# Mangrove Regeneration Status of the Sundarbans, Bangladesh: A Study in the Oligohaline Zone


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LIFE SCIENCE SCHOOL
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**Course Title:** Project Thesis

**Course No:** FWT-4114

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Course Title: Project Thesis

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Project Thesis has been submitted to Forestry and Wood Technology Discipline, Life Science school, Khulna University, Khulna, Bangladesh for the partial fulfillment of the requirements for the Degree of Bachelor of Science (Hons.) in Forestry and Wood Technology.


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I, Md. Minhaj Uj Siraj, declare that this thesis reports the original research work of the author, except as otherwise stated. The material presented has not been submitted either in whole or in part for a degree from this or any university.

The findings of the research has not been or will not be published anywhere without the concurrence of the concerned supervisor.

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Session: 2016-2017

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**Dedicated to….**

**My Beloved Parents**

# APPROVAL

Project Thesis has been submitted to Forestry and Wood Technology Discipline, Life Science school, Khulna University, Khulna, Bangladesh for the partial fulfillment of the requirements for the 4-years professional B.Sc. of (Hons.) degree in Forestry and Wood Technology. I have approved the style and format of the project thesis.

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# ABSTRACT

The structure and natural regeneration patterns was examined along the oligohaline zone of the Sundarban reserve forest, Bangladesh, at two forest sites: Karamjol and Ghagramari. A total of five plots with an area of 2000 $m^2$ were sampled and evaluated for tree species and ten regeneration plots with an area of 10 $m^2$ for mangrove regeneration. Results of vegetation characteristics showed that the composition of mangroves differed significantly between the two sites. Based on the species importance values, the order of dominant mangrove trees in Karamjol is *H. fomes* > *B. sexangula* > *E. agallocha* > *A. officinalis* > *A. cucullata* > *X. mekongensis* and in Ghagramari is: *A. officinalis* > *X. mekongensis* > *H. fomes* > *E. agallocha* > *B. sexangula. Heritiera fomes* regeneration gives rise to high importance value in the study area. The order of dominant regeneration species is *Heritiera fomes* > *Bruguiera sexangula* > *Excoecaria agallocha* > *Aglaia cucullata*. There is no significant difference of regeneration density between the two study areas, but in case of tree density, there is a significant difference between the studied areas.

The occurrence of both RC1 (seedling height < 40 cm) and RC2 (seedling height between 40-150 cm) were higher in Karamjol area than those in Ghagramari area. Mature mangrove stands had the greater diversity than the regeneration stands in the studied area. This study revealed a clear idea about the capacity of mangrove regeneration as well as their vegetation type under the mature stands in the oligohaline zone of the Sundarbans which may help in decision making process for better management of the Sundarban reserve forest.

# CONTENTS


| Subject | Page No. |
|---|---|
| Title | i |
| Declaration | ii |
| Dedication | iii |
| Approval | iv |
| Acknowledgement | v |
| Abstract | vi |
| Contents | vii- viii |
| List of Tables | ix |
| List of Figures | x |
| **Chapter One** | 01-03 |
| **Introduction** | 01 |
| 1.1 Background of the Study | 01-03 |
| 1.2 Objectives of the Study | 03 |
| **Chapter Two** | 04-08 |
| **Literature Review** | 04 |
| 2.1 Forest Stand Structure | 04 |
| 2.1.1 Diameter | 04 |
| 2.1.2 Tree height | 04 |
| 2.1.3 Basal area | 05 |
| 2.2 Mangrove Regeneration | 05 |
| 2.3 Relative Density | 06 |
| 2.4 Relative Frequency | 07 |
| 2.5 Relative Dominance | 07 |

2.6 Importance Value 07

2.7 Effects of Salinity 08

**Chapter Three** 09-11

**Materials and Methods** 09

3.1 Study Area 09

3.2 Materials 10

3.3 Data Collection 10

3.4 Analysis of the Data 10-11

**Chapter Four** 12-26

**Result and Discussion** 12-26

**Chapter Five** 27

**Conclusion** 27

**References** 28-31

# List of Tables


| Title | Page No. |
| --- | --- |
| **Table 1** Mangrove species and regeneration recorded in the oligohaline zone of the Sundarbans. | 12 |
| **Table 2** Specific (and relative) density, basal area (and derived % dominance), and relative frequency of mature trees in mangrove communities along the oligohaline zone of Sundarbans. Relative values are expressed as %. | 13 |
| **Table 3** Structural composition of mangrove regeneration in the oligohaline zone of the Sundarbans for a combined data of Karamjol and Ghagramari sites. | 14 |
| **Table 4** Regeneration classes (RCs) in mangrove forest stands in the oligohaline zone of the Sundarbans. RC1 and RC2 corresponded to seedling heights of < 40 cm and between 40 cm and 150 cm, respectively. | 14 |

# List of Figures


| | |
|---|---|
| **Figure 1** Number of trees/ha in Karamjol | **15** |
| **Figure 2** Number of trees/ha in Ghagramari | **15** |
| **Figure 3** Number of seedling per ha for both Karamjol and Ghagramari. | **16** |
| **Figure 4** Seedling Stand Density/ha in Karamjol and Ghagramari | **16** |
| **Figure 5** Tree Stand Density/ha in Karamjol and Ghagramari | **17** |
| **Figure 6** Relationships between mean stem diameter at H/10 height and mean height of a) *H. fomes* and b) *B. sexangula*, the dominant mangrove regeneration in the study area. | **18** |
| **Figure 7** Relative frequency distribution of tree height of the mangrove regeneration for a combined data of Karamjol and Ghagramari sites. (HEFO: *H. fomes*, BRSE: *B. sexangula*, EXAG: *E. agallocha*, and AGCU: *A. cucullata*). | **19** |
| **Figure 8** Relative frequency distribution of stem diameter ($D_{0.1H}$) of the mangrove regeneration for a combined data of Karamjol and Ghagramari sites. (HEFO: *H. fomes*, BRSE: *B. sexangula*, EXAG: *E. agallocha*, and AGCU: *A. cucullata*). | **20** |
| **Figure 9** Relative frequency distribution of stem diameter ($D_{0.1H}$) of the mangrove regeneration for a combined data of Karamjol and Ghagramari sites. (HEFO: *H. fomes*, BRSE: *B. sexangula*, EXAG: *E. agallocha*, and AGCU: *A. cucullata*). | **21** |
| **Figure 10** Importance values of individual species for each plot / Vegetation type of each individual plot | **21** |
| **Figure 11** IVI values of trees and seedlings for the combined data of Karamjol and Ghagramari | **22** |

# 1. Introduction

## 1.1 Background of the Study

The word 'mangrove' has been used to refer either to the constituent plants of tropical intertidal forest communities to the community itself (Tomlinson, 1986; Kasawani et al.,2007). Mangroves are woody plants that grow at the interface between land and sea in tropical and sub-tropical latitudes. Mangrove trees therefore grow in soil that is more or less permanently water-logged and in water those salinity fluctuates and may be as high as that of open sea (Peter, 1999). It covers only 0.2% of total area occupied by terrestrial ecosystems in the New World. However, mangrove ecosystems hold a wide diversity of aquatic and terrestrial species of different taxonomic groups, and when all species are considered, mangrove ecosystems rival many other tropical habitats in alpha diversity (Dinerstein et al., 1995). Mangrove forest ecosystem support important wetland community of plants and animals, they are characterized by unique species of trees and shrubs that fringe the intertidal zone along sheltered coastal, estuarine and riverine areas in tropical and subtropical latitudes (Kasawani et al.,2007; Kasawani, 2004). The relatively high plant productivity and the active biological processes characteristic of mangrove ecosystems yield many goods and services of direct or indirect benefit to humans (Kasawani et al., 2007).

