Ecological restoration through natural regeneration in Chunati Wildlife Sanctuary – a protected area of South-East Bangladesh

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Received 10 June 2020
Revised 25 November 2020
Accepted 13 January 2021

Abstract

Purpose – In this paper, the authors show that ecological restoration potential through natural regeneration of degraded tropical rainforest is possible. This is significant because at present most of the tropical forest of the world, including of Bangladesh, are degraded.

Design/methodology/approach – Regeneration status of Chunati Wildlife Sanctuary (CWS) was assessed through stratified random sampling method using sample plots of 5 × 5 m in size covering 269 sample plots.

Findings – A total of 3,256 regenerating seedlings/saplings of 105 species belonging to 35 families were recorded from CWS. From regenerating tree species, maximum (37.83) family importance value (FIV) index was found for Euphorbiaceae followed by Myrtaceae (18.03). Maximum importance value index (IVI) was found for *Aporosa wallichii* (21.62) followed by *Grewia nervosa* (16.41). Distribution of seedlings into different height classes of regenerating tree species was also calculated.

Practical implications – Forest scientists are working to find out the best nature-based solution for ecological restoration of tropical rainforests to attain climate resilient ecosystem in a sustainable way. Tropical rain forest has huge plant diversity, and we find that ecological restoration is possible through natural regeneration from its rich soil seed bank. Natural regeneration is the best nature-based solution for sustainable management of the forest.

Social implications – The authors believe that the findings presented in our paper will appeal to the forest and environmental scientists. The findings will allow readers to understand degraded tropical hill forest ecosystem and its management strategy.

Originality/value – The authors believe that this manuscript will give a clear picture about degraded tropical hill forest ecosystem and its genetic composition, diversity and soil seed bank status to apply appropriate management strategy.

Keywords Natural regeneration, Diversity, Conservation, Chunati, Sanctuary, Importance value index, Restoration

Paper type Research paper

Funding: This research was funded by the Arannayk Foundation, Dhaka, Bangladesh.

Ecofeminism and Climate Change
Vol. 3 No. 1, 2022
pp. 41-55
Emerald Publishing Limited
e-ISSN: 2633-4070
p-ISSN: 2633-4062
DOI 10.1108/EFCC-06-2020-0019

Introduction

Natural regeneration is essential for preservation and maintenance of biodiversity in natural forests (Hossain *et al.*, 2004; Rahman *et al.*, 2011). Knowledge about the pattern of natural regeneration is important to answer the basic question of forest management (Hossain *et al.*, 1999). It is an important indicator to assess overall condition of forest ecosystem (Rahman *et al.*, 2011). Wyatt-Smith (1987) mentioned information on species composition of a forest is essential for its wise management in terms of economic value and natural regeneration potential. Plants maintain and expand their populations in time and space by the process of regeneration. Regeneration is a complex ecosystem process involving asexual and sexual reproduction, dispersal and establishment in relation to environmental factors (Barnes *et al.*, 1998). The strategies by which plants regenerate are soil seed banks, seedling banks and vegetative parts (Grime, 1979; Garwood, 1989; Barnes *et al.*, 1998). The pattern of population structure of woody plants can show the regeneration profile, which is used to determine their regeneration status (Bekele, 2000; Teketay, 1996). Assessment of soil seed banks and population structure has practical importance in forest conservation and management. Database of the regeneration status of the plant species is important for developing management strategies and setting priorities for the wise management of the wildlife sanctuary.

The Chunati Wildlife Sanctuary (CWS), formerly a part of the Reserve Forests of Chittagong Forest Division, was designated a Protected Area on March 8, 1986. Primary objectives to establish a wildlife sanctuary are to dedicate an area as undisturbed breeding ground primarily for the protection of wildlife inclusive of all natural resources such as vegetation, soil and water. Basic information of the sanctuary is essential to achieve the objectives of the wildlife sanctuary establishment. This natural forest is important not only as renewable resources but also as an essential in the conservation of wildlife and environment. Khan (1990) and Khan and Huq (2001) prepared annotated checklist for flora of the CWS. Rahman and Hossain (2003) assessed fodder and non-fodder plant species of the CWS. Regeneration study is still absent. Again, biodiversity monitoring and evaluation is essential for taking effective conservation measures.

Therefore, natural regeneration status of tree species was assessed to identify a sustainable management strategy for the purposes of ecological restoration and biodiversity conservation in CWS.

