Journal of Tropical Forest Science 11(4):690–703 (1999)

EFFECTS OF ABIOTIC AND BIOTIC FACTORS ON THE SEEDLING RECRUITMENT OF *HERITIERA FOMES* IN THE MANGROVES OF THE SUNDARBANS, BANGLADESH

Neaz Ahmad Siddiqi

Bangladesh Forest Research Institute, Chittagong 4000, Bangladesh

Received February 1997

SIDDIQI, N. A. 1999. Effects of abiotic and biotic factors on the seedling recruitment of *Heritiera fomes* in the mangroves of the Sundarbans, Bangladesh. Influences of abiotic and biotic factors on the seedling regeneration of *Heritiera fomes* Buch.-Ham. were investigated. The average number of seedlings appearing in a year was 6680 ha^{-1} although recruitment density varied among different parts of the forests and from year to year. Of the many mangrove species in the area, *H. fomes* alone constituted 24% of the recruits. Salinity of the area apparently influenced the recruitments which decreased with increasing levels of salinity. Seedling half-life values for *H. fomes* in less, moderate and strongly saline zones were 13.7, 8.8 and 6.3 months respectively. The relationship between seedling recruitment and stand density was insignificant. Similarly, up to 33 months, canopy closure was not found to affect the seedling recruitment and survival. A lower recruitment and survival of seedlings were noticed in areas with higher level of tidal inundation. As regards the biotic factors, the spotted deer *(Axis axis)* was not found to affect the natural regeneration of *H. fomes*; rather it might influence the dominance of this mangrove species through its preferential browsing habit. The wild boar *(Sus scrofa)* did not appear to have any significant impact on regeneration. Crabs were not found to cause mortality of seedlings, while the role of the rhesus macaque *(Macaca mulatta)* also appeared to be insignificant. However, the black rat *(Rattus rattus)* caused substantial damage to the new seedlings of *H. fomes*, but only in relatively raised and less saline areas.

Key words: Seedling regeneration - *Heritiera fomes* - abiotic - biotic - mangrove - Bangladesh

SIDDIQI, N. A. 1999. Kesan faktor abiotik dan faktor biotik terhadap penokokan *Heritiera fomes* di hutan bakau di Sundarbans, Bangladesh. Pengaruh faktor abiotik dan biotik terhadap pemulihan anak benih *Heritiera fomes* Buch.-Ham. dikaji. Purata bilangan anak benih yang muncul dalam setahun ialah 6680 ha^{-1} walaupun kepadatan penokokan berubah-ubah di kalangan bahagian-bahagian yang berbeza di hutan tersebut daripada setahun ke setahun. Daripada banyak spesies bakau di kawasan tersebut, *H. fomes* sahaja membentuk 24% daripada penokokan. Kemasinan kawasan tersebut jelas mempengaruhi penokokan yang berkurang dengan bertambahnya tahap kemasinan. Nilai-nilai anak benih separuh-hayat bagi *H. fomes* di zon yang kurang, sederhana dan kuat kemasinannya masing-masing ialah 13.7, 8.8 dan 6.3 bulan. Kaitan antara penokokan anak benih dan kepadatan dirian adalah tidak bererti. Begitu juga, sehingga 33 bulan, penutupan sudur tidak mempengaruhi penokokan dan kemandirian anak benih. Penokokan dan kemandirian yang rendah bagi anak benih dapat dilihat di kawasan yang mempunyai penimbunan pasang surut yang lebih tinggi. Mengenai faktor biotik, rusa berbintik (*Axis axis*) tidak mempengaruhi pemulihan semula jadi *H. fomes*. Kemungkinan ia lebih mempengaruhi keunggulan

spesies bakau ini melalui keistimewaan tabiat meragutnya. Babi hutan (*Sus scrofa*) tidak mempengaruhi pemulihan dengan bererti. Ketam tidak menyebabkan kematian anak benih, manakala peranan monyet resus (*Macaca mulatta*) juga tidak bererti. Bagaimanapun tikus hitam (*Rattus rattus*) menyebabkan kerosakan yang teruk kepada anak benih baru *H. fomes*, tetapi hanya di kawasan yang secara relatifnya bertambah dan kurang masin.

Introduction

Heritiera fomes Buch.-Ham. has a limited distribution and is restricted to the mangroves of Myanmar, Bangladesh and the Indian Sundarbans (Troup 1921, Kostermans 1959). In the Bangladesh Sundarbans, the tree is moderate in size and grows to a height of 15 to 20 m. Once trees of girth up to 2 m were found, but owing to heavy exploitation, trees over 1 m in girth are no more common. *Heritiera fomes* is a highly valuable species and noted for its use in house construction, boat building, electric poles, fuelwood, etc. (Das & Siddiqi 1985). This alone constitutes 63.8% of the merchantable timber (Rahman 1990). It is the dominant species in 52.7% and codominant in 14.8% of the forest area (Chaffey *et al.* 1985) .

The Sundarbans is managed under a selection system on sustained yield basis (Khuttak 1979, Imam 1982). But a depletion by 40% of the merchantable growing stock of *H. fomes* was noticed through two successive forest inventories (Forestal 1960, Chaffey *et al.* 1985). A number of factors may have contributed to this decline. Nevertheless, an adequate regeneration, which depends on a variety of abiotic and biotic factors, would assist in improving the stocking. Chaffey *et al.* (1985) recommended carrying out research into the factors affecting the natural regeneration of the main tree species.

