
Analysis of vegetation structure causing top-dying in mangrove forest trees in the Sundarbans in Bangladesh

Awal Mohd Abdul

Environmental Scientist, Founder & Chief Advisor, Health & Pollution Research Farm, Long Island City, New York, USA

Email address:

abdul_awal2004@yahoo.com

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Abstract: Sundarbans is the largest, biologically richest, and most extensive mangrove forest in the world (Christensen, 1984; Seidensticker and Hai, 1983; Hussain and Karim, 1994). *Heritiera fomes* (Sundri) is the predominant tree species, supporting about 65% of the total merchantable timber (Chaffey *et al.*, 1985, and Siddiqi, 2001). A unknown and serious-killer disease (top dying) of *H. fomes* in Sundarbans is affecting millions of the trees. An inventory by Chaffey *et al.*, (1985) revealed that there were about 45.2 million top dying trees in the Sundarbans of which 20 million had more than 50% of their crown affected by top dying. The loss of *H. fomes* will have a major impact on the Sundarbans mangrove ecosystem, which leads to economic losses. The vegetation structure was assessed in terms of tree height, bole diameter, species present, and regeneration status; and the intensity of top-dying within the plots was recorded on a rank scale. Most of the elements studied had no significant correlation with the top dying of *Heritiera fomes*. Of the hypotheses previously put forward to explain top-dying, the present results do not support enhanced salinity as the cause. It is likely that several of the above-mentioned environmental factors interact with each other to induce top dying in Sundri. However, the present results have showed that Sn, Exchangeable K, soil pH, Pb, Zn and Ni could be directly linked with top-dying of *Heritiera fomes* (Sundri) in Sundarbans, probably particularly by weakening the vigour of the trees and allowing other factors such as pathological agents to attack the plants.

Keywords: Causal Factors, Seedling and Sapling Percentage, Trees Diameter, Height, Structure, Species Density, *Heritiera Fomes*, Mangrove, Sundarbans, Top-Dying

1. Introduction

Sundarbans is the largest, biologically richest, and most extensive mangrove forest in the world and representing 2.5 percent of the world's natural mangrove forest (Saha, 1991), the Sundarban natural mangrove forest is still the largest natural single tract of mangrove forest and habitats in the world (Christensen, 1984; Seidensticker and Hai, 1983; Hussain and Karim, 1994) with 10, 029 km² area. The total area of the part of Sundarban in Bangladesh is now about 6,017 km² (Imam, 1982; Christensen, 1984; Chaffey *et al.*, 1985), which arose due to the eastward shift of the Ganges (Blasco, 1977; Naskar 1999; and Bakshi, 1954; Thom, 1982) in figure 1.0.

1.1. Vegetation

Based on protection for the diversity of its resources, the Sundarban was declared as a reserve in 1876 and also

declared as a world Heritage Site in 1997 (UNESCO,1997). Being situated in an important transition zone, this largest ecological unit was very rich in species and supported the greatest diversity of flora. According to Prain in 1903, the number of species of flora and fauna in Sundarbans was reducing even then. Sundri (*Heritiera fomes*) and tiger (*Panthera tigris*) have been listed as endangered in Bangladesh from early in the twentieth century (Champion, 1936).

Prain (1903) reported a total of 334 species of plants belonging to 245 genera and 75 families in the Sundarbans. The main tree species is *Heritiera fomes* ('Sundri') which is part of a genus that comprises of 29 species and are distributed throughout India, Bangladesh, Burma, Malaysia, New Guinea, the Pacific region, tropical Australia and Africa (Chowdhury, 1984), *Heritiera fomes* occurs in the Sundarbans, down the coasts of Burma and over large areas of the Asian sub-continent. The tidal

forests of the Bassein division of Burma contain large areas of Sundri forests (Kostermans, 1959). Sundri has a limited bio-geographic distribution, and seedlings do not establish themselves except under specific condition (Curtis, 1933). Sundri usually flowers in March–April and fruits, 4 cm in length and breadth, ripen during June–August. The species seeds well and does not show periodicity (Hassan, 1990; Howlader, 1973). There is a transverse ridge on the dorsal

surface of the Sundri fruits, which is characteristic of *Heritiera fomes* and does not occur on any other species of Sundri. A slight soaking favours germination of Sundri which is hypogenuous (Troup, 1921). Within a month the stem may reach a height of 46 cm or more, and the shout tap root may reach a length of about 20 cm, with a number of fairly long lateral roots (Troup, 1921).