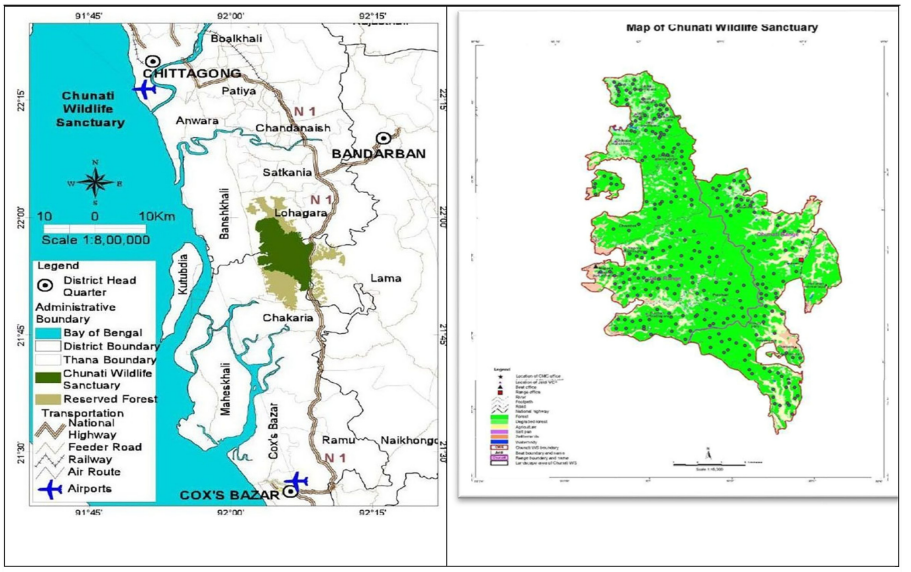
Materials and methods

Study site

The CWS is located about 70 km south of Chattogram city and to the west of the Chattogram–Cox's Bazar highway at 21°48′N to 22°05′ latitude and 91°57′E to 92°07 east longitude (Figure 1). Chunati forest is composed of hills and hillocks with shallow to deep gullies and gentle to steep slopes. The soils on the alluvial plains and valleys in the Chunati are mainly silty to clay loam. The annual rainfall of the area is 2,000–2,500 mm (BBS, 2012). Temperature ranges from 24° (average minimum) to 32.5° during monsoon and from 14.2° to 29.5° during winter season. Humidity in the sanctuary is classified into three climatic seasons. Low relative humidity occurs during spring season and ranges from 28.6% to 98.2% (BBS, 2012).

Methods of the field study

To have an idea of the topography, vegetation composition, accessibility of the whole study area prior to selection of sampling procedure, field visits as well as formal discussion with respective Forest Department staff of CWS. Stratified random sample method was used for the study. A total of 269 sample plots (5 m × 5 m) were laid within the study area for the assessment of regeneration. Regenerated trees having <5 cm diameter at breast height (DBH)



Source(s): Hossain and Hossain (2014)

Figure 1.
GPS location of a sample plot in Chunati Wildlife Sanctuary

were considered as seedlings (Figure 1). Seedlings of all species in each plot were identified and recorded by local and scientific names. The common tree species were identified directly in the field, while the suitable samples of the unknown tree species were collected for the preparation of herbarium specimens.

Collected plant specimens were dried in the sun following standard scientific method. Identification of unknown specimen was done through verification with published journals and reference books (e.g. Prain, 1903; Uddin and Hassan, 2012; Rahman and Hossain, 2003) and *Encyclopedia of Flora and Fauna of Bangladesh* (Ahmed, 2008).

Analysis of collected field data

Identified plant samples were arranged taxonomically and categorized according to their habit form. The relative density, relative frequency, relative abundance and important value index (IVI) were calculated following Shukla and Chandel (2000). IVI of regeneration was calculated following Shukla and Chandel (2000) (Table 1).

Seven diversity and richness indices were analyzed following Kent and Coker (1992), Margalef (1958), Michael (1990), Odum (1971), Pielou (1966), Shannon and Wiener (1963) and Simpson (1949), to get a picture of regeneration status of different tree species in CWS (Table 2). Family relative density (Fd) and family relative diversity (Fr) were calculated following Rahman *et al.* (2011) (Table 1). *Species diversity index* (S_{Di}) starts from 1 when there is only one individuals of one species, the value reach to maximum with the increase of species number (Odum, 1971).

Margalef's index (R) is high in communities that include a greater number of species and in which the number of individuals of each species decreases relatively slowly on passing from more abundant to less abundant ones (Margalef, 1958).

Shannon-Wiener diversity index value is maximum when the number of individuals of all species is equal; value is zero if there is only one species (Shannon and Wiener, 1963).

With Simpson's diversity index (D), 0 represents infinite diversity, and 1 represents no diversity. Simpson's diversity index is neither intuitive nor logical, so to get over the problem, d is

SL no	Phytosociological attributes	Farmula	Reference
1	Family relative density (Fd)	$Fd(\%) = \frac{Nf}{Ti} x\ 100$	Mori *et al.* (1983)
2	Family relative diversity (Fr)	$Fr(\%) = \frac{Ns}{Ts} x\ 100$	Rahman *et al.* (2011)
3	Family importance value (FIV)	FIV=Fd + Fr	Rahman *et al.* (2011)
4	Density (D)	$D = \frac{a}{b}$	Shukla and Chandal (2000)
5	Relative density (RD)	$RD(\%) = n/N\ X\ 100$	Dallmeier *et al.* (1992), Misra (1968)
6	Frequency (F)	$F = \frac{c}{b}$	Shukla and Chandal (2000)
7	Relative frequency(RF)	$RF(\%) = \frac{Fi}{\sum_{i=1}^{n}(Fi)}$	Dallmeier *et al.* (1992), Misra (1968)
8	Abundance (A)	$A = \frac{n}{c}$	Shukla and Chandal (2000)
9	Relative abundance (RA)	$RA(\%) = \frac{Ai}{\sum_{i=1}^{n}(Ai)}$	Misra (1968)
10	Importance value index (IVI)	IVI = RD + RF + RA	Misra (1968), Shukla and Chandal (2000)

Note(s): *Nf:* number of individual in a family; *Ti*: total number of individuals; *Ns*: number of species in a family; *Ts*: total number of species, *a*: total number of individuals of a species in all the quadrats; *b*: total number of quadrats studied; *n*: total number of individuals of the species; *N*: total number of individuals of all the species; *c*: total number of quadrats in which the species occurs; *b*: total number of quadrats studied; *Fi:* frequency of one species; *Ai*: abundance of one species