Materials and methods

Study area

The Bangladesh Sundarbans (20°31'–22°30' N, 89°–90° E) covers an area of about 6200 km^2 and is located in the delta of the Ganges River. Administratively the forest is divided into four ranges and 55 compartments. Tides in the Sundarbans are semi-diurnal with a small diurnal irregularity. The whole forest is in intertidal region, but there is variation in the depth, duration and frequency of tidal inundation. Mean spring tide range in the mouth of the Passur River (east delta) is 2.4 m, whereas this range is 4.3 m in the mouth of the Hoogli River (west delta). The hydrology of the Sundarbans is related to the high seasonal rainfall, as well as the depth and duration of tidal inundation. The entire area is intersected by a complex network of streams and rivers (Figure 1). The forest has been divided into three salinity zones (Hassan *et al.* 1990) based on the degree of soil salinity—(i) less saline (<2mS cm^{-1}), (ii) moderately saline (2–4mS cm^{-1}) and (iii) strongly saline (>4mS cm^{-1}). Salinity reaches its peak in April– May and drops after June with the appearance of the monsoon. The climate of the Sundarbans is humid. Highest

temperatures occur in April and May and lowest in December and January. Mean annual maximum and minimum temperatures vary between 30 and 21°C. Annual rainfall is in the range 1640–2000 mm. June, July and August are the wettest months and December, January and February the driest. Unlike many other mangroves, the Sundarbans is rich in floristic composition. About 70 species of plants have been recorded from the Bangladesh Sundarbans (Khan 1978, Chaffey & Sandom 1985, Khatun & Alam 1987).

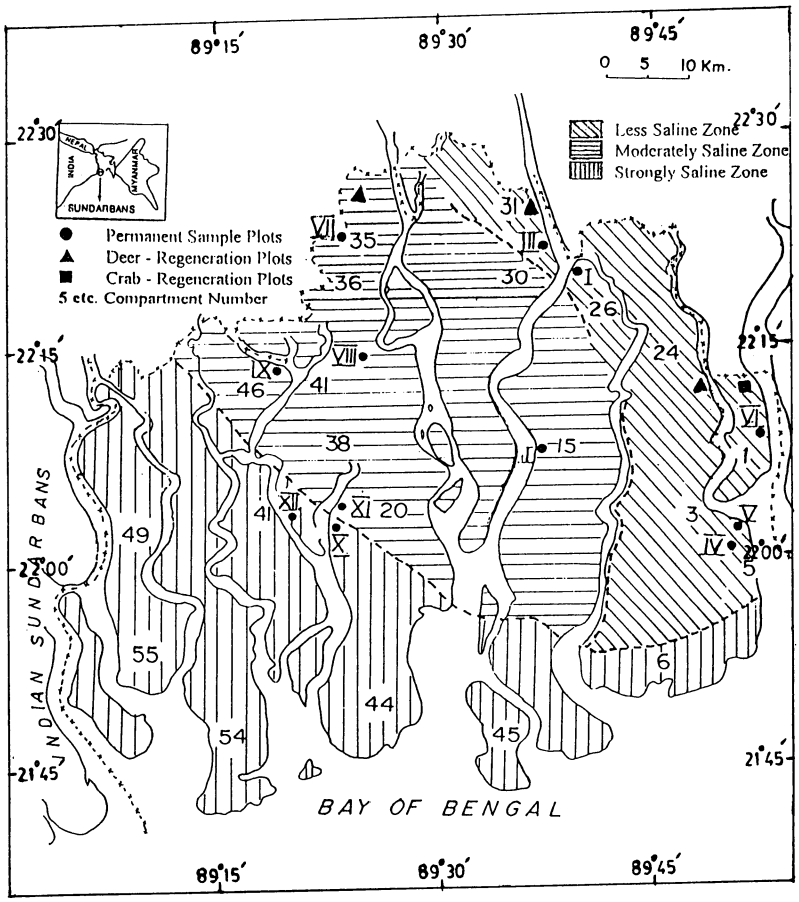

Figure 1. Map of the Sundarbans showing the locations of permanent sample plots and experimental plots

Experiments and observations

Abiotic influences on seedling recruitments (age <3 months) and their survival were studied based on data collected during 1982 to 1991 from twelve permanent sample plots (PSP) established at stratified random design in three salinity zones. Figure 2 shows the lay-out of a PSP. Regeneration data were collected twice a year (pre-monsoon and post-monsoon) from the PSPs (400 m^2 each). Sixteen points

were demarcated in each plot by four stakes each to the north, the south, the east and the west equidistant from the centre of the plot. Data were collected from only these fixed spots using a circular quadrat (0.75 m^2). Soil salinity, soil texture, frequency of tidal inundation, stand density and the canopy closure of the PSPs were also recorded. Soil salinity was determined from 1:2.5: soil: water suspension using electric conductivity meter and soil class texture by the USDA texture classification. Frequency of tidal inundation (days in a year) was assessed by continuous visual observations .

