. By ascertaining the baseline status and indicators chosen, long term monitoring can be carried out.

In general, monitoring an indicator should be measurable, precise, consistent, sensitive, simple, widely distributed, capable of providing a continuous assessment over a wide range of stress, independent of sample size, easy and cost-effective to measure, ecologically significant, and able to differentiate between natural cycles or trends and those induced by anthropogenic stress (Srisikanthan et al. 2008).

Ellison et al. (2012) with support from Secretariat of the Pacific Regional Environment Programme (SPREP) prepared a manual for mangrove monitoring in the Pacific Islands Region for 26-member countries with three levels of intensity of monitoring. In the level one of the monitoring techniques, transect based survey to record mangrove locations, species zones, conditions and pressures has been proposed. In level two, the manual proposed to carry out vegetation plots in each zone recording community structure, height and diameter of trees, and density of seedlings. Sedimentation monitoring and litter productivity has been proposed at the third level of monitoring which could provide good information on mangrove health and sedimentation trends. This manual also urges to develop a regional mangrove research and monitoring database system which will assist users to better understand and utilise system features and functions. This tool could be used as centralised database for national mangrove and survey data as well as an analytical and reporting tool.

In the Marine National Park, Gujarat, India, the mangrove areas were monitored for 25 years on the basis of remote sensing data (Shailesh and Anjali 2001). This has helped in planning various management actions to conserve this vital ecosystem.

In Matang Mangrove Forest Reserve, Malaysia, the satellite images taken in different years were used to monitor the change in forest composition

(Aziz et al. 2015). The stand-age structure map, which highlighted that the mapping and analysis of mangrove species and stand-age structure can play a useful role in achieving cost-efficient and ecologically sustainable outcomes in a production mangrove forest.

In the Philippines, the rate of decline of the country's mangrove forest cover was monitored on the basis of spatiotemporal dynamics (Long et al. 2014). The results were useful for developing conservation strategies, biodiversity loss mitigation efforts, and future monitoring and analysis.

In Mida Creek, Kenya, the mangrove plant species composition, density and distribution were monitored by a double sampling approach – multispectral satellite imagery and ground checks (Gang and Agatsiva 1992). The harvest of mangroves by the local people were also determined and monitored through the same approach.

In Campeche, Mexico, the dynamics of mangrove cover were mapped and monitored on the basis of satellite data, but the local fishing guides were consulted to identify the regional drivers of mangrove degradation (Cissell et al. 2018).

In Queensland, Australia, vegetation survey (Eyre et al. 2015), vegetation condition assessment (Neldner et al. 2012), litter trapping, and crab burrow counting methods are used to monitor mangrove forest health. Mostly vegetation assessment-based indicators are being used here to evaluate biophysical change over time.

The “Mangrove Ecosystem Monitoring Program” in Oman has been developed in March 2014 to monitor the status of mangrove ecosystems that are under threat from natural and human impacts, and to implement conservation and management measures in accordance to the monitoring results. The program consists of monitoring of mangrove forest, fauna and environmental conditions by selecting different indicators or parameters including tree growth, health, faunal indicator species, water quality

(measuring temp., salinity, pH, DO, COD, etc.), sedimentation, water level and threats identification.

In Xuan Thuy National Park of Vietnam which is a mangrove ecosystem, considering of the environmental, biotic and anthropogenic factors, biodiversity indicators were selected as per suggestions provided by the Convention on Biological Diversity (Haneji 2014).

The Wadden Sea, a World Heritage Site and tidal flats system, that extends along the coasts of Denmark, Germany and the Netherlands. A Trilateral Monitoring and Assessment Programme (TMAP) was launched in 1997 that assesses and monitors morphology, ecological processes, wildlife (waterbird census, Harbour Seal census, Harbour Porpoises census, fish monitoring, etc.) and human activities. Also, Wageningen Marine Research has been collecting data on benthic fauna, birds, seals, porpoises, fish, and salt marshes since the 1970s. Such data can be used to better understand the influence of human use and natural dynamics on the system.

To conserve the Himalayan ecosystem – a global biodiversity hotspot, from the adverse impact of climate change Indian National Action Plan for Climate Change undertakes long term ecological monitoring with forest biodiversity specific parameters (basal area, composition, occurrence, status of forest, phenology, regeneration, nativity, biomass, vegetation structure, rarity, invasion, moisture, nutrients and temperature) and indicators (Negi et al. 2019).

To monitor Mangroves in Somalia (Puntland, Somaliland and South-Central Somalia) Mumuli et al. (2010) proposed to interpret satellite images, to collect ecological and vegetation data, and to interview local people on use and management of mangroves. The use of Unmanned Aerial Vehicle (UAV) or drone and remote sensing technology in mangrove ecosystem monitoring is emerging in recent time (Hsu et al. 2020, Navarro et al. 2020, Otero et al. 2018, Cao et al. 2018, Aziz et al. 2015). UAV



Sundarbans in high tide. © IUCN/Kazi Zenifar Azmiri

data can be used in plant species identification, canopy height, stem location, above ground biomass, canopy structure, canopy area calculation thereby contributing in ecological monitoring.

## 2.4 Lesson learned from Bangladesh

IUCN Bangladesh produced a manual on community-based biodiversity monitoring of Tanguar Haor in 2016, under the project Community based Sustainable Management of Tanguar Haor. The manual illustrated methods to monitor an important wetland habitat through community-based approaches. The manual also set indicator species (birds, mammals, fish, reptiles and plants) that need to be monitored to understand the status of biodiversity in TanguarHaor habitat (IUCN Bangladesh 2016b).

USAID's Climate Resilient Ecosystems and Livelihoods (CREL) project launched a long-term ecological monitoring plan through resident forest bird monitoring in order to understand the impact of co-management practices-initiated during 2003-04 in selected forest protected areas in Bangladesh. This long-term ecological monitoring (resident birds as indicators) have been conducted to measure bio-physical change in forest eco-systems. Several indicator bird species were selected for each protected area and the abundance of these were used to analyse and understand the forest health. Birds were selected since birds are more visible and responsive to ecological changes in their habitats than other species groups. Till 2018 EM has been conducted in 14 PAs under CREL by maintaining same methodology and approach to understand better natural resource management through collaborative management (Haque et al. 2018).



Typical Sundarbans creeks © IUCN/Kazi Zenifar Azmiri

IUCN Bangladesh, and BFD implemented a project entitled “Expanding the Protected Area System to Incorporate Important Aquatic Ecosystems (EPASIIAEP)”, supported by UNDP-Bangladesh and Global Environment Facility (GEF). In a publication under this project, Alam et al. (2019) proposed a complete set of iconic and habitat specialist indicator species for monitoring change in this specialised ecosystem to understand the changes due to different natural and anthropogenic reason which

might affect functioning of overall Sundarbans mangrove ecosystem as a whole.

In terms of bees and butterflies, pollinators are effective bio-indicators (both as individual and community) and they can be used to monitor ecological damage caused by chemical and physical alteration, habitat and vegetation modification. Different studies for example, Maleque et al., (2018) Taylor et al., (2001) An & Choi (2021), Griffis et al., (2001) Winarni & Afifah



Masked Finfoot – Critically Endangered avian species in Sundarbans © IUCN/A B M Sarowar Alam

(2020), have indicated the use of pollinator species as an indicator of the ecosystem health of forest.

Among the pollinator species, bees and butterflies are widely used as indicator species. Ghazanfar et al., (2016) stated butterflies as the wild indicators as they react quickly to minor changes in the environment. Study by Winarni & Afifah, (2020) confirmed use of butterfly as useful indicators of ecosystem health in Bali Barat National Park. Moreover, butterfly could be used to assess ecosystem condition of natural forests as well (Lomov et al., 2006). Alternatively, bee response to environmental pollution either via high mortality rate or via high accumulation of heavy metals, fungicides and herbicides in honey, honey hives or even to their body (Celli & Maccagnani, 2003). Honey can characterize the level of soil, plant and air pollution (Jones, 1987) for couple of square kilometers.

The major pollution types of the Sundarbans are air, water and soil pollution. Gaseous emission from tourist ships, motorized vehicles and nearby industries releases toxic chemicals that causes air pollution and affects vegetation of Sundarbans (Rahman et al., 2009). Pesticides used to catch fishes eventually moves through the food chain and affects terrestrial flora and fauna of Sundarbans. Moreover, herbicide effects soil ecology of mangroves detrimentally. During nectar collection, bees directly and indirectly collect samples from both vegetations, air, water and soil (Lazor et al., 2021), therefore they could be used to analyse to measure pollution level. As monitoring (number, distribution and chemical analysis) of bees and honey can reveal information about pollution level, it could be used as indicator species of Sundarbans mangrove forest.

An intensive study carried out by Jiban Bikash Karjocrom 2018, a IUCN member, has been able to prepare inventory of butterflies of the Chandpai and Sarankhola range. Besides preparing the inventory, this study examined effect of climatic parameter on butterfly number of selected areas. Therefore, butterflies monitoring (number and distribution) could be

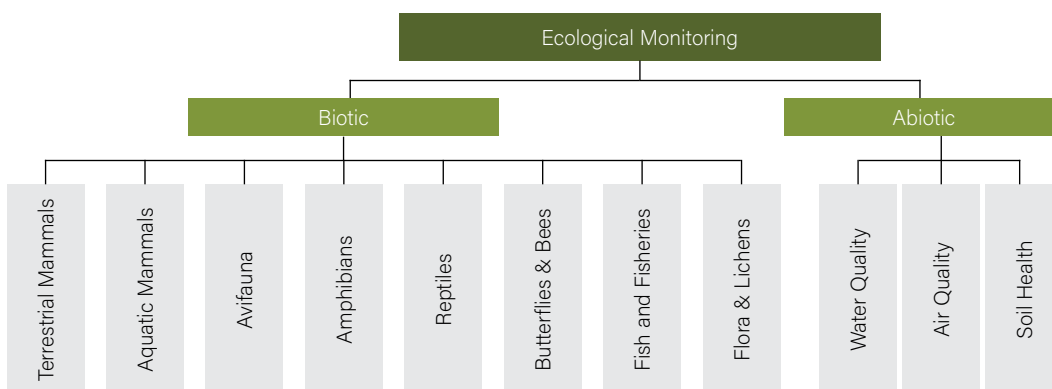
used to understand alteration of micro climatic condition of Sundarbans mangrove forest. As vegetation change has impact on the butterfly distribution; thus, could be used to detect vegetation change (Brown & Freitas 2000) of this unique mangrove forest.

## 2.5 Selection of indicators

Ecological monitoring incorporates retrospective and ongoing recordings of physical, chemical and biological parameters on a regional scale (Reise 1989). A detailed baseline inventory has been formed from available data on Sundarbans that will assist in the ecological monitoring methodologies and framework. Government offices like Bangladesh Forest Department, Bangladesh National Herbarium, Bangladesh Forest Research Institute has been involved for relevant data and methodologies and were adopted or referred where applicable for this framework. Other non-governmental organizations with experience on working in the Sundarbans have been approached for the formation of the baseline inventory.

Detailed methodologies have been developed through expert consultation meetings covering survey techniques, sample collection and analysis for each of the selected parameters. The need for equipment, sampling site, personnel, and cost of survey were also estimated for selection of each of the indicators. Sample plots and data would be collected from throughout the Sundarbans including the three terrestrial wildlife sanctuaries and six dolphin sanctuaries and also in three types of saline zones (strong/moderate/less saline zone) considering seasonal variation.

The Ecological Monitoring framework would provide powerful tools for decision-makers and stakeholders alike to assess forest conditions, identify sources of impact, and determine trends, enabling informed decision-making, public participation, and greater transparency regarding the sustainable use and management of tropical forests.



● Figure 1: The schematic diagram of the indicator framework for ecological monitoring

A set of biotic and abiotic indicators, consisting of flagship, keystone and indicator species of flora and fauna, were selected as a part of ecological monitoring of Sundarbans (Table 1).

**Table 1. Proposed indicators**

| Biotic              | Indicator monitoring                                                                                                                                           | Rationale for Indicator Selection                                                                                                                                                                                                                                        |
|---------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fauna               |                                                                                                                                                                |                                                                                                                                                                                                                                                                          |
| Terrestrial Mammals | Tiger, Spotted Deer, Eurasian Wild Boar                                                                                                                        | Tiger, Spotted Deer, Eurasian Wild Boar<br>Indicate the functionality of ecosystem as well as primary prey population of apex predator of the ecosystems<br><br>Details in Section 3.1(A), Terrestrial Mammals                                                           |
| Aquatic Mammals     | Oriental Small-clawed Otter, Ganges River Dolphin, Irrawaddy Dolphin                                                                                           | Indicates stable aquatic vegetation, estuarine habitat, salinity of water, abundance of fish and other aquatic animals. Regular flow of water current, and level of pollution.<br><br>Details in Section 3.1(B), Aquatic Mammals                                         |
| Avifauna            | Masked Finfoot, Mangrove Pitta, Red Junglefowl, Lesser Adjutant, White-bellied Sea-eagle, Brown-winged Kingfisher, Crimson Sunbird, Streak-breasted Woodpecker | The species were selected covering birds from different strata and micro-habitats of the Sundarbans, including keystone and flagship avifauna species.<br><br>Details in Section 3.1 (C), Avifauna                                                                       |
| Amphibians          | Crab-eating Frog                                                                                                                                               | Indicates the presence of freshwater sources during monsoon and throughout the year. Indicates the presence of highlands within mangroves in Sundarbans. Any change in their population indicates the alteration of freshwater sources.<br><br>Details in Section 3.1(D) |
| Reptiles            | Saltwater Crocodile, Water Monitor Lizard, Monocled Cobra, Common Vine Snake                                                                                   | Indicates the abundance of large fishes in the river as well as other prey species. Also indicates the health of aquatic ecosystems and micro-habitats like smaller wetlands, swamps and lower canopy forests.<br><br>Details in Section 3.1 (D)                         |

| Biotic             | Indicator monitoring                                                                                                                                                                                                                                                                                                 | Rationale for Indicator Selection                                                                                                                                                                                                                                                     |
|--------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Butterflies & Bees | Tree Nymph, Sundarban Crow, Crimson Rose, Giant honey bee, Asian honey bee or Eastern honey bee                                                                                                                                                                                                                      | Details in Section 3.1 (E)                                                                                                                                                                                                                                                            |
| Fish and Fisheries | Barramundi/Seabass, Grey Eel Catfish, Spotted Scat, Goldspot Mullet, Mudskipper, Orange Mud Crab, Giant river Prawn                                                                                                                                                                                                  | Indicates aquatic ecosystem health and overall fish population of Sundarbans<br>Details in Section 3.1 (E)                                                                                                                                                                            |
| Tree species       | Sundri ( <i>Heritiera fomes</i> ), Shingra ( <i>Cynometra ramiflora</i> ), Gewa ( <i>Excoecaria agallocha</i> ), Kakra ( <i>Bruguiera sexangula</i> ), Poshur ( <i>Xylocarpus moluccensis</i> ), Goran ( <i>Ceriops decandra</i> ), Baen ( <i>Avicennia officinalis</i> ), Kholshi ( <i>Aegiceras corniculatum</i> ) | Indicates the forest canopy height and coverage, occurrence and performance in salinity gradients. Data on indicator species also indicates the overall forest ecosystem quality/ health which will be helpful for ecological monitoring of SMF.<br>Details in Section 3.1 (G), Flora |
| Shrub species      | Keya kanta ( <i>Pandanus foetidus</i> ), Nona jhaw ( <i>Tamarix indica</i> ), Nunia ( <i>Aegialitis rotundifolia</i> )                                                                                                                                                                                               | Indicates the ecological succession, salinity trend, and forest type. Data on their occurrence, distribution, abundance, growth performance indicates the forest quality.                                                                                                             |
| Regeneration       | Seedlings, saplings and poles of indicator tree species                                                                                                                                                                                                                                                              | Indicates the future potentiality, forest type, and forest quality                                                                                                                                                                                                                    |
| Lichens            | <i>Cladonia caespiticia</i> , <i>Flavoparmelia caperata</i> , <i>Graphis scripta</i> , <i>Ramalina fraxinea</i>                                                                                                                                                                                                      | Indicates the air quality of the forest ecosystem. Lichens are very sensitive to air pollution, which makes them valuable as indicator species. Their data will be used to monitor the air quality<br>Details in Section 3.1 (G), Lichens                                             |
| Abiotic            | Indicator monitoring                                                                                                                                                                                                                                                                                                 | Rationale for Indicator Selection                                                                                                                                                                                                                                                     |
| Water quality      | Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), pH, Suspended Matter, Salinity                                                                                                                                                                                                  | Water quality of the Sundarbans<br>Details in Section 3.2                                                                                                                                                                                                                             |
| Air quality        | Nitrogen Oxides (NOx), Sulfur Oxide (SOx), Particulate Matter (PM2.5/PM10), Temperature, Humidity                                                                                                                                                                                                                    | Air quality of Sundarbans                                                                                                                                                                                                                                                             |
| Soil Health        | pH, Conductivity, N,P, Visual Indicator, Salinity                                                                                                                                                                                                                                                                    | Soil Health of the Sundarbans ecosystem<br>Details in Section 3.2                                                                                                                                                                                                                     |

Each indicator chosen provides a specific information on forest ecosystem health. Detail information on each indicator and the link to forest health is described in the latter chapters. In summary, the indicators were chosen based on their specific sensitivity, cost effectiveness in data collection, their relative abundance in Sundarbans, and ease of monitoring by forest officials, like forest guards and rangers and volunteers.

Ecological Monitoring (EM) in the Sundarbans will essentially help to assess and predict possible impacts on the ecosystem and to develop adequate responses. Ecological Monitoring will benefit Sundarbans in several ways, including,

- Realizing the ecological conditions (development, deterioration or consistent) of Sundarbans.
- Understanding the biodiversity status and conditions of the forest.
- To adopt strategies to conserve and protect the biodiversity, wildlife, waterbodies of the forest.
- This monitoring will also help to devise effective environmental management plans and policies for the forest.
- This will fulfill the requirement of the UNESCO World Heritage Site.

## 2.6 Basics of monitoring framework: Site selection, monitoring and data interpretation

The Sundarbans is a vast area with a diverse ecosystem. Monitoring a large amount of biodiversity across this vast area and making sound decisions is undoubtedly a daunting task, so the entire Sundarbans has been subdivided into 65 sample units to facilitate the survey work and output visualization process. Each sample unit will be counted as the smallest unit to conduct the survey properly and present it meaningfully on the map. This entire mapping system, as well as its integration with field surveys, is discussed in detail in the following steps.

Bangladesh Forest Department carried out the last tiger census in 2017 and 2018, and conducted khal (small rivers and canals) surveys for understanding the distribution of tiger's prey species. The khal survey followed the framework of 55 management compartments to delineate a total of 65 sample units (Aziz 2018).

The present Ecological Monitoring Framework proposes to use those 65 sample units for collecting data on the biotic and abiotic indicators. The number of sample plots, quadrats or river segments to be surveyed can vary across indicators. This unified framework will not only enable to collect field data with minimum number of volunteers/ researchers at the same time and pace but also to compare and integrate data of different indicators against each sample unit.

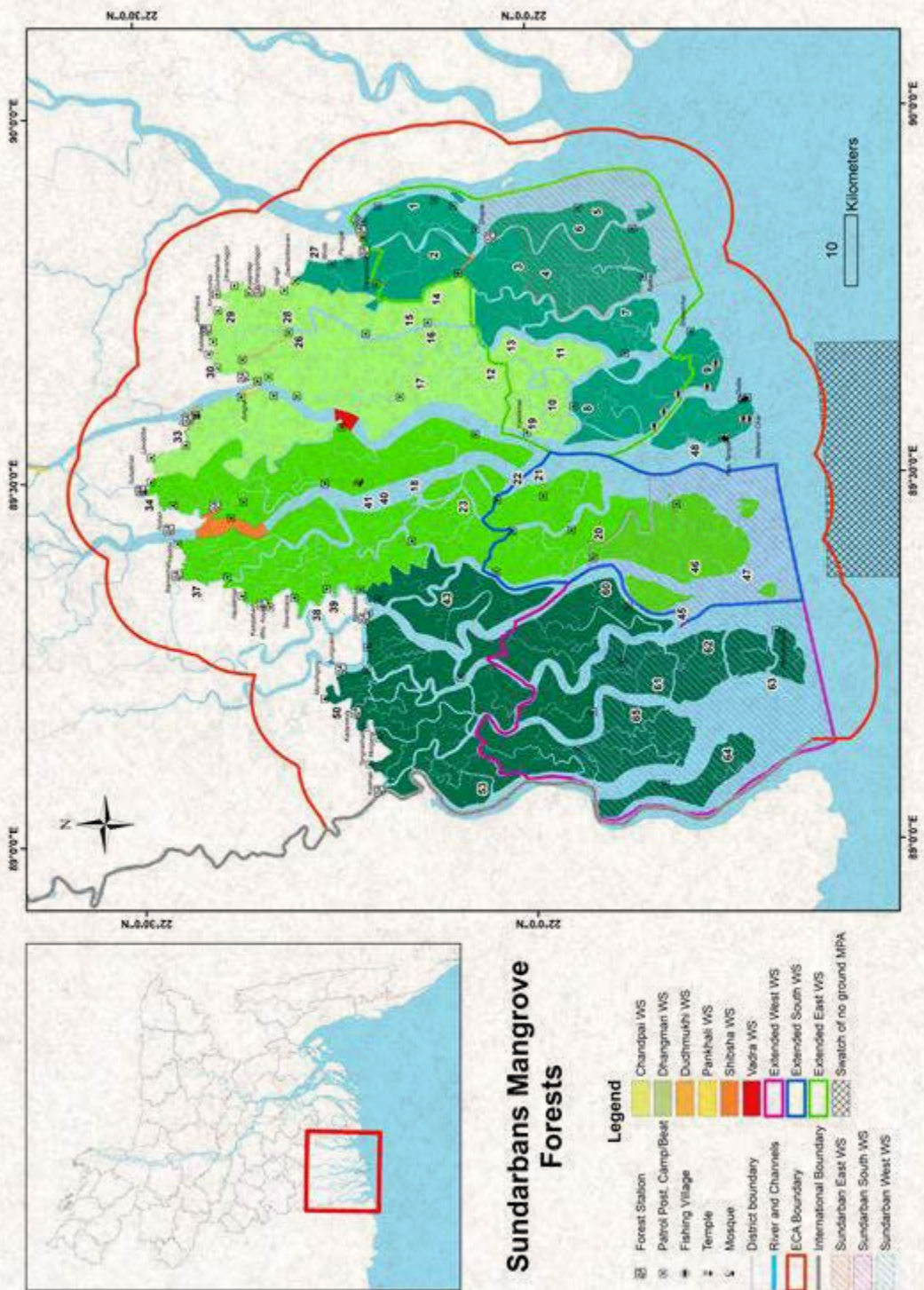
### Step-1: Selection of sampling units/site

The Sundarbans have been divided into a total of 65 compartments (Figure 2) where surveys for ecological monitoring will be conducted. The grids are shown on Figure 2.

Therefore, for accurate and up-to-date data, search for recent satellite imagery was needed. The study analysed Sentinel 2 satellite imagery from the open-source platform USGS to retrieve the latest landforms in the Sundarbans. The satellite imagery used for analysis was taken on January 31, 2022, and it was largely cloud-free. The Sentinel 2 satellites have a Multi-Spectral Instrument (MSI) with 13 spectral bands that range from the visible range to the shortwave infrared (SWIR). Bands come in variable resolutions from 10 to 60 meters and their wavelength is determined based on specific purposes. The land surface of the Sundarbans can be roughly divided into two categories, such as Forest and Wetland. The Modified Normalized Difference Water Index (MNDWI) method has been used to properly map these forests and wetlands of Sundarbans.

$$\text{MNDWI} = (\text{Green} - \text{SWIR}) / (\text{Green} + \text{SWIR})$$

Further, forests and wetlands are separated by reclass process of MNDWI output. With the help of expert opinions and various published literature, the entire forest area is divided into sixty-five sample units and the names of rivers and canals are included. The names and details of rivers and canals have been collected through various published books, articles, and field observations.



● Figure 2. Map of Sundarbans showing 65 sample units (a total of 195 khals are included in the 65 sample units. The list of khals are in Annex 1.)

## Step-2: Sampling plan

From each sample unit, 1-3 khals of 30-100m width to be used for the data collection on the indicator species. Around 20 km segments from selected khals to be surveyed by transects from sample units. To ensure proper detection, the survey boat is needed to be run with an average cruising speed of 4-6 km/hour during low tide. Surveys for majority indicators to be conducted within the sample units at various areas. One exception is to be Olive Ridley Turtle surveys under reptiles, where the surveys are to be conducted in the sandy beaches mainly in Kotka, Kachikhali, Dublar Char and Bangabandhur Char. Teams designated to survey various indicators would be grouped together and conduct the surveys accordingly. Survey teams for Terrestrial Mammals, and Small-clawed Otter from Aquatic Mammals to be grouped with survey teams from avifauna, reptiles and amphibians, and plants. Survey teams for dolphin and fish to be grouped together for surveys.

Detailed data collection plan for each indicator groups of species groups and abiotic factors are given in the respective chapters on each indicator groups.

## Step-3: Data collection and interpretation

Data for both biotic and abiotic should be collected at least every two-years interval. Thus, the monitoring results are expected to exhibit the trends of the Sundarbans ecosystem health.

For biotic indicators, the relative abundance i.e. the frequency of sightings of indicator species or their signs (e.g., pugmark for tigers) per km of khal will be expressed as an index, and weighted against each sample unit for visualization in GIS platform. Both biotic and abiotic parameters selected for EM will produce a range of data on the relative abundance and/or quality of ecosystems. The indicators have been selected from every element of different ecosystems; thus, outcome of EM is expected to provide reflections about overall health conditions of different ecosystems of the Sundarbans.

Visual encounter in line transect survey method has been followed to understand the Relative Abundance (RA) of indicator species from each sampling unit.

### Relative Abundance (RA)= Encounter Number (EN)/Transect Length (TL)

Calculating Relative Abundance (RA) is an established and accepted method worldwide for monitoring ecological status. Relative Abundance (RA) will be calculated for each species by dividing its Encounter Number (EN) with Transect Length (TL). This RA value will be incorporated with Geodatabase along with spatial reference and will be visualized by GIS Mapping and interactive dashboard.

Apart from biotic indicators, abiotic indicators to be monitored following recommended methodology on-site and in laboratory and visualized against respective sample unit in GIS platform. Each indicator species is given a range of maximum and minimum possible sighting rate, and data collected for each indicator from the EM surveys will be compared to the pre-determined range to understand relative abundance. The relative abundance will be illustrated in gradient color codes (Table 2&3).

### Time-frame for data collection

| Groups              | Interval of Time |
|---------------------|------------------|
| Terrestrial Mammals | Three years      |
| Aquatic Mammals     | Three years      |
| Avifauna            | Two years        |
| Amphibians          | Three years      |
| Reptiles            | Three years      |
| Butterflies & Bee   | Two years        |
| Fish and Fisheries  | Five years       |
| Flora               | Five years       |
| Lichens             | Five years       |
| Water quality       | Five years       |
| Air quality         | Five years       |
| Soil Health         | Five years       |

**Table 2: Color codes based on the level of relative abundance of each indicator species**

| Very High | High | Moderate | Low | Very Low | Absent |
|-----------|------|----------|-----|----------|--------|
|-----------|------|----------|-----|----------|--------|

\* Color codes of indicator plant species are to be given based on the level of DAFOR scale according to their RA value, where, D- Dominant (>75%), A- Abundant (51-75%), F- Frequent (26-50%), O- Occasional (11-25%), R- Rare (1-10%), and 0 indicates Absent

**Table 3. List of selected biotic and abiotic indicators with their qualitative ranking and associated range value**

| Sl No                                                                                                                                                                                                                                                        | Indicator Species                                        |                                | Qualitative Ranking |   |   |   |    |   | Range Value |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------|--------------------------------|---------------------|---|---|---|----|---|-------------|
|                                                                                                                                                                                                                                                              |                                                          |                                | 5                   | 4 | 3 | 2 | 1  | 0 |             |
|                                                                                                                                                                                                                                                              |                                                          |                                | VH                  | H | M | L | VL | A |             |
|                                                                                                                                                                                                                                                              | English Name                                             | Scientific Name                |                     |   |   |   |    |   |             |
| The number of indicator species varies between species and groups. Expert judgment will be utilized to provide a justifiable value/range to each particular indicator species and then rank them (5 to 0; Very high, High, Medium, Low, Very Low and Absent) |                                                          |                                |                     |   |   |   |    |   |             |
| <b>Biotic Indicators</b>                                                                                                                                                                                                                                     |                                                          |                                |                     |   |   |   |    |   |             |
| <b>A</b>                                                                                                                                                                                                                                                     | <b>Terrestrial Mammals</b>                               |                                |                     |   |   |   |    |   |             |
| 1.                                                                                                                                                                                                                                                           | Pugmark of Tigers                                        | <i>Panthera tigris</i>         |                     |   |   |   |    |   |             |
| 2.                                                                                                                                                                                                                                                           | Spotted deer                                             | <i>Axis axis</i>               |                     |   |   |   |    |   |             |
| 3.                                                                                                                                                                                                                                                           | Wild boar                                                | <i>Sus scrofa</i>              |                     |   |   |   |    |   |             |
| <b>B</b>                                                                                                                                                                                                                                                     | <b>Aquatic Mammals</b>                                   |                                |                     |   |   |   |    |   |             |
| 1.                                                                                                                                                                                                                                                           | Oriental Small-clawed Otter                              | <i>Aonyx cinereus</i>          |                     |   |   |   |    |   |             |
| 2.                                                                                                                                                                                                                                                           | Ganges River Dolphin                                     | <i>Platanista gangetica</i>    |                     |   |   |   |    |   |             |
| 3.                                                                                                                                                                                                                                                           | Irrawaddy Dolphin                                        | <i>Orcaella brevirostris</i>   |                     |   |   |   |    |   |             |
| <b>C</b>                                                                                                                                                                                                                                                     | <b>Avifauna</b>                                          |                                |                     |   |   |   |    |   |             |
| 1.                                                                                                                                                                                                                                                           | Masked Finfoot                                           | <i>Heliopais personata</i>     |                     |   |   |   |    |   |             |
| 2.                                                                                                                                                                                                                                                           | Mangrove Pitta                                           | <i>Pitta megarhyncha</i>       |                     |   |   |   |    |   |             |
| 3.                                                                                                                                                                                                                                                           | Red Junglefowl                                           | <i>Gallus gallus</i>           |                     |   |   |   |    |   |             |
| 4.                                                                                                                                                                                                                                                           | Lesser Adjutant                                          | <i>Leptoptilos javanicus</i>   |                     |   |   |   |    |   |             |
| 5.                                                                                                                                                                                                                                                           | White-bellied Sea-eagle                                  | <i>Haliaeetus leucogaster</i>  |                     |   |   |   |    |   |             |
| 6.                                                                                                                                                                                                                                                           | Brown-winged Kingfisher                                  | <i>Pelargopsis amauroptera</i> |                     |   |   |   |    |   |             |
| 7.                                                                                                                                                                                                                                                           | Crimson Sunbird                                          | <i>Aethopyga siparaja</i>      |                     |   |   |   |    |   |             |
| 8.                                                                                                                                                                                                                                                           | Streak-breasted Woodpecker                               | <i>Picus viridanus</i>         |                     |   |   |   |    |   |             |
| <b>D</b>                                                                                                                                                                                                                                                     | <b>Amphibians</b>                                        |                                |                     |   |   |   |    |   |             |
| 1.                                                                                                                                                                                                                                                           | Crab-eating Cricket Frog                                 | <i>Fejervarya cancrivora</i>   |                     |   |   |   |    |   |             |
| <b>E</b>                                                                                                                                                                                                                                                     | <b>Reptiles</b>                                          |                                |                     |   |   |   |    |   |             |
| 1.                                                                                                                                                                                                                                                           | Saltwater Crocodile                                      | <i>Crocodylus porosus</i>      |                     |   |   |   |    |   |             |
| 2.                                                                                                                                                                                                                                                           | Water Monitor Lizard                                     | <i>Varanus salvator</i>        |                     |   |   |   |    |   |             |
| 3.                                                                                                                                                                                                                                                           | Monocled Cobra                                           | <i>Naja kaouthia</i>           |                     |   |   |   |    |   |             |
| 4.                                                                                                                                                                                                                                                           | Common Vine Snake                                        | <i>Ahaetula nasuta</i>         |                     |   |   |   |    |   |             |
| <b>F</b>                                                                                                                                                                                                                                                     | <b>Butterflies/bees</b>                                  |                                |                     |   |   |   |    |   |             |
| 1.                                                                                                                                                                                                                                                           | Tree Nymph                                               | <i>Idea agamarschana</i>       |                     |   |   |   |    |   |             |
| 2.                                                                                                                                                                                                                                                           | Sundarbans Crow                                          | <i>Uploea crameri</i>          |                     |   |   |   |    |   |             |
| 3.                                                                                                                                                                                                                                                           | Crimson Rose                                             | <i>Pachliopta hector</i>       |                     |   |   |   |    |   |             |
| 4.                                                                                                                                                                                                                                                           | Giant honey bee                                          | <i>Apis dorsata</i> Fabricius  |                     |   |   |   |    |   |             |
| 5.                                                                                                                                                                                                                                                           | Asian honey bee, Asiatic honey bee, or eastern honey bee | <i>Apis cerana</i> Fabricius   |                     |   |   |   |    |   |             |

| SI No                                                                                                                                                                                                                                                        | Indicator Species                             |                                                      | Qualitative Ranking |   |    |   |   |   | Range Value |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|------------------------------------------------------|---------------------|---|----|---|---|---|-------------|
|                                                                                                                                                                                                                                                              |                                               |                                                      | 5                   | 4 | 3  | 2 | 1 | 0 |             |
|                                                                                                                                                                                                                                                              | VH                                            | H                                                    | M                   | L | VL | A |   |   |             |
|                                                                                                                                                                                                                                                              | English Name                                  | Scientific Name                                      |                     |   |    |   |   |   |             |
| The number of indicator species varies between species and groups. Expert judgment will be utilized to provide a justifiable value/range to each particular indicator species and then rank them (5 to 0; Very high, High, Medium, Low, Very Low and Absent) |                                               |                                                      |                     |   |    |   |   |   |             |
| G                                                                                                                                                                                                                                                            | Fish and Fisheries                            |                                                      |                     |   |    |   |   |   |             |
| 1.                                                                                                                                                                                                                                                           | Orange Mud Crab                               | <i>Scylla olivacea</i> (Herbst 1796)                 |                     |   |    |   |   |   |             |
| 2.                                                                                                                                                                                                                                                           | Giant River Prawn                             | <i>Macrobrachium rosenbergii</i>                     |                     |   |    |   |   |   |             |
| 3.                                                                                                                                                                                                                                                           | Barramundi/Seabass                            | <i>Lates calcarifer</i> (Bloch 1790)                 |                     |   |    |   |   |   |             |
| 4.                                                                                                                                                                                                                                                           | Grey Eel-Catfish                              | <i>Plotosus canius</i> (Hamilton-Buchanan 1822)      |                     |   |    |   |   |   |             |
| 5.                                                                                                                                                                                                                                                           | Spotted Scat                                  | <i>Scatophagus argus</i> (Linnaeus 1766)             |                     |   |    |   |   |   |             |
| 6.                                                                                                                                                                                                                                                           | Goldspot Mullet                               | <i>Chelon parsia</i> (Hamilton-Buchanan 1822)        |                     |   |    |   |   |   |             |
| 7.                                                                                                                                                                                                                                                           | Mudskipper                                    | <i>Boleophthalmus dussumieri</i> (Valenciennes 1837) |                     |   |    |   |   |   |             |
| H                                                                                                                                                                                                                                                            | Flora (Tree Species) *                        |                                                      |                     |   |    |   |   |   |             |
| 1.                                                                                                                                                                                                                                                           | <i>Ceriops decandra</i> (Griff.) W. Theob.    | Family- Rhizophoraceae                               |                     |   |    |   |   |   |             |
| 2.                                                                                                                                                                                                                                                           | <i>Avicennia officinalis</i> L.               | Family- Acanthaceae                                  |                     |   |    |   |   |   |             |
| 3.                                                                                                                                                                                                                                                           | <i>Aegiceras corniculatum</i> (L.) Blanco     | Family- Myrsinaceae                                  |                     |   |    |   |   |   |             |
| 4.                                                                                                                                                                                                                                                           | <i>Heritiera fomes</i> Buch. -Ham.            | Family- Malvaceae                                    |                     |   |    |   |   |   |             |
| 5.                                                                                                                                                                                                                                                           | <i>Cynometra ramiflora</i> L.                 | Family- Fabaceae                                     |                     |   |    |   |   |   |             |
| 6.                                                                                                                                                                                                                                                           | <i>Excoecaria agallocha</i> L.                | Family- Euphorbiaceae                                |                     |   |    |   |   |   |             |
| 7.                                                                                                                                                                                                                                                           | <i>Bruguiera sexangula</i> (Lour.) Poir.      | Family- Rhizophoraceae                               |                     |   |    |   |   |   |             |
| 8.                                                                                                                                                                                                                                                           | <i>Xylocarpus moluccensis</i> (Lam.) M. Roem. | Family- Meliaceae                                    |                     |   |    |   |   |   |             |
| I                                                                                                                                                                                                                                                            | Lichen                                        |                                                      |                     |   |    |   |   |   |             |
| 1.                                                                                                                                                                                                                                                           | <i>Cladonia caespiticia</i>                   | Life form- Crustose                                  |                     |   |    |   |   |   |             |
| 2.                                                                                                                                                                                                                                                           | <i>Graphis scripta</i>                        | Life form- Crustose                                  |                     |   |    |   |   |   |             |
| 3.                                                                                                                                                                                                                                                           | <i>Flavoparmelia caperata</i>                 | Life form- Foliose                                   |                     |   |    |   |   |   |             |
| 4.                                                                                                                                                                                                                                                           | <i>Ramalina fraxinea</i>                      | Life form- Fruticose                                 |                     |   |    |   |   |   |             |
| Abiotic Indicators                                                                                                                                                                                                                                           |                                               |                                                      |                     |   |    |   |   |   |             |
| A                                                                                                                                                                                                                                                            | Soil Health                                   |                                                      |                     |   |    |   |   |   |             |
|                                                                                                                                                                                                                                                              | Chemical parameters                           |                                                      |                     |   |    |   |   |   |             |
| 1                                                                                                                                                                                                                                                            | Nitrogen (N)                                  |                                                      |                     |   |    |   |   |   |             |
| 2                                                                                                                                                                                                                                                            | Phosphorus (P)                                |                                                      |                     |   |    |   |   |   |             |
| 3                                                                                                                                                                                                                                                            | pH                                            |                                                      |                     |   |    |   |   |   |             |
| 4                                                                                                                                                                                                                                                            | Electrical conductivity                       |                                                      |                     |   |    |   |   |   |             |
| 5                                                                                                                                                                                                                                                            | Salinity                                      |                                                      |                     |   |    |   |   |   |             |

| Sl No                                                                                                                                                                              | Indicator                               |   | Qualitative Ranking |   |    |   |   |   | Range Value |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|---|---------------------|---|----|---|---|---|-------------|
|                                                                                                                                                                                    |                                         |   | 5                   | 4 | 3  | 2 | 1 | 0 |             |
|                                                                                                                                                                                    | VH                                      | H | M                   | L | VL | A |   |   |             |
|                                                                                                                                                                                    | Name                                    |   |                     |   |    |   |   |   |             |
| Reference values will be utilized to provide a justifiable value/range to each particular indicator and then rank them (5 to 0; Very high, High, Medium, Low, Very Low and Absent) |                                         |   |                     |   |    |   |   |   |             |
|                                                                                                                                                                                    | Biological parameters                   |   |                     |   |    |   |   |   |             |
| 1                                                                                                                                                                                  | Organic matter                          |   |                     |   |    |   |   |   |             |
| 2                                                                                                                                                                                  | Organic carbon                          |   |                     |   |    |   |   |   |             |
| 3                                                                                                                                                                                  | Enzymes                                 |   |                     |   |    |   |   |   |             |
| 4                                                                                                                                                                                  | Earthworms                              |   |                     |   |    |   |   |   |             |
| 5                                                                                                                                                                                  | Nematodes                               |   |                     |   |    |   |   |   |             |
|                                                                                                                                                                                    | Environmental Health                    |   |                     |   |    |   |   |   |             |
|                                                                                                                                                                                    | Water Quality Parameters                |   |                     |   |    |   |   |   |             |
| 1                                                                                                                                                                                  | pH                                      |   |                     |   |    |   |   |   |             |
| 2                                                                                                                                                                                  | Salinity                                |   |                     |   |    |   |   |   |             |
| 3                                                                                                                                                                                  | Suspended matters (TS, TDS, TSS)        |   |                     |   |    |   |   |   |             |
| 4                                                                                                                                                                                  | Dissolved oxygen (DO)                   |   |                     |   |    |   |   |   |             |
| 5                                                                                                                                                                                  | Biological oxygen demand (BOD)          |   |                     |   |    |   |   |   |             |
| 6                                                                                                                                                                                  | Chemical oxygen demand (COD)            |   |                     |   |    |   |   |   |             |
|                                                                                                                                                                                    | Air Quality Parameters                  |   |                     |   |    |   |   |   |             |
| 1                                                                                                                                                                                  | Nitrogen Oxides (NOx)                   |   |                     |   |    |   |   |   |             |
| 2                                                                                                                                                                                  | Sulfur Oxide (SOx)                      |   |                     |   |    |   |   |   |             |
| 3                                                                                                                                                                                  | Carbon dioxide (CO2)                    |   |                     |   |    |   |   |   |             |
| 4                                                                                                                                                                                  | Particulate Matter (PM2.5/PM10)         |   |                     |   |    |   |   |   |             |
| 5                                                                                                                                                                                  | Temperature                             |   |                     |   |    |   |   |   |             |
| 6                                                                                                                                                                                  | Humidity                                |   |                     |   |    |   |   |   |             |
|                                                                                                                                                                                    | Pollutants                              |   |                     |   |    |   |   |   |             |
| 1                                                                                                                                                                                  | Oil                                     |   |                     |   |    |   |   |   |             |
| 2                                                                                                                                                                                  | Macroplastics                           |   |                     |   |    |   |   |   |             |
| 3                                                                                                                                                                                  | Microplastics                           |   |                     |   |    |   |   |   |             |
| 4                                                                                                                                                                                  | Mesoplastics                            |   |                     |   |    |   |   |   |             |
| 5                                                                                                                                                                                  | Chemical oxygen demand (COD)            |   |                     |   |    |   |   |   |             |
| 6                                                                                                                                                                                  | Heavy metals (As, Cr, Co,Cu, Hg and Pb) |   |                     |   |    |   |   |   |             |

#### Step-4: Data visualization

For better visualization of the results for the decision makers and managers, maps and graphics are to be created for each of the indicators based on their relative abundance. The maps are to indicate the relative health of the ecosystems in each sample plot as well as the over ecosystem health of the Sundarbans. Chapter 4. provides a detailed description on the data visualization protocol.