Table 1.
List of equations used for analyzing phytosociological characteristics of vegetation in Chunati Wildlife Sanctuary

Sl No	Biodiversity indices	Formulas	References
1	Species diversity index (S_{Di})	SDi = S/N	Odum (1971)
2	Shannon–Wiener's diversity index (*H*)	$H = -\sum_{i=0}^{n} Pi \ln Pi$	Michael (1990)
3	Shannon's maximum richness index (H_{max})	Hmax = Ln(*S*)	Kent and Coker (1992)
4	Margalef's species richness index (*R*)	*R* = (*S*-1)/Ln(*N*)	Margalef (1958)
5	Simpson's diversity index (*D*)	$D = \sum_{i=1}^{n} pi^2$	Magurran (1988)
6	Dominance of Simpson's index (*D'*)	*D'* = 1-*D*	Magurran (1988)
7	Species (Pielou's) evenness index (*E*)	$E = \frac{H}{\mathrm{Ln}(S)}$	Pielou (1966)

Note(s): *H*= Shannon–Wiener's diversity index; *N* = total no. of individuals of all the species; P_i = number of individuals of *i*th species/total number of individuals; *S* = total number of species; *n* is the number of individuals of each species

Table 2.
List of equations used for analyzing biodiversity indices of Chunati Wildlife Sanctuary

often subtracted from 1 to give dominance of Simpson's index (*D'*). The value of this index also ranges between 0 and almost 1, but now, the greater the value, the greater the sample diversity.

Species evenness index (E), also known as Shannon's equitable index, assumes a value between 0 and 1, with 1 being complete evenness (Pielou, 1966).

Results and discussion

Natural regeneration status in Chunati Wildlife Sanctuary (CWS)

A total of 3,256 seedlings (4,842 seedling ha^{-1}) of 105 species representing 35 families were recorded from CWS (Table 3). About 34% (12) families were represented by only one species and 45% (16) by more than two species. Maximum (12 species) was found for Euphorbiaceae family followed by Moraceae (11), Myrtaceae (7) family (Figure 2). Highest (26.50%) family relative density (Fd) was represented by Euphorbiaceae family followed by Myrtaceae (11.43%) family (Figure 2). Family relative diversity index (Fr) was also found maximum (11.32%) for Euphorbiaceae family followed by Moraceae (10.38%) family. Maximum (37.83) family importance value (FIV) index was found for Euphorbiaceae followed by Myrtaceae (18.03), Moraceae (16.21), Dipterocarpaceae (14.21) and Fagaceae (12.77) (Table 3).

Family	Species no	No. of seedling	No. of seedlings ha^{-1}	Fd(%) = Nf/ Ti × 100	Fr(%) = Ns/ Ts × 100	FIV
Anacardiaceae	3	16	24	0.49	2.83	3.32
Apocynaceae	2	51	76	1.57	1.89	3.45
Bignoniaceae	3	91	135	2.79	3.77	6.57
Boraginaceae	1	1	1	0.03	0.94	0.97
Burseraceae	1	50	74	1.54	0.94	2.48
Caesalpiniaceae	4	7	10	0.21	3.77	3.99
Celastraceae	1	2	3	0.06	0.94	1.00
Clusiaceae	2	64	95	1.97	1.89	3.85
Combretaceae	4	63	94	1.93	3.77	5.71
Dilleniaceae	1	18	27	0.55	0.94	1.50
Dipterocarpaceae	5	309	459	9.49	4.72	14.21
Elaeocarpaceae	2	4	6	0.12	1.89	2.01
Euphorbiaceae	12	863	1,283	26.50	11.32	37.83
Fabaceae	1	1	1	0.03	0.94	0.97
Fagaceae	4	293	436	9.00	3.77	12.77
Flacourtiaceae	1	21	31	0.64	0.94	1.59
Lauraceae	5	116	172	3.56	4.72	8.28
Lythraceae	1	1	1	0.03	0.94	0.97
Meliaceae	3	29	43	0.89	2.83	3.72
Mimosaceae	6	28	42	0.86	5.66	6.52
Moraceae	11	190	283	5.84	10.38	16.21
Myristicaceae	1	3	4	0.09	0.94	1.04
Myrsinaceae	2	64	95	1.97	1.89	3.85
Myrtaceae	7	372	553	11.43	6.60	18.03
Ochnaceae	1	1	1	0.03	0.94	0.97
Rhamnaceae	1	1	1	0.03	0.94	0.97
Rhizophoraceae	1	26	39	0.80	0.94	1.74
Rubiaceae	2	41	61	1.26	1.89	3.15
Rutaceae	2	20	30	0.61	1.89	2.50
Simaroubaceae	1	1	1	0.03	0.94	0.97
Sterculiaceae	4	74	110	2.27	3.77	6.05
Theaceae	1	2	3	0.06	0.94	1.00
Tiliaceae	2	269	400	8.26	1.89	10.15
Ulmaceae	1	46	68	1.41	0.94	2.36
Verbenaceae	6	118	175	3.62	5.66	9.28
Total	105	3,256	4,842	100.00	100.00	200.00

Table 3. Family and species composition, number of stem in each family, family relative density (Fd), family relative diversity (Fr) index, family importance value index (FIV) in Chunati Wildlife Sanctuary