The Sundarbans is the largest single tract of tidal mangrove forest in the world, covering c.10,000 $km^2$ in the Ganges-Brahmaputra delta of Bangladesh and India. Roughly 60% lies in the south-west of Bangladesh and the rest is in the south-east of the Indian state of West Bengal (Khan,2005).

The Bangladesh part of the Sundarban Mangrove Forest occupies 4.2% of the total area of Bangladesh and constitutes 44% of the forest cover in the country. In the last part of the 20th century, mangrove forests of many countries of the world have been reduced, and the current estimate of the world's stock is less than half of what it had once been and the area that remains has been significantly degraded by increased salinity and pollution. About 35% of mangroves were lost from 1980 to 2000 worldwide and this loss is occurring at a faster rate than that of inland tropical forests and coral reefs. Based on satellite data, it has been concluded that the remaining area is less than previously thought and is 12.3% smaller than the most recent estimate (Spalding et al., 1997; Duke et al., 2007; Aziz and Paul., 2015).

The Sundarban Mangrove Forest is an important natural resource provider of a large number of products such as timber, pulpwood, fuel wood, fish, thatching materials, honey, bee wax and shells. In addition, it also supports a very rich and diverse flora and fauna. The only natural habitat of the endangered flagship species, the Royal Bengal Tiger lies in Sundarban (Rashid et al, 2008).

Mangrove also provides protection and as habitat suitable as breeding and nursery areas for many organisms, and provide important regulatory functions. They reduce coastal erosion and flooding, supply and regenerate nutrients and retard run-off (Lugo and Snedeker, 1974; Kasawani et. al., 2007). Mangroves play an important role in water storage and trapping of sediments and carbon, contributing to the control of the quality and quantity of water, particles, and solutes discharged to the ocean (Dinerstein et al., 1995).

Differences in salinity might be responsible for spatial distribution of plant communities (Ahmed et. al., 2011). Despite the importance of regeneration on sustainability of mangrove ecosystems, few previous studies examined regeneration status (Hamad and Hamisi, 2014;

Mchenga and Ali, 2014; Sukardjo, 1987), factors influencing regeneration (Krauss and Allen, 2003) and success rates of recolonization of the mangrove species (Boisre et al, 2006), around the world. Apparently no previous studies examined the regeneration status and structural complexity of the regenerating species in the Sundarbans mangrove forest, Bangladesh.

Quantitative data on the regeneration structure, distribution patterns of regenerating species, and stocking rates at Sundarbans mangrove communities are lacking especially in the Bangladesh part. However, management and sustainability of the Sundarbans ecosystems solely depend on natural regeneration. Plant structure of the mangroves directly influence conditions and functioning of mangrove ecosystems, and their changes may influence distribution and abundance of the fauna (Cavalcanti et al., 2009). Therefore, it is important to know the regeneration status and patterns of structural complexity in understating potential responses of the mangrove ecosystems to their management practices (Kamruzzaman and Siraj et.al., 2017).

## 1.2 Objectives of the Study

Objectives of the present study were to:

- characterize stand structure of mangrove regeneration along the oligohaline zone of SRF
- estimate regeneration capacity of the existing mangrove species.

Stand characteristics, species density, and its relationship to different parameters such as height and diameter class were described. Patterns of species density vs. soil salinity were also examined and presented.

# 2. Literature Review

## 2.1 Forest Stand Structure

Forest stand structure is defined as "the physical and temporal distribution of trees in a stand" and include within the description of the distribution of species, vertical and horizontal spatial patterns, size of trees or tree parts, tree age, or combinations (Oliver and Larson, 1996; Kasawani et al., 2007). Descriptions of forest stand structure are commonly based on the aggregation of individual plant measures such as density, tree diameter at breast height distribution. In addition to zonation, mangrove forests are also characterized by attributes such as species richness, canopy height, basal area, tree density, age or size class distribution, and understory development (Feller and Sitnik, 2002).

### 2.1.1 Diameter at Breast Height

One of the simplest forms of stand characterization is the measurement of tree diameter. Diameter is usually measured with a tape at 1.3m above ground level and this measurement is referred to as dbh. An important exception however, concerns the mangroves with stilts-roots, such as *Rhizophora spp*, where the diameter measurement should be taken at 30 cm above. Diameter is closely related to stand development and can easily be converted to basal area (Kasawani et al., 2007).

### 2.1.2 Tree height

The height is also useful criterion in forest stand classification. In mangroves forest, stand height can be divided into three or four classes. Stand height at 0 – 9 m considered as regeneration while stand height at 10 – 19 m considered as young stand. Lastly, when a stand height reaches at > 20 m, it considered as old stand (FAO, 1994).

### 2.1.3 Basal area

Basal area is the space covered or area occupied by a trees stem. The basal area of a stand is the sum of the individual basal areas of all trees greater than a certain diameter per unit ground area. It is a good measure of the overall stand development and can be related to wood volume and biomass (UNESCO,1984)

## 2.2 Mangrove Regeneration

Mangroves are sensitive ecosystems, changing dynamically in response to storms, sediment blockage, and fluctuations in sea level and present a "moving target" for Regeneration efforts. Different Regeneration approaches face this challenge in different ways. The most common method simply consists in planting single-species stands of mangroves in areas thought to be suitable, without consideration of whether or not they supported mangroves in the past. This approach usually fails over the long term because the underlying soil and hydrological requirements of the mangroves are not being met. More informed methods aim to bring a damaged mangrove area back into its preexisting condition, taking into account not only ecosystem factors but also social, cultural and political perspectives. These approaches begin with the understanding that a damaged mangrove area may be able to repair itself through the natural processes of secondary succession, without being physically planted, provided that it's tidal and freshwater hydrology is functioning normally and there is an adequate supply of seedlings. Taking this into account, it becomes crucial to the success of a regeneration project to evaluate what the hydrology of a disturbed mangrove site should look like under normal conditions, and the ways in which it has been modified. One example of this approach is the ecological mangrove regeneration method which recommends the following steps, to be undertaken using healthy mangroves of the surrounding area as a reference:

1. Assess the ecology, especially reproduction and distribution patterns, of the mangrove species at the disturbed site;
2. Map the topographical elevations and hydrological patterns that determine how seedlings should establish themselves at the site;
3. Assess the changes made to the site that currently prevent the site from recovering by itself;
4. Design a regeneration plan that begins by regenerating the normal range of elevations and tidal hydrology at the site; and
5. Monitor the site to determine if the regeneration has been successful in light of the original objectives.