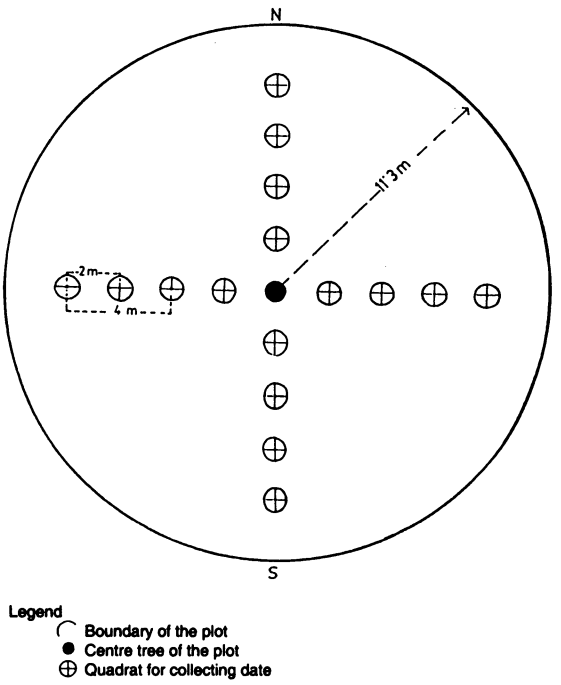

Figure 2. Sketch diagram of a permanent sample plot

Biotic influences were studied during 1990 and 1991 by laying out experimental plots, direct observations and indices (browsing of deer, girdling by crabs, cutting collars by rats, trampling or soil digging by wild boars). To ascertain the role of deer, the experiment was set in Randomised Complete Block Design (RCBD) in three salinity zones with different floristic composition (Figure 1). In each place, five plots each with an area of 25 m^2 (5 × 5m) were fenced with barbed wire to prevent access by deer. Five more unfenced plots of the same size, accessible to deer, were established 5 m apart from the fenced plots. Data on the availability and survival of new seedlings (age < 1 year) of *H. tomes* in the plots were recorded every two months up to 10 months following the appearance of seedlings. Similar data on

old seedlings (age> 1 year, height < 1.3m) were recorded up to 14 months. Mortality of seedlings due to browsing by deer was identifiable by careful observations of the dead or damaged seedlings. So, a comparison of the seedling survivals between fenced and unfenced plots would provide information on the damage caused by deer.

As regards wild boars, they were more active in the dark. So, the role of this animal was studied by the indices, e.g. earth digging, trampling, uprooting. To access the role of crabs, an experiment was set with *H. fomes* and six other species in Factorial Design in a less saline zone (Figure 1). Sixteen seedlings of *H. fomes* (one month old) were planted in cages with additional 16 seedlings outside each cage. The cage (0.25 m^2 surface area and 1 m tall) was covered with nylon mesh (1 × 1 cm) in all six sides to prevent entrance of the crabs. There were three replicate pairs. Final data on seedling survival were collected one year after initiation of the experiment. The activities of the monkeys on regeneration were directly observed. Rodents use incisors for cutting which can be distinguished clearly. So, their role was studied from the nature of the damage to the seedlings.

Results and discussion

A. Influences of abiotic factors on regeneration

Seedling recruitment status

The condition of seedlings was recorded in November after the monsoon. These three-month-old seedlings were regarded as seedling recruits. In addition to *Heritiera fomes,* recruits of 12 other species were found in the PSPs during the study period. *Heritiera fomes* alone constituted 24% of the total recruits.

A total of 962 new seedlings of *H. fomes* were recorded during ten years in the PSPs over an area of 144 m^2 (0.75 × 16 × 12 m). The average number of seedlings appearing per year was 6680 ha^{-1}. Recruitment density varied considerably among the PSPs. At PSP No. 6, recruits were 28 165 seedlings ha^{-1}, whereas at PSP No. 7, no recruit was there. Chaffey *et al.* (1985) recorded an average of 11 630 seedlings ha^{-1} (height < 1.3 m) of *H. fomes* for the entire Sundarbans.

Yearly variation in recruitments

A remarkable yearly variation in seedling recruitments of *H. fomes* was noticed. In 1982 and 1986, recruitment was much higher (Table 1, Figure 3). The reason was not clearly understood. Usually, there is a significant reduction in seed production following a very heavy seed year for different species (Hocker 1979). However, Hasan and Howlader (1970) claimed no periodicity in *H. fomes.* Siddiqi *et al.*(1991) reported probable existence of periodicity in fruit production of this species. Jimenez (1988) reported year to year variation in seedling density for *Rhizophora racemosa* in the mangroves of Costa Rica.