Quantitative characters of naturally regenerating tree species of Chunati Wildlife Sanctuary

The quantitative structure of naturally regenerating tree species in the CWS was studied on the basis of conservation status, density, relative density, relative frequency, relative abundance and IVI. The highest number of seedlings per hectare was accounted for *Aporosa wallichii* (596) followed by *Grewia nervosa* (385), *Syzygium fruticosum* (274), *Lithocarpus polystachia* (242) and *Dipterocarpus alatus* (199) (Table 4). Lowest number of seedlings per hectare was (3), *Albizia odoratissima* (4) (Table 4). Maximum relative density (12.32%) recorded for *Cassia fistula* (1), *Chukrasia tabularis* (1) followed by *Bhesa robusta* (3), *Eurya acuminata* was recorded for *A. wallichi* followed by *G. nervosa* (7.96%), *S. fruticosum* (5.66%), *L. polystachia* (5%), *D. alatus* (4.11%) (Figure 3). Maximum relative frequency (7.28%) was recorded for *A. wallichi* followed by *G. nervosa* (7.12%), *Ficus hispida* (4.50%) and *S. fruticosum* (4.35%). The highest (4.64%) relative abundance was calculated for *Aphanamixis polystachya* followed by *Gluta elegans* (2.79%), *Dipterocarpus costatus* (2.60%), *Shorea robusta* (2.38%) and *D. alatus* (2.30%). The maximum IVI was found for

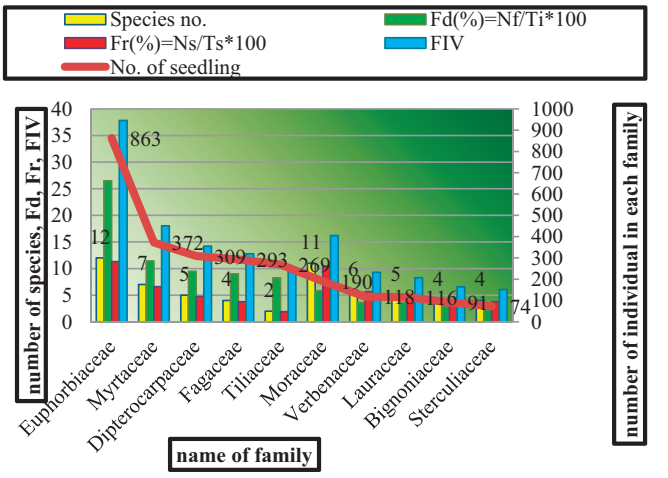


Figure 2.
Top 10 families in Chunati Wildlife Sanctuary based on species distribution

A. wallichi (21.62) followed by *G. nervosa* (16.41), *S. fruticosum* (11.56), *Lithocarpus polystachya* (9.9), *F. hispida* (9.45) and *D. alatus* (8.56) (Table 4).

It has been found that regeneration of tree species is originated either from soil seed banks or from the coppices. The study shows that 13% (423 individuals) of the regeneration is coppice origin and the rest 87% (2,823 individuals) regeneration is seed origin (Figure 4). Again, it has been found that 33 species (31%) were both coppice and seed originated and 72 species (69%) were seed originated regeneration (Figure 4). The study reveals that both *L. polystachya* and *Lithocarpus elegans* has maximum (11) Shoot-growing capabilities followed by *Quercus gomeziana* (10) and *D. alatus* (9) (Table 5). Regeneration potential of 8 keystone tree species has been analyzed (Table 5) on the basis of their individual number and coppicing capability. *G. nervosa* showed maximum (35 stem ha^{-1}out of 259 stem ha^{-1}) regeneration from coppice followed by *L. polystachya* (45 stem ha^{-1}out of 163 stem ha^{-1}) and *D. alatus* (20 stem ha^{-1}out of 134 stem ha^{-1}) (Table 5).

In addition, all the recorded plants/tree species were found to be represented by seven conservation categories, namely, conservation-dependent (CD), data-deficient (DD), endangered (EN), least concern (LC), not evaluated (NE), not evaluated but seems to be rare (NE^1), not threatened (NT) and endangered (EN).

A total of 47% plant species (50 species out of 105) were found as LC which represents maximum plant species among all the categories (Figure 5).

Distribution of seedlings into different height classes

The percentage (%) distribution of all the seedlings of all species into six height (cm) classes is shown in (Figure 6). It was found that maximum (39%) seedlings were within a height range of 50 to <100 cm, whereas 1% seedlings were found only in 250 to <300 cm height range (Figure 6). It indicates disturbance in early stage of regeneration. It may be due to environmental and anthropogenic factors.