## 2.7 General Survey Protocols

### Preparation for Surveys

Proper plan and arrangement of logistics are prerequisite for execution of surveys of the indicators. Funding and human resources are to be ensured beforehand so that survey teams be mobilized timely. All team members are to be thoroughly briefed and informed ahead of time so that they can make them available during the surveys. Survey boats (sampans or country boats) and accommodation (launches) boats are to be arranged accordingly at least one month ahead of the survey. All necessary equipments are to be readied and tested before surveys. Printed maps of each sample unit showing the intended survey locations, along with the entire map of the Sundarbans are to be available, along with data sheet for each team during the survey. It is absolutely essential to check the weather forecast before conducting the surveys. Survey plan should be made in such way that the team can obtain these goods from nearby markets located on the fringes of the Sundarbans. First-aid box containing basic medicines and supplies should be made available which is needed to be carried by each team in the field. To manage any emergencies of sickness as well as any incidence, a speedboat attached to houseboat is recommended.

### Team Formation

The survey team should comprise at least one expert from each group of parameters for data collection.

An integrated approach is being proposed for an effective survey of each indicator species. Teams designated to survey various indicators are to be grouped together and conduct the surveys accordingly.

The number and composition of team members will depend on each of the indicators. Details of

number and composition of team members are given with each of the indicators in the Chapter 3.

### Code of Conduct

During the survey time, the team members should be calm and quiet. They should wear dull colored or camouflaged cloths. Should not wear any bright color clothes and should not use any perfume.

Team spirit and work ethics among team members are the key for making the survey works a success. Assigning responsibilities of each team member is must for effective execution of monitoring activities. Verbal communication and movement team members should be maintained in a way that not cause any disturbance to the wildlife. Team members should follow the instructions strictly given by the team leader during the survey.

### Site Selection

The majority of the surveys for the selected indicators are to be conducted in the 65 sample units. Details of site selection is included under each indicator to provide clarifications. Only for Olive Ridley Turtles, the site will extend to the sandy beaches on Kotka, Kochikhali, Dubla, Dimer Char and Bangabandhur Char. For plants and lichens, Permanent Sampling Plots (PSPs) already used by BFD inside the 65 sample units are to be surveyed.

### Survey Month and Time

Survey times are to be decided in accordance to each of the indicators, as species availability and correct time of survey vary in a case to case basis. Details of survey time are provided in the Table 4, as well as under each of the indicator.

Surveys for Terrestrial Mammals, and Small-clawed Otter from Aquatic Mammals along with parts of Avifauna, Reptiles, Amphibians, and Flora & lichen surveys are to be conducted together in combined teams. Surveys for dolphin and fish are to be conducted together in combined teams.

**Table 4: Summary of the sample collection timing of different indicator groups.**

|                     | Jan | Feb | Mar | April | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---------------------|-----|-----|-----|-------|-----|------|------|-----|-----|-----|-----|-----|
| Terrestrial Mammals |     |     |     |       |     |      |      |     |     |     |     |     |
| Aquatic Mammals     |     |     |     |       |     |      |      |     |     |     |     |     |
| Birds               |     |     |     |       |     |      |      |     |     |     |     |     |
| Amphibians          |     |     |     |       |     |      |      |     |     |     |     |     |
| Reptiles            |     |     |     |       |     |      |      |     |     |     |     |     |
| Bee & Butterfly     |     |     |     |       |     |      |      |     |     |     |     |     |
| Fish and Fisheries  |     |     |     |       |     |      |      |     |     |     |     |     |
| Flora               |     |     |     |       |     |      |      |     |     |     |     |     |
| Abiotic             |     |     |     |       |     |      |      |     |     |     |     |     |

## Essential Equipment

Some essential equipment is required to conduct surveys for each of the selected indicator. Some of the common equipment required for each of the indicators are GPS, binoculars, high-powered flashlights and head-lamps with batteries, pen/pencil, notebooks, survey data sheets, camera traps, DSLR/point and shoot cameras, solar panel, small wooden country boats, and equipments for the collection of samples from abiotic indicators. Details of equipment required to conduct biotic and abiotic surveys are added for each of the indicators in Chapter 3.

## Recording and Reporting Data

All data from the field will be recorded in specialized data sheets, developed for each of the indicators, attached in Annex 2 to 8. The details overall reporting and visualizing of the data is given in Chapter 4.

### Using Data from SMART patrolling for Ecological Monitoring

Within the Sundarbans, the Bangladesh Forest Department is actively engaged in SMART patrolling,

an approach to monitoring species and other aspects of Sundarbans, including Tigers, Masked Finfoot, and other indicators, some of which may also be included in the ecological monitoring framework.

This ongoing SMART patrolling initiative serves as a continuous source of data collection, capturing information on the distribution, threats etc. The information from SMART patrolling may be a useful database for ecological monitoring, given the data are taken following the ecological monitoring framework methodology and timeframe.

Ecological monitoring will be conducted in the 65 sample units of Sundarbans. If there are any data on ecological monitoring indicator species collected during SMART patrolling from those sample units, using standard ecological monitoring methodology and timeframe, the data may be considered for incorporation in ecological monitoring, after review. It is to be considered that ecological monitoring is used to understand ecosystem health and management measures, while SMART patrolling is used for more operational aspects, and the data from SMART should be considered carefully before incorporation into the ecological monitoring.

# CHAPTER 3

## DETAILS OF BIOTIC AND ABIOTIC INDICATORS

### 3.1 Biotic Indicators

#### A. Terrestrial Mammals

##### 3.1.1 Methodology Framework for Ecological Monitoring of Terrestrial Mammals

The Sundarbans of Bangladesh and India have one of the largest tigers, *Panthera tigris* populations in the world, giving it the status of a Tiger Conservation Unit Class III (Aziz et al. 2017; Sanderson et al. 2010). It is a unique tiger habitat and considered as the last resort for tigers in Bangladesh. From ecological viewpoint, tiger is the flagship species for this landscape and a candidate for monitoring ecosystem health of this fragile forest. Consequently, the conservation of the tiger deserves high priority for: i) the tiger is endangered worldwide and is critically endangered in Bangladesh; ii) the Sundarbans population is one of five top tiger populations in the world; iii) tiger plays a key role in the Sundarbans ecosystem being the largest predator; iv) its charisma potentially attracts many tourists; v) it guards the entire forest, the danger of its presence discourages human intrusions in the forest and hence contributes to its conservation; vi) it is the national animal of Bangladesh; and vii) it has however an adverse effect on humans due to human-tiger incidents.





Bengal Tiger *Panthera Tigris* © Adnan Azad

The survival of tigers in the Sundarbans is entirely dependent on its prey – mostly on the Spotted Deer and to a lesser extent Wild Boar which needs particular attention from the wildlife managers. Both of this prey species provide 79% of tiger's diet which are also being persecuted by humans through poaching (Aziz et al. 2020). Therefore, adaptive management is a priority for their conservation actions through regular monitoring of their populations. Management of these prey species also deserves priority, because: i) the presence of ungulates particularly Spotted Deer and Barking Deer plays a key role in the structure of the vegetation due to their preferences for plant species and plant parts; ii) the survival of tigers depend primarily on deer and secondarily on Wild Boar, being the principal prey species; iii) their significant ecological role in the ecosystem, being the most important link between primary production and the tiger; and iv) the abundance of deer makes it one of the most conspicuous attractions for tourism.

Monitoring change in abundance of any wild animals is central to evaluating the effectiveness of management strategies. As outlined by the Bangladesh Tiger Action Plan (Khan et al. 2018), a monitoring programme is needed to track the changes in the tiger population and their prey species to evaluate the impact of conservation activities. However, many of the above methods rely on needing a high level of scientific and technical skills. Although there is no substitute for good scientific design in implementing an effective monitoring scheme for tigers and their habitats but for such a scheme to succeed the vast resources of the government machinery and sheer manpower of the forest department need to be harnessed (Jhala et al. 2017).

Animal sign has been used to assess tiger populations (Hayward et al. 2002, Linkie et al. 2006), and has been successfully implemented in the Sundarbans landscape since 2007 which is now commonly termed as khal survey (Barlow et al. 2008). Considering all the currently available

techniques and the setting in question, it seems that khal survey may be the best possible approach to ecological monitoring of tiger and its prey population in the Sundarbans. One of the important aspects of khal survey is its applicability that can be implemented by frontline forest staffs with less effort, time, analysis and cost.

## Survey Methods

The khal survey relies on counting tiger tracks along the khal banks to give an index of relative tiger abundance for each of the surveyed sample units covering 80-95% of Sundarbans across its four ranges. The survey does not estimate the total number of tigers or their density because there is no direct evidence to quantify the relationship between the number of tiger track sets/km. of khal surveyed and the actual size of the tiger population. However, there is strong evidence from a large-scale survey in India, that the frequency of tiger tracks is a very good indication of the actual tiger population (Jhala et al. 2011). Therefore, if track numbers per kilometre of khals increase, it can be assumed there has been an increase in the absolute tiger abundance and likewise, if track numbers decrease, it can be assumed that there has been a decrease in the absolute tiger abundance.

On the other hand, Spotted Deer and Wild Boar are commonly seen across river banks, so direct sightings of these prey species can be easily made. The experience from khal surveys show that alongside recording pugmark (which in fact infrequent giving the chance of making direct sighting of prey species) tiger's prey species can be efficiently surveyed. The same khal selected for tiger monitoring can be surveyed for selected ungulate monitoring as well; however, a separate datasheet can be used for recording ungulate sightings.

## Species Selection

A total of three terrestrial mammal species have been selected as part of this indicator (Table 5).

**Table 5: Justification of selecting Tiger and its prey species for ecological monitoring of the Sundarbans.**

| Species      | Trophic level            | Justification for selection                                                                                                                                                                                                                                                                                                      |
|--------------|--------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Tiger        | Carnivore (top predator) | As a top predator, tigers play an important role in maintaining the consonance of the Sundarbans ecosystem and its health. By preying on herbivores, tigers help to keep the balance between the ungulates and the forest vegetation which they feed upon. Its presence indicating the functionality of ecosystem of Sundarbans. |
| Spotted Deer | Herbivore                | Prime species upon which the survival of tiger depends (Tigers get 68% diet). Increase or decrease of its abundance will indicate changes in tiger numbers as well as habitat disturbance (e.g., poaching of deer)                                                                                                               |
| Wild Boar    | Omnivore                 | Ecosystem engineers that turn extensive areas of leaf litter, soil and vegetation. Niche invaders, perceived to be adaptable to areas unsuitable for Spotted Deer                                                                                                                                                                |

## Survey Sites for Terrestrial Mammals

A total of 65 sample units have been selected for the terrestrial mammals survey, with mean area of 63.3 square km (range = 40-100 square km) (Barlow et al. 2008). Repeated survey of three-years interval will be required to see the effects of management strategies.

The width of a waterway may at some stage become a barrier to regular tiger movements within its home range, so a cut-off value of 100m will be maximum width of khal to be surveyed. Any khal that is over 100m in width will not be surveyed. Khals will be checked approximately in low tide when tiger tracks below the high water-mark could be detected in the soft mud of khal banks. To ensure high track detection rate, the boat should be kept 1-3 meters from khal bank with an average cruising speed set at 4-6 km/ hour. Any obscure tiger sign should be double checked by inspecting the suspected tracks after immediate revisit, and sometimes after getting down from the boat. Only one side of each khal deemed suitable will be surveyed. All tiger track sets, direct sighting of prey species and khals will be marked using handheld Geographical Positioning System (GARMIN GPSmap 64s). On an average, approximately 20 km of khals comprising 1- 3 khals will be surveyed for each sample unit.

## Time of the Survey

All 65 sample units will be surveyed within approximately 2-3 months by three survey teams; expected to be completed by 1-3 sample unitsevery day. Winter months are ideal for monitoring of selected terrestrial mammals including pugmarks considering weather condition of the Sundarbans. A timeframe starting from November to January is preferable to avoid extreme weathers and disturbance caused by golpata collectors. Exposed khal banks are crucial for detecting tiger pugmarks, therefore survey period from mid- low tide to mid-high tide has to be followed strictly. Team will select the time of the day for surveying selected khals considering tide cycles. Adequate visibility (daylight) will be required to detect pugmarks and indicator species. To ensure sufficient survey coverage, houseboat can be moved after/before survey time so that next day survey will not be hampered.

## Essential Equipment for the Survey

Three GPS will be needed for 3 survey teams to record data and survey tracks. One binocular, 1 point-and- shoot camera, and 1 torch for each team are suggested. Knife, bear spray/ pepper spray, sticks and umbrella are also recommended. The houseboat should be equipped with generator for charging of the equipment, mobile phone and laptops. If dry

cells are used for GPS, then at least one pair of batteries would be needed for one set of GPS for every day

## Survey Arrangements and Protocols

### Survey teams

Major vessels required for the survey include 1 accommodation boat, 3 sampan boats and 1 speedboat. A team of 17 members (1 team leader/ wildlife biologist, 9 surveyors, 4 boat staffs, and at least 3 forest guards) will be needed for the survey. BFD Officers specially wildlife officers from the Nature and Wildlife Conservation Division, Khulna can be engaged for in-house

capacity development of the Forest Department. Given the long-term work- schedule, citizen scientists (local honey hunter, fishermen, etc.) having prior similar experience can be helpful to conduct the khal survey. Before embarking the survey work, an orientation training on the entire process of monitoring and safety for the team would be imperative.

GIS-based map for each sample unit will be needed to aid finding of surveying khals and proper navigation. The khal survey will be carried out by 3 teams, with each team having two observers of tiger signs and prey sightings respectively; one person for recording the data, one boatman and two forest guards.



● A sampan is useful for khal survey in the Sundarbans | © Dr. M. A. Aziz

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### Code of conduct during the survey

Team spirit and work ethics among team members are the key for making the survey works a success. Assigning responsibilities to each team member is must for effective execution of monitoring activities. Survey boat should be run within the recommended speed

and suitable time of the day. Camouflage clothes are preferable. Verbal communication and movement on boat by team members should be maintained in a way which wouldn't make any disturbance to the wildlife. Team members should follow the instructions strictly given by the team leader during the survey.

## Data Management and Handling

### Field data collection

The selected mammalian species are commonly seen across river banks, so direct sightings of these prey species can be made easily. Experience from pilot khal surveys show that alongside recording pugmark (which is in fact infrequent, thus allowing observers of making direct sighting of indicator species), tiger's prey species can be surveyed efficiently. The same khal selected for tiger monitoring can be surveyed for prey monitoring as well; however, a separate datasheet can be used for recording prey sightings. Data sheet attached in Annex 3. These datasheets will be deposited to a central depository.

The basic set of data will include GPS coordinates of each sighting, whether it is pugmark or direct sightings of selected mammals, and their number. Sample unit, name of khals, bank of the river, etc. will also be recorded. Each transect/khal length is covered during the survey will be measured and recorded for data analysis. Survey track should be saved after each transect.

### Data entry and analysis

The recorded data will be needed to arrange and entry into the Microsoft Excel program for analysis. In the Excel spreadsheet, first two columns should contain the GPS coordinates followed by survey unit, khal name, length of surveyed khal in kilometer, number of sightings and notes if any. An index value will be enumerated against each sample unit (Table 6) which will be useful for preparing maps in the ArcGIS platform.

**Table 6: Parameters and index calculation methods**

| Species            | Parameters to be measured                                              | Formula for index calculation                               |
|--------------------|------------------------------------------------------------------------|-------------------------------------------------------------|
| Tiger              | Number of pugmarks set per km of khal surveyed for each sample unit    | Index = number of pugmark set recorded/km of khals surveyed |
| Spotted Deer       | Number of individual deer per km of khal surveyed for each sample unit | Index = number of spotted deer sighted/km of khals surveyed |
| Eurasian Wild Boar | Number of individual boar per km of khal surveyed for each sample unit | Index = number of wild boar sighted/km of khals surveyed    |

### Reporting

The report on the survey outcomes should follow the basic structure of any technical report. A special section of management implications should be included for frontline managers of the Sundarbans.

### Interpretation and application of results

The khal survey is used to be extremely simple and do not require any high level of technical skill. The data generated would be such that they permit scientifically reliable inference regarding relative tiger population trends, and prey status with a high level of spatial resolution. The systematic surveys would enable to detect site-specific changes (specifically for each sample unit) in time to address them with timely intervention by management and policy decisions. The same is true for selected prey species of tigers. The interpreted data will be visualized through maps and graphics. Details of data visualization is in Chapter 4.





# INDICATOR SPECIES OF THE TERRESTRIAL MAMMALS



● Bengal Tiger | © Dr. M. A. Aziz



● Tiger's Pugmark | © Dr. M. A. Aziz



● Spotted Deer | © Dr. M. A. Aziz



● Wild Boar | © Dr. M. A. Aziz



METHODOLOGY FRAMEWORK  
FOR ECOLOGICAL MONITORING  
OF AQUATIC MAMMALS OF THE  
SUNDARBANS

## B. Aquatic Mammals

### 3.1.2 Methodology Framework for Ecological Monitoring of Aquatic Mammals of The Sundarbans

Nearly one third of the Sundarbans comprises of water bodies, around 177 rivers and numerous canals or waterways (khals) submerge the whole area twice a day during high tide. Accordingly, not only the life of aquatic animals but also the terrestrial animals are interrelated with the changing/tidal influences in water levels. But aquatic animals are directly affected by any fluctuations in the aquatic ecosystem, and the changes are apparent in some of the sensitive species which reflect the variations in the ecosystem as well. Among the aquatic higher vertebrates, mammals are more sensitive to varying environment and act as an indicator species for ecological monitoring of a particular ecosystem. Therefore, both dolphin and otter are good indicator species for monitoring the Sundarbans ecosystem in a regular basis



Smooth-coated Otters © IUCN/A B M Sarowar Alam

## Survey Methods

Dolphins of the Sundarbans are extensively studied mostly on their status, distribution and conservation (Smith et al. 2006, Alam et al. 2019). Using the abundance of some selective indicator bird species for monitoring the health of some protected areas has already been practiced (Khan 2016), but no study has been focused on the evaluation of the health status of the Sundarbans by using mammals as an indicator species. Most of the wildlife surveys and monitoring are based on Line Transect sampling (Feeroz 1999, 2013, 2014; Feeroz et al. 2011a, 2012,) since this technique is easy to use and the data can be compared. On the other hand, specific dolphin survey technique has already been practiced in the Sundarbans (Smith et al. 2010.). For the present study, a simple and effective method should be developed so that the Bangladesh Forest Department (BFD) staffs can easily continue the monitoring throughout the year. We have to keep in mind that the survey technique for aquatic mammals should be easy enough for the BFD official which can be easily practiced in the field while they become adequately trained up. So, the data will be generated by many BFD personnel throughout the year from different sites of the Sundarbans which can readily be compared. For the present study, relative abundance survey is more appropriate than the absolute abundance survey considering the above-mentioned facts. Though relative abundance survey is not suitable for population abundance or density estimation, however it is useful to detect population trend using index e.g. sightings/unit of time in a given survey area. An aerial scanning sampling technique might be developed by using drone for a relative abundance of dolphin in the survey area. The survey will be conducted in every three years interval.

## Species Selection

The conservation of biodiversity is a major goal in nature conservation, but measuring the total biodiversity of a site or a region is not quite easy; thus, there is a great demand for studying and monitoring indicator species to measure

biodiversity richness. To be able to make use of indicator species, firstly criteria must be established for their selection, and the degree to which the indicators meet the criteria must be tested (Heink and Kowarik 2010). Dolphins are completely depending on aquatic habitats of the Sundarbans and otters partially depend on the aquatic ecosystem of the Sundarbans. Both are the top predator and play a vital role in the energy flow of the ecosystem. Thus, any changes in the ecosystem will be reflected through their abundance and distribution.

Two species of otters viz., Smooth-coated Otter (*Lutrogale perspicillata*) and Asian Small-Clawed Otter (*Aonyx cinereus*) are found in and around the Sundarbans (Feeroz et al 2011b,c). However, Smooth-coated Otters are mostly found in the periphery areas of the Sundarbans and very rarely seen inside. On the other hand, Asian Small-clawed Otter is widely distributed throughout the Sundarbans. Both these species are known as wetland ambassador. These species are only found in a healthy wetland which provides enough food and a pollution free environment. So, the presence of Asian small-clawed otter in any river or small canal inside

the Sundarbans indicates the good health of the surrounding environment.

Ganges River Dolphins (*Platanista gangetica*) are found in the Sundarbans. Ganges river dolphin is an obligate riverine species while Irrawaddy Dolphin is a facultative or opportunist riverine species. Sundarbans is an excellent habitat for both of these species. No facultative freshwater cetaceans occur within the range of Ganges dolphins, except in a very narrow, seasonally mobile band of distributional overlap between Irrawaddy and Ganges dolphins in the Sundarbans mangrove forest (Smith and Reeves 2012). This is an opportunity to use these species in ecological monitoring since both of them are the top predators of the ecosystem and play a vital role in keeping the aquatic ecosystem healthy and balanced. Considering the present environments of the Sundarbans, aquatic mammals like Irrawaddy Dolphin (*Orcaella brevirostris*) and Ganges River Dolphin (*Platanista gangetica*) and semi aquatic adapted mammals like Asian Small-clawed Otter (*Aonyx cinereus*) might be a good indicator species for ecological monitoring of the whole ecosystem (Table 7).

**Table 7. Justification of three aquatic mammals used as indicator species for ecological monitoring in the Sundarbans**

| Sl. No. | English Name             | Scientific Name              | Presence indicates                                                                                                       |
|---------|--------------------------|------------------------------|--------------------------------------------------------------------------------------------------------------------------|
| 1       | Asian Small-clawed Otter | <i>Aonyx cinereus</i>        | Stable aquatic vegetation, abundance of fish and other aquatic animals, undisturbed terrestrial breeding facilities      |
| 2       | Ganges River Dolphin     | <i>Platanista gangetica</i>  | Regular flow of water current, abundance of fish and other aquatic animals, pollution free water surface                 |
| 3       | Irrawaddy Dolphin        | <i>Orcaella brevirostris</i> | Suitable estuarine habitat, salinity of water, abundance of fish and other aquatic animals, pollution free water surface |

## Survey Sites for Aquatic Mammals

There are five dolphin sanctuaries inside the Sundarbans which will be the primary sites (Dhangmari, Chandpai, Dudhmukhi, Shibs,

Vodra) for dolphin monitoring during the study period. Other dolphin sanctuary (Pankhali) is just on the periphery of the Sundarbans will also be included for the survey. Supoti khal will

be the other location outside these sanctuaries where regular dolphin monitoring should be conducted. Both tourism and fishing activities are uncontrolled in this site and hence, a comparison can be made with the previously mentioned three sites.

All the five dolphin sanctuaries will also be explored to study otters as indicator species. Moreover, three other sites, viz., Jamtala khal, Trikon khal and Konchir varany will also be explored to study otters as an indicator species. Kotka khal is highly disturbed by the tourist while the other two sites are less disturbed areas. Presence of at least one otter family (one adult male, one adult female and their cubs) in a given area during the survey period will indicate a healthy habitat of that area.

All these areas fall under the pre-determined 65 sample units.

### Time of the Survey

Survey on aquatic mammals should be conducted between mid-October and mid-May. Survey on both otter and dolphin should be conducted during low tide, which is the best time. All surveys should be conducted in the early morning and afternoon.

### Essential Equipment for the Survey

GPS, pair of binoculars, camera, stop watch, data sheet, pen/pencil.

## Survey Arrangements and Protocols

### Survey Teams

Since only presence or absence of the targeted species are recorded, two team members having adequate knowledge on species identification will be enough to survey aquatic mammals. Each of them will record targeted species in either side of the boat and so double counting can be carefully avoided.

## Data Management and Handling

### Field Data Collection

The survey data sheets will be deposited to a central depository. Then the data will be input to the computer for periodic analyses. Sample data sheet is given in Annex 3.

### Data Entry and Analysis

The recorded data will be needed to arrange and entry into the Microsoft Excel program for analysis. The Excel spreadsheet should contain the GPS coordinates, followed by survey unit, number of sightings and notes regarding the survey site if any. These data will be used for preparing maps in the ArcGIS platform.

### Reporting

The report on the survey outcomes should follow the basic structure format of any technical report.

### Interpretation and Application of Results

The annual survey will provide relative abundance of these three indicator species in different years and these data will be compared to see the temporal changes of the abundance trend. The increase or decrease of indicator species abundance throughout the years will indicate improvement or deterioration of the aquatic vegetation as well as the terrestrial health of the Sundarbans. The results will also be tested statistically to see if there is any significant correlation with any factor that has potential impact to the ecosystem of the Sundarbans. Since both biotic and abiotic factors along with different anthropogenic factors affect the environment of the Sundarbans, population abundance change of these aquatic mammals will clearly indicate the improvement or deterioration of the ecosystem. Thus, a comparison could be made which will eventually contribute to ecological monitoring of the Sundarbans by using aquatic mammals as indicator species. The interpreted data will be visualized through maps and graphics. Details of data visualization is in Chapter 4.

# INDICATOR SPECIES FOR AQUATIC MAMMALS



● Asian Small-clawed Otter | © Kazi Zenifar Azmiri



● Ganges River Dolphin | © Monirul Khan



● Irrawaddy Dolphin | © ABM Sarowar Alam



METHODOLOGY FRAMEWORK  
FOR ECOLOGICAL MONITORING  
OF AVIFAUNA IN THE  
SUNDARBANS

## C. Avifauna

### 3.1.3 Methodology Framework for Ecological Monitoring of Avifauna in the Sundarbans

Birds are one of the best indicators of ecological changes, because they are visible, relatively fast-breeder and responsive to any change (Johnston 1956, Morrison 1986, Welsh 1987, Temple and Wiens 1989, Browder 2002). Therefore, some selective bird species have been chosen to use for the ecological monitoring of the Sundarbans. Different species of birds occur in different storeys of an area and are adapted to varied types of plant and animal food, so the avian population abundance and species diversity reflect the temporal changes of their habitat conditions. In other words, birds indicate the health of different storeys of the forest. Determination of the extent to which ecological systems are experiencing changes is critical for long-term conservation of biotic diversity in the face of changing landscapes and land use (Canterbury et al. 2000). Bangladesh is exceptionally rich in avifaunal diversity and abundance, and Sundarbans is no exception to that. Not only is the avifauna, the country is unique in its biodiversity, both wild and domestic. In an area of only 147,570 km<sup>2</sup>, Bangladesh harbors 690 species of bird that includes 337 residents, 208 winter visitors, 12 summer visitors, 14 passage visitors, and 119 vagrants (Khan 2018). This can be compared with the total number of bird species in the whole of Europe, or the United States, each of which is about 800 in a much larger area. The total number of bird species recorded in Bangladesh is 50% of the total of the Indian Subcontinent, and 7% of the world's total (Harvey 1990). A total of 374 species of bird have been recorded in the Sundarbans of Bangladesh and India since the 1970s, of which 13 are globally threatened species (Khan 2021, IUCN 2021). Chowdhury (2020) mentioned that a total of 299 species of bird have been documented in the Bangladesh Sundarbans of which 160 were residents and 139 migratory. Other notable publications that

have valuable information on the bird diversity of the Sundarbans, and of Bangladesh as a whole, are Thompson and Johnson (1996), Siddiqui et al. (2008), IUCN-Bangladesh (2015), and Khan (2015).

### Survey Methods

The methods were selected on the basis of simplicity and effectiveness so that the local BFD officials and the local communities could participate in the survey. Taking this into account, the transect survey (Buckland et al. 2001) to estimate the abundance of the selective indicator bird species. It is a simple method that provides a uniform way of counting birds over time or across locations. Similar method was successfully implemented in Bangladesh for monitoring the health of some protected areas (Khan 2016), and for monitoring the abundance of Tigers (*Panthera tigris*) in the Sundarbans through 'khal' (creek) survey (Bangladesh Forest Department 2015).

The transect survey will be conducted once every month during the six months of relatively dry season (November to April) when the Sundarbans is most accessible and the weather remains favorable. In the field the transect survey will be conducted by trained teams using small boats running slowly along the small and medium rivers and creeks. The sighting locations will be recorded by a Global Positioning System (GPS) and numbers of each of the indicator species of bird will be observed by binoculars, identified, and recorded on pre-designed data sheets. Moreover, all the species of bird that will be sighted during the survey will be identified and recorded. The birds will be identified by using some authentic books (e.g., Ali and Ripley 1987, Grimmet et al. 1998; Rasmussen and Anderton 2005). The relative abundance of birds will be assessed on the basis of their relative frequencies of sightings in the field. The survey will be conducted in every two years interval.

A total of 08 species of bird have been selected as indicators for assessment of the overall condition of the Sundarbans (Table 8). The

indicator species were finalized in a validation workshop with the stakeholders. Since all the indicators prefer mangrove forest, it is assumed that the improvement or degradation of the forest condition will have a direct impact on the feeding and breeding of the indicators, which in turn will be reflected by the change in the abundance of these species (Morrison 1986, Temple and Wiens 1989, Canterbury et al. 2000, Browder et al. 2002).

## Species Selection

Ten indicator bird species that represent the different storeys of the Sundarbans. Selection criteria code: i) they prefer mangrove forest, ii) they live in different storeys of the forest, iii) they are either colourful or noisy birds (least likely to miss during the survey) and iv) they are breeding residents (Table 8).

**Table 8: Justification for the selection of species**

| Sl. No. | English Name               | Scientific Name               | Forest Storey Where Occurs | Selection Criteria                                                          |
|---------|----------------------------|-------------------------------|----------------------------|-----------------------------------------------------------------------------|
| 1       | Masked Finfoot             | <i>Heliopais personata</i>    | Lower                      | Very sensitive, strongly linked with undisturbed mangroves, large           |
| 2       | Mangrove Pitta             | <i>Pitta megarhyncha</i>      | Lower                      | Exclusively linked with mangroves, colourful, noisy in breeding season      |
| 3       | Streak-breasted Woodpecker | <i>Picus viridanus</i>        | Middle                     | Exclusively linked with mangroves, noisy                                    |
| 4       | Red Junglefowl             | <i>Gallus gallus</i>          | Lower                      | Large, very colourful, subject to poaching                                  |
| 5       | Lesser Adjutant            | <i>Leptoptilos javanicus</i>  | Upper                      | Very large, strongly linked with wetlands                                   |
| 6       | White-bellied Sea-eagle    | <i>Haliaeetus leucogaster</i> | Upper                      | Very large, exclusively linked with coastal wetlands                        |
| 7       | Ruddy Kingfisher           | <i>Halcyon coromanda</i>      | Middle                     | Exclusively linked with mangroves, very colourful, noisy in breeding season |
| 8       | Crimson Sunbird            | <i>Aethopyga siparaja</i>     | Middle                     | Very colourful, noisy, exclusively linked with flowering plants             |

## Survey Sites for Avifauna Indicators

The survey can be the same as those of tiger khal survey, i.e. 2-3 khals covering about 20 km total length in each survey block of the Sundarbans. This way the entire Sundarbans will be covered more or less uniformly. All the khals fall under the pre-determined 65 sample units.

### Time of Survey

The best time for bird monitoring is early morning, followed by late afternoon, when the birds remain most active, so they can be easily spotted. It can be done in any tide condition except very low tide. Since the monitoring will be done along the riverbanks, from a boat, the habitats will include mangrove woodlands, bushes, grasses and mudflats. Details of months surveyed in Table 4.

### Essential Equipment

A small country boat will be the best for cruising through the small rivers of the Sundarbans and will allow the maximum sighting of indicator birds. The essential equipments that will be required are one or more pairs of binoculars and at least one each of GPS unit, camera, watch, data sheet and pen.

## Survey Arrangement and Protocol

### Survey Teams

Ideally, the bird monitoring team should have three or four members and each of them should know the survey method and should be able to identify the birds by their appearance and their call. At least one of them should be an expert in the relevant field. Therefore, all members should have necessary training on monitoring and identification of birds. It will be good to have an advisor who can be contacted in case the survey team face any

difficulty while surveying or in identification of the indicator species.

### Code of Conduct during Surveys

In order to make sure that the birds are not disturbed by the monitoring team, the team members should avoid wearing bright clothes (camouflaged clothes are the best), should not make sound, should not make too much movement, and should not use perfumes.

## Data Management and Handling

### Field Data Collection

The survey data sheets will be deposited to a central depository and then entered to the computer for periodic analyses. Sample of data sheet is provided in Annex 4.

### Data Entry and Analysis

The raw data will feed into an Excel file which will be analysed regularly to see the trend of increase or decrease of the indicator bird abundance in different units of the Sundarbans.

### Interpretation and Application of Data

The annual abundance data of each of the 12 indicator bird species will be compared with the similar data of the following years to see the temporal changes of the abundance trend. The increase or decrease of indicator bird abundance across the years will indicate improvement or deterioration of the forest health. Since the indicator birds represent the health of different storeys of the forest, the condition trend of the different storeys can be shown separately. The results can also be tested statistically to see if there is any significant correlation with any factor that has potential impact to the ecosystem of the Sundarbans. The interpreted data will be visualized through maps and graphics. Details of data visualization are in Chapter 4.