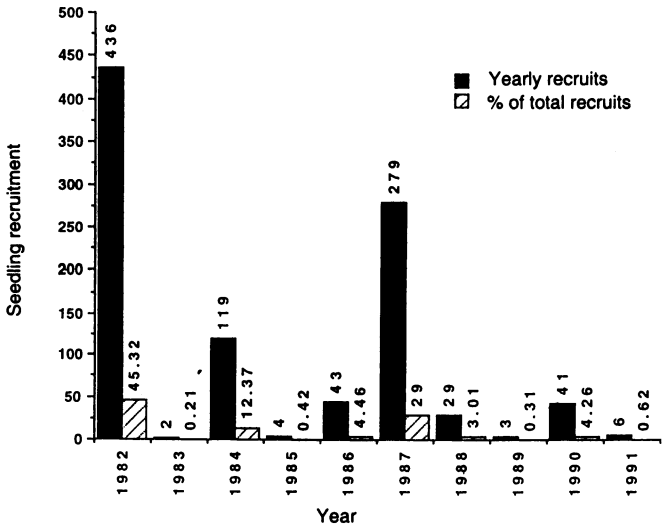

Figure 3. Yearly seedling recruitments (3 months) of *Heritiera fomes*

Table 1. Characteristics of the permanent sample plots (PSPs) and seedling recruitments of *Heritiera fomes*

PSP No.	Location compt/ zone	Mean soil salinity (mS cm^{-1})	Soil texture	Inundation (days per year)	*H. fomes* trees (No.)	Total trees (No.)	Canopy closure (%)	*H. fomes* seedling (No.)	Survival up to 33 months (%)
1	26/LS*	2.85	Silty-clay-loam	105–120	102	168	90	164	19.38
2	15/MS	3.80	-do-	105–120	85	121	70	28	3.85
3	30/LS	2.85	-do-	90–105	42	145	60	80	0
4	3/LS	1.80	-do-	105–120	92	148	80	102	16.30
5	5/LS	1.80	-do-	105–120	106	168	70	109	12.48
6	1 /LS	0.78	-do-	75–90	02	18	30	338	18.95
7	35/MS	3.50	Silty-clay	120–135	14	47	80	0	0
8	36/MS	4.00	-do-	120–135	04	165	70	17	0
9	46/SS	3.85	-do-	135–150	23	29	30	6	0
10	20/MS	4.05	-do-	135–150	58	68	40	11	0
11	38/SS	4.00	-do-	135–150	37	81	40	64	0
12	41/SS	4.75	-do-	135–150	46	87	50	43	0

• LS: Less saline, MS: Moderately saline, SS: Strongly saline.

Tree density and recruitment

A non-significant relationship (r = 0.06) was obtained between the number of *H. fomes* trees in the PSPs and seedling recruitments (Table 1). The fruits of the species are non-viviparous and buoyant in nature. Possibly the seeds, after falling on the floor of the PSPs were washed away by tide water and either failed to

germinate or germinated elsewhere. Jimenez (1991) pointed out that in the mangroves of Costa Rica, propagule establishment seemed to be unrelated to the occurrence of the reproductive trees.

Salinity and recruitment

The number of newly appearing seedlings for ten years in different PSPs was plotted against soil salinity of the respective plots (Figure 4). Seedlings of *H. fomes* significantly decreased with increasing level of salinity ($r = -0.815$; $p<0.01$). This species prefers a level of lower salinity (Troup 1921, Saenger 1986). Salinity plays a vital role on the distribution of species in the Sundarbans (Choudhury 1968). *Heritiera fomes* predominates in the less saline areas of the forests.

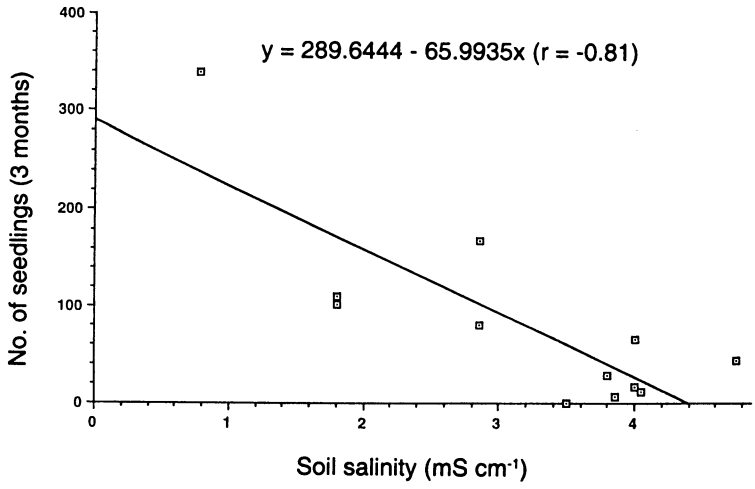

Figure 4. Relationship between salinity and seedling recruitment of *Heritiera fomes*

Salinity and seedling survival

Seedling survival was recorded for a period of 33 months following appearance. A large proportion of seedlings disappeared during this period. Only 16.53 and 1.92% seedlings of *H. homes* survived up to 33 months in less and moderately saline zones respectively with no survival in the strongly saline zone. Seedling half-life values (i.e. time required for 50% of seedlings to disappear) in less, moderate and strongly saline zones were 13.7, 8.8 and 6.3 months respectively (Figure 5). This shows greater preference of the species for lower salinity level. In the Indian Sundarbans, where salinity is higher, this species is not abundant (Karim 1988) and natural regeneration is unsatisfactory (Mukherjee 1975). With regard to growth, Latif *et al.* (1992) mentioned higher increment in diameter in less saline areas.