Biological diversity indices of regeneration species

Functional diversity is the structural heterogeneity and for variation in the special arrangements of the tree population (Huston, 1994). As per environmental heterogeneity hypothesis, increased heterogeneity should increase diversity (Levin, 1974). Different biological diversity indices, that is, species diversity index (S_{Di}), species richness index (R),

Sl No	Family	Local name	Scientific name	*R	Co	N	Stem ha^{-1}	RD (%)	RF (%)	RA (%)	IVI
1	Mimosaceae	Akashmoni	*Acacia auriculiformis*	cs	LC	9	13	0.28	0.55	0.60	1.43
2	Lauraceae	Modanmosta	*Actinodaphne angustifolia*	s	NE	9	13	0.28	0.40	0.84	1.51
3	Mimosaceae	Chakua Koroi	*Albizia chinensis*	s	LC	7	10	0.21	0.47	0.54	1.23
4	Mimosaceae	Tetua Koroi	*Albizia odoratissima*	s	LC	3	4	0.09	0.08	1.39	1.57
5	Mimosaceae	Sada Koroi	*Albizia procera*	s	LC	6	9	0.18	0.24	0.93	1.35
6	Apocynaceae	Chatim	*Alstonia scholaris*	s	LC	9	13	0.28	0.55	0.60	1.43
7	Combretaceae	Sheori	*Anogeissus acuminata*	s	VU	28	42	0.86	1.42	0.72	3.01
8	Euphorbiaceae	Banshyalbuka	*Antidesma bunius*	s	LC	115	171	3.53	3.32	1.27	8.13
9	Euphorbiaceae	Khudi Jam	*Antidesma ghaesembilla*	s	LC	3	4	0.09	0.16	0.70	0.95
10	Euphorbiaceae	Reshmi Salishialbuka	*Antidesma velutinum*	s	LC	25	37	0.77	0.79	1.16	2.72
11	Meliaceae	Pitraj, Royna	*Aphanamixis polystachya*	s	VU	20	30	0.61	0.16	4.65	5.42
12	Euphorbiaceae	Phata Karoola	*Aporosa dioica*	s	NE	79	117	2.43	3.56	0.82	6.80
13	Euphorbiaceae	Castoma	*Aporosa wallichii*	cs	LC	401	596	12.32	7.28	2.03	21.62
14	Myrsinaceae	Sheea Barela	*Ardisia colorata*	cs	VU	3	4	0.09	0.16	0.70	0.95
15	Moraceae	Chapalish	*Artocarpus chama*	s	NE[1]	9	13	0.28	0.47	0.70	1.45
16	Moraceae	Kanthal	*Artocarpus heterophyllus*	s	LC	3	4	0.09	0.24	0.46	0.79
17	Moraceae	Borta	*Artocarpus lacucha*	s	LC	19	28	0.58	1.11	0.63	2.32
18	Fabaceae	Chakakola	*Bauhinia purpurea*	s	LC	4	6	0.12	0.08	1.86	2.06
19	Celastraceae	Ban Agar	*Bhesa robusta*	s	VU	2	3	0.06	0.16	0.46	0.68
20	Tiliaceae	Moos	*Brownlowia elata*	s	VU	10	15	0.31	0.63	0.58	1.52
21	Verbenaceae	Bormala	*Callicarpa arborea*	s	NE[1]	43	64	1.32	1.74	0.91	3.97
22	Rhizoporeaceae	Raskao	*Carallia brachiata*	s	LC	26	39	0.80	1.50	0.64	2.94
23	Caesalpiniaceae	Sonalu	*Cassia fistula*	cs	LC	1	1	0.03	0.08	0.46	0.57
24	Euphorbiaceae	Attalia	*Chaetocarpus castanoarpus*	s	VU	4	6	0.12	0.16	0.93	1.21
25	Meliaceae	Chickrassi	*Chukrasia tabularis*	s	VU	1	1	0.03	0.08	0.46	0.57
26	Lauraceae	Tez-Bohu	*Cinnamomum iners*	s	VU	12	18	0.37	0.47	0.93	1.77
27	Rutaceae	Dulia moricha	*Clausena excavata*	s	LC	4	6	0.12	0.16	0.93	1.21
28	Rutaceae	Moricha	*Clausena heptaphylla*	s	LC	16	24	0.49	0.40	1.49	2.37
29	Borgniaceae	Bohal	*Cordia fragrantissima*	s	VU	1	1	0.03	0.08	0.46	0.57
30	Crypteroniaceae	Ojha	*Cryptocarya amygdalina*	s	NE[1]	21	31	0.64	1.03	0.75	2.42
31	Fabaceae	Miringa	*Derris robusta*	s	LC	1	1	0.03	0.08	0.46	0.57
32	Dilleniaceae	Hargeza	*Dillenia scabrella*	s	VU	18	27	0.55	0.71	0.93	2.19

(*continued*)

Table 4.
Phytocomposition, regeneration type (R), conservation status (Co), number of stem ha^{-1}, relative density (RD), relative frequency (RF), relative abundance and importance value index (IVI) of Chunati Wildlife Sanctuary

Table 4.