# INDICATOR SPECIES FOR BIRDS



● Masked Finfoot | © Monirul Khan



● Mangrove Pitta | © Monirul Khan



● Streak-breasted Woodpecker | © Monirul Khan



● Red Junglefowl | © Monirul Khan



● Lesser Adjutant I © Monirul Khan



● White-bellied Sea-Eagle I © A B M Sarwar Alam



● Brown-winged Kingfisher I © Monirul Khan



● Crimson Sunbird I © Monirul Khan



METHODOLOGY FRAMEWORK  
FOR ECOLOGICAL MONITORING  
OF AMPHIBIANS AND REPTILES  
IN THE SUNDARBANS

## D. Amphibian and Reptiles



### 3.1.4 Methodology Framework for Ecological Monitoring of Amphibians and Reptiles in the Sundarbans

Amphibians are effective indicators for monitoring changes of wetland ecosystem due to their sensitivity to perturbation (Stapanian et al. 2015, Lindstedt 2005).

Crocodiles act as biological indicator and responses of crocodilians are directly related to suitability of environmental conditions. Positive or negative trends of crocodilian populations relative to hydrologic changes permit assessment of positive or negative trends in the ecosystem (Mazzotti, et al. 2009).

As a top predator, crocodile can be useful in examining ecosystem processes because of their dependence on other organisms and tendency to influence trophic dynamics (Matthews et al. 2002). Snakes have also been using as indicator

organisms (Stafford et al. 1977, Matthews et al. 2002, Lind et al. 2005, Beaupreand Douglas, 2009).

Indicator species have been selected for the ecological monitoring in Sundarbans on the basis of their availability, easy detection and their habitat. Two species of frogs, Water Monitor Lizard, Saltwater Crocodile, Olive Ridley Turtle and four species of snakes have been selected for the monitoring.

### Survey Methods

Though there are several methods for assessing the population of amphibians and reptiles, simple methods have been selected for this ecological monitoring. Since, species from frogs, lizard, crocodile and snakes have been selected (Table 9), their survey methods are quite different from each other. Some of the sites with freshwater sources like Kotka, Kochikhali, Kokilmoni, Harbaria, Koromjol, Laodob have been selected for the amphibian survey. The survey will be conducted in every three years interval.

## Amphibian Survey Method

Due to the saline water all over the Sundarbans, it is not a suitable habitat for any amphibian species. Amphibians are only observed in some areas where freshwater ponds, seasonal rainwater ditches are available. They are surviving in some of the highlands of Sundarbans which usually do not inundate in regular tidal activity. Since, amphibians are nocturnal and they are mostly active at night it is preferable to conduct survey at night but in the Sundarbans, it would not be possible all the time. In that case, survey will be conducted at the evening where possible. Transect survey along the freshwater sources will be conducted in every 100 meters and the survey will chiefly depend on visual encounter method. Selected amphibian species will be counted following transect lines. Alternately, active searching for amphibians in suitable habitats will be conducted where night survey would not be possible. Using small fish net for capturing amphibians from the freshwater ponds and seasonal rainwater during daytime to see the presence of amphibian species could be carried out. Other indices like, breeding calls or regular call (Green frog) would be used for the monitoring. Setting up audio recording device in breeding pools at the evening time for call recording would be additional methods for the monitoring.

## Snake and Water Monitor Survey Method

Among the selected snakes, cobras are found in all kinds of habitats in the Sundarbans. The Common Vine Snake is found in lower canopy of the forest. Khal survey will be conducted during low tide to see the abundance of water snakes. Cobras and Common Vine Snake will also be surveyed during the Khal survey. During the Khal survey abundance of water monitor would also be recorded. Cobras and Common Vine Snakes will also be surveyed following the transect lines in appropriate habitats. 65 khals from the 65 sample units (approximately 20 km) will be surveyed for this study.

## Crocodile Survey Methods

Line transect survey using boat along the rivers and canals of Sundarbans will be conducted for crocodile survey. Considering the physical condition of the forest, survey will be conducted during day time. Basking crocodiles will be counted during low tide in winter months. All the selected Khals of the 65 compartments will be surveyed.

## Olive Ridley Turtle Survey Methods

Marine turtles come to the coasts and islands of Sundarbans for egg laying. Dead turtles are also found in the coasts. Turtle survey will be conducted during winter months (November to March) to see their breeding status in the coasts. Dead turtles will also be surveyed to see their entangled status in the fishing nets. Fishermen in the Sundarbans will also be consulted to know the status of Olive Ridley Turtle in the Sundarbans area. Olive Ridley Turtle surveys under reptiles, where the surveys are to be conducted in the sandy beaches mainly in Kotka, Kachikhali, Dublar Char, Mandarbaria Char, Putni Island and Bangabandhur Char.

## Species Selection

The survey will come up with the abundance of selected indicator species. The annual survey will provide the annual abundance data of the indicator species, which will be compared with the previous published data (if available) or similar data of the following years to see the temporal changes of the abundance trend. Any changes in the abundance of the population of indicator species (increase, decrease or no change) will indicate the health of the respective ecosystem. Since, the indicator species have been selected from different habitats, regular monitoring of these species will indicate the overall health of the Sundarbans ecosystem. The breeding status of indicator species will indicate the breeding suitability of the species in that particular habitat. Table 9 provides details of the indicators.

**Table 9. Indicator species of amphibians and reptiles for the Ecological Monitoring (EM) of Sundarbans**

| Sl. No.           | Name of the Species                              | Niche and Ecology                                                                                                                                                                                                     | Role / Indication to the environment                                                                                                                                                                                                                               | Parameters                                                                                       |
|-------------------|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------|
| <b>Amphibians</b> |                                                  |                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                    |                                                                                                  |
| 1                 | Crab-eating Frog<br><i>Fejervarya cancrivora</i> | Lives in marshy grasslands.<br><br>Feeds on insects.<br><br>Breeds rainwater ditches.<br><br>Can tolerate certain range of salinity.                                                                                  | Indicates the presence of freshwater sources during monsoon.<br><br>Indicates the presence of highlands within mangroves in Sundarbans.                                                                                                                            | Population status and relative abundance.<br>Monitoring habitats                                 |
| <b>Reptiles</b>   |                                                  |                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                    |                                                                                                  |
| 2                 | Saltwater Crocodile<br><i>Crocodylus porosus</i> | Lives in mangrove swamps, estuary and rivers in the Sundarbans.<br><br>Adults prey upon wide range of animals including large fishes, birds, wild boar, deer and other mammals.                                       | Indicates the abundance of large fishes in the river as well as other prey species.<br><br>Also indicates a healthy aquatic ecosystem.<br>Presence of different age classes indicates a healthy ecosystem.                                                         | Population status and abundance in different seasons.<br><br>Monitoring of population structure. |
| 3                 | Water Monitor Lizard<br><i>Varanus salvator</i>  | In Sundarbans, they inhabit in a wide range of habitats; they are good runner, swimmer and tree climber.<br><br>Active predator, feeds on fish, crabs, rodents, eggs, snakes, other lizards and anything it can grab. | Indicates the abundance of its prey species as well as the indicator of a healthy, complex and dynamic ecosystem.<br><br>Presence of immature individuals indicate the suitability of breeding habitat of this species as well as for other ground nester animals. | Population status and relative abundance.<br><br>Monitoring breeding status.                     |
| 4                 | Common Vine Snake<br><i>Ahaetulla nasuta</i>     | Diurnal and inhabits lower canopy of the forest and bushes.<br><br>Active predator and feeds on lizards, frogs and small birds.                                                                                       | Indicates the health of lower canopy of the forest and bushes.                                                                                                                                                                                                     | Relative abundance of the species.                                                               |
| 5                 | Monocled Cobra<br><i>Naja kaouthia</i>           | Fond of marshy areas of Sundarbans.<br><br>Feeds mostly on fishes, frogs, lizards, rodents, small birds and small snakes.                                                                                             | Indicates a healthy aquatic / swamp ecosystem.<br><br>Indicates the presence of enough prey species in the environment.                                                                                                                                            | Abundance of the species in different habitats.                                                  |

## Time of the Survey

Amphibians are most active during their breeding time at monsoon. So, the amphibian survey would be typically conducted between the month April and July. Opportunistic survey will also be conducted during the survey of other species. Reptile survey will also be conducted during this time.

Crocodile survey will be conducted in winter months (November to March) to increase the chance of spotting basking crocodiles (Choudhary and Roy1982), while Olive Ridley Turtle survey will be conducted in Winter months (November to March). Details of months surveyed in Table 4.

## Survey Sites for Amphibians, and Reptiles

The survey sites will fall under the pre-determined 65 sample units. Amphibians will be surveyed in and around selected Forest Department offices inside Sundarbans. Surveys for crocodile, snakes, and Monitor Lizard will be conducted alongside khal survey during tiger surveys. Only for Olive Ridley Turtles, the sites to be surveyed are sandy beaches in Kotka, Kochikhali, Dublar Char and Bangabandhur Char.

## Essential Equipment for the Survey

For amphibian and reptile surveys, snake-stick and snake-tongue are required, along with powerful flashlights, headlamps, binoculars, cameras, species identification field guides and data sheet. For movement and accommodation, fully functional an equipped motorized water vessels are required.

## Data Management and Handling

### Field Data Collection

The raw data will be collected in specialized data sheets (sample data sheet in Annex 5) and later

feed into an Excel file. These datasheets will be deposited to a central depository.

## Data Entry and Analysis

The data in the Excel file will be analysed regularly to see the trend of increase or decrease of the indicator bird abundance in different units of the Sundarbans.

## Reporting

Once the data analyses are done the head of the monitoring team will prepare the report and will submit to the management authority of the Sundarbans. The report will follow a basic reporting structure including the background, objectives, field methods, data analysis approach, interpretation of the data, trend of each of the indicator bird's abundance in different parts of the Sundarbans, discussion, and recommendations for the managers.

## Interpretation and Application of Data

The abundance data of each of the 10 (ten) indicator amphibian and reptile species will be compared with the similar data of the following years to see the temporal changes of the abundance trend. The increase or decrease of indicator species abundance across the years will indicate improvement or deterioration of the forest health. Since the indicator species represent the health of different storeys of the forest and mangrove ecosystem the condition trend of the different storeys can be shown separately. The results can also be tested statistically to see if there is any significant correlation with any factor that has potential impact to the ecosystem of the Sundarbans.

The interpreted data will be visualized through maps and graphics. Details of data visualization are in Chapter 4.

# INDICATOR SPECIES FOR AMPHIBIANS AND REPTILES

## AMPHIBIANS



● Crab-Eating Frog | © Samir Saha

## REPTILES



● Saltwater crocodile | © Kamrul Hasan



● Water Monitor Lizard | © Kamrul Hasan



● Variable-Coloured Vine Snake | © Kamrul Hasan



● Variable-Coloured Vine Snake | © Kamrul Hasan



METHODOLOGY  
FRAMEWORK FOR  
ECOLOGICAL MONITORING  
OF BUTTERFLIES AND BEES  
OF THE SUNDARBANS

## E. Butterflies and Bees

### 3.1.5 Methodology Framework for Ecological Monitoring of Butterflies and Bees of the Sundarbans

#### Butterflies

Aside from performing multiple ecological roles and contributing to the maintenance of a healthy environment, the pollinator species especially butterflies as a taxon have a strong appeal for their beauty. Butterflies can serve as useful ecological indicators (species/taxa that can be connected with a community or habitat type) because they respond swiftly to environmental changes such as community dynamics and/or vegetation patterns that influence their species composition (Carignan and Villard 2002; De Cáceres et al. 2010; Erhardt and Thomas 1991; Rákósy and Schmitt 2011). Moreover, butterflies are simple to see, and frequent monitoring of their populations can offer an early warning of environmental changes (Sreekumar and Balakrishnan 2001). Additionally, understanding the community structure of butterflies at the local level is valuable for tracking the fast changes occurring in the landscape as a result of anthropogenic activities (Purvis and Hector 2000). As a result, butterfly assemblages have successfully been used to classify vegetation pattern and monitor ecological changes (Sawchik et al., 2005; Erhardt 1985).

Sundarbans is being threatened by a wide range of natural and manmade pressures for example-land use changes, effluent discharges from nearby industry, agricultural run-off, oil spillage from seaports, etc. (Islam and Bhuiyan.,2018). Those pressure harms have a negative impact on the biodiversity of the forest. Though different studies have assessed the biodiversity of the mangrove forest, very few focused on studying the pollinator species.

The following section of the proposal presents a methodology for the ecological mentoring (EM)

on incomparable habitat, ecosystems, and bee and butterfly, to understand the best practices, and formulate methodology, sampling design, and strategic planning for EM focusing on bee and butterfly.

Bangladesh is noted for having diverse butterfly species with a potential number of 400 or more butterflies due to its humid tropical environment and unusual geographic position. Butterflies are sensitive to changes in climatic factors, e.g., temperature, humidity, and rainfall (Sparrow et al., 1994; Brown and Freitas, 2000; Fordyce and Nice, 2003; Zhang and Chen, 2011; Ojjanwuna, 2015; Kumar et al., 2017). Therefore, studying butterflies could provide information regarding the change of vegetation and the health of the forest.

#### Survey Methods

The methodology of the study is designed keeping in mind the simplicity and effectiveness of data collection so that, the non-expert individuals, including the local officials and communities could collect data from the field. At those circumstances, line transect is identified as the most suitable methodology for data collection to estimate abundance of selected pollinator species. Similar method of data collection was adopted in the previous study for inventory preparation of butterflies of Chandpai and Sarankhola range in 2019. Poku, & Marfo 2007, used the butterfly community for Rapid Assessment Program (RAP) to acquire quick, accurate, and cost-effective data from Atewa Range Reserve Forest which also adopted the "Transect method" of data collection. Another study (Naik et al 2022,) adopted butterfly for ecological monitoring in the western ghat of India which also used Transect method for data collection from the field.

The study area (1km radius from the patrol post/ forest office/stations) will be divided into 4 transects to ensure precise and organized data collection. Quantitative data on Tree Nymph (*Idea agamarschana* C. & R. Felder, 1865), Crimson Rose (*Pachliopta hector* Linnaeus, 1758) and

Sundarban Crow (*Euploea crameri* Nicevillei Moore, 1890) will be collected through time-constrained count method by walking at a slow but steady pace and counting the individuals present within the transect. The sighted butterfly of the mentioned species image will be captured by digital camera and be further analysed by an expert for confirmation. The butterflies will be identified by using authentic books (e.g., Bangladesh Forest Department, GIZ, JBK, 2018). However, the total number of butterflies will also be counted by the trained data collectors and be recorded on pre-designed data sheets. Data of the major vegetation of the transect along with host plants will also be noted down.

Identification of host plants is the plant on which a certain butterfly species lay eggs and also feeds the caterpillar. Primarily, direct observation methods will be used by the study team. The team needs to observe female taxon when laid eggs on plant species or caterpillar feeding on

leaves is also need to be considered during the identification of host plants.

The study will collect data from the field for three months, from November to January for each year and will be conducted in every two years interval. Details of months surveyed in Table 4.

### Species Selection

For the assessment of the overall ecological condition of the Sundarbans, 3 species of butterflies have been selected as indicators species (Table 10). The indicator species were selected based on the literature review and previous experience of working in the project area. As all of those species live in the forest, it is believed that improvements or declines in forest conditions is very likely to have a direct influence on the indicators' feeding and breeding, which results in changes in their abundance.

**Table 10: Indicator Butterfly species**

| SL. | English name   | Scientific name                               | Host plant                                  |
|-----|----------------|-----------------------------------------------|---------------------------------------------|
| 1   | Sundarban Crow | <i>Euploea crameri</i> Nicevillei Moore, 1890 | Unknown                                     |
| 2   | Tree Nymph     | <i>Idea agamarschana</i> C. & R. Felder, 1865 | Unknown                                     |
| 3   | Crimson Rose   | <i>Pachliopta hector</i> Linnaeus, 1758       | Ishwarmul<br>( <i>Aristolochia indica</i> ) |

Butterflies are important pollinators. They are also good indicators of the ecological quality of a habitat. Some butterflies are vital for economically important plants and also in general an important component of the food chain.

The presence or absence of butterflies acts like an environmental litmus test. Simply put, the presence of butterflies is a good sign, while the absence of butterflies could be a sign of a degraded or otherwise unhealthy environment. So the presence of butterflies can help biologists and ecologists begin to interpret the overall health of an ecosystem.

Besides, butterflies are known to be highly sensitive to climate change (Parmesan et al., 1999) as temperature strongly affects butterflies throughout their life histories (Sadat et al., 2016). A number of studies have already determined the impact of seasonal climate change on butterfly population, for example Panjaitan et al., 2016 identified the effect of temperature on butterfly community. Roy et al., 2001, determined effect of weather on butterfly numbers and future effect of climate change.

As "cold blooded" insects, butterflies are particularly affected by changes in climate. Numbers are influenced every year by weather

patterns, but increases in mean temperatures over a sustained period can lead to significant changes in range, population size, the rate of colonization or extinction, phenology, number of generations each year, choice of larval food plant and other ecological and evolutionary factors. It is important to understand and monitor change, not just because of its intrinsic interest but because these changes may have considerable implications for conservation management.

## Survey Sites for Butterflies

For data collection, bush and vine patches, being located within 1 km radius from the patrol post/forest office/stations from the

pre-selected 65 sample units. The following Figure 3 shows distribution of the patrol post and stations located inside the Sundarbans Forest. A buffer of 1 km around those stations/posts has been created using ArcGIS to illustrate the potential locations. However, patrol post/forest office/stations, which are easily accessible with water vehicles (preferably small boats accessible to khals), will be selected for data collection. Moreover, the sampling location will be recorded by Global Positioning System (GPS). Though previous study has collected information from Sarankhola and Chandpai Range, those locations are also need to be considered under the survey scope for long-term ecological monitoring and health check.

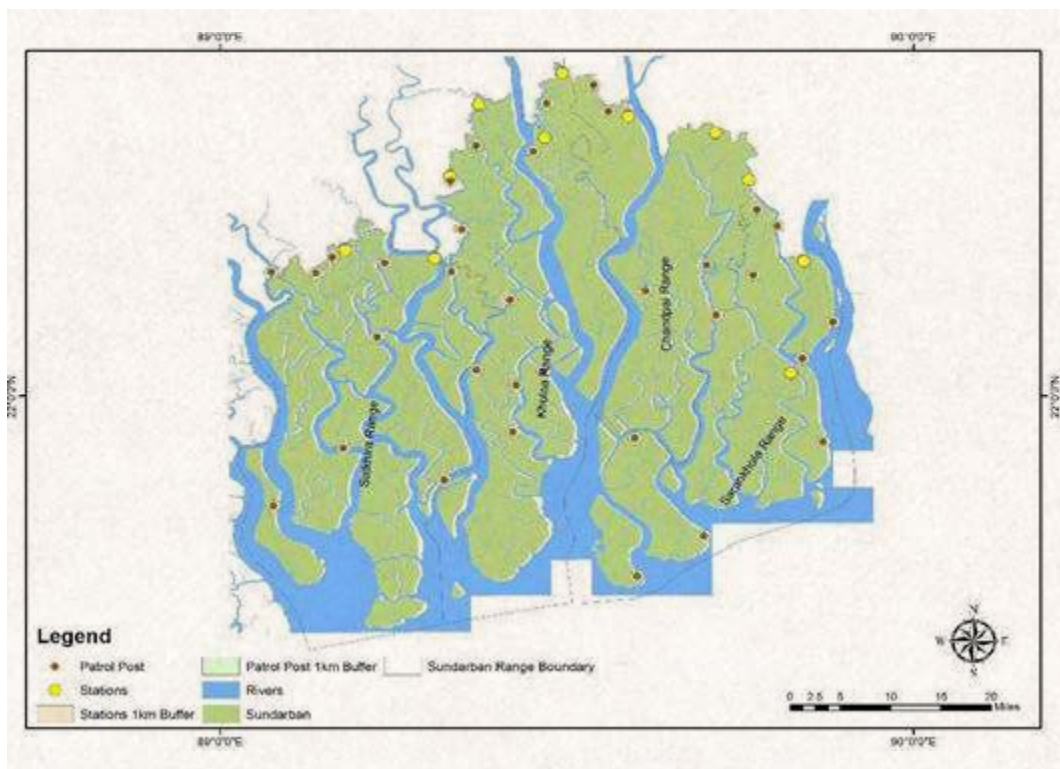


Figure 3: Potential locations for of the study

## Time of Survey

From November to January, is one of the suitable periods to observe butterflies since there are fewer tropical cyclones, less rain, and the weather is reasonably quiet. It is expected that, during this time most of the local patrol post/forest office/stations will be accessible. Butterfly will be monitored during 09:00 AM to 4:00 PM every day, thus each transect will be monitored for 1 hour and continue to cover each transect line one after another. In this way, eight hours are likely to be studied. Each transect will get overall 2 hours at the day end. At each site data will be collected for whole month (four weeks)

## Essential Equipment

As the survey team has to travel to identify the study areas, a small country boat will be a suitable medium of transport. The essential equipment that will be required are one or more pairs of cameras, temperature meters and at least one GPS unit, watch, data sheet and pen/pencil.

## Survey Arrangement and Protocols

### Survey Teams

Usually, the standard team for butterfly survey consists of three to four members, each of whom familiar with the survey procedure and capable of identifying the selected species. It is also anticipated that, at least one of them should have prior knowledge in the topic. Moreover, all members should get necessary training in butterfly monitoring and identification. It will be beneficial to have an adviser who can be called if the survey crew has any difficulties while conducting the survey or identifying the indicator species.

### Code of Conduct during the survey

To ensure that the butterflies are not disturbed by the survey team, members should avoid wearing bright clothing (camouflaged clothing is preferred), making noise, moving too much, and using strong scents.

## Data Management and Handling

### Field Data Collection

Data collected during field survey will be recorded in a data sheet (sample of data sheet attached in Annex 6) and deposited to a central depository.

### Data Entry and Analysis

The survey data sheets will be deposited to a central depository that can be called as the 'Sundarbans Ecological Monitoring Cell'. Then the data will be entered to the computer for periodic analyses.

The raw data will be fed into Excel program, and will be evaluated on a regular basis to assess if the abundance of those indicator butterflies is increasing or decreasing in different range or areas of Sundarbans.

The equation for analysis is as follows:

Total number of butterflies "Z" = sampling location  $\times$  sampling frequency.

The equation for calculating relative abundance and normalized abundance will be:

$$\text{Relative abundance} = \frac{xi}{N}$$

$$\text{Normalized abundance} = \frac{xi - \min(x)}{\max(x) - \min(x)}$$

Where "x" is the absolute frequency and "N" is the total number.

On the other hand, Correlation coefficient (r) will be used to measure degree of relationship between two variables- butterfly population and temperature. In this process, the range of correlation coefficient value ranges between 1 to -1 where, a correlation of 1.0 will show a perfect positive correlation and -1.0 will depict a perfect negative correlation.

However, there might be many other factors that could have an impact on the number of butterflies

as they live in a complex ecosystem. Hence, this sort of study helps to address possible climate change induced threats to butterfly abundance and biodiversity.

## Reporting

A report on the survey outcomes will be prepared following the basic reporting structure. Background, goals, data collection and analysis techniques, data interpretation, trend of each indicator butterfly's abundance in different regions of the Sundarbans, and suggestions for future management will all be covered in the report.

## Interpretation and Application of Data

To examine the temporal variations in the abundance trend, the yearly abundance data of each of the three indicator butterfly species will be compared with data from the following years. The number of indicator butterfly increases or decreases over time, indicating whether the forest health is improving or deteriorating. Findings of the monitoring also might be statistically analysed to determine if there is any significant link with any element that could have an influence on the Sundarbans health and condition.

The interpreted data will be visualized through maps and graphics. Details of data visualization is in Chapter 4.

# INDICATOR SPECIES FOR BUTTERFLIES



● Sundarban Crow, *Euploea crameri* (Dorsal & Ventral view)  
I © Mirza Shamim Ahasan Habib



● Tree Nymph, *Idea agamarschana*  
I © Mirza Shamim Ahasan Habib



● Crimson Rose, *Pachliopta hector* I © Mirza Shamim Ahasan Habib

## Bees

The pollinator species plays the most important role to run the whole ecosystem service of the forest through pollination, fruit and honey production. Unfortunately, a very little is known about the health condition of the ecosystem services provided by the pollinator species. Though, few studies regarding the value of ecosystem service of Sundarbans have been done, no study has been done yet to assess overall ecological mentoring (EM) to understand the best practices, and formulate methodology, sampling design, and strategic planning for EM focusing on bee species.

Accordingly, Forest Department of Sundarbans East, in the fiscal year 2019 -2020, they have earned 12,81,500/- (BDT) from the production of 1220.50 quintal honey and 366.15 quintal wax from their east territory. (Source -UNB, Sept 2020). On the other hand, East division collected 7,86,400/- (BDT) from honey and wax in the fiscal year 2018-2019, which was merely half from the 2019-2020 fiscal year.

Besides the pollination activities, bee then serves as an environmental pollution detector in two ways. It sends out signals through high death rates, even blanket apicides, the presence of poisonous compounds, or residues in honey, pollen, larvae, and other foods, the presence of some heavy metals, as well as many fungicides and herbicides that are safe for it (Celli, 1983; Porrini et al., 2002). Therefore, it appears that, if the bees, beehives, and the honey are monitored it could provide information about the ecological condition of the forest. This section of the proposal illustrates the methodology for the data collection and analysis of bees

## Survey Method

### Data Collection Technique

The combine team of Forest department staff and honey collector will work together during honey collection process of those grids. Staff need to carefully observed and fill up the survey sheets. (as attached).

Besides, the forest department also maintains register for each office / bit office for quantify honey and wax collection during honey collection seasons.

The honey collectors, who are approved by the Forest Department, go to the forest to collect honey from the forest each year. They are the group that has first-hand experience regarding bees, honey, and how to find beehives and thus will be considered as the main respondent for data collection in this study. A list of the honey collectors who were permitted in the last 5-10 years will be collected from the Forest Department office to get their contacts. On the other hand, the local forest department is responsible for approval for honey collection and keeps an official record of honey production each year. Therefore, representatives from the Forest department are considered as another main respondent for this study. They will join with the honey collector in order to collect survey data. A comprehensive data sheet designed for this study is enlisted in Annex 6.

## Species Selection

For the assessment of the overall ecological condition of the Sundarbans, 2 species of bees have been selected as indicators species (Table 11). The indicator species were selected based on the literature review and it was recorded only three species of bees are available at the Sundarbans. As there is no primary data collected earlier for monitoring purposes for species, all the available three species have been considered under this monitoring scope.

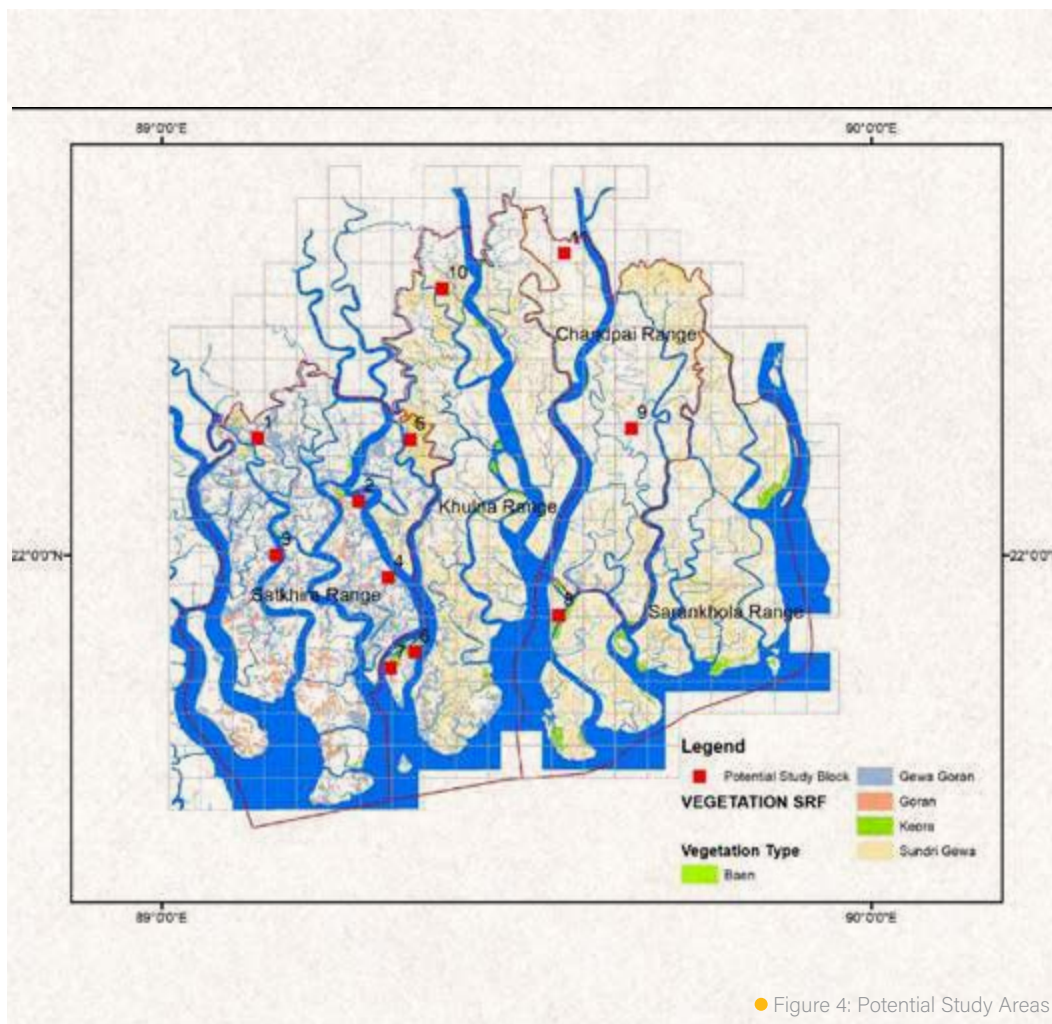
**Table 11: Indicator bee species**

| SL. | ENGLISH NAME                                             | SCIENTIFIC NAME                        |
|-----|----------------------------------------------------------|----------------------------------------|
| 1   | Giant honey bee                                          | <i>Apis dorsata</i><br>Fabricius, 1793 |
| 2   | Asian honey bee, Asiatic honey bee, or eastern honey bee | <i>Apis cerana</i><br>Fabricius, 1793  |

## Study Sites for Bees

The Satkhira range alone produces around 90% of the honey of the Sundarbans. According to the secondary information, the presence of a higher number of flowering plants plays an important role in a higher amount of honey production. According to the analysis based on the data from the BFD, around 98% of the major vegetation of

the Sundarbans of Satkhira range is composed of Gewa, Goran and Sundari which are the major honey-producing plants. Therefore, it is proposed to collect data from the mainly from Satkhira range as well as other ranges in order to understand overall health condition of this species. A map of the proposed study area showing the vegetation composition is illustrated (Figure 4).



● Figure 4: Potential Study Areas

## Sample Grids

In the selection of the survey area, honey production and pollination is considered as one of the determining factors. In this study it is considered that, the rate of fruit production is same all over Sundarbans.

Firstly, the literature review suggested that, in the Sundarbans the pollinator species, i.e; predominantly bee along with butterfly, are responsible for more than 90% of the natural pollination. Therefore, it is expected that, all over the Sundarbans, the pollinators provide this service. Considering this, the whole Sundarbans can be considered as the study area.

**Table 12: Distribution of Sampling Grids**

| Sundarbans range | Grid number | Grid count |
|------------------|-------------|------------|
| Satkhira range   | 1, 2,3,4,5  | 5          |
| Khulna range     | 6,7,10      | 3          |
| Sarankhola range | 8           | 1          |
| Chandpai range   | 9,11        | 2          |

The areas covered by Goran, Gewa, Keora, Sundri, Kholshi and Baen will be given more focus.

Sundarbans will be divided into 50m×50 m grid totaling 200 grids. Among the 200 grids, 11 grids of 10m×10 m size will be primarily selected based on abundance of the above mentioned honey producing plants. A vegetation map will be collected from the Department of Forest Bangladesh to identify potential suitable study locations. The potential locations of the study area are highlighted in red color in the below map.

## Survey Arrangement and Protocol

### Formation of the Team

Usually, the standard team for bee's survey consists of two to three members, each of whom is familiar with the survey procedure and capable of collection of required data from the field. It is also anticipated that, at least one of them should

have prior knowledge in the topic. Moreover, all members should get necessary training in bee monitoring and identification. From the honey hunter side, there is no limitation of number. They will act as usual their own procedure. It is obvious both teams should be present during the site of each grid survey.

### Code of Conduct

To ensure that the bees are not disturbed by the survey team, members should avoid wearing bright clothing (camouflaged clothing is preferred), making noise, moving too much, and using strong scents.

### Essential Equipment

As the survey team has to travel to access the study areas, a small country boat will be a suitable medium of transport. The essential equipment that will be required are one or more pairs of cameras, temperature meters, handheld salinity meter, at least one GPS unit, gloves, standard suit having with covered with whole body and face with transparent net, long boot, portable weight machine, measuring tape, plastic jar for soil sample collection, data sheet and pen/pencil. (4 sets of equipments required to cover each range).

## Data Management and Handling

### Data Collection

Data collected during field survey will be recorded in a data sheet. The survey data sheets will be deposited to a central depository that can be called as the 'Sundarbans Ecological Monitoring Cell. Then the data will be analysed periodic basis based on methodology.

### Data Analysis

The proposed project is designed to find the applicability of bees for ecological monitoring of the forest. The collected data from the respondents of the study will be analysed statistically to achieve the goal. The study intends to find a relationship (correlation) between

the parameters, for example, vegetation type, vegetation change (with the support of forest department GIS and remote sensing data), honey production, wax production, weather condition (rainfall, temperature) and salinity level. Those parameters will be analysed to examine if it is a statistically strong ( $r \geq 0.8$ ) relationship between them.

The study will also analyse the different types of bees and their contribution to the overall honey production from the Sundarbans. It will analyse the data of how much of the total honey is produced by the wild bees and if there is any contribution of the domesticated bees. Usually, *Apis dorsata*, which is the main honey bee of the Sundarbans, is wild and cannot be domesticated. On the other hand, if the contribution of the domesticated bee is found to increase, it would indicate that there is a change in the pollinator species. For this reason, statistical software for example Excel and SPSS will be used.

The study will also intend to identify the change of the vegetation due to the change of salinity

level if proper data is available. Based on the outcome of the analysis, the study could anticipate the potential impact of change of salinity level and vegetation on bees.

The study also proposes to investigate the presence of heavy metals for example Fe, Zn, Cu, Pd, in the land and honey production and it will be analysed as well to understand the pollution level of the forest as well. The analysis will help to understand if the concentration is higher than standard.

## Reporting

The expert of the monitoring team will create a report and submit it to the Sundarbans management authority after the data analysis is completed. Background, goals, data collection and analysis techniques, data interpretation, trend of each indicator butterfly's abundance in different regions of the Sundarbans, and suggestions for future management will all be covered in the report.

# INDICATOR SPECIES FOR BEES



● Giant honey bee, *Apis dorsata* | © Mirza Shamim Ahsan Habib



● Asian honey bee, *Apis cerana* | © <https://alchetron.com/cdn>



METHODOLOGY  
FRAMEWORK FOR  
ECOLOGICAL MONITORING  
OF FISH AND FISHERIES OF  
THE SUNDARBANS

## F. Fish and Fisheries

### 3.1.6 Methodology Framework for Ecological Monitoring of Fish and Fisheries of the Sundarbans

Consequently, the Sundarbans ecosystem supports rich diversity of fishes, shrimps and crabs, which are significant to fisher's livelihoods and local economy (Mustafa et al. 2019). The area, abundance of tidal rivers, flora and fauna, productivity and significance in the ecological balance make the Sundarbans a unique ecological site (Mamun et al. 2009). The highly interwoven rivers and complex estuarine ecosystems are known for their rich aquatic biodiversity, which includes 164 fish, 11 shrimp, 5 prawn and 5 crab species from the major rivers of Sundarbans (Uddin et al. 2021).

Fisheries are important component of aquatic ecosystems through their role as consumers of other organisms and they can have a significant influence on the function of these ecosystems. In this connection, adverse effects on fisheries species can have adverse flow-on effects on other aquatic organisms even if they are not directly affected by those changes in water quality (Pidgeon 2004). Thus, monitoring of fisheries species can provide valuable indicator to the aquatic ecosystem health.

#### Survey Methods

Observation of fishing/shrimping/crabbing boats, landing centers, and local fish markets during full moon and new moon phases are

important to count and record the selected species of fishes, shrimps and crabs to understand the fish diversity and relative abundance in the Sundarbans.

Alternately, selected fishing gears (e.g. net, trap, hook) will be used for capturing the selected fisheries species from specific river, stream and creek to assess the abundance and diversity of species by the trained surveyors from 20 selected points to assess the abundance and diversity of fish.

Moreover, interview, focus group discussion (FGD; 8-10 members of professional fishers) and questionnaire survey with specialized data sheet forms (Annex 7) will be conducted among concerned stakeholder groups from each of the 20 sites to generate both qualitative and quantitative data on abundance, distribution, seasonality, historical trends and ecological aspects of target species.

Additionally, high resolution maps (e.g. 1:10,000) or satellite imagery of the study area can be classified into different zones and include in the survey works to address the indigenous technical knowledge of fishing community in identifying the geo-spatial habitat hotspots of the flagship species across the lifecycle with movement routes. The survey will be conducted in every five years interval.

#### Species Selection

A total of 07 species of fisheries has been selected for the monitoring purposes. Table 13 below presents the fisheries species along with associated details.