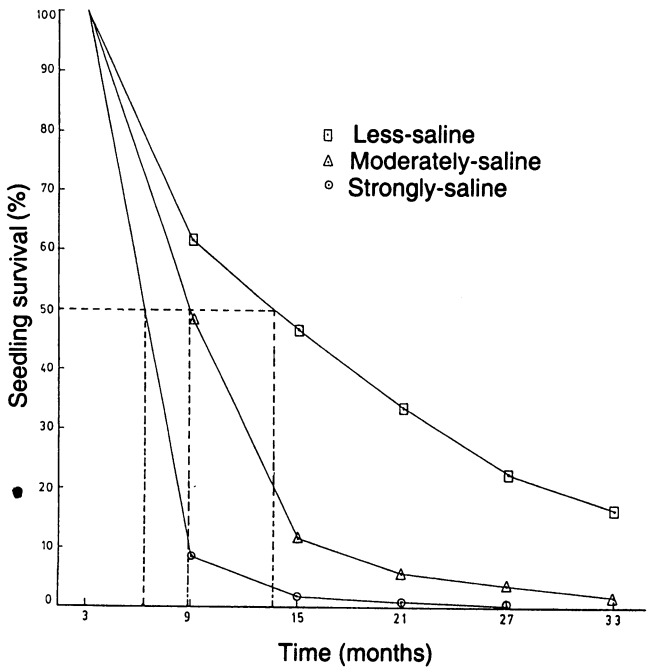

Figure 5. Depletion curves showing seedling half-life for *Heritiera fomes* in different salinity zones

Canopy closure and recruitment

Usually some plants are shade tolerant while others are light demanding. Thus recruitment and disappearance of seedlings are influenced by the canopy closure of the forests (Whitmore 1986, Kimmins 1987). No significant relationship was found between canopy closure and recruitment ($r = 0.14$). The relationship was also insignificant at 33 months with respect to seedling survival ($r = 0.11$). *Heritiera fomes* is shade tolerant in the early stage (Troup 1921, Dalmacio *et al.* 1991). It seems that factors other than canopy closure, e.g. tidal range, current, salinity, seed availability, etc., affect seedling recruitment.

Inundation and recruitment

The rate of inundation was higher in the western part of the Sundarbans. Maximum growth of *H. fomes* is noticed in areas where the forest floor remains dry for about 3–4 months a year. Seedling recruitment and survival were higher in PSPs where inundation rate was lower (Figure 6). No seedling of *H. fomes* survived up to 33 months from emergence where the PSPs got inundated for more than 120 days a year. However, PSP 3 (inundation 90–105 days a year) was subjected

to much wave action and that might be a reason for failure of *H. fomes* to survive. Mangrove seedling establishment is regulated by depth and frequency of tidal inundation (McMillan 1971, Chapman 1975, Kjerfve 1990, Siddiqi & Khan 1990, Jimenez 1991).

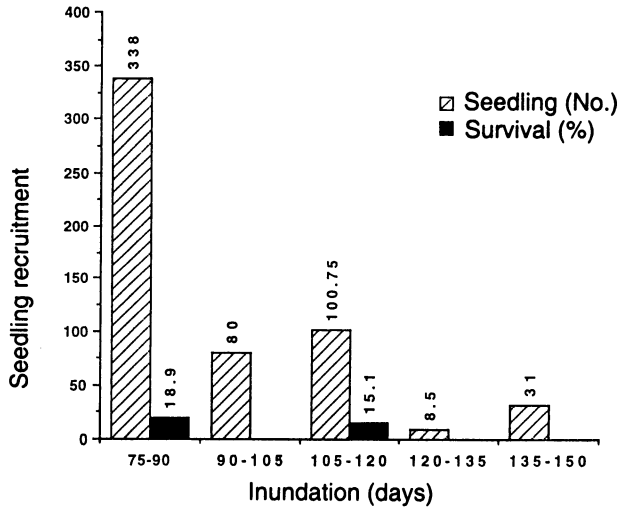

Figure 6. Seedling recruitment and survival up to 33 months for *Heritiera fomes* in relation to degree of inundation

B. Influences of biotic factors on regeneration

Role of deer

Data collected on seedling survival from the fenced and unfenced plots were analysed in RCBD with several observations per cell. Seed shedding continued up to September. So, for new seedlings the analysis was based on the data collected after September (Table 2). For old seedlings, analysis was made for the data collected from July (Table 3). The survival of seedlings showed non-significant difference between fenced and unfenced plots at compartment 24 for new ($F_{1,48}$= 1.09) and old ($F_{1,64}$ = 0.96) seedlings. The difference was also insignificant for new ($F_{1,48}$= 0.98) and old ($F_{1,64}$ = 0.38) seedlings at compartment 31. Only a few seedlings of *H. fomes* appeared at compartment 35 and were inadequate for analysis. Plots in compartments 24 and 31 were located in *Excoecaria agallocha–Heritiera fomes* and *H. fomes–E. agallocha* forest types respectively. The plot in compartment 35 was in *Heritiera fomes–Xylocarpus mekongensis–Bruguiera sexangula* forest type.

Hendrichs (1975) gave a rough estimate of population size of the spotted deer *(Axis axis)* as 80 000 individuals for the Bangladesh Sundarbans. Deer are considered to play a vital role in regulating regeneration density of the forests through their browsing habits (Champion *et al.* 1965, Choudhury 1968, Blasco 1977, FAO 1982,

Gomez *et al.* 1986). They cause substantial damage to the natural regeneration. Deer are reported to cause damage to mangrove seedlings in Myanmar (Troup 1921) and Malaysia (Chai & Lai 1984). In Bangladesh, deer were harmful to the regeneration of *Avicennia officinalis, Sonneratia apetala, Xylocarpus mekongensis, Bruguiera sexangula* and *Aegiceras corniculatum* (Siddiqi & Husain 1994), but they were not found to feed on the leaves of *H. fomes*. It is possible that deer influenced the dominance of *H. fomes* through their preferential browsing habits.