Sl No	Family	Local name	Scientific name	*R	Co	N	Stem ha^{-1}	RD (%)	RF (%)	RA (%)	IVI
33	Dipterocarpaceae	Dhulia Garjan	*Dipterocarpus*	cs	VU	134	199	4.12	2.14	2.31	8.56
34	Dipterocarpaceae	Baitta Garjan	*Dipterocarpus costatus*	s	CD	28	42	0.86	0.40	2.60	3.86
35	Dipterocarpaceae	Telia Garjan	*Dipterocarpus turbinatus*	cs	LC	54	80	1.66	1.34	1.48	4.48
36	Elaeocarpeace	Jalpai	*Elaeocarpus tectorius*	s	EN	1	1	0.03	0.08	0.46	0.57
37	Elaeocarpeace	Banjalpai	*Elaeocarpus varunua*	s	EN	3	4	0.09	0.16	0.70	0.95
38	Myrtaceae	Eucalyptus	*Eucalyptus camaldulensis*	cs	NE	12	18	0.37	0.40	1.12	1.88
39	Theaceae	Ramjani	*Eurya acuminata*	s	CD	2	3	0.06	0.08	0.93	1.07
40	Moraceae	Lal Dumur	*Ficus auriculata*	s	LC	6	9	0.18	0.24	0.93	1.35
41	Moraceae	Jiribot	*Ficus benjamina*	s	LC	1	1	0.03	0.08	0.46	0.57
42	Moraceae	Dol Dumur	*Ficus conglobate*	s	NE	1	1	0.03	0.08	0.46	0.57
43	Moraceae	Bot	*Ficus geneculata*	s	LC	2	3	0.06	0.08	0.93	1.07
44	Moraceae	Dumur	*Ficus hispida*	cs	LC	127	189	3.90	4.51	1.04	9.45
45	Moraceae	Boro Dumur	*Ficus lanceolata*	s	VU	1	1	0.03	0.08	0.46	0.57
46	Moraceae	Churkigola	*Ficus semicordata*	s	NE	2	3	0.06	0.16	0.46	0.68
47	Clusiaceae	Kao	*Garcinia cowa*	cs	VU	62	92	1.90	2.14	1.07	5.11
48	Clusiaceae	Kao	*Garcinia speciosa*	cs	VU	2	3	0.06	0.16	0.46	0.68
49	Euphorbiaceae	Paniatori	*Glochidion multiloculare*	s	LC	23	34	0.71	1.42	0.59	2.72
50	Anacardiaceae	Kattula	*Gluta elegans*	s	EN	6	9	0.18	0.08	2.79	3.05
51	Verbenaceae	Gamar	*Gmelina arborea*	s	LC	4	6	0.12	0.32	0.46	0.90
52	Tiliaceae	Assargola	*Grewia nervosa*	cs	LC	259	385	7.95	7.12	1.34	16.41
53	Apocynaceae	Kuruch	*Holarrhena antidysenterica*	cs	LC	42	62	1.29	1.66	0.93	3.88
54	Dipterocarpaceae	Telsur	*Hopea odorata*	s	LC	1	1	0.03	0.08	0.46	0.57
55	Verbenaceae	Chalmugra	*Hydnocarpus laurifolius*	s	VU	21	31	0.64	0.63	1.22	2.50
56	Lythraceae	Jarul	*Lagerstroemia speciosa*	s	LC	1	1	0.03	0.08	0.46	0.57
57	Anacardiaceae	Jialbhadi	*Lannea coromandelica*	s	LC	2	3	0.06	0.16	0.46	0.68
58	Fagaceae	Dholi Batna	*Lithocarpus acuminata*	s	EN	102	152	3.13	2.29	1.63	7.06
59	Fagaceae	Kali Batna	*Lithocarpus elegans*	cs	EN	16	24	0.49	0.47	1.24	2.21
60	Fagaceae	Batna	*Lithocarpus polystachya*	cs	NT	163	242	5.01	2.77	2.16	9.94
61	Lauraceae	Menda	*Litsea glutinosa*	cs	LC	73	109	2.24	3.32	0.81	6.37
62	Euphorbiaceae	Bura	*Macaranga denticulata*	cs	LC	39	58	1.20	1.42	1.01	3.63
63	Myrsinaceae	Lalmoricha	*Maesa ramentacea*	cs	CD	61	91	1.87	1.82	1.23	4.93

(*continued*)

Table 4.