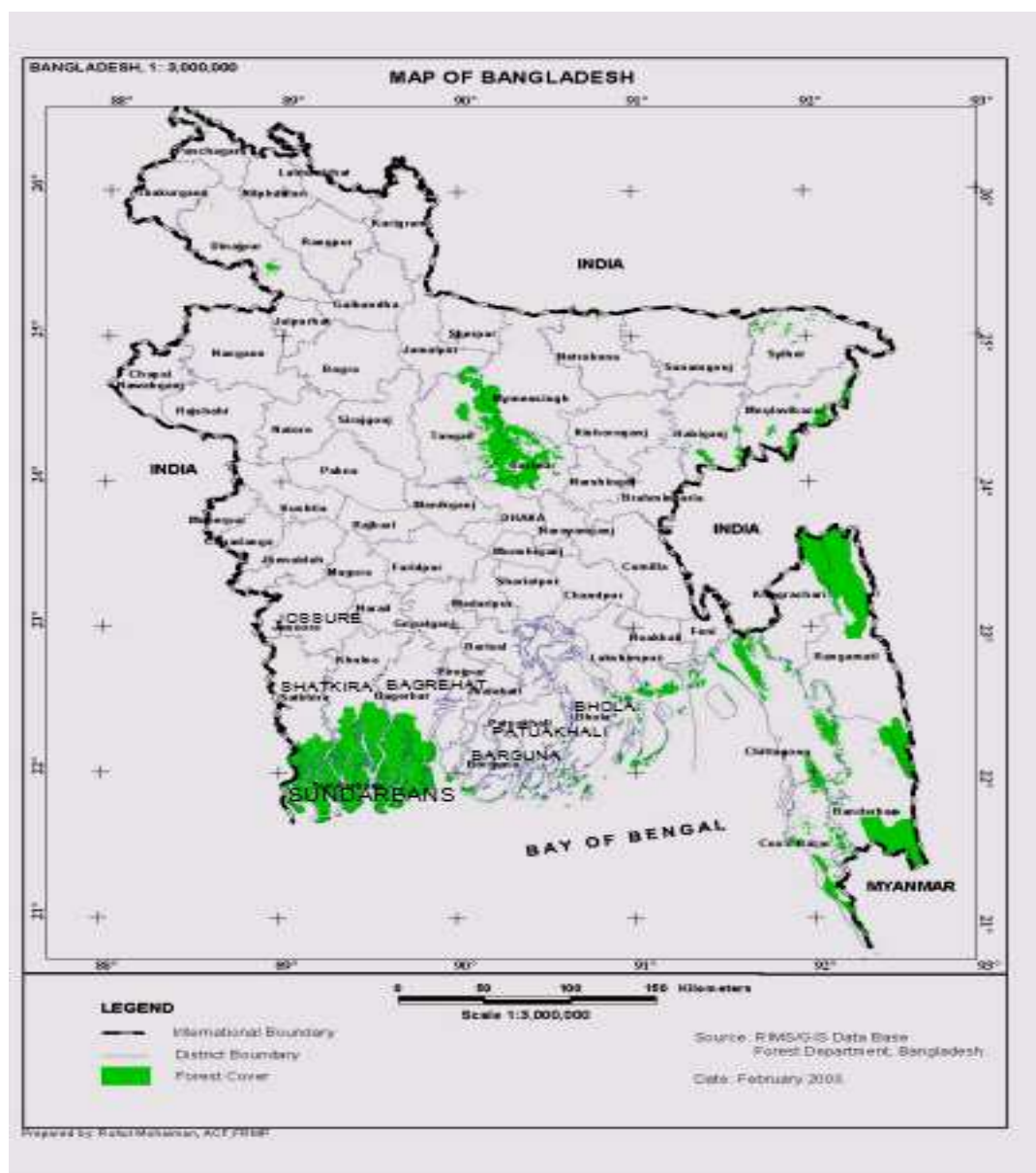


Figure 1.0. Map showing the administrative districts of Bangladesh, including the location of the Sundarbans (the shaded area in the south-west of the country)

The second dominant species in the Sundarbans is *Excoecaria agallocha* ('Gewa'), which occasionally grows 60 to 70 ft in height in the north-eastern parts of the forest. Normally, it reaches 30 to 35 ft high, depending upon the site and location within the forest. The 'Golpatta' (*Nipa fruticans*), occurs in low salinity estuaries and tidal channels throughout the Indo-Pacific (Khan, 1986). Other common species include *Imperata cylindrica*, which are

widespread and prevalent on mud flats (Khan, 1986). Large stands of *Sonneratia apetala* are found on newly accreted mudbanks and provide important wildlife habitats (Salter, 1984). A list of common important plants of Sundarban is given in Table 1.0.

The west Sundarbans occurs within the salt-water zone (Awal, 2007), which constitutes and supports sparse *Excoecaria agallocha* (Awal, 2007), a dense understory of

Ceriops decandra ('Goran'), and dense patches of *Phoenix paludosa* (Hantal palm) on drier soils (Awal, 2007), *Xylocarpus granatum* (Dhundal) and *Xylocarpus mekongensis* (Passur) and *Bruguiera gymnorrhiza* (Kankra) occur irregularly throughout the area (Awal, 2007),

Table 1.0. A list of common and important plant species of the Sundarban, listed by family, together with their scientific and vernacular names

Family	Scientific Name	Vernacular Name
Sterculiaceae	<i>Heritiera fomes</i>	Sundri
Euphorbiaceae	<i>Excoecaria agallocha</i>	Gewa
Sonneratiaceae	<i>Sonneratia apetala</i>	Keora
	<i>Sonneratia caseolaris (acida)</i>	Ora
	<i>Xylocarpus mekongensis</i>	Possur
Meliaceae	<i>Xylocarpus granatum</i>	Dhundal
	<i>Amoora cucullata</i>	Amur
	<i>Hibiscus tiliaceus</i>	Bhola
Avicenniaceae	<i>Avicennia officinalis</i>	Baen
	<i>Bruguiera gymnorrhiza</i>	Kankra
Rhizophoraceae	<i>Ceriops decandra</i>	Goran
	<i>Rhizophora mucronata</i>	Garjan
Leguminosae	<i>Cynometra ramiflora</i>	Shingra
Malvaceae	<i>Pongamia pinnata</i>	Karanja
Myrsinaceae	<i>Aegiceras corniculatum</i>	Khalshi
Palmae	<i>Nypa fruticans</i>	Golpata
	<i>Phoenix paludosa</i>	Hantal
Combretaceae	<i>Lumnitzera racemosa</i>	Kirpa
	<i>Eriochloa procer</i>	Nolgash/Nol
Gramineae		Khagra
	<i>Saccharum cylindricum</i>	Ullu
	<i>Typha elephantina</i>	Hogla

(Source: Banik, 1995; Nazrul-Islam, 1995).

Sundri and Gewa cover most of the Sundarbans (Awal, 2007). Goran is a modified or adaptative and facultative mangrove species (Awal, 2007). It can grow in stunted form in more saline environments in the southern and south-western part of the Sundarbans (Awal, 2007). Its best growth and development occur in the north and north-eastern moderately fresh water and slightly saline water zones (Awal, 2007). Sundri, by contrast, prefers largely fresh water in which it resembles the mesophytes, but the species is adapted to the wet swampy condition of the Sundarbans by virtue of its leaves having partly xerophytic adaptations and plentiful pneumatophores which help cope with the saline swamps of the Sundarbans (Awal, 2007).