**Table 13. Indicator fisheries species for regular monitoring from the Sundarbans mangrove ecosystem**

| Sl. No. | Name of indicator species                                                                   | Ecology and Niche                                                                                                   | Indication to the environment | Methods of monitoring                                                                     |
|---------|---------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|-------------------------------|-------------------------------------------------------------------------------------------|
| 1.      | <i>Lates calcarifer</i> (Bloch 1790)<br>Barramundi/Sea bass<br>Family: Latidae              | Found in coastal water, estuary, river, mangrove and tidal swamp                                                    | Euryhaline species            | Local fishers catch<br>Fish landing centers<br>Local fish markets<br>Interview/FGD/survey |
| 2.      | <i>Plotosus canius</i> (Hamilton-Buchanan 1822)<br>Grey eel-catfish<br>Family: Plotosidae   | Inhabits mangrove, estuary and coastal water                                                                        | Mangrove abundance indicator  | Local fishers catch<br>Fish landing centers<br>Local fish markets<br>Interview/FGD/survey |
| 3.      | <i>Scatophagus argus</i> (Linnaeus 1766)<br>Spotted Scat Family: Scatophagidae              | Found in coastal water, estuary, river, mangrove and tidal swamp                                                    | Mangrove abundance indicator  | Local fishers catch<br>Fish landing centers<br>Local fish markets<br>Interview/FGD/survey |
| 4.      | <i>Chelon parsia</i> (Hamilton-Buchanan 1822)<br>Goldspot mullet<br>Family: Mugilidae       | Found in estuary, coastal water and ascending rivers                                                                | Mangrove abundance indicator  | Local fishers catch<br>Fish landing centers<br>Local fish markets<br>Interview/FGD/survey |
| 5.      | <i>Boleophthalmus dussumieri</i> (Valenciennes 1837)<br>Mudskipper<br>Family: Gobiidae      | Found in estuary, coastal water and intertidal mudflat/marshes                                                      | Mangrove abundance indicator  | Local fishers catch<br>Fish landing centers<br>Local fish markets<br>Interview/FGD/survey |
| 6.      | <i>Scylla olivacea</i> (Herbst 1796)<br>Orange mud crab<br>Family: Portunidae               | Inhabits mangrove ecosystem                                                                                         | Mangrove abundance indicator  | Local fishers catch<br>Fish landing centers<br>Local fish markets<br>Interview/FGD/survey |
| 7.      | <i>Macrobrachium rosenbergii</i> (De Man 1879)<br>Giant river prawn<br>Family: Palaemonidae | Inhabits freshwater ecosystems influenced by adjacent brackish water areas including estuary, mangrove, tidal swamp | Mangrove abundance indicator  | Local fishers catch<br>Fish landing centers<br>Local fish markets<br>Interview/FGD/survey |

## Survey Sites for Fish Survey

A total of 10 sites have been selected from inside of Sundarbans as survey points for fish and fisheries (Figure 5).

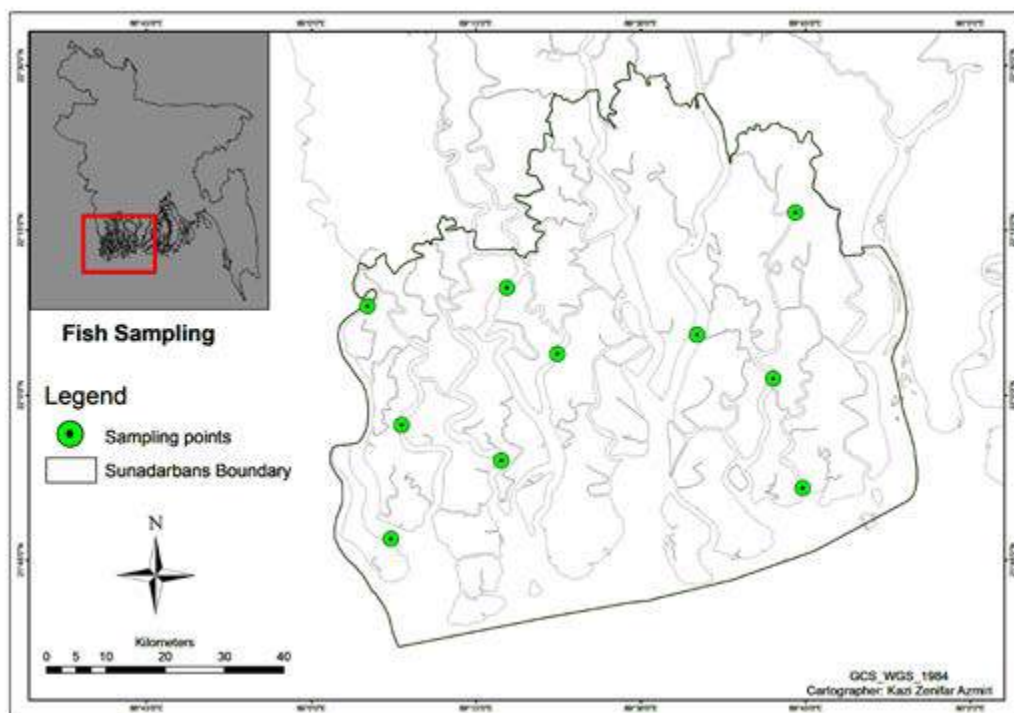


Figure 5: Geographical location of regular fisheries data sampling sites in the rivers and streams of the Sundarbans (Satellite imagery source: USGS Earth Explorer, access 1 May 2022)

## Time of the Survey

Considering the remoteness and physical accessibility in the Sundarbans mangrove forest, dry months are recommended for data collection and survey works in the ground. Thus, November to April can be the suitable period, while extreme cold and extreme hot days can be avoided (considering weather forecasting). Selected aquatic ecosystems (Figure 5) will be used for water and fisheries sample/data collection for further analysis. Tidal periods (i.e. high tide and low tide) need to adjust in daily schedule of ground works after discussion with citizen scientists (local honey hunter, fishermen, golpata collector). Sunset rules need

to strictly follow during the ground operation due to remoteness and frightful environment of the Sundarbans. To ensure smooth ground works and efficient use of time, houseboat can be moved after/before daily survey time so that next day survey will not be hampered.

## Essential Equipment for the Survey

Water sample collection and in-situ analysis (e.g. temperature, salinity, dissolved oxygen, pH, turbidity, current, and depth) are recommended. Required equipment including Nansen Bottle, Ruttner sampler, plastic bottle, rope, bucket, tray, thermometer, refractometer, DO meter, pH meter, flow meter, Eco-sounder, and measuring

tape. In addition, burette, pipette with associated chemicals and reagents are necessary for hands-on analysis in the field.

Navigation facilities (e.g. GPS, cellular phone) are needed for the team to record data and survey tracks. Binocular, camera, torch, power bank, charger are suggested for safe ground operation. Moreover, knife, bear spray/pepper spray, mosquito repellents, sticks, ropes, raincoats and umbrella are also recommended. The houseboat should be equipped with generator for charging of the equipment, cellular phone, camera, torch and laptops. If dry cells are used for GPS, then sufficient number of batteries would be needed.

## Survey Arrangements and Protocols

### *Survey Teams*

Major vehicles required for the data collection and survey works include accommodation boat, speedboat, and jeep. A team of 15-20 members (1 team leader/fisheries expert, 2 field supervisors, 4 data enumerators, 2 sample collectors, 2 photographers/videographers, 4 boat staffs, and at least 3 forest guards) will be needed for data collection and survey works. Wildlife officers from the Nature and Wildlife Conservation Division of Khulna and district/upazila level Fishery Officers from Satkhira and Bagherhat can be engaged for in-house capacity development of the Forest and Fishery Departments. Given the long-term work-schedule, citizen scientists (local honey hunter, fishermen, golpata collector, etc.) having local indigenous knowledge and experience can be helpful to conduct the survey activities. Before embarking the survey works, an orientation training and demonstration on the entire processes of safety and security for the team members would be imperative. GIS-based high-resolution maps and updated satellite imagery for each survey site will be needed to aid finding of surveying locations with proper navigation.

## Data Management and Handling

### *Field Data Collection*

The selected fisheries species (e.g. fish, shrimp, crab) may commonly observe in the daily catch basket of local fishermen, so direct observation, counting, measuring, photography/videography of the species along with ecological characteristics of the river/stream/creek can be recorded for further analysis. In-situ analysis of water quality can be completed for the required parameters. Moreover, semi-structured interview, quick discussions with fishers can be conducted focusing their life, foods, fishing gears, fishing time, post-catch processing, landing, marketing/selling, market price, middlemen presence/role and the likes without hampering their fishing activities. In case of their busy schedule in fishing, detailed address and contacts of the fishers can be collected to visit their village/places during leisure time for FGD and questionnaire survey.

A separate datasheet can be used for recording fisheries and ecological data from each site (Annex 7). The basic set of data will include GPS coordinates of each site, direct observation of selected species with number and measuring the parameters. Sample location, name of river/stream/creek, important benchmarks will also be recorded. Specification of fishing boat, gear, number of fishers, fishing duration and months, dominant species with quantity, distance of landing centers/markets will be recorded for further analysis. Survey track should be saved for each location and the datasheets will be deposited to a central depository.

### *Data Entry and Analysis*

The recorded and collected data will arrange and entry into database such as Microsoft Excel/Access program for analysis. Moreover, SPSS and/or R software can be used for advance statistical analysis. The base map of the study area will be generated in GIS software. ArcGIS for windows developed by Environmental Systems

Research Institute Inc., USA will be used for GIS analysis. The spatial extension module will be used for surface interpolation in ArcGIS. Given the variety of scales on which all parameters were measured, multicriteria decision analysis requires that the values contained in the various layers be transformed to comparable units. This is known as multicriteria evaluation and will be accomplished by appropriate decision rules, which are formal mathematical expression that combine the weights and scores of each of the layers used. Model verification will be carried out by making comparison between the predicted hotspots and indigenous knowledge of fishers. For this, village level FGD, KII and participatory observations will be carried out in different locations. An important assumption

will be considered that local people with their indigenous knowledge preferred more suitable fisheries hotspots.

### *Reporting*

A report will be produced following the basic structure of reporting format.

### *Interpretation and Application of Results*

The periodic survey will provide information on temporal changes and trends in relative species abundance. The interpreted data will be visualized through maps and graphs. This will eventually indicate improvement or deterioration of fishery resources.

# INDICATOR SPECIES FOR FISH



● Seabass, *Lates calcarifer* | © M. Shahadat Hossain



● Grey eel-catfish, *Plotosus canius* | © M. Shahadat Hossain



● Spotted Scat, *Scatophagus argus* | © M. Shahadat Hossain



● Goldspot mullet, *Chelon parsia* | © M. Shahadat Hossain



● Mudskipper, *Boleophthalmus dussumier* | © M. Shahadat Hossain



● Orange mud crab, *Scylla olivacea* | © M. Shahadat Hossain



● Giant tiger shrimp, *Penaeus monodon* | © M. Shahadat Hossain



METHODOLOGY FRAMEWORK  
FOR ECOLOGICAL  
MONITORING OF FLORA: TREE,  
SHRUB, REGENERATION AND  
LICHEN

## G. Flora: Tree, Shrub, Regeneration and Lichen

### 3.1.7 Methodology Framework for Ecological Monitoring of Flora: Tree, Undergrowth, Epiphyte, IAS and Lichen

Plants are very dynamic component in an ecosystem and are highly variable in both spatially and temporally due to their range of tolerance. Plants can provide quantitative information on the quality of the environment without examining the whole ecosystem processes. Therefore, different groups of plant species are increasingly being used as highly effective and reliable biotic indicator for recognizing and predicting the ecosystem quality.

#### Survey Methods

The concept development is based on literature review from various secondary sources, and extensive field surveys will provide data regarding ecosystem conditions for long-term ecological monitoring of the study area. Field survey will be conducted to the selected quadrats/plots during different seasons of a particular year and continued it in every five years interval.

#### Selection of Indicators

The present study area, the Sundarbans mangrove forest harbored different groups of plants such as non-vascular (algae, fungi, lichens and bryophytes) and vascular (pteridophytes and angiosperms) plants. According to the project design, following plant species from different groups were selected as biotic indicators for ecological monitoring of the Sundarbans-

**Table 14: Selected indicator plant species under different groups.**

| Plant groups                        | Sub groups    | Indicator species                                                                                                                                                                                                                                                                                                    |
|-------------------------------------|---------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Vascular plant<br>(Higher plant)    | Tree species  | Sundri ( <i>Heritiera fomes</i> ), Shingra ( <i>Cynometra ramiflora</i> ), Gewa ( <i>Excoecaria agallocha</i> ), Kakra ( <i>Bruguiera sexangula</i> ), Poshur ( <i>Xylocarpus moluccensis</i> ), Goran ( <i>Ceriops decandra</i> ), Baen ( <i>Avicennia officinalis</i> ), Kholshi ( <i>Aegiceras corniculatum</i> ) |
|                                     | Shrub species | Keya kanta ( <i>Pandanus foetidus</i> ), Nona jhaw ( <i>Tamarix indica</i> ), Nunia ( <i>Aegialitis rotundifolia</i> )                                                                                                                                                                                               |
|                                     | Regeneration  | Seedlings, saplings and pols of indicator tree species                                                                                                                                                                                                                                                               |
| Non-vascular plant<br>(Lower plant) | Lichens       | <i>Cladonia caespiticia</i> , <i>Flavoparmelia caperata</i> , <i>Graphis scripta</i> , <i>Ramalina fraxinea</i>                                                                                                                                                                                                      |

## Selection of sampling units/sites

To achieve the cherish goals of the project, the Sundarbans will be divided into 65 sample units, each consisting of 3-5 'khals'. In each sampling unit, three representative 'khals' will be selected, and 3-5 (4) sampling plots will be selected from both sides of each designated 'khal' with reasonable intervals. At each sampling plot, the following three types of plot and sub-plots will be applied for vegetation sampling and data collection:

**Table 15: Types, shape, size and area plot and sub-plots applied for different categories of vegetation.**

| Type of plot & sub-plot | Vegetation type   | Shape of plot & sub-plot | Size of plot & sub-plot | No. of units per plot | Total area in each plot |
|-------------------------|-------------------|--------------------------|-------------------------|-----------------------|-------------------------|
| Type-I (Main plot)      | Trees & poles     | Rectangle                | 100m × 20m              | 1                     | 0.2 hectare             |
| Type-II (Sub-plot-I)    | Shrubs & saplings | Quadrat                  | 2m × 2m                 | 4                     | 0.0016 hectare          |
| Type-III (Sub-plot-II)  | Seedlings         | Quadrat                  | 1m × 1m                 | 4                     | 0.0004 hectare          |

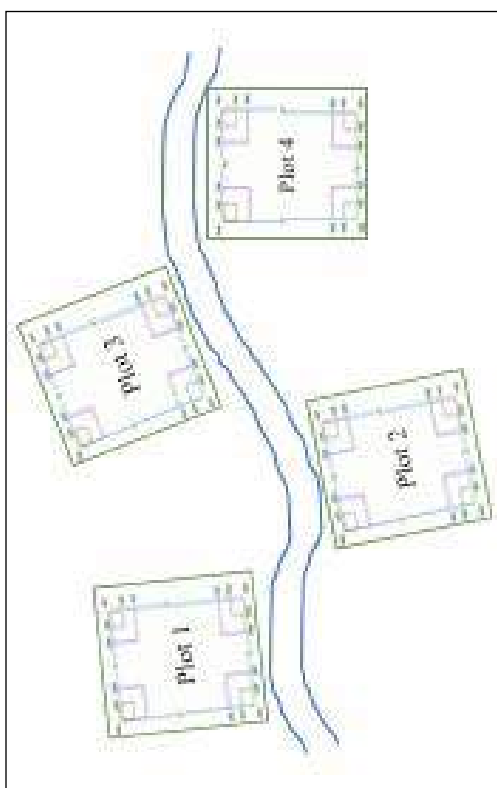


Figure 6: Layout of sampling plots along the selected 'khal'.

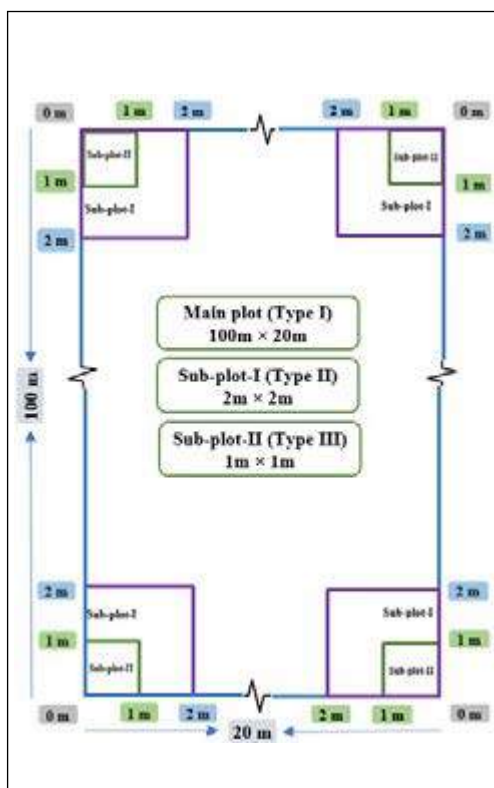


Figure 7: Detailed sampling design for different categories of vegetation applied in each plot.

It is essential that all plots can be exactly relocated, even after several years. The selected plots will be permanently marked with paint and a sign board with proper information for future recognition and data collection. The starting point of each plot will be cleared, and four trees will be banded with red paint. A sign board will be fixed at the starting point bearing plot no., range, compt. no., block no., distance, bearing line, etc. Red paint will be used as direction for the plot throughout the bearing line. If one can recognize the starting point of the plot, it will be relocated very easily.

## Shrubs species

Selected indicator shrub species indicates the ecological succession, salinity trend, and forest type. Data on their occurrence, distribution, abundance, and growth performance indicate the forest quality, which will be helpful for ecological monitoring.

## Regeneration

The regeneration potentiality of the indicator tree species will be used as a potential indicator for ecological monitoring. The regeneration status of a particular site will indicate the future forest type and quality of that site.

## Measurement of indicator plant species

Special attention to the selected eight indicator tree plant species (*viz.*, *Ceriops decandra*, *Avicennia officinalis* and *Aegiceras coeniculatum* as high salinity indicator species, *Heritiera fomes* and *Cynometra ramiflora* as low salinity indicator species, and *Exoecaria agallocha*, *Bruguiera sexangula* and *Xylocarpus moluccensis* as the medium salinity indicator species) (Table 15) in three different saline zones. Phytosociological status, species diversity, canopy height, canopy coverage, regeneration potentiality, association and interaction with other plants will be measured following standard procedure.

**Table 16: Indicator tree species that represent different salinity zones of the Sundarbans**

| Sl. no. | Name of indicator species                                        | Ecology and Niche                                                                            | Indication to the environment | Methods of monitoring                                                                                                                   |
|---------|------------------------------------------------------------------|----------------------------------------------------------------------------------------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 1.      | <i>Ceriops decandra</i> (Griff.) W.Theob. Family- Rhizophoraceae | Preferable to grow in developed soil of mature mangrove habitat                              | High salinity indicator       | Phytosociological attributes. Canopy height and coverage. Regeneration potentiality. Stresses by external factors.                      |
| 2.      | <i>Avicennia officinalis</i> L. Family- Acanthaceae              | Preferable to grow in developing soil as pioneer tree species of intertidal mangrove habitat | High salinity indicator       | Phytosociological attributes. Canopy height and coverage. DBH of mature plant. Regeneration potentiality. Stresses by external factors. |
| 3.      | <i>Aegiceras corniculatum</i> (L.) Blanco Family- Myrsinaceae    | Preferable to grow in developing soil as pioneer tree species of intertidal mangrove habitat | High salinity indicator       | Phytosociological attributes. Canopy height and coverage. Regeneration potentiality. Stresses by external factors.                      |
| 4.      | <i>Heritiera fomes</i> Buch.-Ham. Family- Malvaceae              | Preferable to grow in developed soil of mature mangrove habitat                              | Low salinity indicator        | Phytosociological attributes. Canopy height and coverage. DBH of mature plant. Regeneration potentiality. Stresses by external factors  |

| Sl. no. | Name of indicator species                                       | Ecology and Niche                                               | Indication to the environment | Methods of monitoring                                                                                                                   |
|---------|-----------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|
| 5.      | <i>Cynometra ramiflora</i><br>L. Family- Fabaceae               | Preferable to grow in developed soil of Mature mangrove habitat | Low salinity indicator        | Phytosociological attributes. Canopy height and coverage. Regeneration potentiality. Stresses by external factors                       |
| 6.      | <i>Excoecaria agallocha</i> L. Family- Euphorbiaceae            | Preferable to grow in developed soil of mature mangrove habitat | Medium salinity indicator     | Phytosociological attributes. Canopy height and coverage. Regeneration potentiality. Stresses by external factors.                      |
| 7.      | <i>Bruguiera sexangula</i> (Lour.) Poir. Family- Rhizophoraceae | Preferable to grow in developed soil of mature mangrove habitat | Medium salinity indicator     | Phytosociological attributes. Canopy height and coverage. DBH of mature plant. Regeneration potentiality. Stresses by external factors. |
| 8.      | <i>Xylocarpus moluccensis</i> (Lam.) M. Roem. Family- Meliaceae | Preferable to grow in developed soil of mature mangrove habitat | Medium salinity indicator     | Phytosociological attributes. Canopy height and coverage. DBH of mature plant. Regeneration potentiality. Stresses by external factors. |

## Data Management and Handling

### Field Data Collection

The primary field data of the selected indicator species under different plant groups will be collected from the respective sample quadrat/plot following standard field data sheet. Data on indicator epiphytic orchids and ferns will be recorded from supporting trees observed in the respective sampling plots. Data on indicator lichen species will be recorded from trunk of ten selected common trees within each sample plot following specific quadrat technique and documented in the specific field data sheet(Annex 8).

### Data Analysis

**Taxonomic identification:** All the collected vascular plant specimens of each study sites will be identified by taxonomic expertise and through cross-checking with herbarium specimens preserved at BNH/ JUH and also matching the taxonomic description, keys or the photographs/illustrations in the relevant literatures, especially the recent Floras and Manuals. Identification of non-vascular lichen flora will be completed by evaluation of the morphology and biochemical spot tests with the following published literature and database index.

**Canopy height and canopy coverage:** Altimeter or a measuring pole, and a spherical densiometer will be used to measure the forest canopy height and canopy coverage respectively.

**DBH:** Diameter at breast height (DBH) of the indicator tree species will be measured using dia tape.

**Regeneration:** Number of seedlings, saplings and poles of the indicator tree species in the sampling plots will be counted for the future prediction of the forest type and quality.

**Phytosociology:** Phytosociological attributes (i.e. density, relative density, frequency, relative frequency abundance, relative abundance and important value index) of the recorded plant species were calculated following formulae described by Barker (2001), Dallmeier (1992).

Categorization of each indicator plant species under DAFOR scale according to their RA value, where, D- Dominant (>75%), A- Abundant (51-75%), F- Frequent (26-50%), O- Occasional (11-25%), R- Rare (1-10%), and 0 indicates Absent.

**Table 17: Formula used for the calculation of following phytosociological attributes**

| SN | Phytosociological attributes | Formula                                          |
|----|------------------------------|--------------------------------------------------|
| 1  | Density (D)                  | $D = \frac{a}{b}$                                |
| 2  | Relative density (RD) %      | $RD = \frac{n}{N} \times 100$                    |
| 3  | Frequency (F) %              | $F = \frac{c}{b} \times 100$                     |
| 4  | Relative frequency (RF) %    | $RF = \frac{F_i}{\sum_{i=1}^s (F_i)} \times 100$ |
| 5  | Abundance (A)                | $A = \frac{n}{c}$                                |
| 6  | Relative abundance (RA) %    | $RA = \frac{A_i}{\sum_{i=1}^s (A_i)} \times 100$ |
| 7  | Importance Value Index (IVI) | $IVI = RD + RF + RA$                             |

Here, a = total number of individuals of a species occurred in all the quadrats; b = total number of quadrats studied; c = total number of quadrats in which the species occurred; N = total number of individuals of all the species; n = number of individuals of ith species; Fi = Frequency of each species; Ai = Abundance of each species.

**Diversity index:** Shannon's diversity index of the respective plant groups will be determined using the following formula-

$$H' = - \sum p_i \ln p_i$$

where,  $H'$  = Shannon's Diversity Index,  $p_i$  = the proportional abundance of the *ith* species.

Four diversity index classes of lichen flora such as- very high, high, moderate and low diversity will be considered for different magnitude of ecosystem quality (Khastini et al. 2019).

## Reporting

A report of the survey outcomes will be prepared following the basic reporting structure.

## Interpretation and Application of Results

The interpreted data will be visualized through maps and graphics. Details of data visualization is in Chapter 4.

# INDICATOR SPECIES OF TREES



● Black mangrove, *Aegiceras corniculatum* | © Gazi Mosharof Hossain



● Indian mangrove, *Avicennia officinalis* | © Gazi Mosharof Hossain



● Upriver orange mangrove, *Bruguiera sexangula* | © Gazi Mosharof Hossain



● Flat-leaved Spurred Mangrove, *Ceriops decandra* | © Gazi Mosharof Hossain



● Katong laut, *Cynometra ramiflora* | © Gazi Mosharof Hossain



● Milky mangrove, *Excoecaria agallocha* | © Gazi Mosharof Hossain



● Sundari, *Heritiera fomes* | © Gazi Mosharof Hossain



● Cedar mangrove, *Xylocarpus moluccensis* | © Gazi Mosharof Hossain

# INDICATOR SPECIES OF LICHEN



*Cladonia caespiticia* | © Gazi Mosharof Hossain



*Pyxine cocos* | © Gazi Mosharof Hossain



*Graphis scripta* | © Gazi Mosharof Hossain



*Ramalina fraxinea* | © Gazi Mosharof Hossain

# INDICATOR SPECIES OF SHRUB



Nuniya, *Aegialitis rotundifolia* | © Gazi Mosharof Hossain



Common sea-shore screw pine/ Keya kanta, *Pandanus foetidus*  
| © Gazi Mosharof Hossain



Salt cedar/ Nona jhaw, *Tamarix indica* |  
© Gazi Mosharof Hossain



METHODOLOGY FRAMEWORK  
FOR ECOLOGICAL MONITORING  
OF ENVIRONMENTAL PARAMETER,  
ENVIRONMENTAL QUALITY,  
MONITORING METHODOLOGY  
AND TESTING PROCEDURE

## 3.2. Methodology Framework for Ecological Monitoring of Environmental Parameters

### 3.2.1 Environmental Parameter (Soil Health) monitoring methodology and testing procedure

In ecological monitoring, it is prime important to select the parameters and standardized them for the field and laboratory analysis. Parameters will cover the different aspects to monitor biodiversity, vegetation, soil, and water quality. Primary ecological monitoring concentrates on field parameters and observations. Among the ecosystem components, the soil is vital to support the growth and development of plants, forest productivity maintaining the water quality, and the aquatic ecosystem of mangroves (Mahmood, 2004, Yi et al., 2011, Jaing et al., 2020). Plant growth and forest productivity are linked with soil quality. On the other hand, soil's physical, chemical, and biological properties influence the soil quality of a mangrove ecosystem (Hossain and Nuruddin, 2016).

#### Selection of Parameters and Development of Methodology

Mangrove ecosystem consists of biotic, abiotic components and their interaction (Hutchings and Saenger, 1986). The health of mangrove ecosystem can be assessed with the combination of biotic (litter production, seedling regeneration, canopy cover, leaf area index, forest structure, crab density, snail density, phytoplankton and diatom diversity and density etc.) and abiotic (parameters of soil, water and air) components of the forest (Snedaker et al., 1984, English et al., 1997, Ellison et al., 2012, Faridah-Hanum, et al., 2019). Among the abiotic components, mangrove soil is complex and variable. It composed of river and marine alluvium, transported as sediment and deposited in rivers and seas. It is a matrix that contains residues, inorganic, and organic particles that is relatively heterogeneous in terms of physicochemical and biological characteristics (Sarkar, 2018).

Mangrove soil is the important component that shapes floral and faunal composition of forests. Conversely, floral and faunal composition significantly influences the parameters of soil in a positive way. The positive improvement in soil quality enhances growth of plants; changes the site to a more diversified one, and improve the environmental quality (Rosa and Sobral, 2008). Unlike water and air quality, single parameter of soil does not appear to be sufficient to monitor the soil quality. A trade-off must be considered during the selection of soil parameters for ecological monitoring of soil components. A complex integration of static and dynamic parameters of chemical, physical, and biological components of soil need to understand before selecting as indicators of ecological monitoring (Braimoh and Vlek, 2008, Cherubin et al., 2016).

#### Listing and selection of soil parameters for assessing the soil quality

A good number of physical, chemical, and biological parameters are identified for soil components of a terrestrial ecosystem (Table 21), and they significantly influence each other (Rosa and Sobral, 2008). Sustaining biological productivity, biodiversity, regulating water flow, storing and cycling of nutrients and carbon, filtering, buffering, and transforming organic and inorganic materials, regulation and partitioning of water and solute flow, and providing the physical stability for plants are the major functions of soil parameters to a mangrove ecosystem (Clough, 1982 Hutchings, and Saenger, 1986, Mahmood, 2004). Common parameters are in Table 18.

**Table 18: Common parameters of mangrove soil**

| Major categories | Parameters                                                                                                                                |
|------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Physical         | Colour, texture, structure, porosity, bulk density, particle density, consistence, aggregate stability, and temperature                   |
| Chemical         | pH, redox potential, electrical conductivity, salinity, cation exchange capacity, amount of plant available nutrients and other elements. |
| Biological       | Organic matter, organic carbon, enzymes, earthworms, nematodes, respiration, microbial biomass (fungi and bacteria) microorganisms        |

The basic assessment of mangrove soil quality is necessary to evaluate the degradation status and changing trends with time and natural and anthropogenic activities. Soil properties that are sensitive to changes with the management operations, natural and anthropogenic activities can be used as indicators for the field and laboratory assessment. The physical, chemical, and biological parameters can serve as indicators for soil quality assessment.

The selection of field indicators/parameters is a difficult task to cover the soil's physical, chemical, and biological parameters considering the site condition and level of interferences. Visual indicators that can be obtained from observation or photographic interpretation. The field indicators have a clear indication that soil

quality is threatened or changing. Sundarbans mangrove forest is a vast coastal wetland that experiences natural and human-induced harmful activities. There are several threats have been identified to the Sundarbans mangrove forest (Mahmood et al., 2021). It is now a crying need for developing an ecological monitoring framework for the Sundarbans soil component. MDS for monitoring the soil component of the Sundarbans requires the incorporation of some field indicators along with physical, chemical, and biological parameters. The possible list indicators/ parameters (MDS) for the monitoring of the Sundarbans soil has been presented in Table 20, which may help in selecting MDS for the ecological monitoring of the Sundarbans soil. The sample collection can be done from the permanent sample plots.

**Table 19: List of indicators/parameters for the ecological monitoring of the Sundarbans soil**

| Indicator category   | Parameters                            | Functions                                                                                                                                                                                                                                                                                                                                                                    | Field/ Lab |
|----------------------|---------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Chemical indicator   | pH                                    | <ul style="list-style-type: none"> <li>● Influence the activities of soil bacteria</li> <li>● Influence the mobility and availability of nutrient, toxic elements, and soil structure</li> </ul>                                                                                                                                                                             | Field/Lab  |
|                      | Electrical conductivity               | <ul style="list-style-type: none"> <li>● It measures the soil salinity</li> <li>● Affect the productivity</li> <li>● Availability nutrients for plant uptake</li> <li>● Influence the soil microorganism activity</li> <li>● Influence several soil physical and chemical properties like availability of nutrients, soil texture, cation exchange capacity, etc.</li> </ul> | Field/Lab  |
|                      | Available Nitrogen                    | <ul style="list-style-type: none"> <li>● Productivity and plant growth</li> </ul>                                                                                                                                                                                                                                                                                            | Lab        |
|                      | Available Phosphorus                  | <ul style="list-style-type: none"> <li>● Productivity and plant growth</li> </ul>                                                                                                                                                                                                                                                                                            | Lab        |
|                      | Available Potassium                   | <ul style="list-style-type: none"> <li>● Productivity and plant growth</li> </ul>                                                                                                                                                                                                                                                                                            | Lab        |
|                      | Heavy metals (As, Cr, Co, Cu, Hg, Pb) | <ul style="list-style-type: none"> <li>● Ecological health risk</li> </ul>                                                                                                                                                                                                                                                                                                   | Lab        |
| Biological indicator | Organic matter                        | <ul style="list-style-type: none"> <li>● Soil structure</li> <li>● Nutrient retention</li> <li>● Carbon sequestration</li> <li>● Microbial population</li> </ul>                                                                                                                                                                                                             | Lab        |
|                      | Organic carbon                        | <ul style="list-style-type: none"> <li>● Carbon sequestration</li> </ul>                                                                                                                                                                                                                                                                                                     | Lab        |

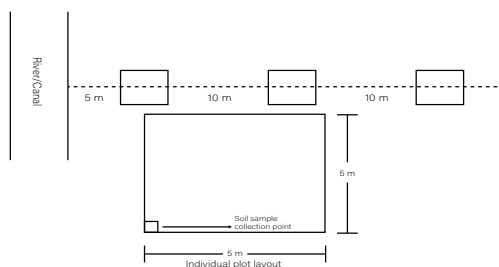
| Indicator category | Parameters                                            | Functions                                                                                                                                                                                                                                                                                                                                                                                                                         | Field/ Lab |
|--------------------|-------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Visual indicator   | Snail on the forest floor and tree trunk              | <ul style="list-style-type: none"> <li>Habitat quality</li> </ul>                                                                                                                                                                                                                                                                                                                                                                 | Field      |
|                    | Crab burrow density                                   | <ul style="list-style-type: none"> <li>Soil aeration condition</li> <li>Crab mount facilities natural regeneration</li> <li>Consumption and mechanical breakdown of the mangrove litter that accelerate the decomposition of litter</li> <li>Enhance microbial decomposition of litter that support nutrient cycling and adding of organic matter to the mangrove soil and supply of detritus to the aquatic ecosystem</li> </ul> | Field      |
|                    | Natural drainageways after any event                  | <ul style="list-style-type: none"> <li>Indication of changing the surface hydrology</li> </ul>                                                                                                                                                                                                                                                                                                                                    | Field      |
|                    | Burial and exposing of pneumatophores                 | <ul style="list-style-type: none"> <li>Evidence of sediment accretion and erosion</li> </ul>                                                                                                                                                                                                                                                                                                                                      | Field      |
|                    | Occurrence and coverages of weed species (Tiger fern) | <ul style="list-style-type: none"> <li>Less tidal inundation due to sediment accretion</li> </ul>                                                                                                                                                                                                                                                                                                                                 | Field      |
|                    | Occurrence of oil of the forest floor                 | <ul style="list-style-type: none"> <li>Oil pollution cause rapid destruction of the habitats of soil micro-organism and organisms living among the roots and branches of mangroves.</li> </ul>                                                                                                                                                                                                                                    | Field      |
|                    | Collection of plastic material on the forest floor    | <ul style="list-style-type: none"> <li>Indicator of urban pollution. The microplastic from the degradation of the plastic compound may carry disease-causing organisms and act as a vector for diseases. Microplastics can also interact with soil fauna, affecting their health and soil functions.</li> </ul>                                                                                                                   | Field      |
|                    | Leaf litter on forest floor                           | <ul style="list-style-type: none"> <li>High amount of organic matter</li> <li>Less tidal inundation</li> </ul>                                                                                                                                                                                                                                                                                                                    | Field      |

## Sampling Design

The indicators/parameters for the ecological monitoring of the Sundarbans will be collected from PSP to ensure long-term monitoring. However, considering resource availability, 10 forest range stations within the Sundarbans can be considered for sample collection. Three permanent sample plots (5 m x 5 m) for soil quality will be established systematically with the 10 forest ranges or PSPs, at 10 m interval across the river/ canal bank inside the forest.

The first plot will be established at 5 m away from the river/canal bank to avoid the edge effect. One set of such plot complex (Figure 6) will be established for each selected site. Each corner of sample plot will be demarcated permanently using concrete pillar (10 cm x 10 cm x 1 m).

Samples for the physical, chemical and biological parameters, and information on visual indicators (except natural drainageways after any event and collection of plastic material on the forest floor) will be collected from these permanent sample plots.



● Figure 8: Layout of permanent sample plots for ecological monitoring of soil component for the Sundarbans Field and laboratory testing methodology for the selected soil parameters

## A. Soil Chemical Indicators/Parameters

### Soil pH

Soil pH will be measure from the same collected and processed sample. 1:2 soil extraction (Allen, 1974) will be followed to determine soil pH using high precision pH meter (Hach sensION 3 Benchtop pH/mV Meter, 110 VAC (Figure 9). Seasonal variation will also be observed for soil pH.

The steps involve in soil pH determination are as follows

- Take 10 g of processed samples in 250 ml conical flask
- Take 20 ml of distilled water into the samples
- Shake the sample and water on an orbital shaker for 15 minutes
- Allow 20 minutes to settle-down the soil
- Pour the supernatant liquid into a test-tube
- Insert probe of high precision pH meter to record the pH value of the sample



Figure 9: Hach sensION 3 Benchtop pH/mV Meter, 110 VAC

### Soil Conductivity

Soil EC will be measured from the same collected sample. 1:2 soil extraction (Allen, 1974) will be followed to determine soil EC using high precision Bench-Top Conductivity Meter with ATC 230V, Hanna Instruments HI 2315-02 (Figure 10).

The steps involve in soil conductivity determination are as follows

- Take 10 g of processed samples in 250 ml conical flask
- Take 20 ml of distilled water into the samples
- Shake the sample and water on an orbital shaker for 30 minutes
- Allow 20 minutes to settle-down the soil
- Pour the supernatant liquid into a test-tube
- Insert probe of high precision EC meter to record the conductivity value of the sample



Figure 10: Bench-Top Conductivity Meter with ATC 230V, Hanna Instruments HI 2315-02

### *Available Nitrogen*

Ammonium is held in the exchangeable form in soils in the same manner as exchangeable metallic cations. Fixed  $\text{NH}_4^+$  is present in soil primarily as  $\text{NH}_4^+$  in interlayer positions of the 2:1 layer silicates, in the same way as K, by the closure of interlayer space. Extractable  $\text{NH}_4^+$  is extracted with 2M KCl. Weight of 5 g soil into a conical flask and 50 ml of 2M KCl will be added and will be shaken for 30 minutes. The extractant will be filtrated. The filtrated extractant sample will be used to determine extractable  $\text{NH}_4^+$  in soil.