Sl No	Family	Local name	Scientific name	*R	Co	N	Stem ha^{-1}	RD (%)	RF (%)	RA (%)	IVI
64	Euphorbiaceae	Chuta Bura	*Mallotus roxburghianus*	cs	NE	131	195	4.02	2.22	2.17	8.41
65	Anacardiaceae	Aam	*Mangifera indica*	s	LC	8	12	0.25	0.47	0.62	1.34
66	Rubiaceae	Dakuram	*Mitragyna parvifolia*	cs	CD	37	55	1.14	1.82	0.75	3.70
67	Myristacaceae	Am Barela	*Myristica linifolia*	s	VU	3	4	0.09	0.08	1.39	1.57
68	Rubiaceae	Kadam	*Neolamarckia cadamba*	s	LC	4	6	0.12	0.24	0.62	0.98
69	Ochnaceae	Ochna	*Ochna squarrossa*	s	EN	1	1	0.03	0.08	0.46	0.57
70	Bignoniaceae	Khona	*Oroxylum indicum*	s	LC	3	4	0.09	0.24	0.46	0.79
71	Lauraceae	Chaongri	*Phoebe pallida*	cs	Rare	1	1	0.03	0.08	0.46	0.57
72	Euphorbiaceae	Amloki	*Phyllanthus emblica*	s	LC	24	36	0.74	1.34	0.66	2.74
73	Simaroubaceae	Lohamorich	*Picrasma javanica*	s	Rare	1	1	0.03	0.08	0.46	0.57
74	Mimosaceae	Kuramara	*Pithecellobium angulatum*	s	NE	1	1	0.03	0.08	0.46	0.57
75	Burseraceae	Gutgotiya	*Protium serratum*	s	VU	50	74	1.54	1.34	1.37	4.25
76	Myrtaceae	Peyara	*Psidium guajava L.*	s	LC	3	4	0.09	0.24	0.46	0.79
77	Sterculiaceae	Moos	*Pterospermum acerifolium*	s	VU	1	1	0.03	0.08	0.46	0.57
78	Sterculiaceae	lana ashar	*Pterospermum semisagittatum*	cs	VU	3	4	0.09	0.16	0.70	0.95
79	Sterculiaceae	Budda narkel	*Pterygota alata*	cs	VU	67	100	2.06	2.37	1.04	5.47
80	Fagaceae	Koissa Batna	*Quercus gomeziana*	s	DD	12	18	0.37	0.24	1.86	2.47
81	Euphorbiaceae	Chamfata	*Sapium baccatum*	cs	VU	9	13	0.28	0.40	0.84	1.51
82	Caesalpiniaceae	Minjiri	*Senna siamea*	s	LC	1	1	0.03	0.08	0.46	0.57
83	Dipterocarpaceae	Sal	*Shorea robusta*	cs	LC	92	137	2.83	1.42	2.38	6.63
84	Sterculiaceae	Udal	*Sterculia foetida*	cs	very rare	3	4	0.09	0.16	0.70	0.95
85	Bignoniaceae	Dharmara	*Stereospermum colais*	s	NE[1]	71	106	2.18	3.24	0.80	6.23
86	Bignoniaceae	Parul	*Stereospermum suaveolens*	cs	LR	17	25	0.52	1.27	0.49	2.28
87	Moraceae	Sheora	*Streblus asper*	s	LC	19	28	0.58	1.11	0.63	2.32
88	Euphorbiaceae	Moricha	*Suregada multiflora*	cs	NE	10	15	0.31	0.40	0.93	1.63
89	Myrtaceae	Noli Jam	*Syzygium claviflorum*	s	LC	58	86	1.78	2.14	1.00	4.92
90	Myrtaceae	Kalo Jam	*Syzygium cumini*	s	LC	9	13	0.28	0.32	1.05	1.64
91	Myrtaceae	Dhaki Jam	*Syzygium firmum*	s	LC	104	155	3.19	3.01	1.27	7.47
92	Myrtaceae	Puti Jam	*Syzygium fruticosum*	cs	DD	184	274	5.65	4.35	1.55	11.56
93	Myrtaceae	Khudi Jam	*Syzygium syzygioides*	s	LC	2	3	0.06	0.08	0.93	1.07
94	Caesalpiniaceae	Tentul	*Tamarindus indica*	s	LC	1	1	0.03	0.08	0.46	0.57

(*continued*)

Table 4.

Sl No	Family	Local name	Scientific name	*R	Co	N	Stem ha^{-1}	RD (%)	RF (%)	RA (%)	IVI
95	Verbenaceae	Segun	*Tectona grandis*	cs	LC	8	12	0.25	0.47	0.62	1.34
96	Combretaceae	Bohera	*Terminalia bellirica*	cs	LC	2	3	0.06	0.16	0.46	0.68
97	Combretaceae	Arjun	*Terminalia arjuna*	s	VU	32	48	0.98	1.50	0.78	3.27
98	Combretaceae	Haritaki	*Terminalia chebula*	cs	VU	1	1	0.03	0.08	0.46	0.57
99	Meliaceae	Toon	*Toona ciliata*	s	CD	8	12	0.25	0.40	0.74	1.38
100	Ulmaceae	Naricha	*Trema orientalis*	s	LC	46	68	1.41	1.58	1.07	4.06
101	Verbenaceae	Arsol	*Vitex glabrata*	cs	LC	2	3	0.06	0.16	0.46	0.68
102	Verbenaceae	Goda	*Vitex peduncularis*	s	VU	55	82	1.69	2.06	0.98	4.73
103	Verbenaceae	Horina arsol	*Vitex pinnata*	cs	VU	6	9	0.18	0.16	1.39	1.74
104	Mimosaceae	Loha Kath	*Xylia xylocarpa*	s	LC	2	3	0.06	0.08	0.93	1.07
105	Rhamnaceae	Jangli baroi	*Ziziphus rugosa*	s	NE	1	1	0.03	0.08	0.46	0.57
Total						3,256	4,842	100	100	100	300

Note(s): *R: mode of regenerations; s: seed origin seedling; C: coppice; Co: conservation status; N: number of individuals; CD: conservation-dependent; CR: critically endangered; DD: data deficiency; En: endangered; LC: least concern; NE: not evaluated; NE[1]: not evaluated but seems to be rare; NT: near-threatened; VU: vulnerable; EN: endangered