The actual planting of seedlings is a last resort, since it fails in many cases; it should be considered only if natural recruitment of seedlings fails to reach the restoration objective (Lewis & Roy, 2015)

## 2.3 Relative Density

Relative density is the ratio of the density (mass of a unit volume) of a substance to the density of a given reference material. Specific gravity usually means relative density with respect to water. The term "relative density" is often preferred in scientific usage. It is defined as a ratio of density of particular substance with that of water.

If a substance's relative density is less than one then it is less dense than the reference; if greater than 1 then it is denser than the reference. If the relative density is exactly 1 then the densities are equal; that is, equal volumes of the two substances have the same mass.

Relative density can be calculated directly by measuring the density of a sample and dividing it by the (known) density of the reference substance. The density of the sample is simply its mass divided by its volume (Schetz et al;1999)

## 2.4 Relative Frequency

Relative frequency is the frequency of a given species expressed as a percentage of the sum of frequency values for all species present

Relative frequency = (number of trials that are successful)/(total number of trials)

## 2.5 Relative Dominance

Relative dominance is the basal area of a given species expressed as a percentage of the total basal area of all species present.

## 2.6 Important Value Index (IVI)

The sum of relative density, relative frequency and relative dominance is termed as Important value Index and it lies between 0 and 300.

## 2.7 Effects of Salinity

The BSMF is divided into three subsystems almost in a north-south direction where salinity varies due to hydrological regimes

- The eastern subsystem is situated between Passur and Baleswar rivers and receives freshwater from the Ganges through Gorai-Madhumati (which holds little freshwater during the dry period) and lower Meghna. The subsystem is of low salinity (Oligohaline, <5%).
- The central subsystem is located west of Passur and east of Sipsa. The Passur is connected with the Ganges through the Gorai River. However, the connection is blocked in the lean period by sand bars (chars). Due to reduced flow in the Ganges, the catchment area is extensively sedimented resulting in degradation of BSMF mainly due to increasing salinity (Mesohaline, 5% to <18%).
- Western subsystem is located in the west of Sipsa river to the east of Raimangal-Harin Bhanga river along the border. The subsystem originated from several perennial water bodies (moribund delta). The Sipsa is connected with Passur which is already with low freshwater flow.

Thus, the system does not receive any surface water from upstream during the dry period except local run off. Seawater intrudes making the subsystem saline (Polyhaline, 18% to 30%). In the northern part (eastern and central subsystem) of BSMF, water salinity varies from 4% to 28%in April and May, while in the post-monsoon it is 1% to 9% (Siddiqi, 1992). In a period of eight months (from September to May), water salinity increased three to eight-fold, while the soil salinity increased two to five-fold(Karim, 1994; Aziz and Paul, 2015).

# 3. Materials and Methods

## 3.1 Study Area

The Sundarban forest in Bangladesh part is at 21°38′10.18″ and 22°29′51.65″ N and 89°02′22.87″ and 89°53′13.93″ E from Harinbhanga River to the west of Baleswar river in the east .The forestland surface is flat and ground elevation is about 0.9 to 2.11 m above the mean sea level (Khan, 2011, Aziz and Paul, 2015)

This forest is situated in the warm, humid tropical region where mean annual minimum and maximum temperatures are 21 and 30 °C, respectively, mean annual relative humidity varies from 70% to 80% and annual rainfall varies from 1640 and 2000 mm (Aziz and Paul, 2015)

My study was conducted in Karamjol and Ghagramari areas of Sundarbans Reserve Forest (SRF) from March to December 2016. Karamjol and Ghagramri area are within the oligohaline zone of the Sundarbans Reserve Forest (SRF). These two areas receive regular tidal inundation through the River Passur.

Firstly I randomly established three plots in Karamjol area and two plots in Ghagramari area, which are located in the oligohaline zone of the Sundarbans. The number of the plots differed between the areas because of the accessibility of the stands. Within each sample plot of 20 m × 20 m, we also randomly established 2 sub-plots as regeneration plots with an area of 1 m × 1 m each. The size of the plots differed between plots and sub-plots because of the differences in size and density of the mature trees and seedlings. All plots were established about 200 meters away from the shore of the river for avoiding potential destruction of the plots due to river erosion and damages due to storms.

## 3.2 Materials

Several materials have been used along this data collection. Tape measurement for plot and transets establishment, diameter tape for DBH measurement, and compass for guide the pathway, Global Positioning System (GPS) for coordinate recorded. A digital Vernier caliper was used to measure $D_{0.1H}$ of the seedlings. Soil salinity was estimated by a handheld salinity meter (Model No. BK8391).

## 3.3 Data Collection

All trees taller than 150 cm in the study plots were numbered and height (H) and diameter at breast height (DBH) were measured. Within each regeneration plot, all the regenerating seedlings were marked, counted, and identified to species level. Then height and stem diameter at $H/10$ ($D_{0.1H}$) were measured in March 2016. Following Stoddard and Stoddard (1987) we classified the regeneration classes (RC) of the seedlings: RC1 is shorter than; 40 cm and RC2 is taller than or equal to 40 cm, but shorter than150 cm, and RC3 (>150 cm). According to Cintron and Schaeffer-Novelli, 1984, structural index was calculated: importance value, $I_v$: relative density + relative frequency + relative dominance.

## 3.4 Analysis of the Data

The data gathered were types of species, DBH, Height. Mean of stand DBH, mean of stand height, basal area and DBH size class distribution were calculated for each mangrove tree species found in the study area. I also calculated mean seedling height and mean $D_{0.1H}$ to calculate relative density, relative frequency and relative dominance.

The ecological importance of each species was calculated by summing its relative density, relative frequency and relative dominance. The complexity indexes of the forests were obtained as the product of a number of species, basal area, maximum tree height (m).

Density was measured species wise and total in each plot as follows:

Density of each species (no/ha) = no. x 10,000 $m^2$ / area of plot in $m^2$

Total density of all species = sum of all species densities

Basal area was measured species wise and total in each plot as follows:

Basal area ($m^2$) of each species = 0.005 x DBH

Total basal area of all species ($m^2$/ha) = sum of all species basal area / area of plot in $m^2$ x 10,000 $m^2$

Relative density = no. of individuals of a species / total no. of individuals of all species x100

Relative dominance = total basal area of a species / basal area of all species x 100.