Ammonium content in the digested samples will be measured according to Weatherburn (1967). Ammonium stock solution will be prepared by dissolving 0.2965 g Ammonium chloride ( $\text{NH}_4\text{Cl}$ ) in 1000 ml deionized water. The stock solution will be diluted to prepare different concentration of standard solution. One ml of solution A (2.5 g Phenol and 12.5 mg Natrium nitroprusside per 250 ml deionized water) and 1 ml of solution B (1.25 g Sodium hydroxide and 2.1 ml Natrium hypochloride per 250 ml deionized water) will be added with 1 ml of standard solution or samples. The mixture will be incubated in water bath at 37°C for 20-30 minutes and absorbance was measured at 625 nm by UV-Visible Recording Spectrophotometer. The total nitrogen content will be calculated from the following calculation.

### *Available Phosphorus*

Bray and Kurtz extractant [0.03 N  $\text{NH}_4\text{F}$  in 0.025 N HCl (1945)] was used for determining the available phosphorus for the acid soil ( $\text{pH} < 5.5$ ). Four grams of air-dried soil was taken into a conical flask and 40 ml of extractant was added. The content was shaken for 5 minutes and filter with Whiteman No-1. Both the total and available phosphorus in the sample extracts were measured using colorimetric method as prescribed by Timothy et al. (1984).

A mixed solution will be prepared by adding 100 ml Ammonium molybdate (15 g in 500 ml

deionized water), 250 ml  $\text{H}_2\text{SO}_4$  (140 ml to 900 ml deionized water), 100 ml Ascorbic acid (27 g in 500 ml deionized water) and 50 ml Antimony potassium tartrate (0.34 g in 250 ml deionized water). Phosphate stock solution will be prepared by diluting 1.433 g  $\text{KH}_2\text{PO}_4$  in 1000 ml deionized water. Stock solution will be diluted to prepare different concentration of standard solution. One ml of mixed solution will be added with 10 ml of standard solution or sample. After 5-minute, absorbance will be measured at 885 nm by UV-Visible Recording Spectrophotometer

1N  $\text{NH}_4\text{OAc}$  (1N, pH-7) extractant were to measure the available form of potassium (K) in soil. The extractant [1N  $\text{NH}_4\text{OAc}$  (1N, pH-7)] was used at 1:5 ratio, shake for 5 minutes, and filter with Whiteman No-1 (Stanford and English, 1949). However, a Research Flame Photometer, Jenway PFP7/C will be used to determine the concentration of potassium in the sample extracts.

## **B. Visual Indicator**

The visual indicators are very useful to understand the situation of an ecosystem at the field level. This sort of indicator is very easy to monitor but gives very strong pieces of evidence of changing condition of a particular ecosystem. The following visual indicators are believed to work in monitoring the ecological condition of the soil components of the Sundarbans. The measurements will include the existence, extent, and counting in number, which can be very easy for recording by the field staff of the Sundarbans. The monitoring of such indicators will be done during the pre-monsoon and post-monsoon season.

### **Snail on the Forest Floor and Tree Trunk**

The existence of snails on the forest floor and tree trunk will be noted with their extent (plenty, moderate, rare, and none) at the plot level. Moreover, the number of snails on the forest floor and the trunk of the tree inside the sample plots will also be counted and recorded according

to the plot. Finally, the sample plot basis the average number of snails will be estimated.

### Crab Burrow Density

The existence of crab burrow will be noted with their extent (plenty, moderate, rare and none) at the plot level. Number of crab burrows will also be counted and recorded according to plot. Average number of crab burrow will be estimated for the plots.

### Natural Drainageways after any Event

Developed of natural drainageways usually observed after any natural events (tidal surges, and cyclone) in the mangroves. Any record of such drainageways will be recorded (occurred and none) for a particular forest area.



● Figure 11: Porcelain cup, high precision analytical balance and muffle furnace

### Burial and Exposing of Pneumatophores

Events of burial and exposing of pneumatophores inside the sample plots will be recorded as high, medium, low, and none.

### Occurrence and Coverages of weed species (Tiger fern)

Occurrence of weed species (tiger fern) inside the plots will be observed and noted as plenty, moderate, rare and none.

### Occurrence Oil on the Forest Floor

The occurrence of oil on the forest floor can be expected in the Sundarbans. Any accumulation of oil on the forest floor inside the sample plots will be recorded as plenty, moderate, rare and none.

### Collection of Plastic Material on the Forest Floor

Plastic material and its residue are now quite common along the bank of the larger river of the Sundarbans. The occurrence of plastic material on the forest floor along the river/canal bank will be recorded for a 100 m walk and recorded as plenty, moderate, rare, and none. All the plastic materials on the way to the walk will also be collected and counted.

### Leaf Litter on Forest Floor

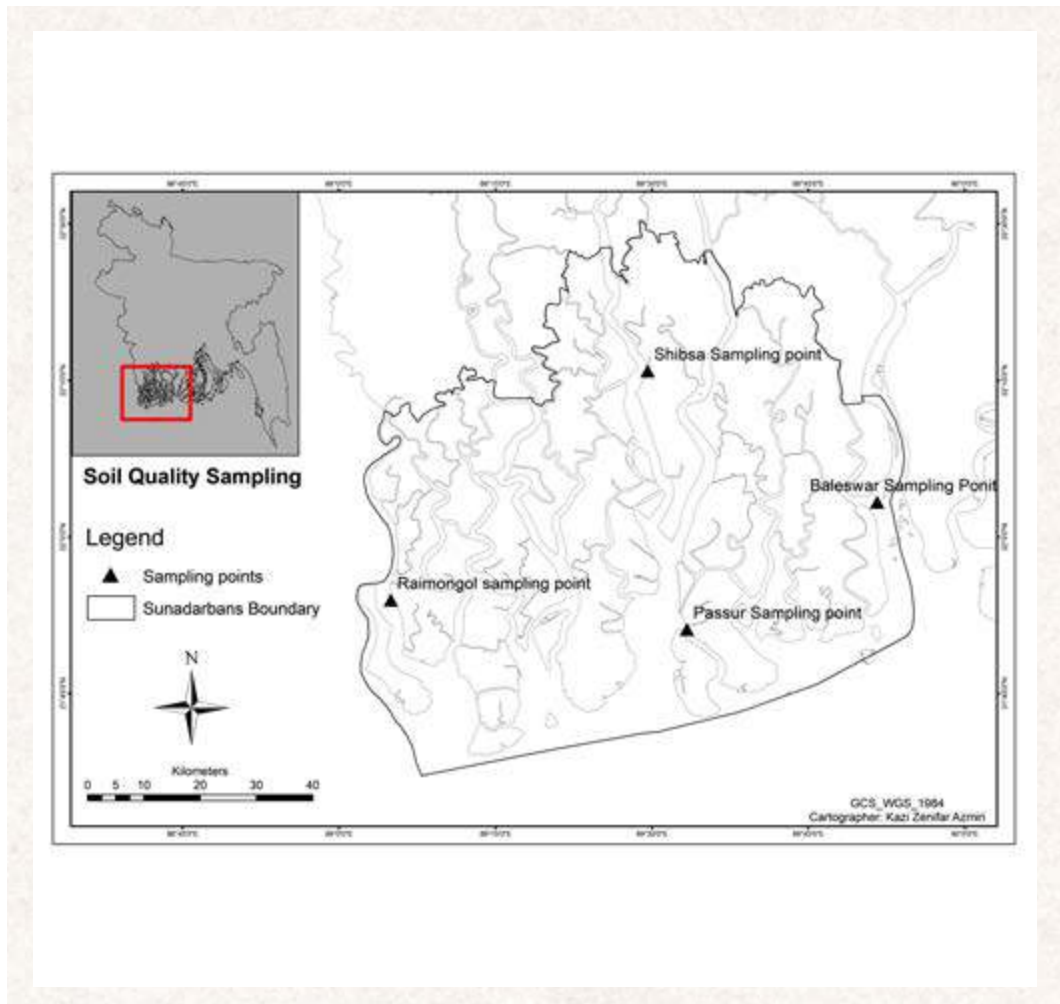
The occurrence of fresh to partially decomposed leaf litter in the sample plots will be noted and recorded as plenty, moderate, low and none.

### Site Selection for the Ecological Monitoring

The site selection for ecological monitoring is a prime important task. The pilot sites for the ecological monitoring of the soil components of the Sundarbans will be selected strategically considering the record, literature, and present situation. The Pasur River channel is the lifeline of the Mongla Seaport and maintains the international and domestic navigation route. Four important tourist destinations (Karamjal, Harbarya, Hironpoint, and Dubla fishermen's hut) are also located downstream of the Pasur River. On the overhand, this channel is connected with the Rupsha River, which may carry urban and industrial pollutants. Similarly, the Sutarkhali River is also a potential site for receiving agrochemicals from the vicinity of agricultural activities including aquaculture. Considering these factual analyses, the sites of Raimangal, Passur, Shibsha, and Baleswar can

be a good choice for selecting the pilot sites for the ecological monitoring of the soil components (Figure 12). Soil sample will be collected from

eight points from nearest forest stations from these four rivers.



● Figure 12: Location of the proposed pilot sites for the ecological monitoring of the soil components

### 3.2.2 Environmental Parameter (water quality) Monitoring Methodology and Testing Procedure

The keys to understanding the hydrological behavior of the mangrove ecosystem, as determined by upstream freshwater flow, river mouth tidal flow, currents and waves, ecosystem topography, and so on, lead one to realize the

conglomerate nature of hydrology as a science, integrating a number of separate disciplines, such as meteorology, soil physics, water quality, hydrodynamics, and so on. This implies that a large amount of data is required for such a study. Unfortunately, there is a scarcity of systematic hydrological data on the Sundarbans (Wahid et al., 2007). By managing the delivery of nutrients, the water quality and circulation pattern in a

mangrove system is a significant component in influencing production rates in coastal ecosystems. Water pollution from numerous businesses in upstream areas, as well as suspected oil contamination from adjacent ports of Khulna and Mongla, have a significant impact on the ecosystem's water quality (Rahaman et al., 2015).

## Listing and Selection of Parameters for Assessing the Water Quality through field testing and laboratory analysis

**Table 20: List of parameters for the environmental quality monitoring in the Sundarbans (water, pollutant)**

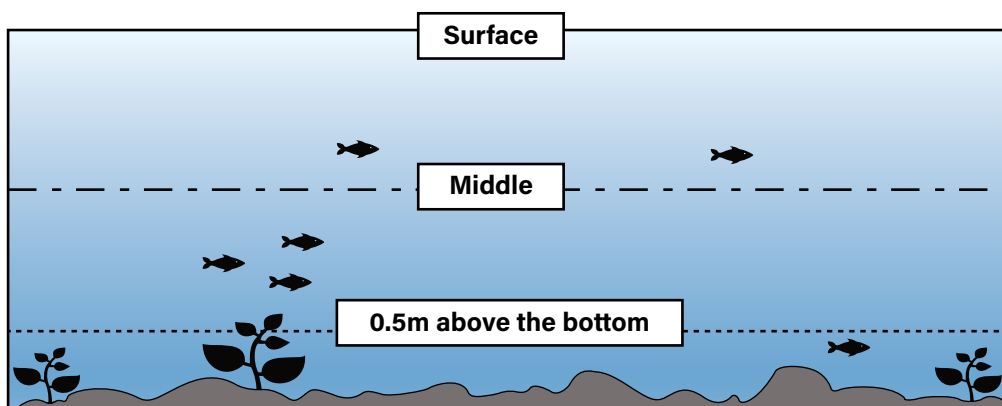
| Indicator category | Parameters                       | Functions                                                                                                                                                                                                                                              | Field/ Lab |
|--------------------|----------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------|
| Water Quality      | pH                               | Most watery chemical and biological processes are pH-dependent.<br>In watery habitats, it limits species dispersal.<br>Acidic and alkaline environments sustain a diverse range of life.                                                               | Field/ Lab |
|                    | Salinity                         | Restricts mangrove growth and spread.<br>Salinity intrusion alters soil and water physiography, impacting vegetation, wildlife, and fishing services.<br>Plants and animals lose habitat due to salinity intrusion.<br>The Fish nursery is diminishing | Field/ Lab |
|                    | Suspended matters (TS, TDS, TSS) | Raise water temperature and decrease dissolved oxygen (DO)<br>Absorb more solar heat than water molecules.<br>Conduction transfers this heat to the water.                                                                                             | Lab        |
|                    | Dissolved Oxygen (DO)            | Fish, invertebrates, microorganisms, and plants need dissolved oxygen. Like terrestrial organisms, these breathe oxygen.                                                                                                                               | Field/ Lab |
|                    | Biological Oxygen Demand (BOD)   | It determines respiration rate. BOD measurement gives inorganic COD.<br>It shows water's contaminating potential.                                                                                                                                      | Lab        |
|                    | Chemical Oxygen Demand (COD)     | Rapid indicator of organic pollutant in water                                                                                                                                                                                                          | Lab        |

## Sampling Design

Water samples will be taken from three different depths (surface, middle, and 0.5 m above the bottom) at the research points during two different seasons for in situ measurement and laboratory analysis (Figure 13). Water samples will be taken under both high and low tide levels to study tidal changes. Each season, three samples will be taken from each water stratum at high and low tide. The indicators/parameters for water and air samples for the ecological monitoring of the Sundarbans will be collected from PSP to ensure long-term monitoring. However, considering resource availability, 10 forest range stations within the Sundarbans can be considered for sample collection.

Sampling should be done in the main river, away from the streambank. Stuck water should never be sampled. Because the main current tends to hug the bank on the outside curve of the stream, it's a nice area to sample. Wade into the center current in shallow areas to obtain the sample. For deep sites, a boat will be needed. To obtain a water sample, try to position the boat in the middle of the main current. To collect water samples with screw-cap sample bottles, follow the steps below.

- Write the site number, date, and time on the bottle. Just before sampling, remove the cap from the bottle.
- Make as minimal disturbance to the bottom sediment as possible. In any event, avoid collecting water containing silt from bottom disturbance. Sample collector should place him/herself upstream. Collect the water sample in front of him/her on the upstream side. If you want to sample from deeper water, clip your bottle to an extension pole. Reach over the side of the boat and grab the water sample on the upstream side.



● Figure 13: Water sampling points from different layers of waterbodies

- Hold the bottle towards its base and plunge it into the water (opening downward). Remove the cap, turn the bottle upside down, and plunge it into the river facing upstream if you're using an extension pole. If the stream reach is shallow, collect a water sample 8 to 12 inches beneath the surface or halfway between the surface and the bottom.
- Submerge the bottle in the stream and turn it away from you. Push the bottle beneath the surface and away from you in an upstream direction in slow-moving stream sections.
- Leave a 1-inch space between each item (Except for DO and BOD samples). Do not totally fill the bottle (so that the sample can be shaken just before analysis). Carefully

close the bottle, being careful not to touch the interior.

- Fill in the appropriate field data sheet with the bottle number and/or site number. This is crucial since it informs the lab coordinator which bottle corresponds to which location.
- Place the samples in the cooler for transit to the lab if they will be tested there.

## Field and laboratory testing methodology for the selected parameters

### A. Water quality indicators/parameters (abiotic)

#### pH

pH measures the amount of hydrogen ions in water. pH is the negative logarithm of hydrogen ion concentration (mol/L) in water:  $\text{pH} = -\log_{10}(\text{H}^+)$ . It is commonly accepted that water with a pH ranging from 6.0 to 9.0 is optimal for the growth of organisms and the survival of aquatic animals (Akhter et al., 2018; Baker et al., 1990).

High precision pH meter (i.e., Hach sensION 3 Benchtop pH/mV Meter, 110 VAC) is used to measure pH of water for on-site/ laboratory location (Figure 14). Whether in the field or in the lab, the process for measuring pH is the same.

Following procedures are essential for pH measurement of the collected samples:

- Deionized water should be used to rinse the electrode well.
- In the sample, place the pH meter's electrode.
- In the appropriate column on the data sheet, read and record the pH.
- Deionized water should be used to rinse the electrode well.
- Check the pH of the 4.01 and 7.0 buffers on a regular basis to ensure the meter is not out of calibration. Recalibrate it if it has wandered.



● Figure 14: Hach sensION 3 Benchtop pH/mV Meter, 110 VAC

#### *Ecological significance of pH*

- The majority of aqueous chemical and biological reactions are influenced by pH.
- In aquatic environments, it is one of the most significant environmental variables restricting species dispersal.
- Acidic and alkaline conditions support a wide spectrum of organisms.

#### *Indicator value*

- It is commonly accepted that water with a pH ranging from 6.0 to 9.0 is optimal for the growth of organisms and the survival of aquatic animals (Akhter et al., 2018; Baker et al., 1990).

#### Salinity

Electrical conductivity (EC) is a property of dissolved materials in aqueous solutions that relates to their ability to conduct electricity. The EC of a water or soil sample is measured in Siemens per unit area (e.g. mS/cm, or Millisiemens per centimeter). Thus, EC is a proxy measurement of water salinity and is used widely. HANNA pH/mV and EC/TDS/Salinity/Resistivity Meter - HI5521 can be used to measure the salinity level of the water samples (Figure 15).

### Ecological significance of salinity

- Salinity limits mangrove forest development and dispersion.
- Salinity intrusion changes the physiographic nature of soil and water, affecting flora, wildlife, and fishery services like habitat.
- As a result of salinity intrusion, plants and animals lose habitat.
- Fish breeding nursery site is also dwindling (Haque and Reza, 2017).



● Figure 15: HANNA pH/mV and EC/TDS/Salinity/ Resistivity Meter - HI5521

### Suspended Matters (TS, TDS and TSS)

Total suspended solids are measured in milligrams per liter of water (mg/L). Total suspended solids and suspended sediment concentration readings are based on filtered and dried water samples. TSS includes any particles with a diameter of more than 2 microns. A dissolved solid is defined as any particle smaller than this. Suspended solids can include everything from silt or sediment to plant debris like leaves or branches. Even bug larvae and eggs can be classified as TSS. TSS levels beyond a certain threshold can make a body of water appear unsightly.

### Measurement of Total Solids (TS)

- Take a clear dry glass beaker (which was kept at 103°C in an oven for 1 hour) of 150ml. capacity and put appropriate identification mark on it. Weight the beaker and note the weight.

- Pour 100ml. of the thoroughly mixed sample, measured by the measuring cylinder, in the beaker.
- Place the beaker in an oven maintained at 103°C for 24 hours. After 24 hours, cool the beaker and weight. Find out the weight of solids in the beaker by subtracting the weight of the clean beaker determined in first step.

Calculate total solids (TS) as follows:

Total solids, TS (mg/l) = mg of solids in the beaker x 1000 / (volume of sample)

### Measurement of Total Dissolved Solids (TDS)

- Same as above (step 1 of total solids).
- Take a 100 ml. of sample and filter it through a double layered filter paper and collect the filtrate in a beaker.
- The repeat the same procedure as in steps 3rd and 4th of the total solids determination and determine the dissolved solids contents as follows:

Total Dissolved Solids, TDS (mg/l) = mg of solids in the beaker x 1000 / (volume of sample)  
Total Suspended Solids, TSS (mg/l) = TS (mg/l) - TDS (mg/l)

### Dissolved Oxygen (DO)

The physical, chemical, and biological processes in the water body influence dissolved oxygen (DO) levels in natural and wastewaters. DO analysis is an important part of water pollution control. DO meters or Winkler method can be used. The DO meters can be used in samples that interfere with iodometric methods (such as Winkler method), such as samples that are highly colored or turbid, or samples that contain easily oxidizable or other interfering substances, such as sulfite, thiosulfate, polythionate, mercaptans, or free chlorine.

Winkler procedure to measure DO is given below:

- Remove the stopper from the BOD bottle and add 1.0 ml manganous sulfate reagent,

followed by 1.0 ml alkaline-iodine-azide solution, using pipettes set just below the water surface.

- Recap the bottle and shake vigorously for at least 20 seconds, or until all of the precipitated manganous and manganic hydroxide is uniformly distributed. There should be no trapped air bubbles in the bottle. Allow two to three minutes to pass before shaking the bottle again.
- Allow at least one-third of the precipitation in the sample to settle down the bottle (about 10 to 20 minutes required). Allow 1.0 mL of concentrated, reagent-grade H<sub>2</sub>SO<sub>4</sub> to run down the neck of the bottle. Recap the bottle and gently shake until the precipitation has dispersed.
- Transfer 100 mL of solution from the BOD bottle to an Erlenmeyer flask using a pipette.
- Titrate with thiosulfate solution to a pale straw color right away. 4 drops of the starch solution Continue titrating until the blue color fades completely.

Calculate the sample's dissolved oxygen content as follows:

$$\text{DO (mg/L)} = \frac{N \times V \times 8 \times 100}{99.3}$$

Where, N= normality of sodium thiosulfate solution, V= volume of sodium thiosulfate solution used in the titration

## Biological Oxygen Demand (BOD)

Immediately after filling one vial with sample (or diluted sample), determine the initial DO (DO<sub>i</sub>). Keep the other bottle in the dark at 20°C for a few days (typically 5), then check the DO (DO<sub>f</sub>) in the sample (or diluted sample). The process for determining dissolved oxygen (DO) is as follows:

- Using a pipette, add 1 mL of manganous sulfate solution to the BOD bottle, dipping the end of the pipette just below the water's surface.

- In the same way, add 1 mL of alkaline potassium iodide solution to the BOD bottle.
- Remove the stopper and invert the container several times to combine.
- Mix again once the "precipitates" have settled halfway.
- Let the "precipitates" settle halfway again.
- Pour 1 mL of pure sulfuric acid into the mixture. Replace the cork and continue to mix as before.
- Let the mixture sit for at least 5 minutes.
- Pour 100 mL of the solution into an Erlenmeyer flask and add 0.025N sodium thiosulfate from a burette drop by drop until the yellow tint is practically gone.
- Add roughly 1 mL of starch solution and keep adding thiosulfate solution until the blue hue fades completely. Keep track of how much thiosulfate solution you used (disregard any return of the blue color).

Dissolved oxygen, DO (mg/L) = mL of 0.025N sodium thiosulfate added x Multiplying Factor (M.F.)

The five-day BOD of a diluted sample is given by, BOD<sub>5</sub> = [DO<sub>i</sub> - DO<sub>f</sub>] × D.F.

## Chemical Oxygen demand (COD)

The COD exam has a significant benefit in terms of evaluation time. Instead of the 5-days necessary for BOD measurement, the determination can be made in roughly 3 hours. As a result, it is frequently used as a replacement for the BOD test. The procedure is as follows:

- 100 mL of the sample should be pipetted into a 250 mL Erlenmeyer flask.
- Combine 10 mL diluted sulfuric acid and 10 mL standard KMnO<sub>4</sub> solution in a mixing bowl.
- Place the flask in a boiling water bath for 30 minutes, keeping the water level in the

bath above the solution level in the flask. The rate of oxidation process in the flask is accelerated by heating.

- If the solution turns a pale yellow color, the majority of the potassium permanganate has been used to oxidize organic materials. In this scenario, repeat the procedure with a smaller sample diluted in distilled water to 100 mL.
- Fill the flask with 10 mL of standard ammonium oxalate  $[(\text{NH}_4)_2\text{C}_2\text{O}_4]$  solution after 30 minutes in the water bath. This reducing agent, 10 mL ammonium oxalate, is exactly the same as the oxidizing agent, 10 mL potassium permanganate, which was introduced before. The amount of reducing agent  $[(\text{NH}_4)_2\text{C}_2\text{O}_4]$  left in the flask now matches the amount of oxidizing agent ( $\text{KMnO}_4$ ) utilized in the oxidation of organic materials.
- Titration with standard potassium permanganate is used to determine how much ammonium oxalate is left in the flask. Titrate the contents of the flask with normal potassium permanganate to the first pink coloring while the flask is still heated. Keep track of how much potassium

Calculate the sample's COD content as follows:

$$\text{COD(mg/L)} = \frac{\text{mL of KMNO}_4 \text{ used} \times 100}{\text{mL of sample used}}$$

## B. Water Pollutants Indicator/Parameters

### Macroplastics

Macroplastics are a crucial component of land-to-ocean plastic transmission. Nevertheless, observation and comprehension of the process remain limited. In recent years, numerous approaches have been developed to monitor macroplastics in rivers. A summary of these techniques, which include tracking, net sampling, ocular observation, and passive sampling, is provided (Vriend, 2020). For each method, the most important factors that can be

modified to maximize its application are outlined. There are global examples of these applications, along with a concise summary of the findings. Additionally, the forecast for future approaches and those now in development is provided.

### Microplastics and Mesoplastics

Microplastics and mesoplastics in rivers are sampled using comparable techniques as macroplastics. Manta trawls or neuston catamarans are smaller than those used in marine research, and the majority of freshwater studies employ nets with mesh sizes of less than 300 microns. With a 30-centimeter manta trawl, around 20–50 m<sup>3</sup> of water can be sampled in 10–30 minutes. Finer nets gather more particles, particularly fibers, however the sample volume will be smaller if this method is utilized. (Barrows et al., 2018). It is challenging to study the movement of microplastics in situ. The majority of current estimations are based on theoretical considerations. In general, the lateral and vertical structure of big rivers necessitates the modification of existing sampling equipment in order to simultaneously sample multiple depths (Liedermann et al., 2018). They also demonstrate a minor propensity for microplastic buildup along riverbanks. Many popular polymers, such as polyethylene (0.91–0.97 g/mL), polypropylene (0.94 g/mL), polyvinyl chloride (1.4 g/mL), and polystyrene (1.05 g/mL), can be determined using this approach. The plastic trash studied by this approach is microplastic, with a size range of 5 mm to 0.3 mm. This approach defines microplastic debris as any solid item in the relevant size range that is resistant to wet peroxide oxidation, floats in a 5 M NaCl (d=1.15 g/mL) or 5.4 M lithium metatungstate (d=1.62 g/mL) solution, and passes positive visual inspection under a 40X microscope.

### Underwater Noise Measurement

Underwater noise has emerged as a primary issue of concern for the marine ecosystem, and government organizations and conservation organizations are putting pressure on the industry to investigate and remedy the negative

consequences that underwater noise has on marine fauna. There are several channels in the mangroves of the Sundarbans that are utilized for water vessels (for example, the Pashur river channel), and the noise from these vessels has a harmful effect on living things that are submerged in the water.

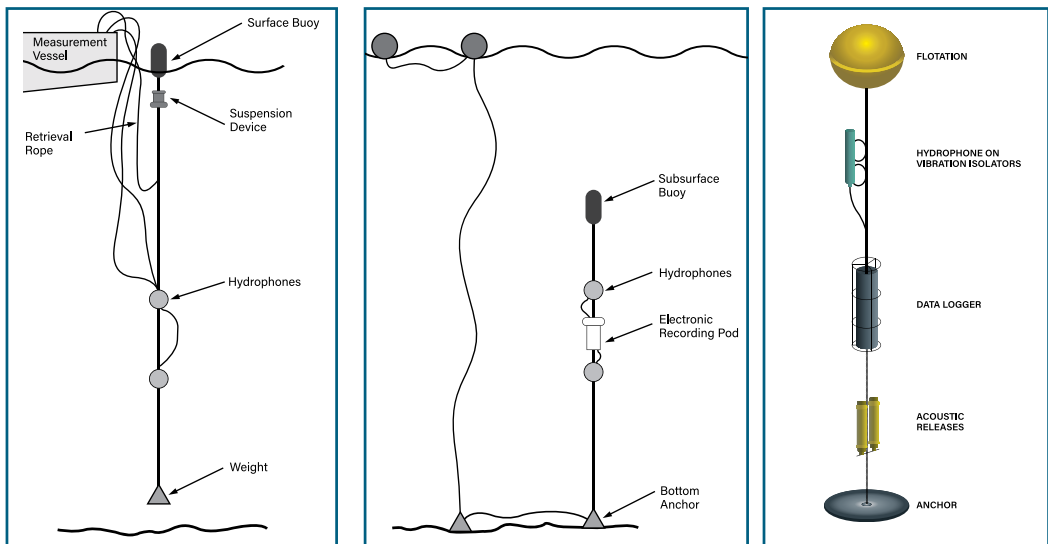
Underwater sound pressure varies with depth. In the highest water column, within a quarter of an acoustic wavelength of the surface, depth dependency is stronger (for sound at 100 Hz, one quarter of a wavelength is about 3.7 m; at 1 kHz, it is about 37 cm) (Trinh and Robey, 1994). This is due to the pressure-releasing water-air surface and the constructive and destructive interference between direct and reflected sound waves. This effect is called Lloyd's mirror.

Measurements at the bottom can be affected by interference, especially if the bottom is reflective. For measuring sound in shallow waters, situate the measuring hydrophone in the lower half of the water column, ideally between 1/2 and 3/4 of the total depth (measured from the sea surface). In shallow water, tidal depth can affect sound propagation and should be documented precisely.

## Methods

A hydrophone detects noises in the water and transforms the acoustic energy into electrical

energy, much like a microphone does for sounds in the air. Hydrophones are passive listening devices since they only pick up noises from the water and do not transmit any sound.



● Figure 16: Examples of hydrophone deployment designs include surface vessel deployment (left), bottom mounting with a surface float (center), and bottom mounting with an acoustic release (right)

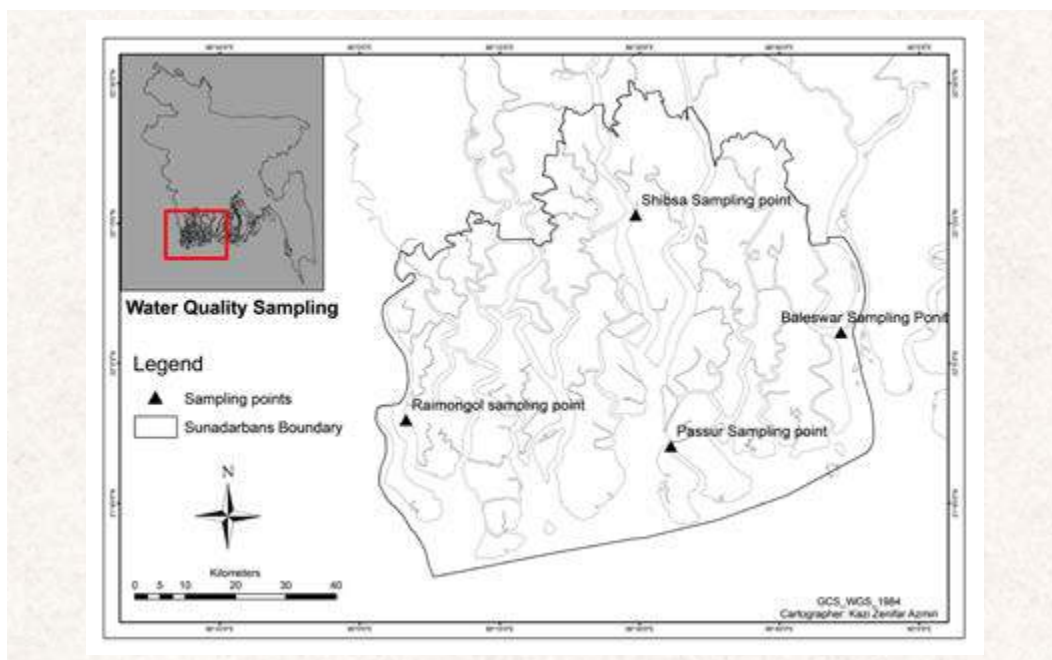
## Site Selection for the Ecological Monitoring (water)

One of the most significant tasks in ecological monitoring is site selection. The pilot sites for ecological monitoring of the Sundarbans' water

components will be carefully chosen based on previous experience, literature, and current conditions. The Mongla Seaport's lifeline is the Pasur River channel, which keeps the international and local shipping routes open. The Pasur River is also home to four popular tourist destinations:

Karamjal, Harbarya, Hironpoint, and the Dubla fishermen's hut. The Rupsha River, which may carry urban and industrial pollution, is collected on the other side of this channel. Similarly, the Sutarkhali River could receive agrochemicals

from agricultural activities such as aquaculture. In light of these findings, the sites in Raimangal, Passur, Shibsha, and Baleswar are an excellent choice for pilot sites for ecological water component monitoring.



● Figure 17: Location of the proposed pilot sites for the ecological monitoring of the water parameters

### 3.2.3 Environmental Parameter (air quality) Monitoring Methodology and Testing Procedure

#### Air Pollutants (SOX, NOX, PM2.5, PM10)

The Sundarbans is one of the world's largest mangrove ecosystems, but over the years, it has seen a steady increase in population in addition to a number of unplanned economic activities, all of which have had a negative impact on the rich biodiversity and air quality found there. In light of the fact that the ecosystem of the Sundarbans is quite delicate and susceptible to damage, it is imperative that the region's air pollution be accurately quantified. This section focuses on one of the most significant air pollutants, the

particulates, as well as their occurrence and effects in the area.

**Table 21: List of parameters for air quality monitoring**

| Indicator category | Parameters                       | Function                                 |
|--------------------|----------------------------------|------------------------------------------|
| Air pollutants     | SOx                              | For emissions of Sulphur and its oxides  |
|                    | NOx                              | For emissions of Nitrogen and its oxides |
|                    | Particulate Matter (PM2.5, PM10) | For presence of particulate matter       |

Consequently, PM2.5 refers to particulate mass of particles with a diameter smaller than 2.5 mm. PM10 stands for particulate mass of particles with a diameter smaller than 10 mm (Tiwari et al., 2017). Due to the fact that particles smaller than 10 mm can be inhaled below the nasopharynx

region and those particles smaller than 2.5 mm move down below the tracheobronchial region, these two size groups have been established. The local minimum in particle concentration between coarse and fine particles, as well as between the natural and anthropogenic fractions, also occurs at the same time as the PM<sub>2.5</sub> cutoff size. Population growth and unplanned commercial activity have harmed the Sundarbans' biodiversity and air quality over the years (Mukherjee et al., 2011, Duarte et al., 2022). Given the Sundarbans' delicate ecosystem, thorough quantification of air contaminants is essential.

### Methods (PM<sub>2.5</sub> and PM<sub>10</sub>):

The Aeroqual PM<sub>10</sub>/PM<sub>2.5</sub> Portable Particulate Monitor measures PM<sub>10</sub> and PM<sub>2.5</sub> accurately and simultaneously in ambient outdoor situations. By simply switching the PM sensor head for the gas sensor head of our choice, we may measure gaseous contaminants (gas sensor heads available separately). suitable for use on a variety of projects, including personal exposure monitoring, interior and outdoor air quality testing, and short-term fixed monitoring.



● Figure 18: PM<sub>10</sub> / PM<sub>2.5</sub> Portable Particulate Monitor Aeroqual's Series 500

### Methods (SOX, NOX):

In-situ and extraction emissions monitoring systems are the two main varieties. While extractive samples are extracted for

measurement distant from the point source, in-situ samples are measured at the point source.

The gas sensor / detector used for in-situ monitoring is positioned right at or inside the duct or stack. The phrase "in-situ" refers to a measurement method where a piece of the measurement apparatus is submerged in the sample gas. These analyzers could have optical or electrochemical sensor types. These systems always produce a signal that is related to the gas reading.



● Figure 19: GM32 In-situ gas analyzers

Extractive-style systems collect a continuous gas sample from the process stream, filter it to eliminate pollutants and water, and then pump it to an analyzer that may be placed some distance away from where the extraction point was.



● Figure 20: Extractive gas analyzer GME700

## Weather station

The micro weather station's objective is to conduct research into the climatic characteristics of the mangroves, including variations in air

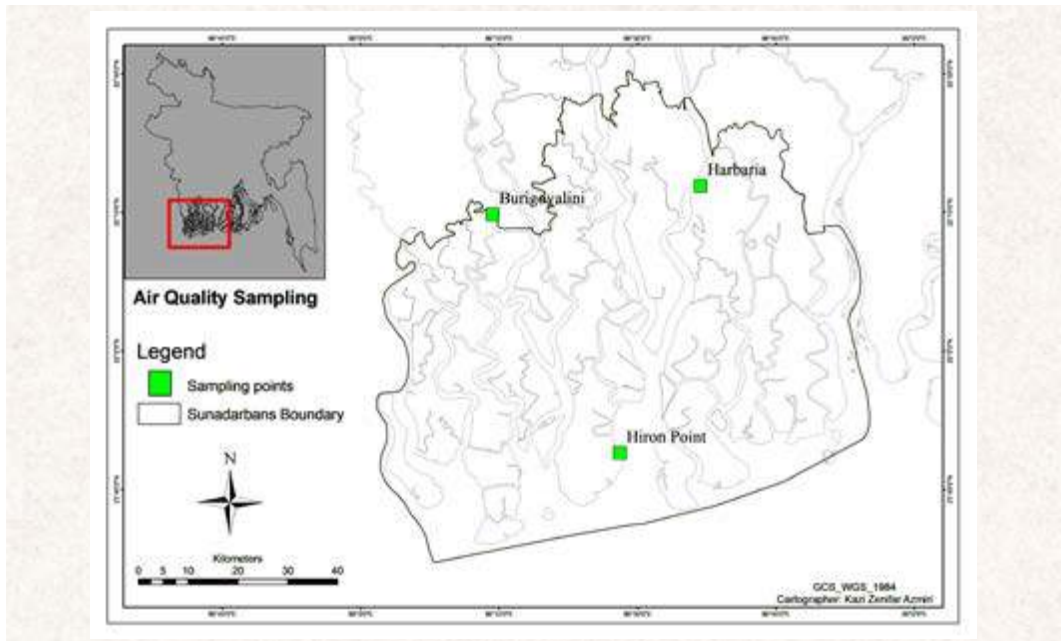
temperature, relative air humidity, global solar radiation, wind speed, and precipitation.



● Figure 21: Mini weather station (WS0232)

## Site Selection for the Ecological Monitoring (air)

The sites selected for the collection of air samples have been selected as Harbaria, Burigachalini and Hiron Point.



● Figure 22: Air sample collection points









## CHAPTER 4

# DATA VISUALIZATION OF RESULTS BASED ON INDICATORS MONITORING

### Spatial Decision Support System (SDSS) for Sundarbans Reserve Foerst (SRF)

A Web based interactive SDSS is a Spatial Decision Support System using Geographic Information System (GIS) as platform for storing and analysing data and Internet technologies for trafficking data within storages (e.g., cloud) and analyses allowing their use by experts and laymen (Fiduccia, et al., 2016). However, the GIS data has the aging issues as it requires upgradation over time and which can be resolved by the incorporation of the remote sensing-based earth observation techniques (Fiduccia, et al., 2016). The obtained information can be stored and classified in a GIS database integrated with the remote sensing images and it can be updated on a regular basis.