2. Methodology

In this avid research work the various field and laboratory methods used in this study will be discussed.

2.1. Field Sampling Methods

The Sundarbans Reserved Forest is located at the south west corner of the Ganges River Delta close to the Bay of Bengal, mainly on the sea-shore line, river banks, channels, and small creeks. The location of the Sundarbans within Bangladesh has been shown in Figure 1.0.

2.2. Site Selection and Location of the Study Area

General reconnaissance of possible sites was made by visiting all the possible regional areas before categorizing and selecting plots for sampling. It was decided to sample from the Chandpai area which is the mostly human accessible and ecologically polluted area. Three compartments from this regional area (range), namely numbers 26, 28 and 31, were selected because they were believed to represent a range of severity of top dying disease, based on relevant maps, documents, literature, consultations with forest professionals, and surrounding peoples. The location of these compartments within the Chandpai area, and the location of this area in the wider Sundarbans is shown in Figure 2.0. Among the three compartments, compartment number 26 was selected as an area highly affected by top-dying, where most of the trees were affected severely.

Compartment 26 had pronounced human activities, and also in places is undergoing rapid housing development involving extensive construction activities due to the presence nearby of the Range HQ office in Chandpai. Compartment number 28 was selected as a moderately affected area. This compartment has various human activities including boat making grounds, football-playing grounds, and cattle-grazing fields, all types of major soil erosion, a moderate amount of construction activities and the presence of communities of fishermen.

Compartment number 31 was chosen as being relatively little affected by top-dying disease. Of the three chosen compartments, the nearest compartment to Mongla port is compartment 31, with comparatively modest human activities, but which nonetheless involve clear-cutting of natural vegetation, replanting with other species rather than mangrove or other native species, all types of soil erosion, and construction activities present.

Within each of the three compartments, detailed observations of the regeneration and sampling of soil and water took place within three 20 m x 20 m plots, chosen to reflect a range of top dying intensities (High, medium and Low for that area). The sampling was conducted in a randomised block design, in that a plot was sited within a particular top-dying intensity block, but the precise location of that plot was randomised so as not to bias the detailed data collection. Thus in total nine plots were sampled, representing a range of top-dying intensities. Intensive field data collection was made among these nine selected plots. Observations were performed from observation towers during low and high tides, also traversing the forest floor and vegetation on foot, as well as using a speed boat, trawlers, country-boats, and a launch as required to gain access. All sampling was accompanied by Deputy Rangers, Foresters, and Forest guards armed with a rifle from the local office, Chandpai rang, Bangladesh Forest Department, to prevent a fatal attack by a Bengal tiger (*Panthera tigris*).