Relative frequency = frequency of species/ total frequency of all species in different plots x 100

Importance value of a species = relative density + relative dominance + relative frequency

# 4. Result and Discussion

The mangrove species which are present in the study area is presented in Table 1. I found six mangrove mature tree species belonging to five families. These are *Heritiera fomes, Avicennia officinalis, Excoecaria agallocha, Bruguiera sexangula, Xylocarpus mekongensis, and Aglaia cucullata*. I also found four mangrove regeneration species: *Heritiera fomes, Bruguiera sexangula, Excoecaria agallocha* and *Aglaia cucullata.*

**Table 1.** Mangrove species and regeneration recorded in the oligohaline zone of the Sundarbans.

| Mature mangrove trees | | | Mangrove regeneration | | |
|---|---|---|---|---|---|
| Sl No | Species | Family | Sl No | Species | Family |
| 1 | *Heritiera fomes* Buch-Ham. | Malvaceae | 1 | *Heritiera fomes* Buch-Ham. | Malvaceae |
| 2 | *Excoecaria agallocha* L. | Euphorbiaceae | 2 | *Bruguiera sexangula* (Lour.) Poir. | Rhizophoraceae |
| 3 | *Bruguiera sexangula* (Lour.) Poir. | Rhizophoraceae | 3 | *Excoecaria agallocha* L. | Euphorbiaceae |
| 4 | *Avicennia officinalis* L. | Avicenniaceae | 4 | *Aglaia cucullata* (Roxb.) Pellegr. | Meliaceae |
| 5 | *Xylocarpus mekongensis* J. Koenig | Meliaceae | | | |
| 6 | *Aglaia cucullata* (Roxb.) Pellegr. | Meliaceae | | | |

The composition of mangrove species, relative dominance, density, frequency and importance values of these species are presented in Table 2. Results showed that the composition of mangroves differed significantly between the study sites and species. At Karamjol site, *H. fomes* had the highest density (68.1%) and the importance value is 136.6%. Meanwhile, *A. officinalis* had the significance lowest density with recorded values of 0.4% and X. mekongensis had the less important value of 12.7%. In contrary, *X. mekongensis* had the highest density

(36.6%) and *A. officinalis* had the highest important values (102.7%) in Ghagramari site whereas B. Sexangula had the lowest density (0.8%) and importance value (12.2%).

**Table 2.** Specific (and relative) density, basal area (and derived % dominance), and relative frequency of mature trees in mangrove communities along the oligohaline zone of Sundarbans. Relative values are expressed as %.

| Site | Species | Specific density (relative %) ($ha^{-1}$) | Relative frequency (%) | Basal area (dominance %) ($m^2\ ha^{-1}$) | Importance value $I_v$ | Mean stand H (m) | Mean stand DBH (cm) |
|---|---|---|---|---|---|---|---|
| Karamjol | *H. fomes* | 1975 (68.1) | 22.2 | 10.9 (46.3) | 136.6 | 7.0±0.4 | 7.9±0.5 |
| | *B. sexangula* | 450 (15.5) | 22.2 | 8.6 (36.6) | 74.3 | | |
| | *E. agallocha* | 375 (12.9) | 22.2 | 1.8 (7.8) | 42.9 | | |
| | *A. officinalis* | 12.5 (0.4) | 11.1 | 1.9 (8.2) | 19.7 | | |
| | *A. cucullata* | 62.5 (2.2) | 11.1 | 0.1 (0.5) | 13.8 | | |
| | *X. mekongensis* | 25 (0.9) | 11.1 | 0.2 (0.7) | 12.7 | | |
| Ghagramari | *A. officinalis* | 275 (17.9) | 22.2 | 20.0 (62.6) | 102.7 | 13±2.1 | 13±1.8 |
| | *X. mekongensis* | 563 (36.6) | 22.2 | 7.2 (22.5) | 81.3 | | |
| | *H. fomes* | 350 (22.8) | 22.2 | 3.7 (11.7) | 56.6 | | |
| | *E. agallocha* | 338 (22.0) | 22.2 | 1.0 (3.0) | 47.2 | | |
| | *B. sexangula* | 13 (0.8) | 11.1 | 0.1 (0.3) | 12.2 | | |

For the combined data of both Karamjol and Ghagramari, in term of species, the density was in the order of H. fomes > *X. mekongensis* > *E. agallocha* > *A. officinalis* > *B. sexangula* > *A. cucullata*.

In the regenerating seedling populations, four mangrove species namely *H. fomes*, *E. agallocha*, *B. sexangula*, and *A. cucullata* belonging to four families were recorded in the study area. The mean seedling density (±SE) of the study area was 254000 ±58270 $ha^{-1}$, the mean height (±SE) was 39.3 ± 2.5 cm, and the mean $D_{01H}$ (±SE) was 5.0 ± 0.2 mm. The preponderance of *H. fomes* regeneration gives rise to a high value of its importance value index ($I_v$ = 200.0) in the study area (Table 3). The importance value index for the regeneration of *B. sexangula*, *E. agallocha*, and *A. cucullata* were 81.1, 13.1, and 5.8, respectively. The specific density and relative dominance of *H. fomes* in the studied area was 162000 $ha^{-1}$ and 77.7%, respectively. Based on the specie's importance value, *H. fomes* was the principle mangrove regeneration in the mangrove communities along the oligohaline zone of Sundarbans. Similarly on the basis of relative density, relative frequency and overall importance value index, *B. sexangula* and *E. agallocha* were the species that were secondary in dominance among the mangrove regeneration.

**Table 3.** Structural composition of mangrove regeneration in the oligohaline zone of the Sundarbans for a combined data of Karamjol and Ghagramari sites.

| Species | Specific density ($ha^{-1}$) | Relative density (%) | Relative frequency (%) | Relative dominance (%) | Importance value $I_v$ | Mean $H$ (cm) | Mean $D_{0.1H}$ (mm) |
|---|---|---|---|---|---|---|---|
| *H. fomes* | 162000 | 68.9 | 53.3 | 77.7 | 200.0 | 55.7 ± 5.4 | 6.4 ± 0.3 |
| *B. sexangula* | 75000 | 23.7 | 38.3 | 19.0 | 81.1 | 31.4 ± 2.2 | 4.0 ± 0.3 |
| *E. agallocha* | 16000 | 7.0 | 5.0 | 1.2 | 13.1 | 10.0 ± 0.2 | 2.5 ± 0.1 |
| *A. cucullata* | 1000 | 0.4 | 3.3 | 2.1 | 5.8 | 52.0 ± 2.5 | 3.6 ± 0.1 |

The regeneration characteristic of seedling species is described in terms of RCI (< 40cm in height), RCII (40 – 150cm) which differ significantly in densities and size class in two sites. The number of occurrence of both RCI and RCII was significantly higher in Karamjol (151400 and 137100 seedlings per ha) than Ghagramari site (60000 and 113300 seedlings per ha) (Table 4).