### Methods

The availability of data and the appropriate data structure and analysis could also open up the doorways to assess and understand the status of any ecosystem in three temporal windows (i.e., Past, present, and future). Moreover, the adoption of the powerful tools of Artificial Intelligence (AI) to design queries, analyse and predict the future scenarios can assist to develop an interactive web-based Spatial Decision Support System that can help the policy makers, decision takers and managers to take appropriate conservation decision. In the case of the SRF, the study envisages to develop a web based interactive SDSS system to periodically monitor multiple forest health indicators and at the same time investigate the combined relationships of these indicators for SRF to determine ecosystem health and integrity.

## Selection of the Visualization Unit

The SRF is a vast area and in terms of the geographical, geomorphological, bio-physical, etc. characteristics the forest doesn't possess homogenous characteristics. Therefore, while considering the ecological health, it is not appropriate to consider the whole SRF as the single unit to present the health status. Therefore, the study came out with 65 spatial units to present the health and integrity of the SRF. Although, the SRF has 55 forest administrative units (compartments), the study modified the unit for systematic sample collection and easy graphical representations. The details of selecting 65 spatial units are described in step 1. The map of the data visualization unit is given in Figure 23.

## Selection of the SRF Ecological Health Indicators

The interactions and combinations of indicators are the basic key agents in determining the ecosystem health of the SRF. Therefore, identifying the indicators that have the impact over the ecosystem health is of utmost necessary. The study forms a team of experts that consists multiple experts for different fields. The study with the experts formulated the specialist groups to identify, study and monitor the ecological indicators.

The detail information of the specialist groups and the sub-indicators of each indicator are given in the Chapter 3.

## Translating indicators into Data

The understanding of the indicators and their required monitoring is rooted with the associated data of that indicators. Data can be sorted out into primary data and secondary data. The primary data can again be categorized into two categories (i.e., direct field observation data, and remote sensing-based earth observation data). The secondary data could be of published documents, policies, and agendas.

## Direct Field Observation, and Measurement of Indicators

There are some data that can not be accessed, created, and evaluated without the direct observation and collection from the study area.

The detail list of the indicators that requires direct field observation is given in the Chapter 3.

## Remote Sensing based Earth Observation Data analysis to derive indicators

There are multiple indicators that can be analysed and assessed based on the remotely sensed earth observation technologies. As for example, vegetation status, tree volumes, biomass, carbon etc. are the ecosystems functions that can contribute to assessing the integrity and health of the ecosystem. Therefore, these types of indicators require backend analysis based on different established methods and technologies.

## Data Collection

Data of different indicators are in the center of the development of the SDSS. Since, the proposed SDSS is designed to be web-based and interactive; the data collection methods would be based on application. The data collectors accompanied with each of the specialist group experts would go to the field with GPS enabled Tab and the automatic GPS tracker would determine the spatial information of the field survey. As for example, if the data enumerator visits any particular spatial unit of SRF, the app would automatically document the spatial unit (e.g., compartment 5). The Graphical User Interface (GUI) system would keep provision to select the activities of the user. As for example, from the GUI the user needs to select his role as the data enumerator and as for the data/indicator types the enumerator needs to determine what types of data (indicator) would be documented. The process of data collection as part of the whole data visualization is given in figure 24.

## Direct field observation data

The web based SDSS system would be deployed through an App where the GUI would be presented. The enumerators would be traversing through the transect line (a canal, land transect, under each of the spatial unit) and if they encounter any observable specimen (related with the indicator) they would record it through the app. Therefore, the record would be automatically documented under specific spatial unit and under specific ecological health indicators. The detail description of data under each specialist group has been given from Chapter 3.

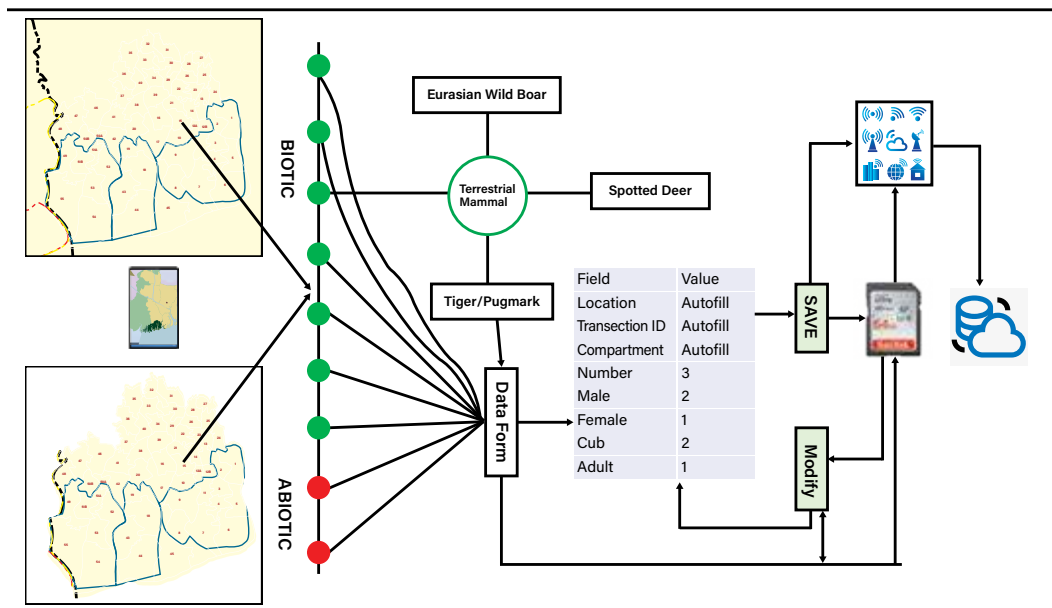
Therefore, this process would facilitate to build a geospatial data as it doesn't only record the locational information of the indicators, but also documents other associated attributes in the database.

As for example, in the case of SRF, the field data collection team may consider recording the pug marks of the tiger through the developed transect. The geospatial database could be like the following (Table 22).

**Table 22. Example of a Geospatial Database**

| FID | Transport | latitude | Longitude | Compartment | Pug Mark | Type  | Gender | Age   | Measurement | Number |
|-----|-----------|----------|-----------|-------------|----------|-------|--------|-------|-------------|--------|
| 1   | Comp 5T   |          |           | 5           | Tiger    | Fresh | Male   | Cub   | xx cm       | 2      |
| 2   | Comp 5T   |          |           | 5           | Tiger    | Old   | Female | Adult | xx cm       | 1      |

Similarly, the database can be developed for deer also. The direct field observed data would be stored in the Google Drive or other convenient cloud storage media following through conventional data architecture (Figure 23).



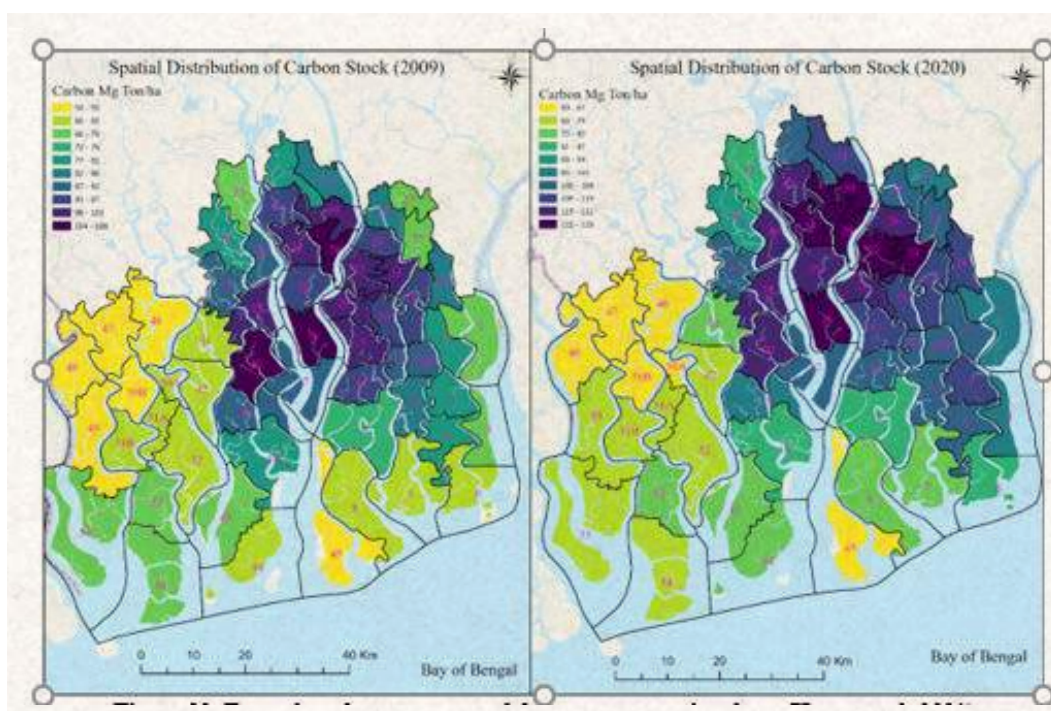
● Figure 23: Interactive Data Collection Portal for SDSS

As we sorted out the data type, all the necessary data would be collected and stored in any cloud platform as geospatial database (Figure 23)

## Remote Sensing Based Data

As long as the ecological monitoring parameters are concerned, there is a huge application of remote sensing stretching from assessing vegetation conditions to soil types. In the earlier section, the data type has been discussed and the study would identify all the required indicators that could be assessed through remote sensing.

As for example, the forest cover is one of the important parameters to assess the ecosystem health. Again, assessing the vegetation health also contributes in determining the health of the ecosystem. Moreover, tree volume, biomass, and carbon storage can also determine the health of the ecosystem. There are various tools, data, and techniques to assess these types of indicators with the support of the freely and commercially available satellite remote sensing data.

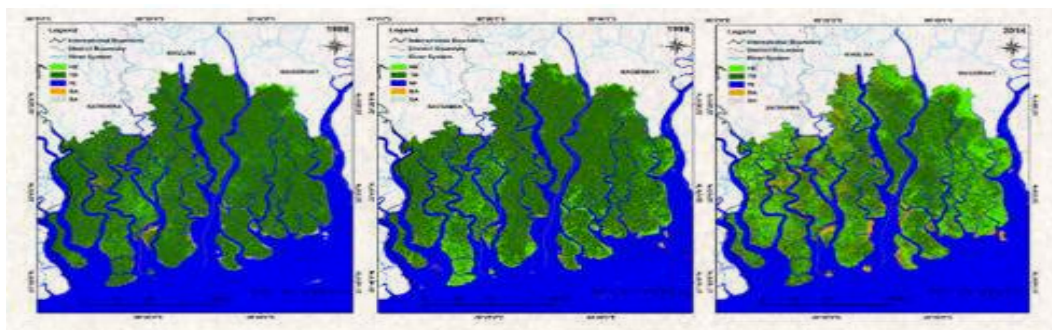


● Figure 24: Examples of maps generated from remote sensing data. (Hasan et al, 2021)

As ecological monitoring envisages to be a continuous task within two years interval, the study aims to target dynamic image processing technique. However, meaningful and necessary data are needed to determine based on the cloud coverage, spatial resolution, seasonality, and other parameters. The study therefore, decided to use Google Earth Engine and existing forest class of SRF that has the collection of long-time dataset. the GEE platform would be used to map the indicators and store them meaningfully as data and maps in the Google Earth Engine platform (Figure 24).

As for example, we can use optical (Sentinel 2, Landsat) and radar sensor (e.g., Sentinel 1, ALOS 2 PALSAR 2) data and classified them into different forest cover class (Figure 25) based on the dB values

of the satellite imageries. Moreover, the study can use multiple remote sensing indices to understand and estimate the vegetation health of any particular compartment of SFR.



● Figure 25: Example of map from Forest Cover data (Hasan et al., 2020)

## Integration of Remote Sensing Data With BFD-PSP and NFI Sample Plots

Bangladesh Forest Department has permanent sample plots that collect different categories of the vegetation data. As biomass and carbon are important ecosystem functions of SRF, the assessment of biomass and carbon can indicate the ecosystem health of the SRF. Therefore, the data of the PSP plots can be transformed into biomass and carbon data for each of the plots based on the appropriate allometric equation for each of the vegetation species. The PSP plots biomass and carbon data can be used for the whole SRF area to estimate the biomass and carbon. However, this estimation doesn't provide the accurate assessment of the biomass and carbon. Therefore, there have been many methods explored within the scientific community to use remote sensing-based earth observation techniques to estimate biomass and carbon through integrating field observation data. Since, BFD has long been collecting the vegetation data from the PSP, the proposed monitoring method kept provision to use the PSP vegetation data with remote sensing-based SAR data to estimate the biomass and carbon. The L band SAR (i.e., ALOS 2 PALSAR 2) and LIDAR data are capable of penetrating vegetation and reach down to the surface that enables the earth observation technology to estimate the biomass. Therefore, the monitoring of biomass and carbon can use SAR data with PSP sample data to periodically monitor the biomass and assess the health of the ecosystem. Figure 26 shows an example of using SAR remote sensing data with field data to estimate biomass and carbon of SRF for two temporal years.

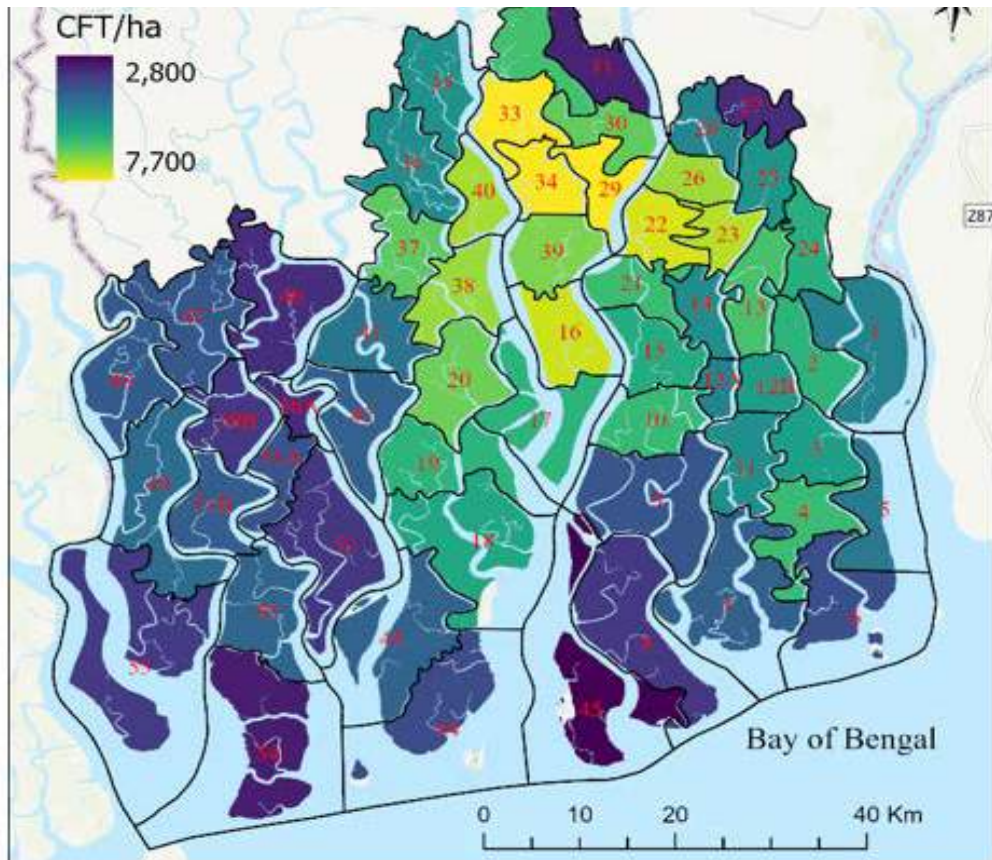
## Development of Data Repository

A data interoperability platform is envisaged to be used to store the data within the NDC server platform which could be called by the GEE and other data mining architecture (e.g., Python, R). The database would be stored as geospatial database, preferably as .shp format along with necessary extensions e.g., .dbf.

## Development of Baseline

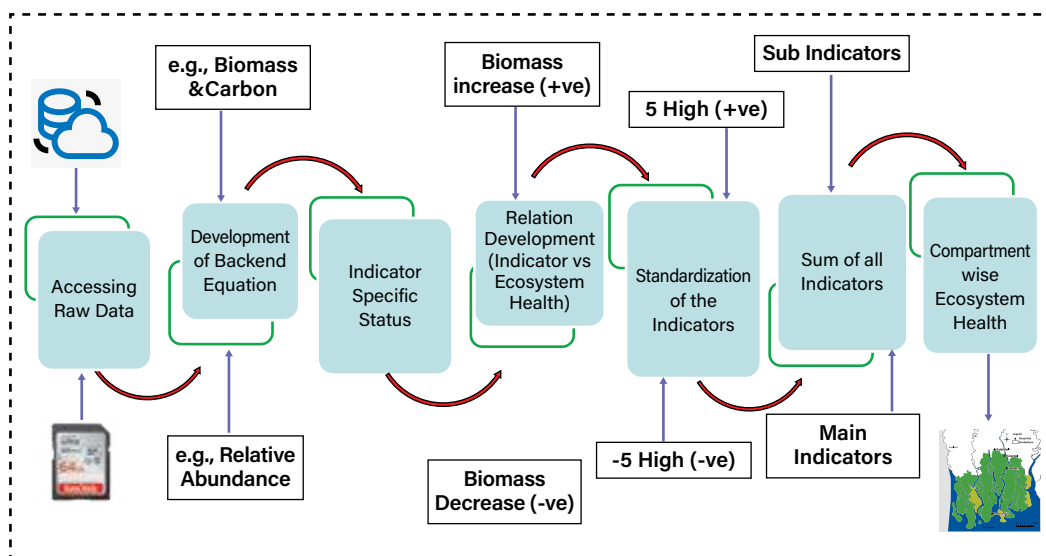
At this stage, it is assumed that data would be collected from the specific compartment of SRF and stored in the relevant cloud platform. However, this data might not be capable of determining the health status of any particular compartment. If we need to translate any data to be an indicator of ecological health, we need to know the threshold value of that particular indicator. There would be some indicators where the increase record of any particular indicator may determine the positive characteristics of

the ecosystem health and vice versa (Figure 26). However, there are some indicators for which this relationship is already known. Therefore, setting up the baseline is not challenging. However, there are some indicators whose relationship regarding abundance and scarcity has not been established. Therefore, the study needs to explore, research, and experiment to find out the threshold to set the baseline value. Primarily the indicators with known baseline values would be considered to cumulative ecosystem health assessment, whereas unknown indicators would be considered to be presented as the data itself.



● Figure 26: Example of a baseline map for the year (2020).

The map (Figure 26) can be considered as the baseline map of the volume stock of trees in SRF, as we know there is a positive relationship between the volume and the ecosystem health. The map shows the volume status of SRF for 2020 and considered as the baseline value of volume per SRF compartment (Hasan et al., 2021).



● Figure 27: Data Analysis and Interpretation

## Development of the Web-based interactive Spatial Decision Support System

Now that our database is ready and we know the relationship of the indicators value towards the positive and negative status of any particular compartment, this is the time where we integrate the interactions of the indicators (Figure 27). As for example, the increased number of tiger pugmark and deer sighting indicates a healthy sign of the ecosystem, whereas, the degraded land, and bad water quality for any particular compartment would represent bad ecosystem health quality. More importantly, all these characteristics might be present for any particular compartment, which might produce different health status. Therefore, the study envisages to apply a simple ranking scale ((-5 to +5)) based on their positive and negative characteristics. Where -5 represents maximum negative and +5 represents maximum positive status of ecosystem health (Figure 27). The simple sample of the scaling would be as follows

**Table 23. Increase in tree volume**

| Indicators<br>(volume) | Tree volume range |         |          |          |          |           |
|------------------------|-------------------|---------|----------|----------|----------|-----------|
|                        | 0                 | 0-20 m3 | 20-40 m3 | 40-60 m3 | 60-80 m3 | 80-100 m3 |
| Rank                   | 0                 | 1       | 2        | 3        | 4        | 5         |

**Table 24. Increase in degraded forest cover**

| Indicators<br>(degraded Land) | Degraded land range |          |          |          |         |                |
|-------------------------------|---------------------|----------|----------|----------|---------|----------------|
|                               | 100 ha              | 80-60 ha | 60-40 ha | 40-20 ha | 20-0 ha | No degradarion |
| Rank                          | -5                  | -4       | -3       | -2       | -1      | 0              |

In this case, if a compartment attain the volume rank 5 and the degradation rank -2, then the compartment secure 3 score on the scale of -5 to + 5 (Figure 27). The result therefore represents a moderate ecosystem health for any particular compartment. Based on this principle, the study will explore and integrate all the indicators in a relationship to get the average rank score which would determine the ecosystem health of a particular compartment.

## Development of Graphical User Interface

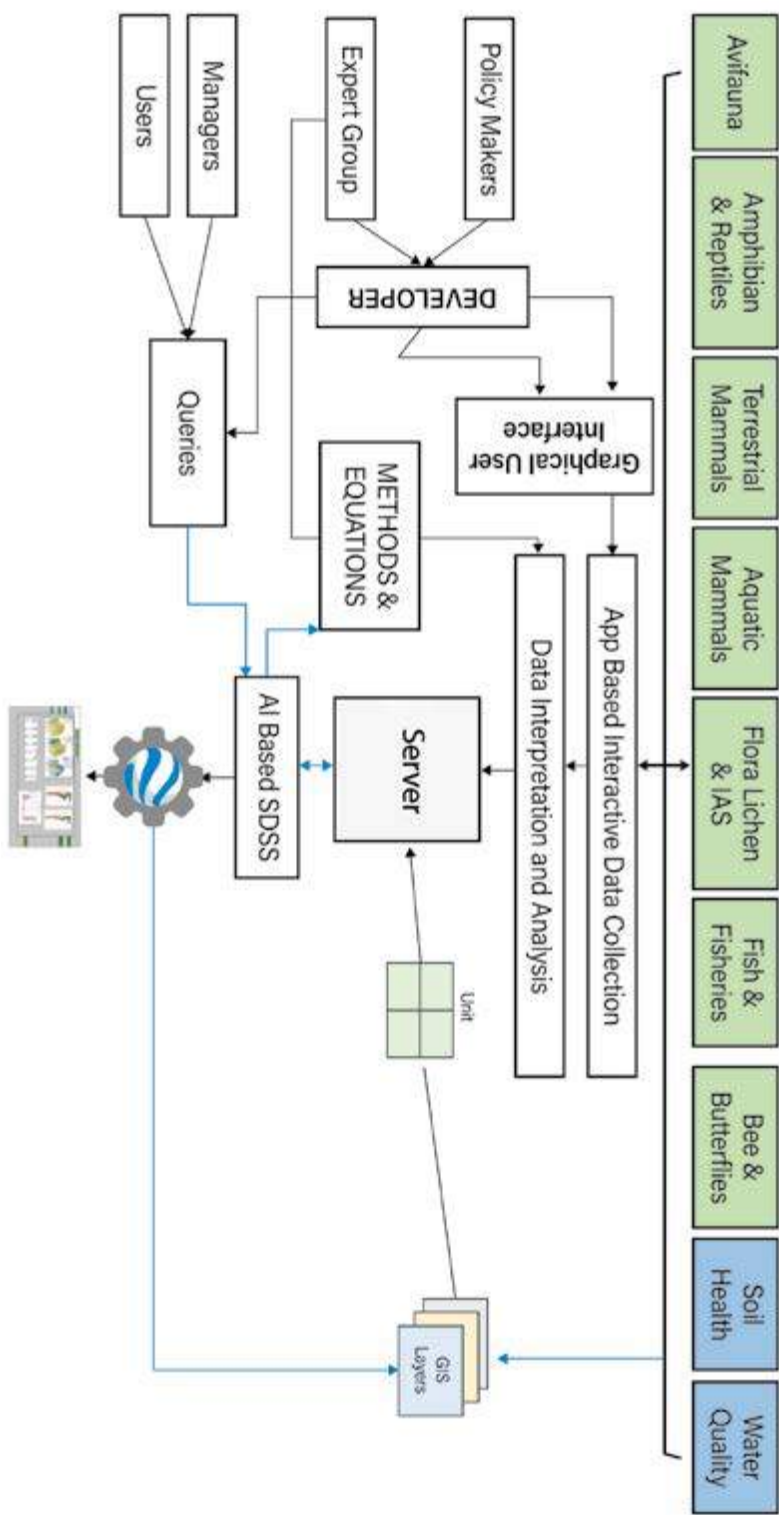
Depending on the budget and sustainability of the future, the project has its own discretion to develop the SDSS within ArcGIS online or Google Earth Engine platform. The Graphical user interface would guide the user to contribute, maintain and utilize the SDSS. As the developer of the SDSS, the system analyst would be working to buildup relationship between indicators and the backend mathematical relationship. As the data enumerator and contributor to the data collection, the enumerator would choose the contributor button and for the policy makers, they would select the policy makers. Through this space, the policymakers could know the current status of the compartment, historical situation and the future prospect.

## Development of the SDSS Equation

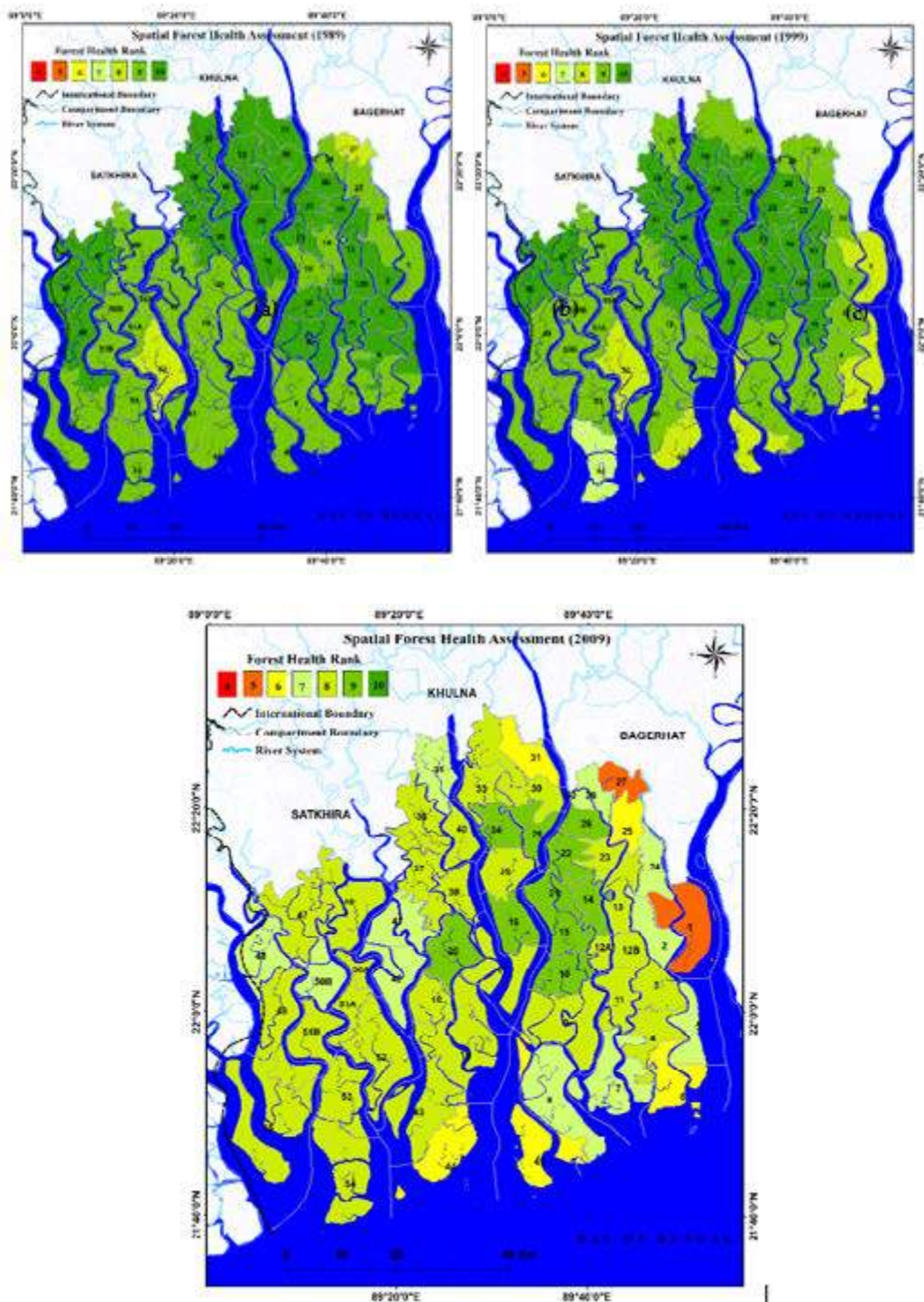
The meaning and interpretation of values for each of the indicators is known at this stage. Therefore, it is time to build a collective relationship for the indicators. At first, under each of the broader indicators, the relationship of the sub indicators need to be assessed and analysed to get the standard value for the main indicators. Once, all the main indicators get their scale value, a combined equation needs to be developed to draw the relationship among the main indicators. The equation finally would determine the positive and negative value for each of the compartment. This task is required to be accomplished by the developer of the SDSS with the support from the expert of the each of indicator groups. The equation would be within the system and as long as the system is fed with the data, the equation would be providing the positive and negative range of scale for each of the compartment. Based on the requirement of the user, the relationship would be built and the system would be analysed based on the set equation.

## Query Building

The overall SDSS is the data driven process and the outcome would be demand oriented. The end user (e.g., BFD officials, policy maker, conservationist, managers) would determine, what would be the output of the SDSS. As for example, a manager may want to visualize the degraded forest compartments of the SRF to impose restriction. Therefore, he would enquire for the forest cover status of the SRF. There would be options within the graphical user interface, to select the options. Again, one BFD officials might be interested to know about the dolphin sighting information for any specific compartment to determine whether the number of dolphins is reduced or not. The system would provide sighting information based on the query. Moreover, one may be interested to assess the fish habitat of any specific component. Therefore, he may consider the indicator like salinity and other abiotic component that influences the fish habit. Based on his selection of indicators and habit, the query will guide the system to analyse all the indicators selected, based on their predefined relationship to suggest habitat status of the fish. Figure 29 suggests the ecosystem health of the SRF by compartment based on the vegetation status.



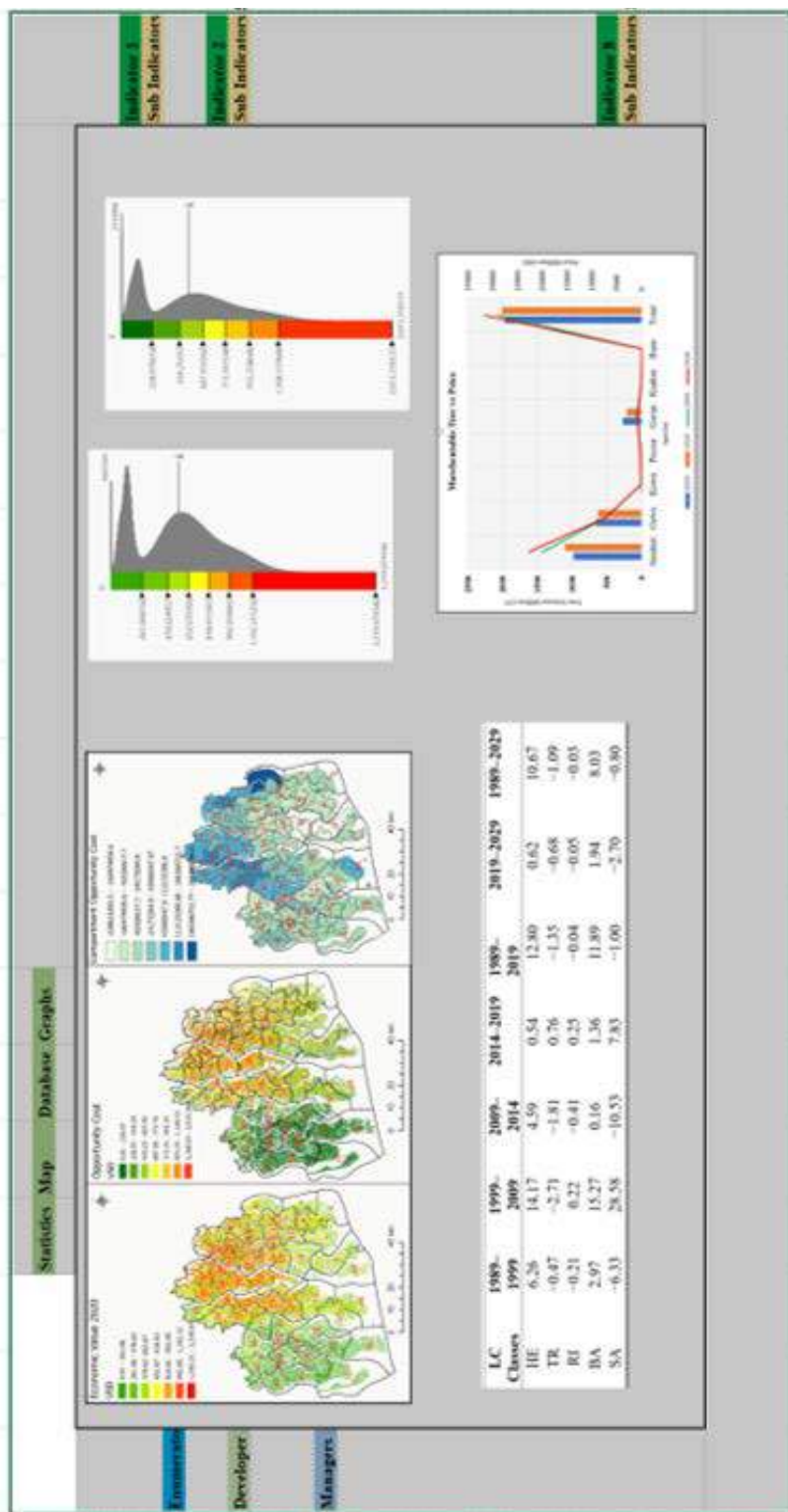
● Figure 28: Architecture of the Interactive Web-based Data Visualization System



● Figure 29: Sample Forest Health Assessment (Hasan et al, 2020)

## Development of the Data Visualization Dashboard

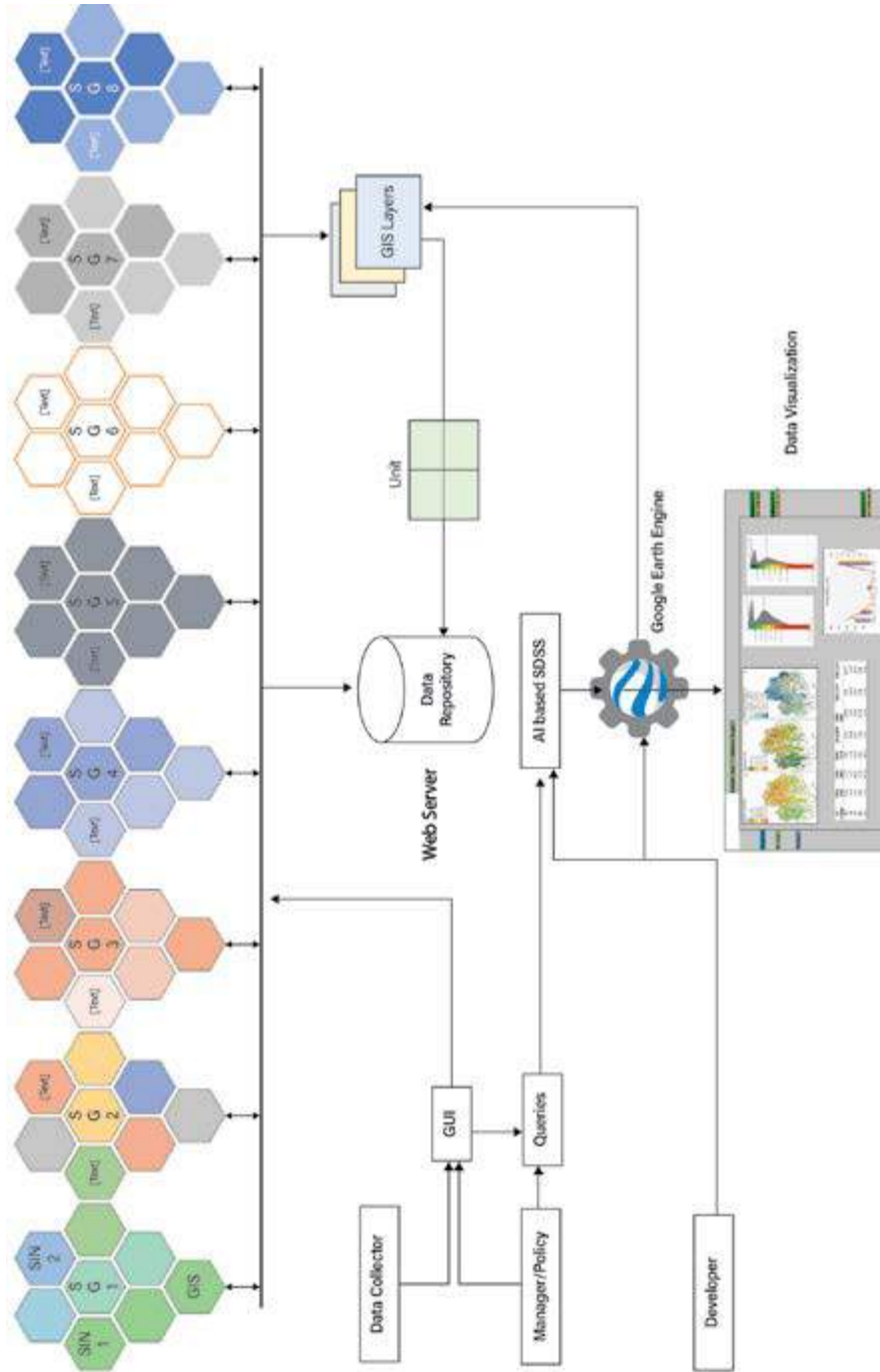
The dashboard is a simple space, where the data would be presented as map, diagram, graphs, tables and other associated forms. The dashboard may come with several key buttons to facilitate data collection, data analysis, and query building. Finally, based on the queries, the analysed data would be visualize on the screen in different forms or presentation.