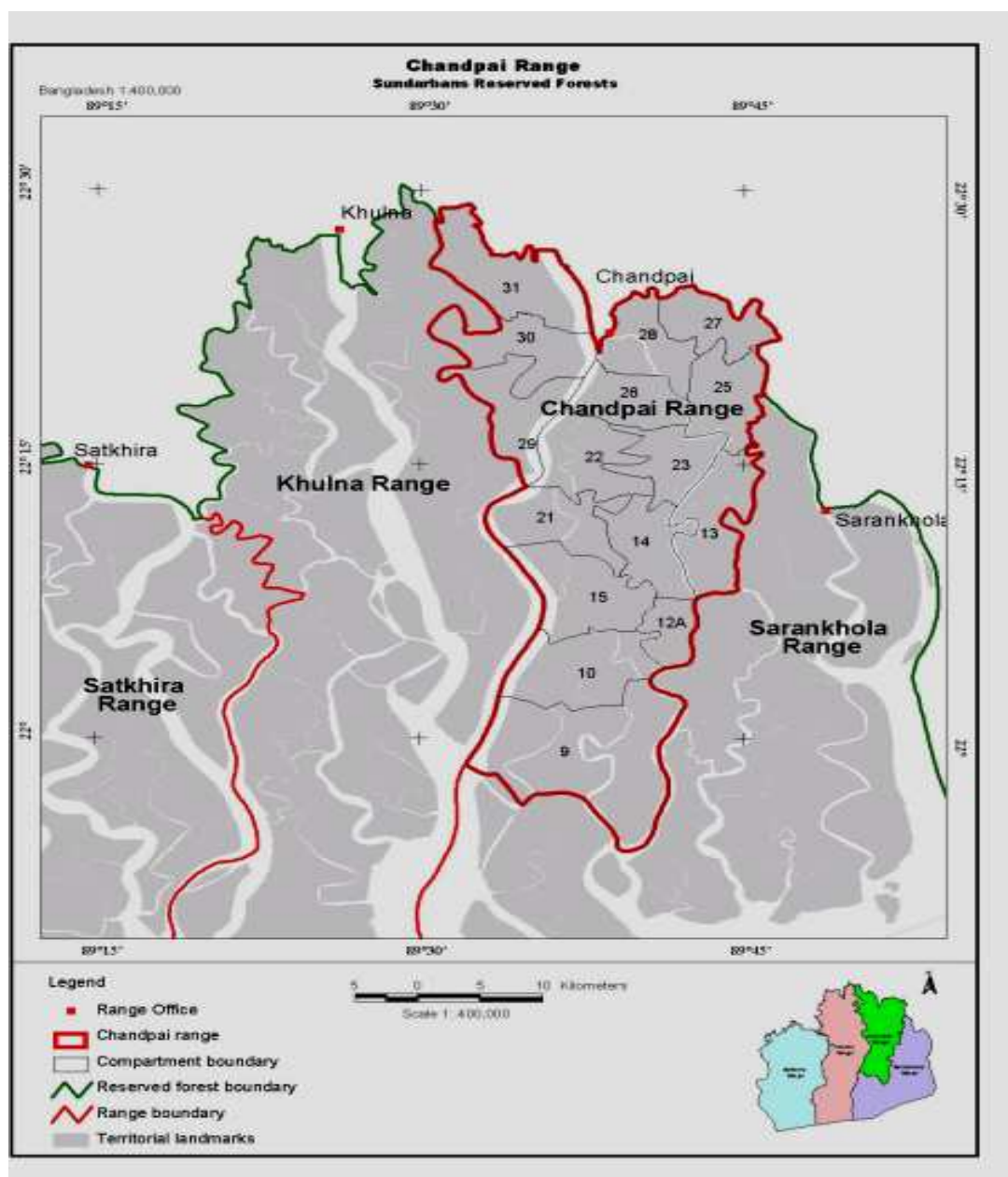


Figure 2.0. Map showing the location of the numbered compartments within the Chandpai area, and the position of this area relative to other parts of the Sundarbans in Bangladesh (darker shaded area).

Table 2.0. Data on locations of plots, as indicated by Geographical Position System (G.P.S).

Compartment Number.	Plot Number.	Geographical Position Systems (GPS) reading.	
		North latitudes	East longitudes
26	1	N 22° 32347'	E 089° 64470'
26	2	N22° 32977'	E089° 64276'
26	3	N 22° 33820'	E 089° 63504'
28	4	N 22° 36728'	E 089° 66538'
28	5	N 28° 36378'	E 089° 66918'
28	6	N 22° 36878'	E 089° 66291'
31	7	N 22° 42821'	E 089° 57611'
31	8	N 22° 42715'	E 089°580440'
31	9	N 22° 44201'	E 089° 58219'

Fieldwork was performed in October, 2003 to March, 2004. Locations of sampling points were determined using a Global Positioning System with a precision of 5-10 m (Table 2.0). For one typical plot, in compartment 31, the altitude was recorded as 4.4 m above sea level.

2.3. Vegetation Recording Methods in the Field

Within each of the nine 20mx20m plots, each adult tree was assessed for three parameters. The diameter at 1 m height was recorded (in cm) by using a measuring tape or slide callipers depending on girth. The tree height to the top of the crown was determined mainly by ocular estimation but some heights were checked by using Clinometers at a set distance of 20 m to test the accuracy of such ocular estimations.



Figure 3.0. Photograph showing the Sundarbans forest trees and understory vegetation. The adult trees behind the author are of *Heritiera fomes*. The forest floor shows dead leaves from trees affected by top-dying.

Finally, the status of the tree in respect of the amount of top-dying was assessed by using a four point qualitative scale of intensity, namely; not affected, little affected, moderately affected or highly affected by top-dying. This was later expressed as a semi-quantitative or rank scale of 0 to 3 respectively, so that a median rank value could be calculated and used as an index of top-dying intensity in that plot.

After that, the total number of seedlings (individuals of the tree species <1 m tall), and saplings (young trees >1 m tall with a diameter of trunk of < 10 cm), were counted within the plots. Care was taken to ensure that trees, saplings and seedlings were not counted more than once or missed in the counting process. After recording, adult trees were marked with white chalk to segregate those marked trees from other trees, seedlings and saplings; red paints were applied to all seedlings and saplings as they were recorded.

2.4. Soil and Water Sampling Methods

As stated above, from the three selected compartments, a total of nine plots of 20m x 20m were selected. From each of these plots, seven soil samples were collected; one from the centre of the plot, four (one each) from all the corners, and two from the middle sides of the plot. Therefore a total of 63 soil samples were taken. Also nine water samples were collected from nearby rivers, creeks or channels, one from the area of each of the sampled plots.

Soil samples were collected from 0-30 cm soil depth by using a stainless steel spatula and steel cylinder

($d=5.25$ cm), and all soil samples were kept in sealed plastic bags. Water samples were collected directly in pre-cleaned plastic-containers. Marking and labelling was performed with a detailed description of the selected sampling site on both the soil-containing plastic bags and water containers, and preserved in portable coolers until arrival at the laboratory at Dhaka University for initial chemical analysis. This field sampling method followed the W.H.O, U.K, and E.P.A systems of standard laboratory and field sampling principles, rules and regulations.

Rainfall for the area during sample collection was not notably different from the respective monthly averages for the Sundarbans of recent years; there was no heavy intensity of rainfall within one month before sampling (Awal, 2007).

2.5. Statistical Analysis

Data on frequencies of seedlings or saplings in each of the plots and compartments were tested by χ^2 contingency table analysis to determine whether there was an association between the selected plot type (severely, moderately or little affected by top-dying) and the three chosen compartments. A similar consideration of the different compartments as comprising one factor, and the plot type as a second, was used to test the pattern of elemental concentrations and other variables by a 2-factor analysis of variance test with replication. This allows an assessment of the significance, not only of the two factors separately but also of the interaction term linking the two factors. It should be noted that the plot type was not a strictly controlled factor, since the three categories of top-dying intensity were relative to each other within any one compartment and might not have been exactly equivalent between the three categories; interpretation of the results from these tests therefore needs to bear this in mind.

3. Result

3.1. Basic Information on the Sites

As indicated in section 2.1 while carrying out the field sampling certain observations were made on whether there was any sign of erosion taking place, and of whether there was evidence of siltation happening in the area of the plots. Therefore, field information and data have been recorded and summarized in Table 3.0 to know the exact information about presence of siltation (deposition of particles of 0.002mm to 0.06mm size), erosion, salinity (determined by taste), and regular inundation (four times in 24 hours; 2 high and 2 low tides) near to each (20 x 20m) plot. Siltation, all types of erosion, regular tides, and salinity were observed in all plot areas (and more generally in Sundarbans), but salinity intensity was somewhat greater in compartment 31 areas where top dying affected trees were scanty. This information is indicated in Table 3.0

Table 3.0. Signs of siltation, erosion, salinity and presence of regular inundation in the study areas of Chandpai Range in Sundarbans, Bangladesh.