**Table 4.** Regeneration classes (RCs) in mangrove forest stands in the oligohaline zone of the Sundarbans. RC1 and RC2 corresponded to seedling heights of < 40 cm and between 40 cm and 150 cm, respectively.

| Site | Species | Seedling density | | | |
|---|---|---|---|---|---|
| | | RC1($ha^{-1}$) | RC2 ($ha^{-1}$) | Sum ($ha^{-1}$) | Proportion (%) |
| **Karamjol** | *H. fomes* | 47140 ± 27660 | 135700 ± 60230 | 182800 ± 66280 | 63.4 |
| | *B. sexangula* | 104200 ± 34920 | 0 | 104200 ± 34920 | 36.1 |
| | *E. agallocha* | 0 | 0 | 0 | 0 |
| | *A. cucullata* | 0 | 1429 ± 1429 | 1429 ± 1429 | 0.5 |
| | Sum | 151400 ± 44550 | 137100 ± 60240 | 288500 ± 74930 | 100 |
| | % Proportion | 52.5 | 47.5 | 100 | |
| **Ghagramari** | *H. fomes* | 0 | 113300 ± 25800 | 113300 ± 25800 | 65.4 |
| | *B. sexangula* | 6667 ± 7598 | 0 | 6667 ± 7598 | 3.8 |
| | *E. agallocha* | 53330 ± 30390 | 0 | 53330 ± 30390 | 30.8 |
| | *A. cucullata* | 0 | 0 | 0 | 0 |
| | Sum | 60000 ± 31320 | 113300 ± 25800 | 173300 ± 40580 | 100 |
| | % Proportion | 34.6 | 65.4 | 100 | |

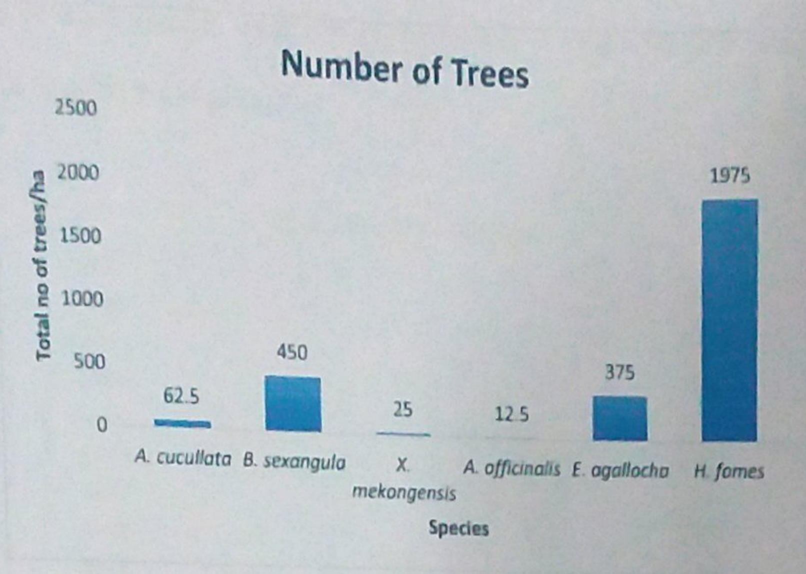



**Fig1**: Number of trees/ha in Karamjol

This figure showed that *H. fomes* was the most abundant tree with 1975 trees/ha followed by *B. Sexangula*(450 trees/ha), *E. agallocha* (375 trees/ha), *A. cucullata* (62.5 trees/ha), *X. mekongensis* (25 trees/ha) and *A. officinalis* (12.5 trees/ha) in Karamjol.

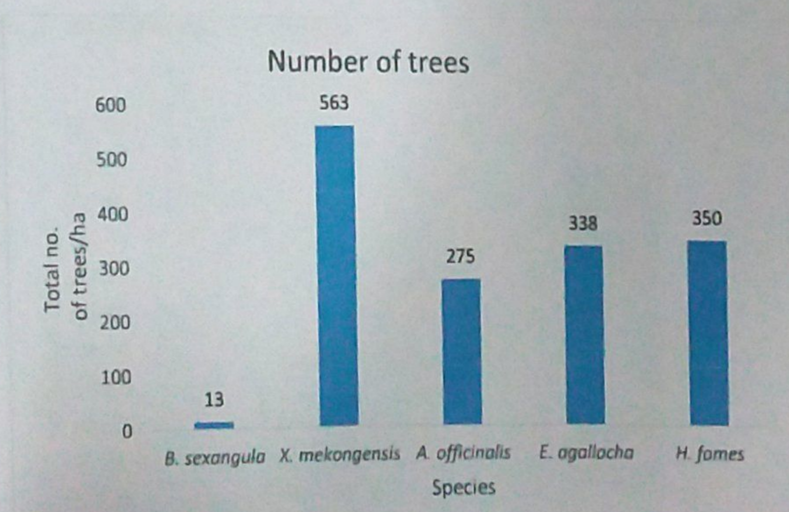



**Fig 2**: Number of trees/ha in Ghagramari

This figure showed that *X. mekongensis* was the most abundant tree with 563 trees/ha followed by *H. fomes* (350 trees/ha), *E. agallocha* (338 trees/ha), *A. officinalis* (275 trees/ha) and *B. sexangula* (13 trees/ha) in Ghagramari.

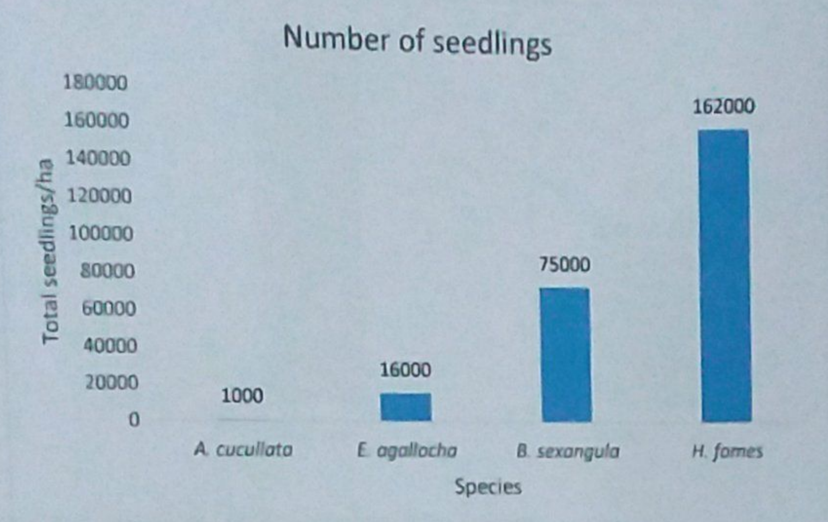



**Fig 3:** Number of seedling per ha for both Karamjol and Ghagramari.

We can see from this figure that the individual stand density is greater for *H. fomes* followed by *B. sexangula, E. agallocha* and *A. cucullata.*

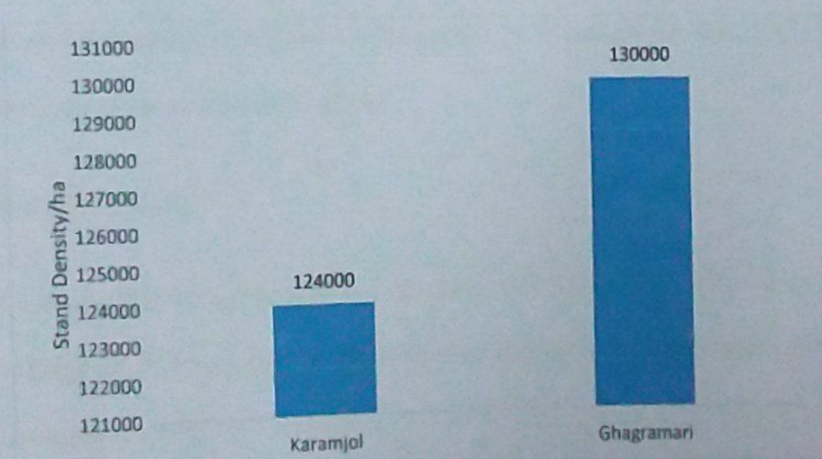



**Fig 4:** Seedling Stand Density/ha in Karamjol and Ghagramari

The density of mangrove Seedlings were 124000 seedlings/ha and 130000 seedlings/ha for Karamjol and Ghagramari respectively.