● Figure 30: Simple data visualization dashboard

## Developing training handbook/guideline for practitioners

The preparation of the training manual or guideline will begin once the parameters of interest, sampling design, and sites for piloting the monitoring have been finalized.



● Figure 31: Thematic diagram for data visualization

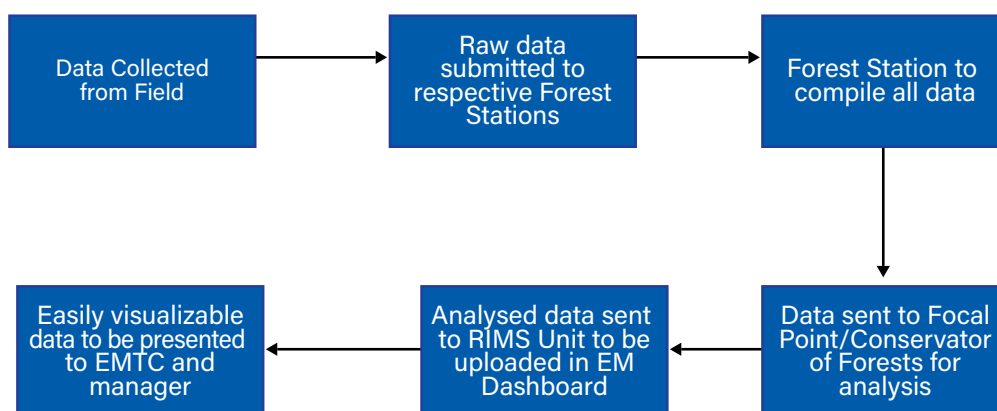
## Institutional Arrangement

An institutional arrangement is required to support the EM process is to be established. Data flow from the field will go through several stages to reach the managers and decision makers to make informed decisions on the need of actions for conservation.

A central data depository, which can be the Resources Information Management System (RIMS) Unit of Bangladesh Forest Department, is to be used to store the data properly and formally.

A central depository is to be formed where the data will be properly and formally stored. Field data collected from the indicator surveys by trained individuals will be submitted to and compiled accordingly by the Bangladesh Forest Department, by respective Forest station, with assistance of experts or institution if required. The collected data will be sent to the focal point of the Ecological Monitoring unit of BFD and/or to the Conservator of Forests, for analysis by relevant BFD staffs and/or experts.

The analysed data will be re-checked by the focal point, and will be sent to the RIMS Unit of BFD for upload into the visualization dashboard. The uploaded data will be forwarded to the Ecological Monitoring Technical Committee and to respective managers and focal points for action. Flowchart in Figure 32.



● Figure 32: Flowchart for institutional setup.





## CHAPTER 5

# CONCLUSION AND WAY FORWARD

**T**his chapter presents the recommendations (general and specific) and way forward for the long-term ecological monitoring of Sundarbans in order to properly manage this vital ecosystem and ensure ecosystem services are enjoyed by local communities and Bangladesh as a whole.

One of the most important aspects of the ecological monitoring is the continuation of the process, temporally and spatially. To ensure long-term ecological monitoring, it is imperative that the initiative is taken under the Government funding scheme under the Bangladesh Forest Department, either through projects like Surokha or through the revenue scheme. For this an established and approved funding mechanism should be developed.

Furthermore, the Ecological Monitoring Technical Committee (EMTC) must hold regular coordination meetings, according to ToR to discuss progress, and implement management prescriptions.

The ecological monitoring framework must also be open to incorporate new aspects of monitoring, such as introduction of drones, remote cameras, satellite imagery, specialized apps, and Artificial Intelligence (AI). In the long run, plans to incorporate portals such as ArcGIS Online, and development specialized apps to make monitoring, data collection and analysis much easier, and effective.

### 5.1. General Recommendation

**Management Planning of the Sundarbans:** As per the monitoring frameworks mentioned in the manual, the management planning of Sundarbans should include the regular ecological monitoring and management planning should be updated and revised as per the results of the ecological monitoring. As per the indicators mentioned in Chapter 2, i.e., deep blue shall reflect the good condition of the indicators, while lighter blue of white shall reflect the bad/worse conditions. Hence, regular ecological monitoring should be conducted in every two years for a long-term period of time. It will help to devise effect management plan for the forest and the resources.

**Contributing to the UNESCO World Heritage Site:** The inscription of the Sundarbans in Bangladesh as a UNESCO World Heritage Site on 7 December 1997 is a manifestation of the international importance of the area's unique ecosystem, and it has been designated as a Ramsar site since 2019.

The Sundarbans meets the Criterion (ii) as a significant example of an on-going ecological process with its exceptional display of the effects

of monsoonal rains, flooding, delta formation, tidal influence and plant colonization. It also meets Criterion (iv) for its exceptional biodiversity and as a haven for many threatened species, especially Bengal Tigers.

UNESCO reported on several important factors of the forest, including the physical feature including air quality, climate, vegetation, faunal species particularly dolphin and cultural heritage, local human population wellbeing, conservation value, conservation management, transboundary management, formation of scientific advisory group, formation of functionally independent advisory panel, ensure that a coordination mechanism is developed involving all relevant Ministries and agencies, actively involve local communities in co-management of the SRF among other important notes.

This framework will thus help to fulfill these recommendations, as well as better to understand the conditions of these multi-dimensional factors identified by UNESCO.

**Understanding the intersectionality of the forest:** The rigorous ecological monitoring of the Sundarbans will benefit to understand the environmental health of the forest. As environmental indicators and conditions are highly vital for the survival and sustainability of the forest flora and fauna, wildlife and other species, an understanding of this intersectionality will be helpful for future planning. Also, a large number of people are also dependent on this forest, hence, this monitoring will help to reflect this intersectional and take effective measures.

**Capacity building of the Forest Officials:** As Forest Department have the mandate to manage Sundarbans properly, this framework will extensively assist them to enhance their capacity. Forest officials will be facilitated to understand the technical procedure and properly conduct the ecological monitoring of this forest. Furthermore, as many other stakeholders are also associated with this forest management, this framework will help to provide the necessary directions for Sundarbans's ecological monitoring.

### **Contributing to the Social and Economic Benefits:**

This framework will provide an additional value to increase the social and economic well-being of the locals as well as national goals. It will ultimately help to devise the effective forest management planning which will increase the economic benefits. It will also contribute to the global goals of Sustainable Development Goals (SDGs), UNESCO World Heritage Sites and help in special conservation, environmental protection and reducing the threats for the forest resources.

**Reflection of SEA Impact Monitoring in EM:** An overall strategic review document - Strategic Environmental Assessment (SEA) report is available to guide the decision maker for any development within the South-western part of Bangladesh, especially in and around Sundarbans. Very particular threats are identified on the SEA report. In the long term, these identified threats will impact the Sundarban and the indicators of the EM will help to understand the impact of the threats and formulate management and conservation strategies.

**Inter-departmental Data exchange/sharing:** Different datasets like fisheries, environmental data like, air quality, soil, water etc will be collected from concerned government and other agencies. A proper mechanism will be followed for sharing those data for ecological monitoring unit to be incorporated in this process through the Ecological Monitoring Committee.

**Baseline Survey of the Indicators:** An immediate and complete baseline survey is necessary for all indicators to know the present status. If the score value of the indicator species needed to be adjusted, then it can be proposed and then adjusted by the Ecological Monitoring Technical Committee (EMTC).

**Incorporating SMART Data into Ecological Monitoring:** Incorporating SMART Data into Ecological Monitoring: There is a large-database collected and stored by Forest Department through SMART patrolling. If applicable, any detailed species-based data collected from the SMART Patrolling can be incorporated into the EM monitoring process as well.

**Strengthening of RIMS Unit:** All information including database of EM should be stored and archived by RIMS unit of Forest Department. Analysis for this monitoring should also be done by RIMS unit using proper management tool. Thus, FD's inhouse RIMS unit can be strengthened and build capacity for long term ecological monitoring.

**Permanent Stations for Environmental Data Collection:** Forest stations inside selected compartment of Sundarbans should be used as stations permanent for collecting abiotic indicator data such as soil, air, water, and overall e-DNA of the forest. For this purpose, selected forest station should be created as Permanent Station as EM data collection station.

**EM Methodology Incorporation in all research inside Sundarbans:** All researchers and scientists willing to work inside Sundarbans must use follow the Ecological Monitoring tools developed in the framework (if applicable) so that a unified database can be created and enhanced.

Reflection of EM in Sundarbans Management Plan: Finally, all tools and findings should be incorporated and reflected in the *Integrated Resource Management Plans for the Sundarbans, Sundarban West Wildlife Sanctuary Management Plan, Strategic Management Plan (SMP) for the Sundarbans Reserved Forest (SRF)*, and any other management plans to be developed or updated for the Sundarbans in the future

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## Annexes

### Annex 1. List of Khals from 65 selected sample units

| No. | Type   | Name                   | Sample unit  | Range      |
|-----|--------|------------------------|--------------|------------|
| 1   | Varani | Khajuria Varani        | SU-07, SU-13 | Sarankhola |
| 2   | Varani | Chandmia Varani        | SU-07        | Sarankhola |
| 3   | Varani | Dhalamia Varani        | SU-09        | Sarankhola |
| 4   | Varani | Kalamia Varani         | SU-09        | Sarankhola |
| 5   | Varani | Munshir varani         | SU-09        | Sarankhola |
| 6   | Varani | Keorabunia Varani      | SU-12        | Chandpai   |
| 7   | Varani | Charaputia Khal Varani | SU-17        | Chandpai   |
| 8   | Varani | Mamar Khal Varani      | SU-18        | Khulna     |
| 9   | Varani | Guri Varani            | SU-22        | Khulna     |
| 10  | Varani | Matiardoni Varani      | SU-20        | Khulna     |
| 11  | Varani | Nilkamal Varani        | SU-46        | Khulna     |
| 12  | Varani | Gazi Fish Varani       | SU-34        | Khulna     |
| 13  | Varani | Arbunia Varani         | SU-35        | Khulna     |
| 14  | Varani | Nalbunia Varani        | SU-36        | Khulna     |
| 15  | Varani | Mankir Varani          | SU-36        | Khulna     |
| 16  | Varani | Noyani Varani          | SU-37        | Khulna     |
| 17  | Varani | Nobirmoral Varani      | SU-37        | Khulna     |
| 18  | Varani | Moterkhal Varani       | SU-37        | Khulna     |
| 19  | Varani | Nolbunia Varani        | SU-37        | Khulna     |
| 20  | Varani | Bariadawani Varani     | SU-38        | Khulna     |
| 21  | Varani | Syttapir Varani        | SU-38        | Khulna     |
| 22  | Varani | Tana Varani            | SU-38, SU-39 | Khulna     |
| 23  | Varani | Kalir Khal Varani      | SU-39        | Khulna     |
| 24  | Varani | Dubla Varani           | SU-48        | Khulna     |
| 25  | Varani | Kater Varani           | SU-49, SU-50 | Satkhira   |
| 26  | Varani | Bagdikhali Varani      | SU-52        | Satkhira   |
| 27  | Varani | Chalitabari Varani     | SU-52        | Satkhira   |
| 28  | Varani | Dingimari Varani       | SU-58        | Satkhira   |
| 29  | Varani | Boyarsingh Varani      | SU-53        | Satkhira   |
| 30  | Varani | Hilshamari Varani      | SU-55, SU-65 | Satkhira   |
| 31  | Varani | Khorbakhali Varani     | SU-57        | Satkhira   |
| 32  | Varani | Kokomari Varani        | SU-57        | Satkhira   |
| 33  | Varani | Gewa Varani            | SU-57        | Satkhira   |
| 34  | Varani | Hizalbunia Varani      | SU-58        |            |
| 35  | Varani | Puspakathi Varani      | SU-58, SU-61 |            |
| 36  | Varani | Meghnadonia Varani     |              |            |
| 37  | Varani | Taltoli Varani         |              |            |
| 38  | Varani | Pakratoli Varani       |              |            |
| 39  | Varani | Baisingh Varani        |              |            |

| No. | Type   | Name                     | Sample unit                                                         | Range                   |
|-----|--------|--------------------------|---------------------------------------------------------------------|-------------------------|
| 40  | Varani | Matiar Varani            |                                                                     |                         |
| 41  | Varani | Bahir Mandarbaria Varani |                                                                     |                         |
| 42  | Varani | Talpatti Varani          |                                                                     |                         |
| 43  | River  | Baleshwar River          |                                                                     |                         |
| 44  | River  | Bhola River              | SU-01, SU-02, SU-03,<br>SU-05, SU-27                                | Sarankhola,<br>Chandpai |
| 45  | River  | Sela Gang                | SU-07, SU-11, SU-12,<br>SU-13, SU-14, SU-15,<br>SU-16, SU-26, SU-28 | Sarankhola,<br>Chandpai |
| 46  | River  | Dudhmukhi Gang           | SU-02, SU-15, SU-27                                                 | Sarankhola,<br>Chandpai |
| 47  | River  | Betmor River             | SU-02, SU-14                                                        | Sarankhola              |
| 48  | River  | Dudhmukhi Gang (y)       | SU-04                                                               | Sarankhola              |
| 49  | River  | Chora Betmore Gang       | SU-04                                                               | Sarankhola              |
| 50  | River  | Ambaria Gang             | SU-07                                                               | Sarankhola              |
| 51  | River  | Betmor Gang (z)          | SU-03, SU-04, SU-07,<br>SU-13, SU-14                                | Sarankhola              |
| 52  | River  | Mara Passur River        | SU-48, SU-09, SU-08                                                 | Sarankhola              |
| 53  | River  | Jafa Gang                | SU-08, SU-10                                                        | Sarankhola,<br>Chandpai |
| 54  | River  | Siala Gang               | SU-08, SU-11                                                        | Sarankhola,<br>Chandpai |
| 55  | River  | Hangsaraj Gang           | SU-19, SU-20, SU-21,<br>SU-22, SU-23                                | Khulna                  |
| 56  | River  | Kaga River               | SU-20, SU-46, SU-47                                                 | Khulna                  |
| 57  | River  | Hilkar Gang              | SU-22                                                               | Khulna                  |
| 58  | River  | Taldup River             | SU-23, SU-40                                                        | Khulna                  |
| 59  | River  | Sonamukhi River          | SU-23, SU-40, SU-43                                                 | Khulna, Sarankhola      |
| 60  | River  | Gewakhali Gang           | SU-23                                                               | Khulna                  |
| 61  | River  | Mara Sela Gang           | SU-29                                                               | Chandpai                |
| 62  | River  | Chochan Gang             | SU-30                                                               | Chandpai                |
| 63  | River  | Jhapsi River             | SU-32                                                               | Chandpai                |
| 64  | River  | Sutarkhali River         | SU-34, SU-35                                                        | Khulna                  |
| 65  | River  | Bhadar Gang              | SU-35, SU-36                                                        | Khulna                  |
| 66  | River  | Sibsa River              | SU-18, SU-34, SU-35,<br>SU-36, SU-37, SU-40,<br>SU-41, SU-42,       | Khulna                  |
| 67  | River  | Arua Sibsa River         | SU-37, SU-42                                                        | Khulna                  |
| 68  | River  | Java River               | SU-39, SU-40                                                        | Khulna                  |
| 69  | River  | Gander River             | SU-38                                                               | Khulna                  |
| 70  | River  | Shankbaria River         | SU-38, SU-39                                                        | Khulna                  |
| 71  | River  | Koyra River              | SU-37, SU-38                                                        | Khulna                  |
| 72  | River  | Arua Sibsa River         | SU-38, SU-39, SU-42                                                 | Khulna                  |
| 73  | River  | Kopanchi Gang            | SU-43, SU-44                                                        | Satkhira                |
| 74  | River  | Bal River                |                                                                     |                         |

| No. | Type  | Name                | Sample unit                                                    | Range      |
|-----|-------|---------------------|----------------------------------------------------------------|------------|
| 75  | River | Balir Gang          | SU-46, SU-47                                                   | Khulna     |
| 76  | River | Bandar Gang         | SU-47                                                          | Khulna     |
| 77  | River | Chuna River         | SU-50                                                          | Satkhira   |
| 78  | River | Mula Gang           | SU-50                                                          | Satkhira   |
| 79  | River | Araibeki River      | SU-49, SU-56                                                   | Satkhira   |
| 80  | River | Khlopetua River     | SU-50                                                          | Satkhira   |
| 81  | River | Madar Gang          | SU-51, SU-53                                                   | Satkhira   |
| 82  | River | Jamuna River        | SU-51, SU-53, SU-54, SU-55, SU-57, SU-58, SU-61, SU-62, SU-65, | Satkhira   |
| 83  | River | Chunkuri Gang       | SU--51, SU-52, SU-57                                           | Satkhira   |
| 84  | River | Firingi Gang        | SU-57                                                          |            |
| 85  | River | Firingi Gang        | SU-57, SU-58                                                   |            |
| 86  | River | Meghna River        |                                                                |            |
| 87  | River | Chhaga Kapura Gang  |                                                                |            |
| 88  | River | Buri Gang           |                                                                |            |
| 89  | River | Harinbhanga River   |                                                                |            |
| 90  | River | Raimangal River     |                                                                |            |
| 91  | River | Arpangasia River    |                                                                |            |
| 92  | River | Malancha River      |                                                                |            |
| 93  | River | Barapanga River     |                                                                |            |
| 94  | River | Chalki Gang         | SU-20, SU-22, SU-23, SU-43, SU-44                              |            |
| 95  | River | Namud Samudra River |                                                                |            |
| 96  | River | Morjat Gang         | SU-18, SU-19, SU-22, SU-23, SU-40                              | Khulna     |
| 97  | River | Passur River        |                                                                |            |
| 98  | River | Bhangra River       |                                                                |            |
| 99  | Khal  | Taka Khal           | SU-02                                                          | Sarankhola |
| 100 | Khal  | Dhaburi Khal        | SU-02, SU-27                                                   | Sarankhola |
| 101 | Khal  | Bogi Khal           | SU-01                                                          | Sarankhola |
| 102 | Khal  | Marabogi Khal       | SU-01                                                          | Sarankhola |
| 103 | Khal  | Terabeka Khal       | SU-01                                                          | Sarankhola |
| 104 | Khal  | Nimua Khal          | SU-01                                                          | Sarankhola |
| 105 | Khal  | Paikudi Khal        | SU-01                                                          | Sarankhola |
| 106 | Khal  | Podabati Khal       | SU-01                                                          | Sarankhola |
| 107 | Khal  | Dumuria Khal        | SU-01                                                          | Sarankhola |
| 108 | Khal  | Gabtala Khal        | SU-02                                                          | Sarankhola |
| 109 | Khal  | Talbaria Khal       | SU-02                                                          | Sarankhola |
| 110 | Khal  | Gara Khal           | SU-02                                                          | Sarankhola |
| 111 | Khal  | Badurtala Khal      | SU-02                                                          | Sarankhola |
| 112 | Khal  | Marabhola Khal      | SU-02                                                          | Sarankhola |
| 113 | Khal  | Sundarmukh Khal     | SU-01                                                          | Sarankhola |
| 114 | Khal  | Shapla Khal         | SU-01                                                          | Sarankhola |

| No. | Type | Name                  | Sample unit  | Range      |
|-----|------|-----------------------|--------------|------------|
| 115 | Khal | Char Khal             | SU-01        | Sarankhola |
| 116 | Khal | Pajraputa Khal        | SU-01        | Sarankhola |
| 117 | Khal | Nalbunia Khal (Z)     | SU-01        | Sarankhola |
| 118 | Khal | Ariabanki Khal        | SU-02, SU-27 | Sarankhola |
| 119 | Khal | Nalbunia Khal         | SU-02        | Sarankhola |
| 120 | Khal | Tik Khal              | SU-02        | Sarankhola |
| 121 | Khal | Arpangashia Khal      | SU-02        | Sarankhola |
| 122 | Khal | Harintana Khalc       | SU-02        | Sarankhola |
| 123 | Khal | Bhaljora Khal         | SU-02        | Sarankhola |
| 124 | Khal | Bara Amgachia Khal    | SU-02        | Sarankhola |
| 125 | Khal | Chota Bari Khal       | SU-02        | Sarankhola |
| 126 | Khal | Bara Showla Khal      | SU-02        | Sarankhola |
| 127 | Khal | Chota Amgachia Khal   | SU-02        | Sarankhola |
| 128 | Khal | Chota Showla Khal     | SU-03        | Sarankhola |
| 129 | Khal | Keoratala Khal (z)    | SU-03        | Sarankhola |
| 130 | Khal | Aruabindi Khal        | SU-03        | Sarankhola |
| 131 | Khal | Phulbaria Khal        | SU-03        | Sarankhola |
| 132 | Khal | Araibani Khal         | SU-03, SU-04 | Sarankhola |
| 133 | Khal | Telkumra Khal         | SU-03        | Sarankhola |
| 134 | Khal | Badamtala Khal (z)    | SU-03, SU-04 | Sarankhola |
| 135 | Khal | Chota Phulbaria Khal  | SU-03        | Sarankhola |
| 136 | Khal | Bekir Khal            | SU-03, SU-04 | Sarankhola |
| 137 | Khal | Kalar Khal            | SU-04        | Sarankhola |
| 138 | Khal | Arkudali Khal         | SU-04        | Sarankhola |
| 139 | Khal | Mirmania Khal         | SU-04        | Sarankhola |
| 140 | Khal | Dora Khal             | SU-04        | Sarankhola |
| 141 | Khal | Bara Katka Khal       | SU-04, SU-06 | Sarankhola |
| 142 | Khal | Bara Sundari Khal (a) | SU-04        | Sarankhola |
| 143 | Khal | Homar Khal            | SU-04        | Sarankhola |
| 144 | Khal | Katka Khal (b)        | SU-04, SU-06 | Sarankhola |
| 145 | Khal | Godipatal Khal        | SU-05        | Sarankhola |
| 146 | Khal | Kateshwar Khal        | SU-05        | Sarankhola |
| 147 | Khal | Chanderara Khal       | SU-05        | Sarankhola |
| 148 | Khal | Chandeshar Khal       | SU-05        | Sarankhola |
| 149 | Khal | Dharjar Khal          | SU-05        | Sarankhola |
| 150 | Khal | Chota Katka Khal      | SU-06        | Sarankhola |
| 151 | Khal | Gabkhali Khal         | SU-06        | Sarankhola |
| 152 | Khal | Kalidha Khal          | SU-06        | Sarankhola |
| 153 | Khal | Chota Kalidah Khal    | SU-06        | Sarankhola |
| 154 | Khal | Tiger Point Khal      | SU-06        | Sarankhola |
| 155 | Khal | Sharoni Khal          | SU-05        | Sarankhola |
| 156 | Khal | Khunar Khal           | SU-05        | Sarankhola |
| 157 | Khal | Sukhpara              | SU-05        | Sarankhola |

| No. | Type | Name                     | Sample unit                | Range      |
|-----|------|--------------------------|----------------------------|------------|
| 158 | Khal | Kashidia Khal            | SU-06                      | Sarankhola |
| 159 | Khal | Supati Khal              | SU-03, SU-04, SU-05, SU-06 | Sarankhola |
| 160 | Khal | Kochikhali Khal          | SU-06                      | Sarankhola |
| 161 | Khal | Chapra Khal              | SU-06                      | Sarankhola |
| 162 | Khal | Jamtala Khal             | SU-06                      | Sarankhola |
| 163 | Khal | Bholadia Khal            | SU-06                      | Sarankhola |
| 164 | Khal | Badamtali Khal           | SU-06                      | Sarankhola |
| 165 | Khal | Kostura Khal             | SU-07                      | Sarankhola |
| 166 | Khal | Ghutar Khal              | SU-29                      | Chandpai   |
| 167 | Khal | Beri Khal                | SU-26, SU-25, SU-16        | Chandpai   |
| 168 | Khal | Harintana Khal           | SU-14, SU-15               | Sarankhola |
| 169 | Khal | Sonamukhi Khal           | SU-30                      | Chandpai   |
| 170 | Khal | Kakramari Khal           | SU-26                      | Chandpai   |
| 171 | Khal | Chori Khal               | SU-15                      | Chandpai   |
| 172 | Khal | Kalamala Khal            | SU-16                      | Chandpai   |
| 173 | Khal | Bara Lathimara Khal      | SU-13                      | Sarankhola |
| 174 | Khal | Keorabunia Khal          | SU-11                      | Chandpai   |
| 175 | Khal | Bara Badaruddin Khal     | SU-04                      | Sarankhola |
| 176 | Khal | Tear Char Gaber Khal     | SU-07                      | Sarankhola |
| 177 | Khal | Chapra Khali Khal (y)    | SU-07                      | Sarankhola |
| 178 | Khal | Dhapa Khali Khal         | SU-07                      | Sarankhola |
| 179 | Khal | Patakata Khal            | SU-07, SU-13               | Sarankhola |
| 180 | Khal | Choto Badaruddin Khal    | SU-04                      | Sarankhola |
| 181 | Khal | Boyar Khal               | SU-04                      | Sarankhola |
| 182 | Khal | Khajurbari Khal          | SU-08                      | Sarankhola |
| 183 | Khal | Chota Ambaria Khal       | SU-08                      | Sarankhola |
| 184 | Khal | Keoratala Khal (x)       | SU-48                      | Sarankhola |
| 185 | Khal | Kukumari Khal            | SU-08                      | Sarankhola |
| 186 | Khal | Jafa Khal (z)            | SU-08                      | Sarankhola |
| 187 | Khal | Khetkhera Khal           | SU-08                      | Sarankhola |
| 188 | Khal | Adhmia Khal              | SU-08                      | Sarankhola |
| 189 | Khal | Kabar Khali Khal         | SU-08                      | Sarankhola |
| 190 | Khal | Bara Ambaria             | SU-09                      | Sarankhola |
| 191 | Khal | Adania Gurguria Khal (y) | SU-09                      | Sarankhola |
| 192 | Khal | Adania Gurguria Khal (Z) | SU-09                      | Sarankhola |
| 193 | Khal | Narikelbaria Khal        | SU-09                      | Sarankhola |
| 194 | Khal | Shelar Khal              | SU-09                      | Sarankhola |
| 195 | Khal | Boga Khal                | SU-10, SU-12               | Chandpai   |
| 196 | Khal | Mata Khal                | SU-12                      | Chandpai   |
| 197 | Khal | Bara Siala Khal (New)    | SU-10, SU-11, SU-12        | Chandpai   |
| 198 | Khal | Andhra Khal              | SU-10                      | Chandpai   |
| 199 | Khal | Siala Khal               | SU-10, SU-11               | Chandpai   |

| No. | Type | Name                 | Sample unit                | Range                |
|-----|------|----------------------|----------------------------|----------------------|
| 200 | Khal | Milgasi Khal         | SU-11                      | Chandpai             |
| 201 | Khal | Kagaboga Khal (z)    | SU-17                      | Chandpai             |
| 202 | Khal | Gusiangara Khal      | SU-12, SU-17               | Chandpai             |
| 203 | Khal | Armal Khal           | SU-12, SU-14, SU-16, SU-17 | Chandpai             |
| 204 | Khal | Kaga Khal (z)        | SU-12                      | Chandpai             |
| 205 | Khal | Kagaboga Khal (y)    | SU-12                      | Chandpai             |
| 206 | Khal | Kagaboga Khal (z)    | SU-10                      | Chandpai             |
| 207 | Khal | Choto Lathimara Khal | SU-13                      | Sarankhola           |
| 208 | Khal | Keyar Khal           | SU-13                      | Sarankhola           |
| 209 | Khal | Majer Khal           | SU-14                      | Sarankhola           |
| 210 | Khal | Nolbunia Khal        | SU-14                      | Sarankhola           |
| 211 | Khal | Chodda Khal          | SU-14                      | Sarankhola           |
| 212 | Khal | Bara Kechuar Khal    | SU-13, SU-14               | Sarankhola           |
| 213 | Khal | Ghutabaria Khal      | SU-27                      | Sarankhola           |
| 214 | Khal | Milta Khal           | SU-27                      | Sarankhola           |
| 215 | Khal | Santir Khal          | SU-15                      | Chandpai             |
| 216 | Khal | Nangli Khal (x)      | SU-15                      | Chandpai             |
| 217 | Khal | Badamtala Khal       | SU-15                      | Chandpai             |
| 218 | Khal | Newazkhali Khal      | SU-15                      | Chandpai             |
| 219 | Khal | Motir Khal           | SU-15                      | Chandpai             |
| 220 | Khal | Tambulbunia Khal (y) | SU-15, SU-27, SU-28        | Sarankhola, Chandpai |
| 221 | Khal | Pangasia Khal        | SU-16, SU-24, SU-25        | Chandpai             |
| 222 | Khal | Armal Khal           | SU-16, SU-24               | Chandpai             |
| 223 | Khal | Nalbonia Khal        | SU-16                      | Chandpai             |
| 224 | Khal | Putia Khal           | SU-24, SU-25               | Chandpai             |
| 225 | Khal | Nalbunia Khal        | SU-17, SU-24               | Chandpai             |
| 226 | Khal | Sundarkota Khal      | SU-17                      | Chandpai             |
| 227 | Khal | Chota Siala Khal     | SU-17, SU-24               | Chandpai             |
| 228 | Khal | Araibanki Khal       | SU-16, SU-17               | Chandpai             |
| 229 | Khal | Kali Khal (z)        | SU-18                      | Khulna               |
| 230 | Khal | Barakalir Khal       | SU-18                      | Khulna               |
| 231 | Khal | Mochasingedali Khal  | SU-18                      | Khulna               |
| 232 | Khal | Tapamari Khal        | SU-41                      | Khulna               |
| 233 | Khal | Jamtala Khal         | SU-18, SU-41               | Khulna               |
| 234 | Khal | Chella Bogi Khal     | SU-18, SU-42               | Khulna               |
| 235 | Khal | Chota Kalir Khal (z) | SU-18                      | Khulna               |
| 236 | Khal | Shai Khal            | SU-18                      | Khulna               |
| 237 | Khal | Meru Khal            | SU-18                      | Khulna               |
| 238 | Khal | Belmari Khal         | SU-18                      | Khulna               |
| 239 | Khal | Nishanbari Khal      | SU-18                      | Khulna               |
| 240 | Khal | Meia Khal            | SU-18                      | Khulna               |

| No. | Type | Name                   | Sample unit  | Range    |
|-----|------|------------------------|--------------|----------|
| 241 | Khal | Mamar Khal             | SU-18        | Khulna   |
| 242 | Khal | Machua Khal (z)        | SU-18        | Khulna   |
| 243 | Khal | Burboria Khal          | SU-18        | Khulna   |
| 244 | Khal | Debur Khal             | SU-18        | Khulna   |
| 245 | Khal | Kochua Khal            | SU-18        | Khulna   |
| 246 | Khal | Nishan khali Khal      | SU-18, SU-19 | Khulna   |
| 247 | Khal | Mochura Khal           | SU-18        | Khulna   |
| 248 | Khal | Pasakhali Khal         | SU-18, SU-19 | Khulna   |
| 249 | Khal | Alkir Island           | SU-40        | Khulna   |
| 250 | Khal | Alakhia Khal           | SU-19        | Khulna   |
| 251 | Khal | Madbari Khal           | SU-40        | Khulna   |
| 252 | Khal | Garani Khal            | SU-19, SU-22 | Khulna   |
| 253 | Khal | Choto Mola Khali Khal  | SU-19        | Khulna   |
| 254 | Khal | Bara Charer Khal       | SU-19        | Khulna   |
| 255 | Khal | Bara Ilishamari Khal   | SU-19        | Khulna   |
| 256 | Khal | Chalibadarpur Khal     | SU-19        | Khulna   |
| 257 | Khal | Bhomor Khal            | SU-21, SU-22 | Khulna   |
| 258 | Khal | Kagadunia Khal         | SU-20, SU-22 | Khulna   |
| 259 | Khal | Kukumari Khal (b)      | SU-21        | Khulna   |
| 260 | Khal | Chaerkhali Khal        | SU-20        | Khulna   |
| 261 | Khal | Taza Kaga Khal         | SU-20        | Khulna   |
| 262 | Khal | Matiardoni Khal        | SU-20        | Khulna   |
| 263 | Khal | Chota Kukumari Khal    | SU-21        | Khulna   |
| 264 | Khal | Agarghotta Khal        | SU-20, SU-46 | Khulna   |
| 265 | Khal | Choto Cheragkhali Khal | SU-20        | Khulna   |
| 266 | Khal | Bara Cheragkhali Khal  | SU-20        | Khulna   |
| 267 | Khal | Mara Kaga Khal         | SU-20, SU-46 | Khulna   |
| 268 | Khal | Netodonia Khal         | SU-20, SU-22 | Khulna   |
| 269 | Khal | Morakaga Khal          | SU-23        | Khulna   |
| 270 | Khal | Patkosta Khal          | SU-22, SU-23 | Khulna   |
| 271 | Khal | Boyarshingh Khal       | SU-22        | Khulna   |
| 272 | Khal | Kalir Khal (z)         | SU-22        | Khulna   |
| 273 | Khal | Sonamolla Khal         | SU-22        | Khulna   |
| 274 | Khal | Badurdunia Khal        | SU-22        | Khulna   |
| 275 | Khal | Hilker Khal            | SU-22        | Khulna   |
| 276 | Khal | Chota Kalir Khal       | SU-23        | Khulna   |
| 277 | Khal | Bara Kalir Khal        | SU-23        | Khulna   |
| 278 | Khal | Kaga Khal (y)          | SU-23        | Khulna   |
| 279 | Khal | Dakatia Khal           | SU-23        | Khulna   |
| 280 | Khal | Bara Chintamoni Khal   | SU-23        | Khulna   |
| 281 | Khal | Chota Chintamoni Khal  | SU-23        | Khulna   |
| 282 | Khal | Bara Dabur Khal        | SU-24        | Chandpai |
| 283 | Khal | Chota Dabur Khal       | SU-24        | Chandpai |

| No. | Type | Name                  | Sample unit         | Range            |
|-----|------|-----------------------|---------------------|------------------|
| 284 | Khal | Metkhali Khal         | SU-24               | Chandpai         |
| 285 | Khal | Moukhali Khal         | SU-24               | Chandpai         |
| 286 | Khal | Relarkhali Khal       | SU-24               | Chandpai         |
| 287 | Khal | Jawakhali Khal        | SU-24               | Chandpai         |
| 288 | Khal | Sonakhali Khal        | SU-24               | Chandpai         |
| 289 | Khal | Iraikhali Khal        | SU-24               | Chandpai         |
| 290 | Khal | Nandabala Khal        | SU-26               | Chandpai         |
| 291 | Khal | Bara Pangasia Khal    | SU-25               | Chandpai         |
| 292 | Khal | Chota Pangasia Khal   | SU-25               | Chandpai         |
| 293 | Khal | Harbaria Khal         | SU-25, SU-26        | Chandpai         |
| 294 | Khal | Maraberi Khal         | SU-26               | Chandpai         |
| 295 | Khal | Banabala Khal         | SU-26               | Chandpai         |
| 296 | Khal | Haider Khal           | SU-27               | Sarankhola       |
| 297 | Khal | Nangli Khal (y)       | SU-27               | Sarankhola       |
| 298 | Khal | Tatulbaria Khal       | SU-27               | Sarankhola       |
| 299 | Khal | Singrabunia Khal      | SU-27               | Sarankhola       |
| 300 | Khal | Gulbunia Khal         | SU-27               | Sarankhola       |
| 301 | Khal | Jhoimunias Khal       | SU-02               | Sarankhola       |
| 302 | Khal | Chota Tengramari Khal | SU-28               | Chandpai         |
| 303 | Khal | Andermanik Khal       | SU-28, SU-30        | Chandpai         |
| 304 | Khal | Arwaber Khal          | SU-28               | Chandpai         |
| 305 | Khal | Mirgamari Khal        | SU-30, SU-26        | Chandpai         |
| 306 | Khal | Kharma Khal           | SU-29, SU-30        | Chandpai         |
| 307 | Khal | Urubunia Khal(y)      | SU-29, SU-30        | Chandpai         |
| 308 | Khal | Chota Morogmari Khal  | SU-30               | Chandpai         |
| 309 | Khal | Bara Moragmari Khal   | SU-30               | Chandpai         |
| 310 | Khal | Surjamukhi Khal       | SU-30               | Chandpai         |
| 311 | Khal | Tetulbaria Khal       | SU-30               | Chandpai         |
| 312 | Khal | Urubunia Khal (z)     | SU-30               | Chandpai         |
| 313 | Khal | Badamtala Khal        | SU-30               | Chandpai         |
| 314 | Khal | Sikri Khal            | SU-31, SU-32        | Chandpai         |
| 315 | Khal | Mara Passur Khal      | SU-31, SU-32        | Chandpai         |
| 316 | Khal | Bhadra River          | SU-31, SU-36, SU-41 | Chandpai, Khulna |
| 317 | Khal | Tambulbunia Khal      | SU-31               | Chandpai         |
| 318 | Khal | Bara Padmawati Khal   | SU-31               | Chandpai         |
| 319 | Khal | Ghagra Khal           | SU-32               | Chandpai         |
| 320 | Khal | Harla Khal            | SU-32               | Chandpai         |
| 321 | Khal | Andaria Khal          | SU-32               | Chandpai         |
| 322 | Khal | Biswas Khal           | SU-33               | Chandpai         |
| 323 | Khal | Lawdobe Khal          | SU-33               | Chandpai         |
| 324 | Khal | Mollar Khal           | SU-33               | Chandpai         |
| 325 | Khal | Dhangmari Khal        | SU-33               | Chandpai         |
| 326 | Khal | Hulo Khal             | SU-33               | Chandpai         |