Comp. No.	Plot No.	Presence of Siltation	Presence of Erosion	Presence of Salinity	Presence of Regular Inundation
26	1	√	√	√ (less)	√
26	2	√	√	√ (less)	√
26	3	√	√	√ (less)	√
28	1	√	√	√ (less)	√
28	2	√	√	√ (less)	√
28	3	√	√	√ (less)	√
31	1	√	√	√ (greater)	√
31	2	√	√	√ (greater)	√
31	3	√	√	√ (greater)	√

Overall, these results indicate that the normal processes found in mangroves are occurring in the Sundarbans, but the presence of erosion and salinity variation (as well as the moisture content data presented later) suggest that there are problems associated with water flow patterns.

3.2. Vegetation Parameters in the Different Areas and the Relative Incidence of Top-Dying

Firstly, this section will describe and summarise the structure and composition of the trees found in the different sample sites, before proceeding to analyse the incidence of top-dying and the regeneration by saplings and seedlings present in the various areas.

3.3. Tree Species Recorded

Table 4.0. Frequencies of the different tree species recorded in the plots sampled, and the total number of tree species per plot.

Comp:	26			28			31		
Plot:	1	2	3	1	2	3	1	2	3
Tree species:									
<i>Heritiera fomes</i>	82	67	76	57	47	58	21	37	27
<i>Excoecaria agallocha</i>	7	3	5	10	10	18	1	2	9
<i>Xylocarpus mekongensis</i>	0	1	0	0	0	0	3	1	13
<i>Amoora cucullata</i>	0	0	1	0	0	1	0	0	0
<i>Bruguiera gymnorrhiza</i>	0	0	0	0	0	0	4	0	2
<i>Avicenniaceae officinalis</i>	0	0	0	0	0	0	0	0	1
Total no. of individuals	89	71	82	67	57	77	29	40	52
Total no. of species	2	3	3	2	2	3	4	3	5

Less pronounced, but also evident, is the difference in the number of species per plot; there is a wider range of tree species found in compartment 31 compared to the others, although even here the number of species is modest (a maximum of five in one plot). The changing number of individuals could be a reflection of the effects of top dying, but could also be associated with features such as the accessibility of the compartment and therefore the frequency of illicit felling of trees, or other factors. The lower number of individuals in compartment 31 might be allowing other species to enter because of reduced competition, but again could be interpreted differently, for example the extra species being ones less commonly targeted by felling operations which allow species such as *Bruguiera gymnorrhiza* to have a selective advantage over *Heritiera fomes*.

The frequencies of the different species recorded in each of the nine plots sampled, together with the number of individuals and the number of different species per plot, are included in Table 4.0. Although several tree species were recorded within the study sites, the overwhelming majority of the trees recorded were of *Heritiera fomes* (Sundri).

There is little difference evident between the plots or compartments in terms of the preponderance of the one species *Heritiera fomes*. However, there are two trends apparent from the data in Table 4.0. Firstly, there was a very noticeable difference in the total number of individuals in the three compartments, with compartment 26 having most trees while compartment 31 had the fewest individuals. The differences between plots within any one compartment were much less marked.

3.4. Vegetation Structure

Besides the species composition in the various areas, it is also valuable to know what the vegetation structure is there. This can be represented by the parameters of the height of the trees, the average bole diameters of the trees, and also their average spacing and density. This information is summarized in Table 5.0. It is observed here that though the density in compartment 26 is the highest, the average bole diameter is greater in Compartment 28. The average and tallest tree heights vary considerably from plot to plot. The relationship between these parameters and the intensity of top-dying can be tested by correlations (Spearman's rank), and the results are summarized table 7.0.

Table 5.0. Parameters of the vegetation structure from the nine sampled sites.

Compartment and Plot No.	Average tree height (m)	Tallest tree height (m)	Average Bole diameter(cm)	Density (no. of trees per m ²)
C 26, Plot 1	17.55	67.0	29.62	0.222
C 26, Plot 2	8.80	25.0	30.37	0.177
C 26, Plot 3	6.60	20.0	25.70	0.205
C 28, Plot 1	8.28	40.0	40.01	0.167
C 28, Plot 2	11.42	30.0	54.35	0.142
C 28, Plot 3	8.50	25.5	39.48	0.195
C 31, Plot 1	5.81	15.0	37.81	0.072
C 31, Plot 2	6.64	11.5	28.85	0.100
C 31, Plot 3	10.64	40.0	32.17	0.130

3.5. Severity of Top-Dying in Different Plots and Compartments

Each individual tree, when it was being recorded, had an estimate made of the severity of top-dying affecting it. In order to be able to calculate an average value per plot, these qualitative assessment categories of severity were assigned a numerical score of 0--3.

Table 6.0. Average index scores of the severity of top-dying per tree for each of the plots sampled.

Compartment / Plot	26	28	31
1	1.88	2.51	2.00
2	1.85	1.57	1.78
3	1.58	1.45	1.07

This score was then summed to give an aggregate score which, when divided by the number of trees included, gave an average index score per plot. These values are included in Table 2.5.0. It should be remembered that the plots had been selected from within each of the compartments to reflect an apparent increase in severity of top-dying, and the compartments had also been selected to reflect differences in this aspect, so it is not surprising that there appears to be differences in this parameter in the table. However, when this was tested by a 2-factor Analysis of Variance, with Compartment as one factor and Plot as the

other, the results were not significant for either compartment and plot ($F_{\text{compartment}} = 0.49$, $df = 2$, $p = > 0.10$; $F_{\text{plot}} = 5.36$, $df = 2$, $p = < 0.10$), although the result for plots came close to significance.