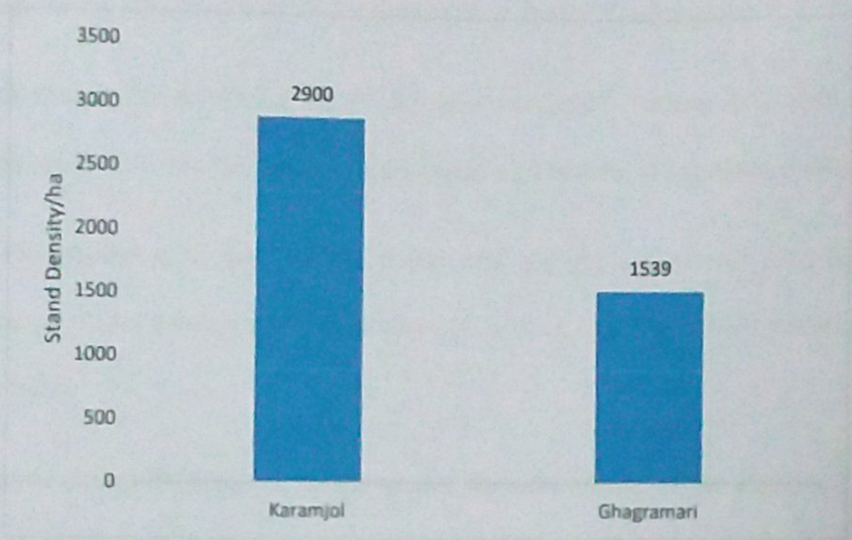



**Fig 5:** Tree Stand Density/ha in Karamjol and Ghagramari

The density of mangrove trees were 2900 trees/ha and 1539 trees/ha for Karamjol and Ghagramari respectively.

From the figure 4 and 5, we have found that tree density is higher in Karamjol. On the other hand seedling density is higher in Ghagramari. So it can be say that, higher number of mature trees reduces the number of seedling.

## Community Structure:

In Karamjol, the highest total basal area was *H. fomes* with 10.9 $m^2ha^{-1}$ followed by 8.6 $m^2ha^{-1}$ *B. sexangula* (Table 2). *H. fomes* also be the dominance species in this study area while the lowest total of dominance recorded by *A. cucullata.*

But in the Ghagramari, the highest total basal area was *A. officinalis* with 20.0 $m^2ha^{-1}$ followed by 7.2 $m^2ha^{-1}$ *X. mecongensis* (Table 2). *A. officinalis* also be the dominance species in this study area while the lowest total of dominance recorded by *B. sexangula*.

Total specific density for Karamjol study area was 2900 $h^{-1}$. Meanwhile, total importance value for this study area was 300 with *H. fomes* be the highest total of importance value.

In case of Ghagramari study area, we found that total specific density was 1539 $ha^{-1}$ whereas total importance value for this study area was 300 with *A. officinalis* be the highest total of importance value.

Figure 6 shows scatter diagrams of height against diameter ($D_{0.1H}$) of the mangrove seedlings. There was no clear relationship between height and diameter of *H. fomes* seedlings (Fig. 6a), whereas, there is a positive relationship between height and diameter of *B. sexangula* seedlings (Fig. 6b).

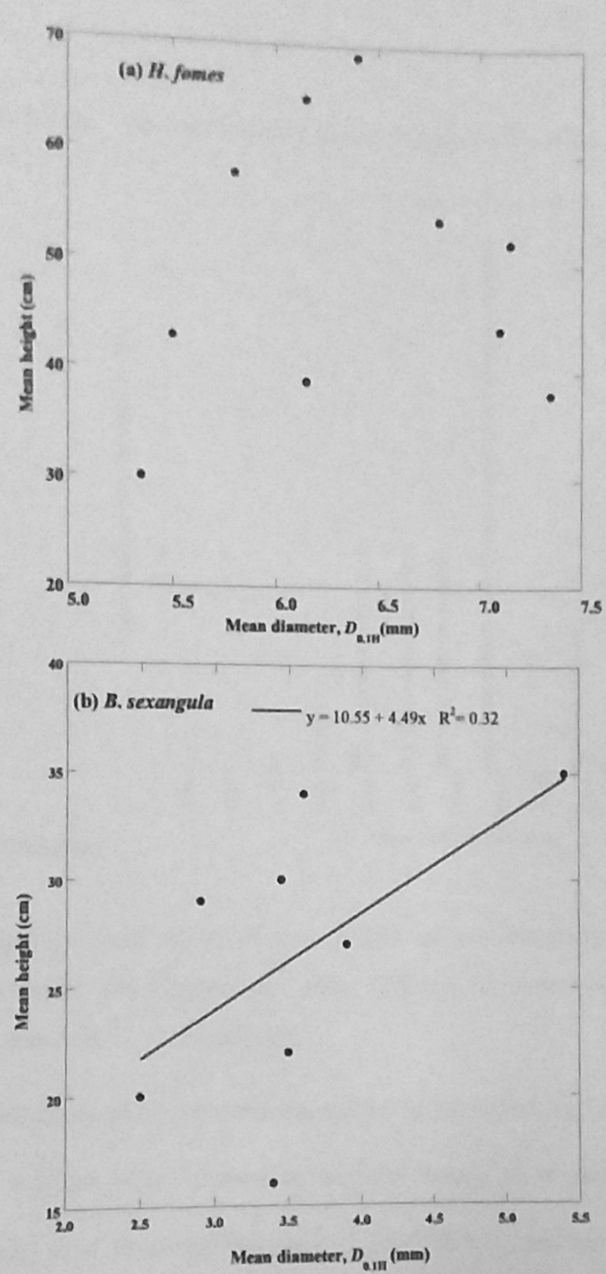
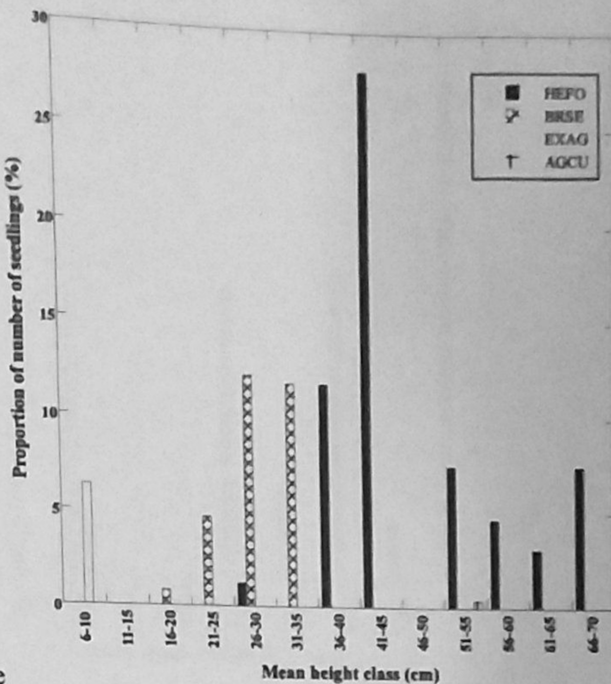



**Fig. 6**: Relationships between mean stem diameter at *H*/10 height and mean height of a) *H. fomes* and b) *B. sexangula*, the dominant mangrove regeneration in the study area.