Table 2. Survival percentages of new seedlings (age <1 year) of *Heritiera fomes* in fenced (protected from deer) and unfenced plots

Location	Condition	Survival percentage overtime (months)					
		0	2	4	6	8	10
Compt.24	Fenced	100	85.00	35.0	26.7	23.3	20.0
	Unfenced	100	80.65	41.9	22.6	19.4	19.4
Compt. 31	Fenced	100	89.2	71.6	71.2	62.2	57.2
	Unfenced	100	83.6	64.1	57.8	53.9	46.1

Table 3. Survival percentages of old seedlings (age >1 year) of *Heritiera fomes* in fenced (protected from deer) and unfenced plots

Location	Condition	Survival percentage overtime (months)							
		0	2	4	6	8	10	12	14
Compt.24	Fenced	100	99.4	98.8	98.4	96.7	96.1	95.6	95.1
	Unfenced	100	99.9	99.5	99.1	98.2	98.0	97.0	96.7
Compt. 31	Fenced	100	100	99.5	96.5	96.9	96.7	96.5	96.1
	Unfenced	100	99.8	99.8	99.8	96.7	96.2	95.8	95.2
Compt. 35	Fenced	100	81.8	81.8	81.8	81.8	91.8	81.8	72.7
	Unfenced	100	83.3	83.3	83.3	83.3	83.3	83.3	50.3

Role of crabs

Seedling mortality of all the seven species including *H. fomes* planted inside cages or in the open was low. In all, 48 (3x16) seedlings of *H. fomes* were planted within the cages and another 48 (3x16) in the open. A total of 42 seedlings in the cages and 46 in the open survived when data were collected after one year. Average seedling survival was 87.5% inside cages and 95.8% in the open (control). The impact of crabs was insignificant ($t = 0.85$ with $p = 0.05$ & d.f. = 4) on regeneration of *H. fomes*.

The crabs belonging to the family Grapsidae were reported to cause severe damage to mangrove regeneration in many countries of the world (Siddiqi 1995, 1996). Hendrichs (1975) reported occurrence of six species of grapsid crabs in less saline areas of the Sundarbans. He estimated population density of crabs as

50 animals m^{-2} at the water edge along the high water line and the density was lower away from the water. Further studies covering all the representative areas of the Sundarbans are necessary to ascertain the role of crabs on regeneration.

Role of monkeys

The rhesus macaque *(Macaca mulatta)* is an arboreal animal. However, in the afternoons the animals are found to play in groups on the banks of rivers and canals in the Sundarbans. They were not found to eat the leaves or damage the seedlings of *H. fomes*. In raised experimental plantations of mangroves, damage attributable to monkeys did not occur. Monkeys are reported to cause damage to mangrove seedlings in Malaysia (Salleh & Chan 1987) and Thailand (Aksornkoae 1987). In the Bangladesh Sundarbans, the population size of the rhesus macaque is 40 000 (Hendrichs 1975) while Gittins and Akonda (1982) estimated it to be 126 000 individuals. The diet of the monkeys consists of plant materials (*S. apetala* leaves, young *Nypa fruticans*, grasses), crabs and fishes (Sanyal 1983, Salter 1984). From visual observations, the monkeys were not found to affect the regeneration of *H. fomes* in the Sundarbans.

Role of wild boars

Unlike deer, the wild boar *(Sus scrofa)* can potentially damage the plants via their roots, even uprooting them. In the Sundarbans, the population size of wild boar is 20 000 individuals (Hendrich 1975). Foraging damage to *H. fomes* seedlings by wild boars was not noticed in the forests. Trampling of these animals might affect some seedlings. But they do not have any substantial role on seedling mortality.

Choudhury (1968) mentioned that in the Sundarbans wild boars used to uproot the seeds and seedlings but the extent of damage was not high. The animals feed on roots, stems, seeds, crustaceans, molluscs, marine turtle eggs, dead fish and other animals (Sanyal 1983). As the food habit of the animals is diverse, they were not found to deliberately harm the seedlings.

Role of rodents

In compartment 24, six-month-old seedlings of *H. fomes* were found to be attacked by rodents as apparent from the nature of injury to the collars. When estimated in a plot, it appeared that 41% of the newly recruited seedlings were destroyed by the black rat *(Rattus rattus)*. Out of 76 seedlings appearing in the plot, 37 seedlings were killed when six months old. Identification of the animals was made following trapping. No seedlings of the previous years were damaged by the rats. Damage to *H. fomes* seedlings was also noticed at compartment 1. Rat attack was not detected in other parts of the forests. Damage was confined to a few places with lower salinity and higher ground elevation. The *R. rattus* in Australia occupied many habitats including mangroves. This species cannot survive on full strength sea water, and consequently must depend on water in its food or perhaps

temporary fresh water during rains (Dunson & Lazell 1982). Higher level of salinity in other parts of the Sundarbans might limit the activities of rats.