The fact that these results for top-dying did not prove to be significant, despite selection of the compartments and plots to reflect a gradient in the prevalence of top-dying may be because of the limited range of values that the top-dying index could take. Also, further replicates of the number of plots would have probably helped make it more likely that a significant result was achieved. At least the difference between plots in their top-dying severity is believed to be valid despite it not quite being proven statistically, and differences between compartments are also thought to be real, if not detectable in this analysis.

This demonstrates that top-dying is varying in intensity as anticipated when the compartments and plots were selected. Treating the average index scores as one variable, the top dying index can be correlated with the various variables given in Table 7.0 in order to test whether there is any relationship between the incidence of top-dying and parameters such as tree height or bole diameter. Since the average top-dying index is a variable that may not be meeting all the assumptions for a parametric test it is better to use the Spearman's Rank Correlation Coefficient for these analyses. A summary of the outcome for these analyses.

Table 7.0. Outcomes from the analyses using Spearman's Rank Correlation Coefficient of the relationship between severity of top-dying and various parameters of tree structure and growth. (Key: NS = $p > 0.05$; * = $p < 0.05$).

Parameters comparing with Top-dying.	Correlation (r-value, with 7df).	Probability (p-value)	Sig. or N.S
Tree height (m)	- 0.113	0.773	N.S
Tallest tree height (m)	0.072	0.854	N.S
Bole diameter (cm)	0.067	0.865	N.S
Tree density (m ²)	0.021	0.956	N.S
Soil Moisture Content Percentage (M.C. %).	-0.736	0.024	*

None of the growth parameters were significantly related to amount of top-dying, but the percentage of soil moisture content was; the lower the amount of moisture, the greater the top-dying.

3.6. Regeneration of Trees

In order to describe the vegetation structure more fully at each of the location it is desirable not only to record the adult trees but also the potential regeneration of new trees

by recording the abundance of seedlings (newly germinated plants) and saplings (young trees less than 10 cm diameter). This information is presented in Tables 8.0 and Table 9.0.

Table 8.0. Frequency of seedlings of all tree species combined in each of the nine plots sampled.

Compartment / Plot	26	28	31	Totals
1	1261	1440	625	3326
2	1326	1501	1430	4257
3	1455	1575	1830	4860
Totals	4042	4516	3885	12443

Table 9.0. Frequency of saplings (trees in m tall) of all tree species combined in each of the nine plots sampled.

Compartment / Plot	26	28	31	Totals
1	282	228	167	677
2	266	172	396	834
3	566	215	343	1124
Totals	1114	615	906	2635

In order to test whether there is any association between the frequency of seedlings or saplings and the compartment or plot in which they were recorded, a chi-square analysis was performed for the data (Awal, 2007). The result for seedlings was that χ^2 gave a value of 344.7 which was very highly significant ($p < 0.001$, $df = 4$), while the value of χ^2 for saplings was 145.9 and was also highly significant ($p < 0.001$, $df = 4$). Clearly, both sets of data for regenerating trees were highly influenced by location, with clear evidence of a reduction in abundance in sites which had been selected as showing high incidences of top-dying, with least regeneration in Compartment 31 Plot 1 and, particularly with the sapling data, with the greatest numbers of regenerating saplings in Compartment 26 Plot 3.

4. Discussion Chapter

In trying to assess which factors might be responsible for the problem of top-dying, particularly of *Heritiera fomes* trees, in the Sundarbans, the work described in this invaluable research has essentially had four components. These were, firstly, a review of the hypotheses of possible causes and the evidence available on each of them. Secondly, local people were questioned in order to find their views on the state of the problem, and to see what they thought was causing it. Thirdly, data on the vegetation composition, structure and regeneration was obtained, in order to assess what the current situation is in the study areas. Finally, particular emphasis has been placed on analysing soil and water samples from the study sites to determine what chemical elements were present, and their concentrations, so that the relationships between these chemical constituents and the severity of top-dying could be explored. The range of views as to the causes of top-dying varied greatly from group to group, presumably reflecting the particular prejudices or local circumstances affecting the people in that area. The top-dying has been

getting worse gradually rather than with an abrupt particular starting point in time (Awal, 2007). The data on vegetation composition showed clearly the importance of the tree species *Heritiera fomes* (Sundri), since this made up over half of the trees in all sites, and in most cases dominated the list of species in its abundance. The total diversity of tree species was quite small. It was difficult to establish a clear pattern in the data on stand structure. There appeared not to be any relationship between the height of a tree and its bole diameter, or between the first of these parameters and the amount of top-dying recorded (Awal, 2007). It should be noted that a complicating factor here is the amount of illicit felling of the bigger trees (Awal, 2007). It is possible that the study sites were affected by this, so that the vegetation might best be described as semi-natural rather than natural, and this particularly might have affected these data on vegetation structure, although selection of sites was done to try to minimise this problem (Awal, 2007). It is less likely to have affected the trees with top-dying (which would be avoided by the fellers). Since the assessment of severity of top-dying was based on the amount of damage on individual trees, this should be reasonably accurate, although the average index estimate per plot may be somewhat inflated by the trees which were not so affected being preferentially removed (Awal, 2007). All study sites were prone to this illegal felling, however, and effects are likely to have been similar to all of them. So observed estimates of the differences in amount of top-dying are probably fair representations of real values for the various areas (Awal, 2007). A further feature which came out of the study of the vegetation present was the very significant differences in regeneration potential between the sites (Awal, 2007). Those sites which were selected on the basis of having more top-dying had much reduced regeneration success than those sites with less top-dying (Awal, 2007). This reduction in regeneration was apparent for both seedlings and for saplings (Awal, 2007). Previous work had found that top-dying was affecting trees over a particular size rather than seedlings/saplings, but the present results indicate that even the youngest and smallest plants are being affected (Awal, 2007). Compared to the conclusions of Chowdhury (1984), this suggests that the effects on regeneration are more severe now than they were (Awal, 2007), again indicating deterioration in the situation in the Sundarbans (Awal, 2007). The majority of the work reported in this research has been on the evaluation of chemical concentrations of a range of elements in soil and water samples (Awal, 2007, 2009, 2014), with particular emphasis on the heavy metals which have been implicated in other problems in Bangladesh (such as Arsenic, Iron, and Lead in ground waters), and which might have been present in elevated concentrations in the Sundarbans because of various sources of contamination (Awal, 2007). It is particularly interesting to note that although many of the elements were present in concentrations that could be considered elevated compared to uncontaminated sites (see later in this chapter), very few of them proved to be