Figure 7 shows a combined distribution patterns of seedling heights for the mangroves in the study area at Karamjol and Ghagramari areas. Though height class distribution of the mangrove regeneration did not show J or reverse J shaped curve (Fig 7), about 48% and 65% of the total individuals reached more than 40 cm in height i.e., RC2 class of the seedlings at Karamjol and

Ghagramari area, respectively. This may indicate that survival ability of the seedlings to the next




stage of its growth is moderate

**Fig.** 7: Relative frequency distribution of tree height of the mangrove regeneration for a combined data of Karamjol and Ghagramari sites. (HEFO: *H. fomes*, BRSE: *B. sexangula*, EXAG: *E. agallocha*, and AGCU: *A. cucullata*).

Figure 8 shows that the study plots were dominated by larger sized seedlings in terms of stem diameter and showed a trend of a J-shaped curve. The largest sized seedlings in the studied mangrove areas belonged to *H. fomes* having $D_{0.1H}$ (7.2 ± 0.08 mm) and height (64 ± 9.6 cm) and the second largest seedlings were *B. sexangula* with $D_{0.1H}$ (5.4 ± 0.6 mm) and height (35 ± 0.5 cm).

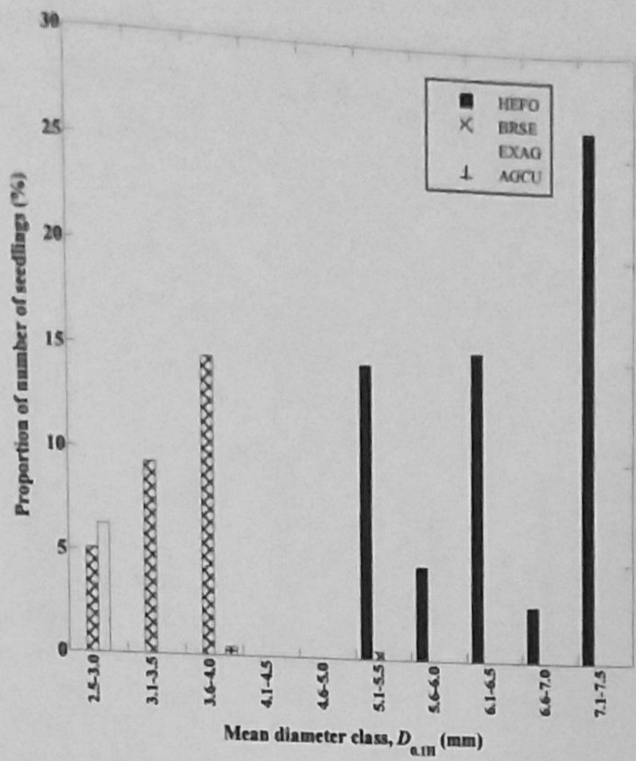



**Fig. 8:** Relative frequency distribution of stem diameter ($D_{0.1H}$) of the mangrove regeneration for a combined data of Karamjol and Ghagramari sites. (HEFO: *H. fomes*, BRSE: *B. sexangula*, EXAG: *E. agallocha*, and AGCU: *A. cucullata*).

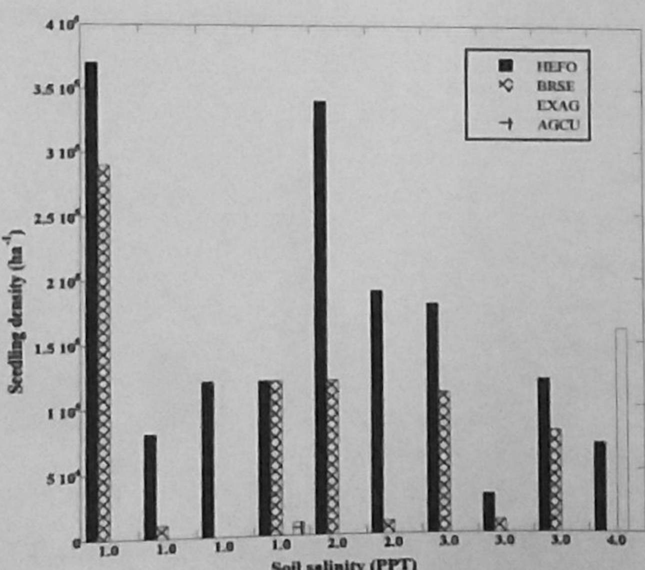


**Fig. 9:** Density of mangrove regeneration by species in relation to soil salinity for a combined data of Karamjol and Ghagramari sites. (HEFO: *H. fomes*, BRSE: *B. sexangula*, EXAG: *E. agallocha*, and AGCU: *A. cucullata*).

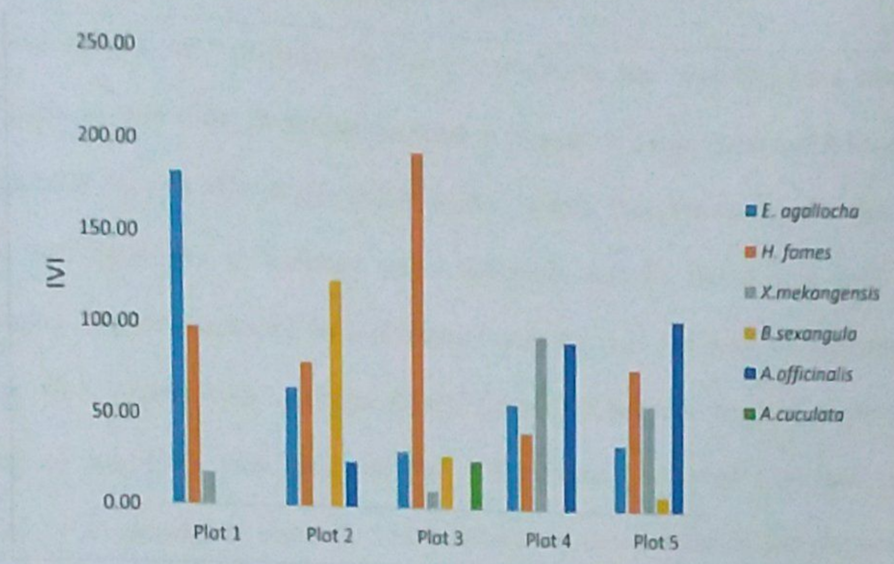



**Fig: 10** IVI values of individual species for each plot

For the combined data of Karamjol and Ghagramari, for both cases of trees and seedlings, it is seen that *H. fomes* had the highest importance value followed by *B. sexangula, A. officinalis, E. agallocha, X. mekongensis* and *A. cucullata.*