Conclusion

Of variously available species, *Heritiera fomes* alone constitutes 24% of the seedling recruits in the Sundarbans. Recruitment density varied considerably among different parts of the forests. Rate of seedling establishment was low.

Level of salinity and tidal inundation influenced the regeneration of *H. fomes*. Higher recruitment and survival of seedlings were noticed with lower level of salinity and inundation. As regards biotic factors, the spotted deer *(Axis axis)* did not adversely affect regeneration; rather they might help dominance of *H. fomes* through their preferential browsing habit. The role of wild boar *(Sus scrofa)*, rhesus macaque *(Macaca mulatta)* and crabs on regeneration was insignificant. The black rat *(Rattus rattus)* caused damage to new seedlings but only in restricted areas.

Heritiera fomes is the dominant species of the mangroves of Bangladesh. It has a great economic importance because of its multiple uses. Decline in stocking of the species has been reported. Therefore, further studies on various factors that affect the survival and establishment of the seedlings of *H. fomes* need to be undertaken. This could help develop methods to ensure adequate natural regeneration and improve the stocking of the species.

Acknowledgements

I am grateful to M. Shahidullah, Research Officer, M. A. H. Shahjalal, Field Investigator, M. M. Rahman, Deputy Ranger, and other staff members of the Mangrove Silviculture Division, Bangladesh Forest Research Institute (BFRI) for their help in the lay-out of experiments, maintenance of the plots, and collection and compilation of data. I also thank M. Shahadat Hossain, of the Minor Forest Products Division, BFRI, for typing the manuscript.

References

AKSORNKOAE, S. 1987. Country report: Thailand. Pp. 231–261 in *Mangroves of Asia and the Pacific.* Status and Management. UNDP/UNESCO (RAS/79/002). Philippines.

BLASCO, F. 1977. Outline of ecology, botany and forestry of the mangals of the Indian subcontinent. Pp. 241–260 in Chapman, V.J. (Ed.) *Wet Coastal Ecosystems.* Elselvier, Amsterdam.

CHAFFEY, D. R., MILLER, F. R. & SANDOM, J. M. H. 1985. *A Forest Inventory of the Sundarbans, Bangladesh. Main Report.* Overseas Development Administration, England. 196 pp.

CHAFFEY, D. R. & SANDOM, J. H. 1985. *Sundarbans Forest Inventory Project, Bangladesh. A Glossary of Vernacular Plant Names and a Field Key to the Trees.* Overseas Development Administration, England. 23 pp.

CHAI, P. P. K. & LAI, K. K. 1984. Management and utilization of mangrove forests in Sarawak. Pp. 785–795 in *Proceedings of Asian Symposium on Mangrove Environment Research & Symposium Mangrove Management.*

CHAMPION, H. G., SETH, S. K. & KHATTAK, G. M. 1965. *Manual of Silviculture for Pakistan.* Pakistan Forest Institute, Peshawar. 543 pp.

CHAPMAN, V. J. 1975. Mangrove biogeography. Pp. 3–22 in Walsh, G. E., Snedaker, S. C. & Teas, H. J. (Eds.) *Proceedings of the International Symposium on Biology and Management of Mangroves.* Vol. 1 . University of Florida, Gainesville.

CHOUDHURY, A. M. 1968. *Working Plan of the Sundarbans Forest Division for the Period for 1960–61 to 1979–80.* East Pakistan Government Press, Dacca. 82 pp.

DALMACIO, M. V., RAHMAN, Z. & AHMAD, I. U. 1991. *Coastal Afforestation Management Manual.* (Draft paper). Bangladesh Forest Department. 95 pp.

DAS, S. & SIDDIQI, N. A. 1985. *The Mangroves and Mangrove Forests of Bangladesh.* Mangrove Silviculture Division Bulletin No. 2. Bangladesh Forest Research Institute. 142 pp.

DUNSON, W. A. & LAZELL, JR., J. D. 1982. Urinary concentrating capacity of *Rattus rattus* and other mammals from the lower Florida Keys. *Comparative Biochemistry and Physiology* 71 A:17–21.

FAO. 1982. *Management and Utilization of Mangroves in Asia and the Pacific.* FAO Environment Paper 3. FAO, Rome.160 pp.

FORESTAL. 1960. *Forest Inventory 1958-59, Sundarbans Forests.* Forestal International Incorporated, Oregon, Canada.

GITTINS, S. P. & AKONDA, A. W. 1982. What survives in Bangladesh? *Oryx* 16(3): 276–81.

GOMEZ, E. D., BINOHLAN, C. D. & CHAVEZ, V. B. 1986. National stressors in a mangrove ecosystem. *Biotrop.* Indonesia :15–22.

HASAN, S. M. & HOWLADER, N. I. 1970. Coastal afforestation in Noakhali district. *Forest Dale News* 2(3):41–49.

HASSAN, M. M., MAZUMDER, A. H., NURUL ISLAM, A. T. M. & EMDAD HOSSAIN, A.T. M. 1990. Soil hydrology and salinity of the Sundarbans in relation to top dying, regeneration and survival of sundri *(Heritiera fomes)* trees. Pp. 1–11 in *Proceedings of the Seminar on Top Dying of Sundri (Heritiera fomes) Trees.* 1988, BARC, Dhaka.