significantly correlated with the amount of top-dying, or to vary in concentrations in a manner consistent with the plots' perceived top-dying status (assessed by ANOVA). Thus, the general conclusion that greater top-dying is directly related to elevated heavy metal contamination is not supported by the present results (Awal, 2014), although generally raised concentrations may well act as a stressor which could contribute to reduction in the health of the trees (Awal, 2007, 2009, 2014).

However, there were certain specific elements and other parameters of the soil or water that did show a significant correlation with top-dying intensities, or which gave significant ANOVA results, or were sufficiently close to significance (<0.10 probability) that they are worth being highlighted for further investigation (Awal, 2007). In order to evaluate better the implications of these findings, it is necessary to give some further information about these elements, namely Pb, Sn, Zn and exchangeable K, and also about soil pH (Awal, 2007). Tin (Sn) is the first trace-metal used in antiquity, and has versatile uses for plant and human benefit. Enrichment factors of three or four orders of magnitude as that of Co (Cobalt), Molybdenum (Mo), etc are possible naturally in Tin-rich soils and mineral deposits (Awal, 2007). Tin concentration in soil had been reported in the range of 1 to 4.6 mg/Kg and 1 to 10 mg/Kg in non-contaminated soils in the U.S.A. with a mean concentration of 1.3 mg/Kg. In contaminated soils, Sn concentrations above 250 mg/Kg are not uncommon (Lepp, et al., 1995). There is a lack of data and information relating to the environmental impact of Sn, because it is only recently that the extremely precise and advanced analytical techniques required for the detection of ppb levels of Sn in the environment have been available (Lepp, et al., 1995). Many questions remain unanswered, and have a very significant role in the redistribution of Sn and how Sn speciation and interaction with soil and plant components affect its bio-availability and distribution within the plant (Awal, 2007), especially in natural mangroves like Sundarbans (Lepp, 1995). In the present data from the Sundarbans, it is present at an average mean concentration range value of (-) 0.414 to 9.68 ppb. These values are thus below the range for uncontaminated soils in the USA reported above (1 ppb = 1 μ g/ Kg). According (Awal, 2007) to the analyses in this research, Tin { r_s - value = (- 0.61) t- approximation = 5.35, $p < 0.1$ }, has shown a tendency to a negative correlation with top-dying ranking index values (Awal, 2007). However, there was no significant pattern to the variation in Sn concentrations across compartments and plots, as tested by ANOVA (Awal, 2007). The statistical result indicated is an inverse relationship (Awal, 2007), that is, the more Sn is present, and the less top-dying there is (Awal, 2007). If it is presumed that this is a real result and is not simply an artefact from the statistical analyses, the implication is that either Sn directly inhibits top-dying, or that it is negatively correlated indirectly because of another factor that is linked directly with top-dying (Awal, 2007). Mangrove forests

generally require a very specific physico-chemical environment to flourish, and changes in one element may have effects on general balance of that environment and affect other elements which could influence top-dying, even if the specific element is not having a direct effect on it (Awal, 2007). A further element which has been highlighted (Awal, 2007) in this research, as perhaps having a direct effect on top-dying was Lead (Pb). The result of the correlation between Pb concentration and top-dying by Spearman's correlation coefficient was $r_s = 0.51$ with a probability of $p < 0.2$ (Awal, 2007). These results indicate Pb was close to significance, therefore deserving further attention (Awal, 2007). Unlike the results for Sn, here the relationship is a positive one, greater Pb concentration being related to more top-dying (Awal, 2007). This trend is perhaps easier to suggest an interpretation for: the increased presence of the metal weakens the trees, and allows them to be more affected by the agents of top-dying such as the pathogens (Awal, 2007). There was also a further result, close to significance ($p = 0.056$), when comparing Pb concentration with tree diameter by Pearson's correlation coefficient (Awal, 2007). The correlation was negative, that is greater Pb may lead to reduced growth of trees in their girth (Awal, 2007). Lead is classed as a trace metal in soil, and its compounds tend to accumulate due to their low solubility and relative lack of microbial degradation (Lepp, et al., 1995). A status report on soil data in mangroves of India in 1987 under the ministry of Environment and Forests, and indicated that the normal range of soil Pb content lies between 0.48 ppb to 1.67 ppb. By comparison, the data presented in in this research, indicated a mean average concentration range value of Pb in Sundarbans soil of 0.322 ppb to 34.190 ppb (Awal, 2007). These values for the Sundarbans are higher than the normal concentrations found in Mangroves of India, and Pb appears to be tending to have an effect (though not quite significant); any further increase in Pb in the Sundarbans could therefore have a marked deleterious effect (Awal, 2007). Since most sources of Pb are from human activities, increased utilization of the Sundarbans by people is of concern (Awal, 2007).