| No. | Type | Name                 | Sample unit                             | Range            |
|-----|------|----------------------|-----------------------------------------|------------------|
| 327 | Khal | Bhadra Khal          | SU-31, SU-32, SU-33, SU34, SU-35, SU-36 | Chandpai, Khulna |
| 328 | Khal | Kultali Khal         | SU-33                                   | Chandpai         |
| 329 | Khal | Ghagramari Khal      | SU-33                                   | Chandpai         |
| 330 | Khal | Charer Khal          | SU-33                                   | Chandpai         |
| 331 | Khal | Karamjal Khal        | SU-33                                   | Chandpai         |
| 332 | Khal | Jongra Khal          | SU-33                                   | Chandpai         |
| 333 | Khal | Sarbatkhali Khal     | SU-34                                   | Khulna           |
| 334 | Khal | Sarwat Khal          | SU-34                                   | Khulna           |
| 335 | Khal | Kalabogi Khal        | SU-34, SU-35                            | Khulna           |
| 336 | Khal | Baintala Khal        | SU-35                                   | Khulna           |
| 337 | Khal | Khodikhali Khal      | SU-35                                   | Khulna           |
| 338 | Khal | Hoddora Khal         | SU-35                                   | Khulna           |
| 339 | Khal | Arbunia Khal         | SU-35                                   | Khulna           |
| 340 | Khal | Bara Kumarkhali Khal | SU-35                                   | Khulna           |
| 341 | Khal | Pauli Khal           | SU-35                                   | Khulna           |
| 342 | Khal | Jhanjania Khal       | SU-35                                   | Khulna           |
| 343 | Khal | Ulubunia Khal        | SU-35                                   | Khulna           |
| 344 | Khal | Nochkhali Khal       | SU-35                                   | Khulna           |
| 345 | Khal | Kundi Khal           | SU-35, SU-36                            | Khulna           |
| 346 | Khal | Chota Nalbunia Khal  | SU-36                                   | Khulna           |
| 347 | Khal | Adachi Khal          | SU-36, SU-41                            | Khulna           |
| 348 | Khal | Bara Saheb Khal      | SU-41                                   | Khulna           |
| 349 | Khal | Chota Saheb Khal     | SU-41                                   | Khulna           |
| 350 | Khal | Kholapatar Khal      | SU-41                                   | Khulna           |
| 351 | Khal | Chintamonir Khal     | SU-36                                   | Khulna           |
| 352 | Khal | Hadda Khal           | SU-37                                   | Khulna           |
| 353 | Khal | Fultala Khal         | SU-37                                   | Khulna           |
| 354 | Khal | Baniakhali Khal      | SU-37                                   | Khulna           |
| 355 | Khal | Joymuni Khal         | SU-37                                   | Khulna           |
| 356 | Khal | Sasanangla Khal      | SU-37                                   | Khulna           |
| 357 | Khal | Muchir Doania        | SU-37                                   | Khulna           |
| 358 | Khal | Lakshmi Prasad Khal  | SU-37                                   | Khulna           |
| 359 | Khal | Jalmuni Khal         | SU-37                                   | Khulna           |
| 360 | Khal | Sipahikathi Khal     | SU-37                                   | Khulna           |
| 361 | Khal | Maramia Khal         | SU-42                                   | Khulna           |
| 362 | Khal | Manki Doani Khal     | SU-42                                   | Khulna           |
| 363 | Khal | Mara Lakshmi Khal    | SU-37                                   | Khulna           |
| 364 | Khal | Kolkhali Khal        | SU-38                                   | Khulna           |
| 365 | Khal | Taltala Khal         | SU-38                                   | Khulna           |
| 366 | Khal | Balia Khal           | SU-38                                   | Khulna           |
| 367 | Khal | Jolakhali Khal       | SU-38                                   | Khulna           |
| 368 | Khal | Keoratala Khal (y)   | SU-38                                   | Khulna           |

| No. | Type | Name                 | Sample unit         | Range            |
|-----|------|----------------------|---------------------|------------------|
| 369 | Khal | Bara Dhagra Khal     | SU-38               | Khulna           |
| 370 | Khal | Chota Dhagra Khal    | SU-38               | Khulna           |
| 371 | Khal | Khar Khatta Khal     | SU-38, SU-39        | Khulna           |
| 372 | Khal | Shalki Khal          | SU-38               | Khulna           |
| 373 | Khal | Satbari Khal         | SU-38, SU-39        | Khulna           |
| 374 | Khal | Mucikhali Khal       | SU-39               | Khulna           |
| 375 | Khal | Bojboja Khal (z)     | SU-39               | Khulna           |
| 376 | Khal | Jajnabhanga Khal     | SU-39               | Khulna           |
| 377 | Khal | Chatkalata Khal      | SU-39               | Khulna           |
| 378 | Khal | Majhlootdunia Khal   | SU-39               | Khulna           |
| 379 | Khal | Chera Khal           | SU-39               | Khulna           |
| 380 | Khal | Khasitana Khal       | SU-39               | Khulna           |
| 381 | Khal | Andharmanik Khal (y) | SU-39               | Khulna           |
| 382 | Khal | Kurulia Khal         | SU-39               | Khulna           |
| 383 | Khal | Murulia Khal         | SU-39               | Khulna           |
| 384 | Khal | Majhabhanga Khal     | SU-39               | Khulna           |
| 385 | Khal | Chota Dudhmukhi Khal | SU-40               | Khulna           |
| 386 | Khal | Bara Dudmukhi Khal   | SU-40               | Khulna           |
| 387 | Khal | Cassikhata Khal      | SU-39, SU-40, SU-43 | Khulna, Satkhira |
| 388 | Khal | Chamta Khal (z)      | SU-40               | Khulna           |
| 389 | Khal | Kanchira Khal        | SU-41               | Khulna           |
| 390 | Khal | Patha Khal           | SU-41               | Khulna           |
| 391 | Khal | Gholer Khal          | SU-18               | Khulna           |
| 392 | Khal | Bojboja Khal         | SU-42               | Khulna           |
| 393 | Khal | Hirkhali Khal        | SU-42               | Khulna           |
| 394 | Khal | Marmuria Khal        | SU-42               | Khulna           |
| 395 | Khal | Baibulla Khal        | SU-43               | Satkhira         |
| 396 | Khal | Matlo Khal           | SU-43               | Satkhira         |
| 397 | Khal | Chand Khal           | SU-43               | Satkhira         |
| 398 | Khal | Charka Khal          | SU-43               | Satkhira         |
| 399 | Khal | Suro Khal            | SU-43               | Satkhira         |
| 400 | Khal | Hoho Khal            | SU-43               | Satkhira         |
| 401 | Khal | Kalilat Khal         | SU-44               | Satkhira         |
| 402 | Khal | Bagna Khal           | SU-44               | Satkhira         |
| 403 | Khal | Hagaldori Khal       | SU-44               | Satkhira         |
| 404 | Khal | Golboksha Khal       | SU-44               | Satkhira         |
| 405 | Khal | Tiger Khal           | SU-46               | Khulna           |
| 406 | Khal | Sadhankhali Khal     | SU-46               | Khulna           |
| 407 | Khal | Khajuria Khal        | SU-46               | Khulna           |
| 408 | Khal | Kuridani Khal        | SU-46               | Khulna           |
| 409 | Khal | Amratani Khal        | SU-46, SU-47        | Khulna           |
| 410 | Khal | Sejkhali Khal        | SU-46               | Khulna           |
| 411 | Khal | Sejkhali Dhone Khal  | SU-46               | Khulna           |

| No. | Type | Name                  | Sample unit  | Range    |
|-----|------|-----------------------|--------------|----------|
| 412 | Khal | Salankhali Khal       | SU-46, SU-47 | Khulna   |
| 413 | Khal | Khajri Khal           | SU-45        | Khulna   |
| 414 | Khal | Keora Suti Khal       | SU-47        | Khulna   |
| 415 | Khal | Nilkomol Khal         | SU-47        | Khulna   |
| 416 | Khal | Dhanda Khal           | SU-47        | Khulna   |
| 417 | Khal | Sakachi Khal          | SU-47        | Khulna   |
| 418 | Khal | Rangbari Khal         | SU-47        | Khulna   |
| 419 | Khal | Dwarikabari Gang      | SU-47        | Khulna   |
| 420 | Khal | Kolatala Khal         | SU-47        | Khulna   |
| 421 | Khal | Gogasi Khal           | SU-47        | Khulna   |
| 422 | Khal | Lighter Khal          | SU-48        | Khulna   |
| 423 | Khal | Haldebunia Khal (Z)   | SU-48        | Khulna   |
| 424 | Khal | Bheda Khal            | SU-48        | Khulna   |
| 425 | Khal | Meherali Khal         | SU-48        | Khulna   |
| 426 | Khal | Moger Khal            | SU-48        | Khulna   |
| 427 | Khal | Machua Khal (y)       | SU-48        | Khulna   |
| 428 | Khal | Manikkhali Khal       | SU-09        | Khulna   |
| 429 | Khal | Kadamtala Khal        | SU-50        | Satkhira |
| 430 | Khal | Chotakoakhali Khal    | SU-50        | Satkhira |
| 431 | Khal | Barakoakhali Khal     | SU-50        | Satkhira |
| 432 | Khal | Palkati Khal          | SU-50        | Satkhira |
| 433 | Khal | Passurtala Khal       | SU-49, SU-50 |          |
| 434 | Khal | Kia Khal (b)          | SU-50        | Satkhira |
| 435 | Khal | Dhangmara Khal        | SU-50        | Satkhira |
| 436 | Khal | Kholshebunia Khal     | SU-49, SU-50 |          |
| 437 | Khal | Kainmari Khal         | SU-50        | Satkhira |
| 438 | Khal | Kateswar Khal         | SU-50        | Satkhira |
| 439 | Khal | Sap Khal              | SU-50        | Satkhira |
| 440 | Khal | Kali Khal (x)         | SU-50        | Satkhira |
| 441 | Khal | Kalir Khal (x)        | SU-49        | Satkhira |
| 442 | Khal | Sonakhali Khal        | SU-49        | Satkhira |
| 443 | Khal | Bogidonia Khal        | SU-49        | Satkhira |
| 444 | Khal | Kalir Khal (y)        | SU-49        | Satkhira |
| 445 | Khal | Badurjhuli Khal       | SU-49        | Satkhira |
| 446 | Khal | Bolbere Khal          | SU-49        | Satkhira |
| 447 | Khal | Talbere Khal          | SU-49        | Satkhira |
| 448 | Khal | Shinglagoalkhali Khal | SU-49        | Satkhira |
| 449 | Khal | Gola Khali            | SU-51        | Satkhira |
| 450 | Khal | Morgang Khal          | SU-51        | Satkhira |
| 451 | Khal | Chagda Khal           | SU-51        | Satkhira |
| 452 | Khal | Horkhali Khal         | SU-51        | Satkhira |
| 453 | Khal | Porakatia Khal        | SU-52        | Satkhira |
| 454 | Khal | Chunkuri Khal         | SU-51, SU-52 |          |

| No. | Type | Name                | Sample unit         | Range    |
|-----|------|---------------------|---------------------|----------|
| 455 | Khal | Singhertali Khal    | SU-52               | Satkhira |
| 456 | Khal | Dumkoli Khal        | SU-52               | Satkhira |
| 457 | Khal | Mathabangha Khal    | SU-51               | Satkhira |
| 458 | Khal | Subdi Khal          | SU-52               | Satkhira |
| 459 | Khal | Jhinbaria Khal      | SU-52               | Satkhira |
| 460 | Khal | Gubdur Khal         | SU-52               | Satkhira |
| 461 | Khal | Maithbhanga Khal    | SU-51               | Satkhira |
| 462 | Khal | Ichamoti Khal       | SU-49, SU-50, SU-52 | Satkhira |
| 463 | Khal | Singartala Khal     | SU-52               | Satkhira |
| 464 | Khal | Rakhali Khal        | SU-51               | Satkhira |
| 465 | Khal | Khasitana Khal (y)  | SU-51               | Satkhira |
| 466 | Khal | Kalindi River       | SU-53               | Satkhira |
| 467 | Khal | Gogari Khal         | SU-53               | Satkhira |
| 468 | Khal | Dalchi Khal         | SU-53               | Satkhira |
| 469 | Khal | Baninkari Khal      | SU-53               | Satkhira |
| 470 | Khal | Paratoni Khal       | SU-53, SU-54        | Satkhira |
| 471 | Khal | Ulua Khal           | SU-53, SU-54        | Satkhira |
| 472 | Khal | Kachikatta Khal     | SU-53, SU-54        | Satkhira |
| 473 | Khal | Khoncha Khal        | SU-54               | Satkhira |
| 474 | Khal | Tonakhali Khal      | SU-54               | Satkhira |
| 475 | Khal | Poshkhali Khal      | SU-54               | Satkhira |
| 476 | Khal | Atharabanki Khal    | SU-54               | Satkhira |
| 477 | Khal | Tekoa Khal          | SU-54               | Satkhira |
| 478 | Khal | Notabeki Khal       | SU-54, SU-55        | Satkhira |
| 479 | Khal | Hilsamari Khal (a)  | SU-54, SU-55        | Satkhira |
| 480 | Khal | Chapura Khal        | SU-55               | Satkhira |
| 481 | Khal | Hilchar Khal        | SU-55, SU-65        | Satkhira |
| 482 | Khal | Chamta Khal (b)     | SU-55, SU-65        | Satkhira |
| 483 | Khal | Agunjala Khal       | SU-65               | Satkhira |
| 484 | Khal | Kalkabari Khal      | SU-65               | Satkhira |
| 485 | Khal | Nagzora Khal        | SU-57               | Satkhira |
| 486 | Khal | Hossain Khal        | SU-57               | Satkhira |
| 487 | Khal | Pangasia Khal       | SU-57               | Satkhira |
| 488 | Khal | Dovashi Varani      | SU-57               | Satkhira |
| 489 | Khal | Kalagachi Khal      | SU-49, SU-56, SU-57 | Satkhira |
| 490 | Khal | Kolu Khal           | SU-57               | Satkhira |
| 491 | Khal | Choto Kokumari Khal | SU-57               | Satkhira |
| 492 | Khal | Mula Khal           | SU-57               | Satkhira |
| 493 | Khal | Keoratala Khal (w)  | SU-57               | Satkhira |
| 494 | Khal | Hari Khal           | SU-56               | Satkhira |
| 495 | Khal | Kalbadoania Khal    | SU-56               | Satkhira |
| 496 | Khal | Angrakona Khal      | SU-56, SU-59        | Satkhira |
| 497 | Khal | Muktabangla Khal    | SU-56, SU-59        | Satkhira |

| No. | Type | Name                    | Sample unit | Range    |
|-----|------|-------------------------|-------------|----------|
| 498 | Khal | Bara Lakshmi Khal       | SU-58       | Satkhira |
| 499 | Khal | Chota Lakshmi Khal      | SU-58       | Satkhira |
| 500 | Khal | Bara Manikkhali Khal    | SU-58       | Satkhira |
| 501 | Khal | Bara Khali Khal         | SU-58       | Satkhira |
| 502 | Khal | Chota Manikkhali Khal   | SU-58       | Satkhira |
| 503 | Khal | Puspakathi Khal         | SU-61       | Satkhira |
| 504 | Khal | Charmeghna              |             |          |
| 505 | Khal | Dania Khal              |             |          |
| 506 | Khal | Jana Khali              |             |          |
| 507 | Khal | Balijhoki Khal          |             |          |
| 508 | Khal | Kholmeghna              |             |          |
| 509 | Khal | Meghna Khal             |             |          |
| 510 | Khal | Chota Monsha Khal       |             |          |
| 511 | Khal | Meghanvatipara Khal     |             |          |
| 512 | Khal | Asasani Khal            |             |          |
| 513 | Khal | Jhalokati Khal          |             |          |
| 514 | Khal | Kusumkhali              |             |          |
| 515 | Khal | Jolghata Khal           |             |          |
| 516 | Khal | Jhanabunia Khal         |             |          |
| 517 | Khal | Tetulbaria Khal         |             |          |
| 518 | Khal | Mandarbaria Khal (z)    |             |          |
| 519 | Khal | Dakhin Mandarbaria Khal |             |          |
| 520 | Khal | Chandbaria Khal         |             |          |
| 521 | Khal | Bahir Mandarbaria Khal  |             |          |
| 522 | Khal | Mandarbaria Khal (y)    |             |          |
| 523 | Khal | Hanif Khal              |             |          |
| 524 | Khal | Keoratala Khal (v)      |             |          |
| 525 | Khal | Garaler Khal            |             |          |
| 526 | Khal | Madardoania Khal        |             |          |
| 527 | Khal | Sarkabana Khal          |             |          |
| 528 | Khal | Haldebunia Khal (y)     |             |          |
| 529 | Khal | Maniksara Khal          |             |          |
| 530 | Khal | Atapata Khal            |             |          |
| 531 | Khal | Khaejurdana Khal        |             |          |
| 532 | Khal | Pantamari Khal          |             |          |
| 533 | Khal | Talpatti Khal (y)       |             |          |
| 534 | Khal | Chapatola Khal          |             |          |
| 535 | Khal | Panir Khal              |             |          |
| 536 | Khal | Kamandaga Khal          |             |          |
| 537 | Khal | Sonamukhi Khal (y)      |             |          |

# Data Sheet for Khal Survey for Tigers

[illegible]

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# Annex 3. Sample data sheet for Aquatic Mammals



## ECOLOGICAL MONITORING OF SUNDARBANS Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II) OTTER MONITORING DATA SHEET

| Date    | Transect Name:      |                        | Starting Time:    |           | Transect Starting WP: |                                       |          |       |
|---------|---------------------|------------------------|-------------------|-----------|-----------------------|---------------------------------------|----------|-------|
| Tide    | Team Members:       |                        | Ending Time:      |           | Transect Ending WP:   |                                       |          |       |
| Sl. No. | Location/<br>GPS WP | Name of the<br>Species | Total Individuals | Age Class |                       | Weather (sunny/<br>cloudy/ fog/ rain) | Activity | Notes |
|         |                     |                        |                   | Adult     | Non-<br>adult         |                                       |          |       |
|         |                     |                        |                   |           |                       |                                       |          |       |
|         |                     |                        |                   |           |                       |                                       |          |       |
|         |                     |                        |                   |           |                       |                                       |          |       |

# Data sheet for Dolphin Surveys



## ECOLOGICAL MONITORING OF SUNDARBANS Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)" DOLPHIN MONITORING DATA SHEET

|      |                  |                 |                       |              |                                  |            |                        |                 |                                      |       |  |  |  |
|------|------------------|-----------------|-----------------------|--------------|----------------------------------|------------|------------------------|-----------------|--------------------------------------|-------|--|--|--|
| Date | Transect Name:   | Starting Time:  | Transect Starting WP: |              |                                  |            |                        |                 |                                      |       |  |  |  |
|      | Team Members:    | Ending Time:    | Transect Ending WP:   |              |                                  |            |                        |                 |                                      |       |  |  |  |
| Tide | Observer Initial | Rain/Fog- 0/1/2 | Wind- 0/1/2           | Glare- 0/1/2 | Weather - Sunny / Cloudy / Windy | Left/Right | Distance from observer | Angle in Degree | Age Class                            | Calf  |  |  |  |
|      |                  |                 |                       |              |                                  |            |                        |                 |                                      | Adult |  |  |  |
|      |                  |                 |                       |              |                                  |            |                        |                 | Total Number                         |       |  |  |  |
|      |                  |                 |                       |              |                                  |            |                        |                 | Sighting time                        |       |  |  |  |
|      |                  |                 |                       |              |                                  |            |                        |                 | Location perpendicular to dolphin WP |       |  |  |  |
|      |                  |                 |                       |              |                                  |            |                        |                 | Location WP                          |       |  |  |  |
|      |                  |                 |                       |              |                                  |            |                        |                 | Species Name                         |       |  |  |  |
|      |                  |                 |                       |              |                                  |            |                        |                 | Sighting number                      |       |  |  |  |

## Annex 4. Example of the data sheet to be used in Avifauna survey



### ECOLOGICAL MONITORING OF SUNDARBANS Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II) INDICATOR BIRD MONITORING DATA SHEET

|                                              |                                                              |                                           |                              |
|----------------------------------------------|--------------------------------------------------------------|-------------------------------------------|------------------------------|
| <b>Date</b>                                  | <b>Transect Name:</b>                                        | <b>Starting Time:</b>                     | <b>Transect Starting WP:</b> |
| <b>Tide<br/>High/ Mid Flow</b>               | <b>Team Members:</b>                                         | <b>Ending Time:</b>                       | <b>Transect Ending WP:</b>   |
| <b>Weather:<br/>sunny/cloudy/foggy/rainy</b> | <b>Riverbank habitat type:<br/>woods/bush-grass/mud-sand</b> | <b>River type:<br/>wide/medium/narrow</b> |                              |

| Sl. No. | Name of Indicator Bird     | Number | Location WP | Total No. | Note | Sl. No. | Name of Non-indicator Bird (Optional) | Note |
|---------|----------------------------|--------|-------------|-----------|------|---------|---------------------------------------|------|
| 1.      | Masked Finfoot             |        |             |           |      | 1.      |                                       |      |
| 2.      | Mangrove Pitta             |        |             |           |      | 3.      |                                       |      |
| 3.      | Streak-breasted Woodpecker |        |             |           |      | 4.      |                                       |      |
| 4.      | Red Junglefowl             |        |             |           |      | 5.      |                                       |      |
| 5.      | Lesser Adjutant            |        |             |           |      | 6.      |                                       |      |
| 6.      | White-bellied Sea Eagle    |        |             |           |      | 7.      |                                       |      |
| 7.      | Buffy Fish-owl             |        |             |           |      | 8.      |                                       |      |
| 8.      | Brown-winged Kingfisher    |        |             |           |      | 9.      |                                       |      |
| 9.      | Ruddy Kingfisher           |        |             |           |      | 10.     |                                       |      |
| 10.     | Crimson Sunbird            |        |             |           |      | 11.     |                                       |      |

# Annex 5. Example of the data sheet to be used in amphibians and reptiles survey including Saltwater Crocodile and Olive Ridley Turtle.



## ECOLOGICAL MONITORING OF SUNDARBANS Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II) Snakes and Water Monitor Lizard Monitoring Data Sheet

| Date    | Transect Name:      |                        | Starting Time: |           | Transect Starting WP: |              |                                             |                                             |                         |       |
|---------|---------------------|------------------------|----------------|-----------|-----------------------|--------------|---------------------------------------------|---------------------------------------------|-------------------------|-------|
| Tide    | Team Members:       |                        | Ending Time:   |           | Transect Ending WP:   |              |                                             |                                             |                         |       |
| Sl. No. | Location/<br>GPS WP | Name of the<br>Species | # Individuals  | Age Class |                       |              | Position (on<br>the bank/<br>water/ plants) | Weather<br>(sunny/<br>cloudy/ fog/<br>rain) | Nearest vegetation type | Notes |
|         |                     |                        |                | Adult     | Non-<br>adult         | Size<br>(ft) |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |
|         |                     |                        |                |           |                       |              |                                             |                                             |                         |       |



**ECOLOGICAL MONITORING OF SUNDARBANS**  
Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)"  
**CROCODILE MONITORING DATA SHEET**

|             |                       |                       |                              |  |  |
|-------------|-----------------------|-----------------------|------------------------------|--|--|
| <b>Date</b> | <b>Transect Name:</b> | <b>Starting Time:</b> | <b>Transect Starting WP:</b> |  |  |
| <b>Tide</b> | <b>Team Members:</b>  | <b>Ending Time:</b>   | <b>Transect Ending WP:</b>   |  |  |

| Sl. No. | Location/<br>GPS WP | # Individuals | Age Class |           | Width of the canal / river | Position (on the bank/ water/ plants) | Weather (sunny/ cloudy/ fog/ rain) | Nearest vegetation type | Notes |
|---------|---------------------|---------------|-----------|-----------|----------------------------|---------------------------------------|------------------------------------|-------------------------|-------|
|         |                     |               | Adult     | Non-adult |                            |                                       |                                    |                         |       |
|         |                     |               |           |           |                            |                                       |                                    |                         |       |
|         |                     |               |           |           |                            |                                       |                                    |                         |       |
|         |                     |               |           |           |                            |                                       |                                    |                         |       |
|         |                     |               |           |           |                            |                                       |                                    |                         |       |
|         |                     |               |           |           |                            |                                       |                                    |                         |       |
|         |                     |               |           |           |                            |                                       |                                    |                         |       |
|         |                     |               |           |           |                            |                                       |                                    |                         |       |



**ECOLOGICAL MONITORING OF SUNDARBANS**  
Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)"  
**Amphibians Monitoring Data Sheet**

|                     |                               |                       |                              |  |  |
|---------------------|-------------------------------|-----------------------|------------------------------|--|--|
| <b>Date</b>         | <b>Transect/Quadrat Name:</b> | <b>Starting Time:</b> | <b>Transect Starting WP:</b> |  |  |
| <b>Quadrat Size</b> | <b>Team Members:</b>          | <b>Ending Time:</b>   | <b>Transect Ending WP:</b>   |  |  |

| Sl. No. | Location/<br>GPS WP | Name of the<br>Species | # Individuals | Habitat information     |                                           |                 | Breeding Status  |     |         | Notes |
|---------|---------------------|------------------------|---------------|-------------------------|-------------------------------------------|-----------------|------------------|-----|---------|-------|
|         |                     |                        |               | Position of<br>the frog | Distance of<br>Vegetation<br>pond/ditches | Vegetation Type | Breeding<br>Call | Egg | Tadpole |       |
|         |                     |                        |               |                         |                                           |                 |                  |     |         |       |
|         |                     |                        |               |                         |                                           |                 |                  |     |         |       |
|         |                     |                        |               |                         |                                           |                 |                  |     |         |       |
|         |                     |                        |               |                         |                                           |                 |                  |     |         |       |
|         |                     |                        |               |                         |                                           |                 |                  |     |         |       |
|         |                     |                        |               |                         |                                           |                 |                  |     |         |       |



**ECOLOGICAL MONITORING OF SUNDARBANS**  
Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)  
Olive Ridley Sea Turtle Monitoring Data Sheet

|                      |                       |  |                       |                              |
|----------------------|-----------------------|--|-----------------------|------------------------------|
| <b>Date</b>          | <b>Transect Name:</b> |  | <b>Starting Time:</b> | <b>Transect Starting WP:</b> |
| <b>Team Members:</b> |                       |  | <b>Ending Time:</b>   | <b>Transect Ending WP:</b>   |

| Sl. No. | Location/<br>GPS WP | # Individuals | Condition of the individual |      | Nest Information |        | Presence of any other sign | Notes |
|---------|---------------------|---------------|-----------------------------|------|------------------|--------|----------------------------|-------|
|         |                     |               | Live                        | Dead | Injury mark      | #nests |                            |       |
|         |                     |               |                             |      |                  |        |                            |       |
|         |                     |               |                             |      |                  |        |                            |       |
|         |                     |               |                             |      |                  |        |                            |       |
|         |                     |               |                             |      |                  |        |                            |       |
|         |                     |               |                             |      |                  |        |                            |       |
|         |                     |               |                             |      |                  |        |                            |       |
|         |                     |               |                             |      |                  |        |                            |       |

Annex 6: Sample data sheet for Butterfly and Bee survey

|               |                |                |                                  |  |           |
|---------------|----------------|----------------|----------------------------------|--|-----------|
| Date          | Transect Name: | Starting Time: | Latitude                         |  | Longitude |
| Team Members: |                | Ending Time:   | Major vegetation of the transect |  |           |

| Sl. No. | Species name   | Tally count (In 1 hour) (09 am-10 am)... | Host plant of the butterfly found | Habitat types |                           |        |
|---------|----------------|------------------------------------------|-----------------------------------|---------------|---------------------------|--------|
|         |                |                                          |                                   | Grassland     | Wetlands (Consider Khals) | Others |
| 1       | Tree Nymph     |                                          |                                   |               |                           |        |
| 2       | Sundarban Crow |                                          |                                   |               |                           |        |
| 3       | Crimson Rose   |                                          |                                   |               |                           |        |

## Bee Monitoring sheet

|                                                                                |                              |                                                                    |                              |                              |
|--------------------------------------------------------------------------------|------------------------------|--------------------------------------------------------------------|------------------------------|------------------------------|
| Date                                                                           | Grid Name:                   | Starting Time:                                                     | Latitude                     | Longitude                    |
| Team Members:                                                                  | Ending Time:                 | Major vegetation's of the grid                                     |                              |                              |
| Temperature                                                                    | Salinity***                  | Presence of heavy metals i.e Fe, Zn, Cu, Pd, along with honey **** |                              |                              |
| Grid no                                                                        | 1, 2, 3, 4, 5                | 6, 7, 10                                                           | 8                            | 9, 11                        |
| Range                                                                          | Satkhira Range               | Khulna Range                                                       | Sarankhola Range             | Chandpai Range               |
| Total Hive found                                                               | YYYY<br>a.<br>b.<br>c.<br>d. | YYYY<br>a.<br>b.<br>c.<br>d.                                       | YYYY<br>a.<br>b.<br>c.<br>d. | YYYY<br>a.<br>b.<br>c.<br>d. |
| Length & width of each hive                                                    | a.<br>b.<br>c.<br>d.         | a.<br>b.<br>c.<br>d.                                               | a.<br>b.<br>c.<br>d.         | a.<br>b.<br>c.<br>d.         |
| Weight of honey & Wax (each hive) after extraction                             |                              |                                                                    |                              |                              |
| Survival status of Queen during collection (death/alive)                       |                              |                                                                    |                              |                              |
| Type of bee hive                                                               |                              |                                                                    |                              |                              |
| Total honey collected under the grid range during study fiscal year (4 ranges) |                              |                                                                    |                              |                              |
| Total wax collected under the grid range during study fiscal year (4 ranges)   |                              |                                                                    |                              |                              |



# **ECOLOGICAL MONITORING OF SUNDARBANS** Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)" **Bee Monitoring Data Sheet**

| Grid no                                                                      | 1, 2, 3, 4, 5         | 6, 7, 10            | 8                       | 9, 11                 |
|------------------------------------------------------------------------------|-----------------------|---------------------|-------------------------|-----------------------|
| <b>Range</b>                                                                 | <b>Satkhira Range</b> | <b>Khulna Range</b> | <b>Sarankhola Range</b> | <b>Chandpai Range</b> |
| Total honey and wax collected from all 4 ranges in the fiscal year 2021-22** |                       |                     |                         |                       |
| Total honey and wax collected from all 4 ranges in the fiscal year 2022-23** |                       |                     |                         |                       |
| Total honey and wax collected from all 4 ranges in the fiscal year 2023-24** |                       |                     |                         |                       |
| Total honey and wax collected from all 4 ranges in the fiscal year 2024-25** |                       |                     |                         |                       |
| Total honey and wax collected from all 4 ranges in the fiscal year 2025-26** |                       |                     |                         |                       |
| Bee's migration movement pattern (auxiliary)                                 |                       |                     |                         |                       |

\* fiscal year 2016-2021, honey collection and wax collection range wise data will be provided by Forest Department of Sundarbans  
 \*\* fiscal year 2022 to onward, honey collection and wax collection range wise data will be provided by Forest Department of Sundarbans  
 \*\*\* at least 4 locations nearest to grid (River, Canal, Pond) sample need to collect during the survey. Four seasons sample data collection also need to be collected during the project implementation tenure.  
 \*\*\* at least 2 locations - one inside the grid and other outside the grid. Four seasons sample data collection also need to be collected during the project implementation tenure and need to be tested for Chemical analysis of the heavy metals from accredited lab of Bangladesh. The chemical composition of heavy metal in honey production also need to be tested by each year followed by each grid.

## Annex 7. Fish and Fisheries data sheet sample

| Fisheries and ecological data sheet |          |           |      |                 |                            |  |
|-------------------------------------|----------|-----------|------|-----------------|----------------------------|--|
| Date                                |          |           |      | Data Collector: |                            |  |
| Sample site                         |          |           |      |                 |                            |  |
| Species name                        | Latitude | Longitude | Code | No.             | Notes (local name, others) |  |
| Lates calcarifer                    |          |           |      |                 |                            |  |
| Plotosus canius                     |          |           |      |                 |                            |  |
| Scatophagus argus                   |          |           |      |                 |                            |  |
| Toxotes chatareus                   |          |           |      |                 |                            |  |
| Chelon parsia                       |          |           |      |                 |                            |  |
|                                     |          |           |      |                 |                            |  |
| Boleophthalmus dussumieri           |          |           |      |                 |                            |  |
| Otolithoides pama                   |          |           |      |                 |                            |  |
| Scylla olivacea                     |          |           |      |                 |                            |  |
| Scylla serrata                      |          |           |      |                 |                            |  |
| Penaeus indicus                     |          |           |      |                 |                            |  |
| Penaeus monodon                     |          |           |      |                 |                            |  |
| Macrobrachiu rosenbergii            |          |           |      |                 |                            |  |

Code: 0 = Observed, PR = Previous Record, LI = Local Information, C = Common, R = Rare, T = Threatened

| Water parameter         | Latitude | Longitude | Value | Notes (local name, others) |
|-------------------------|----------|-----------|-------|----------------------------|
| Temperature (C°)        |          |           |       |                            |
| Salinity (‰)            |          |           |       |                            |
| Dissolved oxygen (mg/l) |          |           |       |                            |
| pH                      |          |           |       |                            |
| Turbidity (mg/l)        |          |           |       |                            |
| Current (m/s)           |          |           |       |                            |
| Depth (m)               |          |           |       |                            |

## Annex 8. IAS and Flora survey Datasheet

# ECOLOGICAL MONITORING OF SUNDARBANS

Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)

# Plants and IAS Monitoring Data Sheet

## Level 1: Field Data Sheet for Undergrowth Vegetation

|                  |                  |                  |                |              |                 |          |
|------------------|------------------|------------------|----------------|--------------|-----------------|----------|
| Date             | 22.03.2022       | Starting Time:   |                | 3.30 p.m.    | Ending Time:    | 5.00p.m. |
| Site name        | Jongra K'hal     |                  |                |              |                 |          |
| Transect no.     | 1                | 2                | 3              | Direction:   |                 |          |
| GPS              | Transect Start:  |                  | Transect end:  |              |                 |          |
|                  | N:               | E:               | N: E:          |              |                 |          |
| Site description |                  |                  |                |              |                 |          |
| Vegetation zone  | Wide of zone     | Tide height (cm) | Salinity (ppt) | Coverage (%) | Impact type*    | Impact** |
| 1-2              | 4-5 m            |                  |                |              |                 |          |
| Species present  | No. of indiv./Q. | RD (%)           | RA (%)         | RF (%)       | Diversity Index |          |
| 1.               |                  |                  |                |              |                 |          |
| 2.               |                  |                  |                |              |                 |          |
| 3.               |                  |                  |                |              |                 |          |
| 4.               |                  |                  |                |              |                 |          |
| 5.               |                  |                  |                |              |                 |          |
| 6.               |                  |                  |                |              |                 |          |
| 7.               |                  |                  |                |              |                 |          |
| 8.               |                  |                  |                |              |                 |          |
| 9.               |                  |                  |                |              |                 |          |
| 10.              |                  |                  |                |              |                 |          |

\* Erosion, sedimentation, extraction, grassing/browsing, pig activities, garbage, fishing/netting, etc.

\*\*No impact (96-100%), slightly impact (76-95%), moderate impact (51-75%), high impact (11-50%), sever impact (0-10%)

## Names of contributors in field work:

1. 2. 3.

Remarks (if any):.....

**ECOLOGICAL MONITORING OF SUNDARBANS**  
Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)"  
**Plants and IAS Monitoring Data Sheet**  
**Level 2: Field Data Sheet for Indicator Plant Species**

|                  |       |   |                   |            |                  |                  |         |
|------------------|-------|---|-------------------|------------|------------------|------------------|---------|
| Date             |       |   | Starting Time:    |            |                  | Ending Time:     |         |
| Site name        |       |   |                   |            |                  |                  |         |
| Transect no.     | 1     | 2 | 3                 |            |                  |                  |         |
| GPS              |       |   |                   |            |                  |                  |         |
| Site description |       |   |                   |            |                  |                  |         |
| Forest type      |       |   | Canopy height (m) |            | Canopy cover (%) |                  |         |
| 1-2              | 4-5 m |   |                   |            |                  |                  |         |
| Species present  |       |   | No. of indiv.     | Height DBH |                  | Seedling/sapling | Threats |
| 1.               |       |   |                   |            |                  |                  |         |
| 2.               |       |   |                   |            |                  |                  |         |
| 3.               |       |   |                   |            |                  |                  |         |
| 4.               |       |   |                   |            |                  |                  |         |
| 5.               |       |   |                   |            |                  |                  |         |
| 6.               |       |   |                   |            |                  |                  |         |
| 7.               |       |   |                   |            |                  |                  |         |
| 8.               |       |   |                   |            |                  |                  |         |
| 9.               |       |   |                   |            |                  |                  |         |

Names of contributors in field work:

- 1.
- 2.
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- 4.
- 5.

Remarks (if any):.....

# ECOLOGICAL MONITORING OF SUNDARBANS

Under the Project "Support to The Management of Sundarbans Reserved Forest (SMP II)

## Plants and IAS Monitoring Data Sheet Level 3: Field Data Sheet for IAS Of Plant

|                       |   |               |                |                  |         |                  |  |  |
|-----------------------|---|---------------|----------------|------------------|---------|------------------|--|--|
| Date                  |   |               | Starting Time: |                  |         | Ending Time:     |  |  |
| Site name             |   |               |                |                  |         |                  |  |  |
| Plot/ Transect no.    | 1 | 2             | 3              |                  |         |                  |  |  |
| GPS                   |   |               |                |                  |         |                  |  |  |
| Site description      |   |               |                |                  |         |                  |  |  |
|                       |   |               |                |                  |         |                  |  |  |
| IAS of Plants present |   | No. of indiv. | Life-form      | Mode of invasion | Effects | Other ( if any ) |  |  |
| 1.                    |   |               |                |                  |         |                  |  |  |
| 2.                    |   |               |                |                  |         |                  |  |  |
| 3.                    |   |               |                |                  |         |                  |  |  |
| 4.                    |   |               |                |                  |         |                  |  |  |
| 5.                    |   |               |                |                  |         |                  |  |  |

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Remarks (if any):.....





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