HENDRICHS, H. 1975. The status of the tiger *Panthera tigris* (Linne, 1758) in the Sundarbans mangrove forest (Bay of Bengal). *Saugetierkundliche Mitteilungen* 23:161–199.

HOCKER, H. W.1979. *Introduction to Forest Biology.* John Wiley and Sons, USA. 467 pp.

IMAM, S. A. 1982. The Sundarbans and its future. Pp. 19–24 in *Proceedings of the Second Bangladesh National Conference on Forestry.* January 21–26, 1982, Dhaka.

JIMENEZ, J. A. 1988. The dynamics of *Rhizophora racemosa* Meyer forests on the Pacific Coast of Costa Rica. *Brenesia*:1–12.

JIMENEZ, J. A. 1991. Structure and dynamics of mangrove forests along a flooding gradient. *Estuaries* 14(1):49–56.

KARIM, A. 1988. Environmental Factors and the Distribution of Mangroves in Sundarbans with Special Reference to *Heritiera fomes* Buch. - Ham. Ph.D. thesis, University of Calcutta. 222 pp.

KHAN, M. S. 1978. *Flora of Bangladesh* No. 7. Family Rhizophoraceae. Bangladesh National Herbarium, Dhaka.19 pp.

KHATTAK, G. M. 1979. History of forest management in Bangladesh. *Pakistan Journal of Forestry* 29(3):121–128.

KHATUN, B. M. & ALAM, M. K. 1987. Taxonomic studies in the genera *Avicennia* Linn. from Bangladesh. *Bangladesh Journal of Botany* 16(1):39–44.

KIMMINS, J. P. 1987. *Forest Ecology.* Macmillan Publishing Company, New York. 531 pp.

KJERFVE, B. 1990. *Manual for Investigation of Hydrological Processes in Mangrove Ecosystems.* UNESCO/ UNDP Regional Project RAS/79/002 and RAS/86/120. 79 pp.

KOSTERMANS, A. J. G. J. 1959. A monograph of the genus *Heritiera* Aiton (Sterenl.). *Reinwardtia* 4(4): 465–583.

LATIF, M. A., RAHMAN, M. F., DAS, S. & SIDDIQI, N. A. 1992. Diameter increments for six mangrove tree species in the Sundarbans forest of Bangladesh. *Bangladesh Journal of Forest Science* 21:7–12.

MCMILLAN, C. 1971. Environmental factors affecting seedling establishment of the black mangrove on the Central Texas Coast. *Ecology* 52(5):927–930.

MUKHERJEE, A. K. 1975. The Sundarbans of India and its biota. *Journal of Bombay Natural History Society* 72(1):1–20.

RAHMAN, M. A. 1990. A comprehensive report on sundri *(Heritiera fomes)* trees with particular reference to top dying in the Sundarbans. Pp. 12–63 in *Proceedings of the Seminar on Top Dying of Sundri (Heritiera fomes) Trees.* 1988, BARC, Dhaka.

SAENGER, P. 1986. *Bangladesh Mangrove Afforestation Project.* Report prepared for the Government of Bangladesh. Shedden Pacific Pty. Limited, Melbourne, Australia. 63 pp.

SALTER, R. E. 1984. *Integrated Development of the Sundarbans Bangladesh (Status and Utilization of Wildlife).* Report prepared for the Government of Bangladesh. FAO, Rome. 59 pp.

SALLEH, M. N. & CHAN, H. T. 1987. Sustained yield forest management of the Matang mangrove. Pp. 319–324 in *Mangroves of Asia and the Pacific. Status and Management.* UNDP/UNESCO (RAS/79/002). Philippines.

SANYAL, P. 1983. Mangrove tiger land, the Sundarbans of India. *Tiger Paper* 10(3):1–4.

SIDDIQI, N. A. 1995. Role of crabs on the natural regeneration of mangroves in the Sundarbans forest of Bangladesh. *Australian Journal of Ecology* 20:340–343.

SIDDIQI, N. A. 1996. A review on the impact of animals on regeneration in the mangroves with particular reference to Bangladesh. *Tiger Paper* 23(1):3–10.

SIDDIQI, N. A. & HUSAIN, K. Z. 1994. The impact of deer on the natural regeneration in the Sundarbans mangrove forest. *Bangladesh Journal of Zoology* 22(2): 223–234.

SIDDIQI, N. A. & KHAN, M. A. S. 1990. Growth performance of mangrove trees along the coastal belt of Bangladesh. *Mangrove Ecosystems Occasional Papers.* UNDP/UNESCO Regional Mangroves Project. Thomson Press No. 8:5–14.

SIDDIQI, N. A., SHAHIDULLAH, M. & SHAHJALAL, M. A. H. 1991. Studies on the size, viability and germination of seeds of sundri *(Heritiera fomes* Buch.-Ham.). *Indian Journal of Forestry* 14(2):119–124.

TROUP, R. S. 1921. *The Silviculture of Indian Trees.* Clarendon Press, Oxford. Volume 1. 336 pp.

WHITMORE, T. C. 1986. *Tropical Rain Forests of the Far East.* English Language Book Society/Oxford University Press. 352 pp.