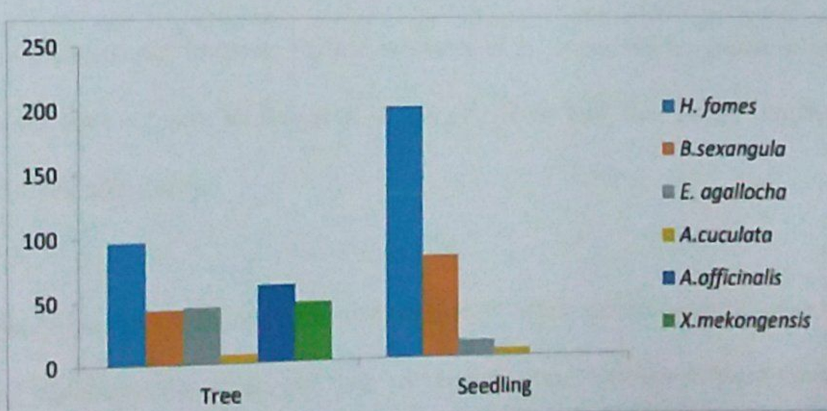



**Fig:11** IVI values of mature trees and seedlings for the combined data of Karamjol and Ghagramari area

The highest total of 162000 seedlings was recorded for *H. fomes*. From this data, total number of seedling per hectare showed a good regeneration potential.

Basal area is the cross-sectional area of a single tree stem, including bark, measured at breast height, or sum of the cross-sectional areas of all stems in a stand measured at breast height and expressed per unit of land area (Kasawaniet.al., 2007). From the result, *H. fomes* was the highest total basal area in Karamjol and *A. officinalis* was the highest total basal area in Ghagramari. The total basal area for the Karamjol study site is 23.5 $m^2$ ha-1 and Ghagramari site is 32 $m^2$ ha-1. Highest total basal area showed the species has wide range of diameter. If the diameter of tree wider, total basal area also will increase. The lowest total basal area was recorded by *A. cucullata* in Karamjol which species was only founded in one plot and low of distribution. In Ghagramari, the lowest total basal area was recorded by *B. sexangula.*

Density is defined as the number of plants or specific plant parts per unit area of ground surface. The counting plant on sample plots of a known area is a simple means of deriving density estimates (Kasawani et.al., 2007). For the combined study area of Karamjol and Ghagramari, *H. fomes* will be dominance seedling species because of high total number seedlings estimation per hectares. 162000 estimates of *H. fomes* will be grown in one hectares area. Density does not give an indication of the size of the individuals unless counts are made and recorded by size classes.

Meanwhile, frequency is the number of plots on which species occurs divided by the total number of plots sampled. Frequency data are used to detect changes in plant abundance and distribution on a range site over time or to identify differences in species responses to varying management practices (Kasawani et.al., 2007). Selection of the proper plot size is extremely important for estimating frequency, and more than one plot size may be needed for varying plant species and plant distribution. Frequency data are easily obtained, but numerous sample plots must often be evaluated before reliable estimates can be derived. We found that most of the species in mangrove forest give frequency above 0.05, which is supported by the findings of Kasawani et.al., (2007) who was reported that Most species in Mixed Mangrove Forest give frequency above 0.05. This indicates that all plot samples found mangrove species. Most of the plot will dominate with *H. fomes* seedling, because this species showed the highest total of frequency (0.53).

One observation that could be considered from Figure 8 is that regeneration having larger diameters shows higher density than seedling with small diameter. However, the relationship is not straight forward and when put into size-frequency diagrams it is not possible to obtain a clear J shaped or reverse J shaped curve. Theoretically, in an uneven-aged forest there may be a normal series of size-gradations, depicted by the reverse J shape curve (Joshi and Ghose, 2014), but in case of regeneration of the present study, there is no evidence for the shape of the size-frequency of mangrove regeneration.

In Karamjol, we found that *H. fomes* indicates the highest total of the important values whereas *A. officinalis* shows the highest importance value in Ghagramari area.

In case of seedling for a combined data of Karamjol and Ghagramari, *H. fomes* indicates the highest total of the important values compared to other mangrove seedlings which was derived from the total relative density, relative dominance and relative frequency. If the species showed a higher important value indicated that species was abundance and can be found diversely in the study area as pioneer species (Kasawaniet.al., 2007).

For the combined data of Karamjol and Ghagramari, we found that the dominance tree species is *H. fomes* as well as the dominance seedling species is also *H. fomes* whereas *E. agallocha* is the second dominance tree species in my study area. But in case of seedling regeneration, we found that *B. sexangula* is the second dominance seedling species in my study area. So it goes to without say that *H. fomes* have the highest regeneration ability than the others species followed by *B. sexangula, E. agallocha* and *A. cucullata*.

From the figure 9, we can see that seedling density is very high in low salinity area compared to high salinity area.

Bowman (1917) mentioned almost same thing that, salinity is an important factor regulating growth, height, survival and zonation of the mangroves (Chowdhury & Acharya, 1994) and Clarke & Hannon (1970) also reported that salinity to have the major effect on the mangrove zonation patterns and is correlated with tree height gradients(Rashid et al., 2008).

The Sundarban has been divided into three ecological zones, based on salinity and distribution of species composition such as i) less saline/fresh water zone, ii) moderately salt water/moderately saline zone and iii) salt water zone/strong by saline zone(Rashid et al., 2008).

Seedling density at Karamjol stands (288500±74930 $ha^{-1}$) had a significantly higher ($p < 0.05$) density than seedling density at Ghagramari stands (173300±40580 $ha^{-1}$). Out of total regeneration in both stands, *H. fomes* occupied 63.4% and 65.4% in Karamjol and Ghagramari areas, respectively (Table 4). The occurrence of both RC1 and RC2 were higher in Karamjol area than that in Ghagramari area. *H. fomes* was the dominant mature mangrove species at Karamjol stands and the most abundant seedlings in the regeneration layer was also *H. fomes.* Whereas, *A. officinalis* was the dominant mature mangrove species at Ghagramari stands and had the most abundant seedlings of *H. fomes.* The order of seedlings recruitment in the mature mangrove stands at Karamjol and Ghagramari areas is *H. fomes*>*B. sexangula*>*A. cucullata*, and *H. fomes*>*E. agallocha* >*B. sexangula* in two areas, respectively.

These observations suggested that mangrove species diversity may become lower in Ghagramari area in the long run. For understanding further processes of tree regeneration, long-term observation of the seedling communities may be required.

# 5. Conclusion

Natural regeneration depends on the condition of the mangrove forest. Regeneration status may differ among different species due to various factors, such as structure of the seed, seed buoyancy, salinity level and other physic – chemical properties of the substrate. I tried to provide new and updated information about the regeneration capacity of mangrove species and the species diversity of the mature stands. This study has found that newly recruited regeneration has differed from the existing dominate mature species in some of the study area. It may be concluded that natural regeneration of mangrove species depends on physical, chemical and/or biological conditions of the mangrove forest, because not all mature mangrove species recolonize proportionately with the previous generation at the same site.

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