Zinc is an essential trace element for higher plants, and acts as a catalytic or structural component in numerous enzymes involved in energy metabolism and in transcription and translation. Zinc deficiency symptoms in plants are failure to function of carbohydrate and protein metabolism that leads to severe growth depression (stunted growth), malformation of stems and leaves, better known as "little leaf" ; and violet-red points on leaves (Kiekens, 1995). In addition, Zn deficiency symptoms in humans and animals are failure to eat, severe growth depression, skin lesions and sexual immaturity. For humans, depression of immunity and change of taste acuity also occur (Kiekens, 1995). The total zinc input to the soil seems to be the major factor affecting zinc concentration in plant tissue (Kiekens, 1995). Data from literature reviews indicated that the average Zn concentration mangrove soil in India studied was 9.64 ppb to 56.20 ppb (Govt. of India, 1987; Nayak,

1993). In respect of Sundarbans soil, the concentration of Zn found was 2.30 to 112.60 ppb (Awal, 2007). Thus, the Sundarbans has an elevated Zn content (Awal, 2007) compared to mangrove soil (Awal, 2007). However in the present research, the Spearman's correlation coefficient test has showed a positive correlation between average Zn concentrations (Awal, 2007) and top-dying (Awal, 2007), (r_s -value = 0.55, $P < 0.05$). As with Pb therefore, greater Zn concentrations tend to be related to more top-dying (Awal, 2007). Furthermore, there were significant differences between compartments for Bi, Sr and V (Awal, 2007), as well as Na (Awal, 2007), P and Sc (Awal, 2007). It is clear that these compartments are very differently affected (Awal, 2007), probably both by tidal influence as well as pollution problems from human influence (Awal, 2007). Soil pH appears to be related to both of these influences (Awal, 2007). Besides the heavy-metal concentrations in the soil, the result presented in this research found that there was not a significant relationship between soluble and exchangeable Na, soluble K, Ca, Mn, and CEC, in either soil or water, and pH of water, with the amount of top-dying, or with parameters of tree growth (Awal, 2007). However, there was a negative correlation between the concentration of exchangeable K and the average tree diameter (Awal, 2007).

There was also a significant ANOVA when testing the variations in soil pH across plots and compartments (Awal, 2007), which was also shown to be the case for top-dying intensity (Awal, 2007). The conclusions that arise from these various analyses of the chemical data are varied (Awal, 2007). Firstly, despite much concern about the possibility of elevated heavy metal concentrations due to the activities of people around the Sundarbans (Awal, 2007), there is evidence that, for the elements discussed above, the concentrations actually found are not particularly elevated (Awal, 2007). In order to extend this conclusion, the mean and maximum concentration values found in the Sundarbans in this study for all elements, together with figures reported by other authors in the literature from other sites (Awal, 2007). Comparing figures in this research result, it would suggest that about one third of the elements have concentrations which are elevated compared to other reference sources (Awal, 2007). Even where the concentration is not as high elsewhere, it may still be sufficiently high (Awal, 2007) to have adverse effects on the vegetation (example Boron, where most plants would be harmed at levels of 77 ppb). This would be consistent with the evidence that heavy metals were having an influence on top-dying intensity (Awal, 2007). The elements Pb, Sn, and Zn were highlighted earlier in this discussion, and although not all of them quite reached statistical significance (Awal, 2007), the positive trend linking two of them to top-dying suggests a likely mechanism of influence (Awal, 2007), namely that greater concentration of the heavy-metal weaken the resistance of the tree to attack by the pathogenic fungi (Awal, 2007). This might well be a process that other elements contribute to as well (Awal, 2007), but has not been picked out by the

analysis as showing a link because of the variability between samples inherent in the data (Awal, 2007). In this respect, the anomaly of the negative relationship indicated for Sn is harder to explain, but a possible process might be an antagonistic response of Sn and another element (Awal, 2007), so that when Sn is less abundant the other element can have a stronger (deleterious) effect on the trees (Awal, 2007) thus allowing more top-dying to occur (Awal, 2007). A further point is that variations in soil pH from site to site (shown to be significant) will also have a marked effect on the bio-availability of some of these heavy metals (Awal, 2007; Awal, 2014), and thus perhaps influence top-dying (Awal, 2007).

The present data also contribute evidence regarding other suggested hypotheses for the causes of top-dying (Awal, 2007). The non-significant relationship between soluble or exchangeable Na and the amount of top-dying (Awal, 2007), or with the amount of tree growth (Awal, 2007), strongly suggests that the hypothesis of salinity changes being the cause of top-dying is not correct (Awal, 2007). However, the data on moisture content percentage do indicate that the Sundarbans has lower values than many other mangrove forests (Awal, 2007), and the values obtained are rather low even compared to others obtained from the Sundarbans (Faizuddin, 2003). This suggests that the Sundarbans is experiencing problems with its water supply (Awal, 2007), which may be linked, at least in part, to the construction of the Farraka barrage (FAO report, 1984). If the drainage system of the water basin is poor, the tendency towards more acidic soil and water may increase (Christensen, 1984).

The evidence presented in this avid research, therefore points not to one specific factor as being entirely responsible (Awal, 2007) for the increasing amount of top-dying (Awal, 2007), but rather to a combination of factors (Awal, 2007); changing water supply and heavy metal contamination in particular (Awal, 2007), coupled with possible pH changes, lead to a weakening of the trees (Awal, 2007), which are then more susceptible to greater attack by pathogens and lowered resistance to them by the trees (Awal, 2007). This combination of factors is also supported by the comments of the people interviewed (Awal, 2007), who suggested many different factors as the cause as well as implying that the change was gradual by not being able to pick out a specific starting date to the problem (Awal, 2007). This would be precisely the pattern that might be expected where no one factor was solely responsible (Awal, 2007), and the combinations of factors might be somewhat different in different areas (Awal, 2007). Of course, having a number of interlinked factors as believed likely causes of the problem makes a solution to the problem more difficult (Awal, 2007). Some suggestions for ways of alleviating the problems, as well as further research to save world famous and wonder of the world natural mangrove forest (Awal, 2007; Awal, 2009; Awal, 2014).

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