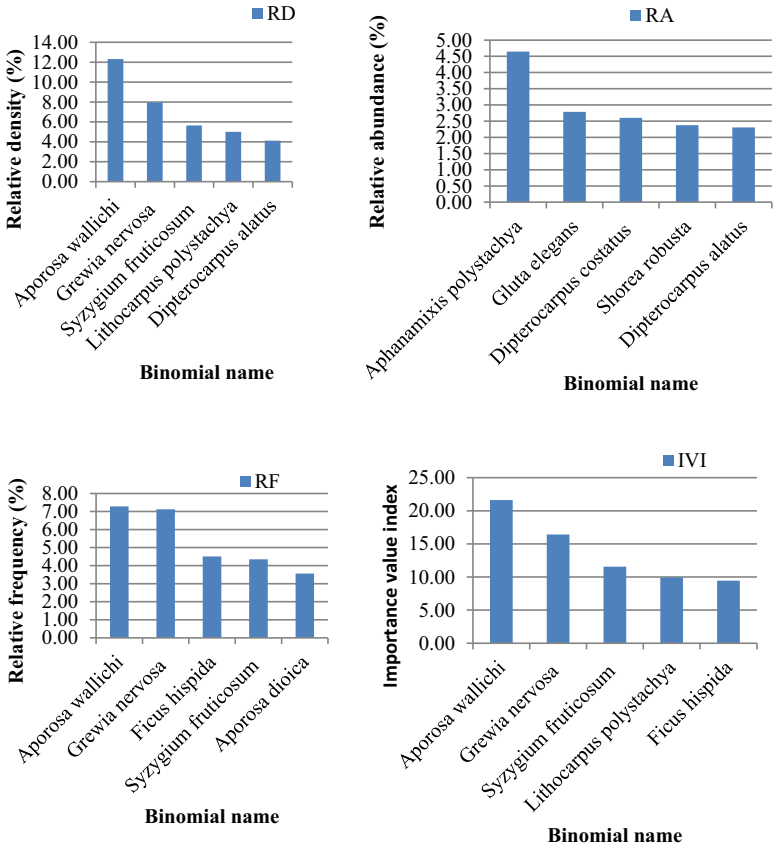


Figure 3.
Phytosociological attributes of five dominant regenerating tree species in Chunati Wildlife Sanctuary

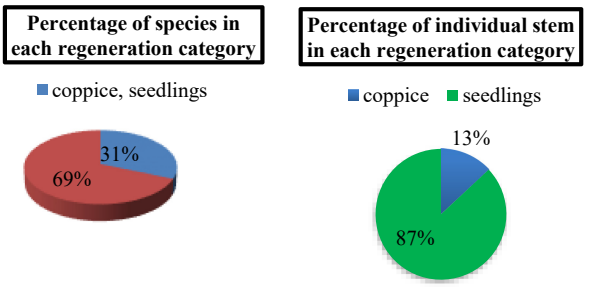


Figure 4.
Mode of regeneration in Chunati wildlife Sanctuary

Shannon–Winner index (H), Shannon's maximum diversity index (H_{max}), species evenness index (E), Simpson index (D) and dominance of Simpson index (D') were studied for Chunati Wildlife Sanctuary to depict natural regeneration status of recorded tree species (Table 6).

Table 5.
Regeneration potential of eight keystone native species in Chunati Wildlife Sanctuary

Scientific Name	Number of coppice ha^{-1}	Total stem ha^{-1}	Maximum shoot	Percentage of coppice ha^{-1}
Grewia nervosa	35	259	8	14
Lithocarpus polystachya	45	163	11	28
Dipterocarpus alatus	20	134	9	15
Syzygium firmum	15	104	8	14
Shorea robusta	15	92	6	16
Dipterocarpus turbinatus	10	54	7	19
Lithocarpus elegans	13	16	11	81
Quercus gomeziana	3	12	10	25

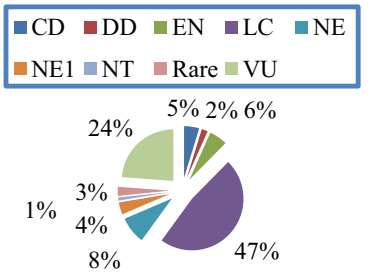


Figure 5.
Conservation status of regenerating species in Chunati Wildlife Sanctuary

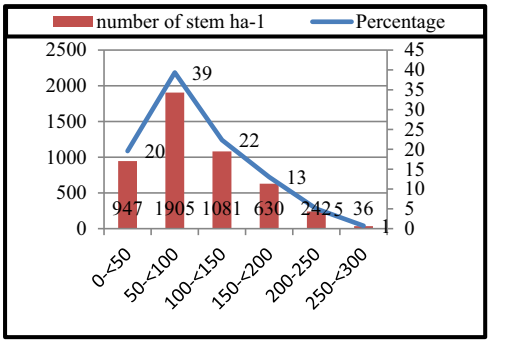


Figure 6.
Percentage distribution of seedlings into different height (cm) classes

Table 6.
Different biological diversity indices for regeneration in Chunati Wildlife Sanctuary

Sl. No	Description	Total for CWS
1	Species diversity index (S_{Di})	0.032
2	Species richness index (R)	12.86
3	Shannon–Winner index (H)	3.67
4	Shannon's maximum diversity index (H_{max})	4.65
5	Species evenness index (E)	0.789
6	Simpson's diversity index (D)	0.042
7	Dominance of Simpson's index (D')	0.96

Discussions

Information on regeneration helps to conserve plant species diversity of a forest (Verma *et al.*, 1999). It is an important and reliable tool for evaluating overall condition of forest ecosystem (Rahman *et al.*, 2011). In CWS, the number of naturally regenerating species (105) and family (35) was higher than that of similar natural forests of Bangladesh. Rahman *et al.* (2019) enumerated 56 naturally regenerating species from Durgapur hill forest. Hossain *et al.* (2004) reported 64 naturally regenerating tree species from natural forests of Chittagong (South) Forest Division. Motaleb and Hossain (2007) recorded 29 regenerating tree species under 16 families from a semi-evergreen forest of Chittagong (South) Forest Division. Rahman *et al.* (2011) reported 55 regenerating tree species from Khadimnagar National Park and Tilagar Eco Park. However, the present study found that the number of regenerating tree species in initial stage (0–<50 cm) is lower than second stage (50–<100), similar to Misbahuzzaman and Alam's (2006) reported highest (617) seedlings in height class 1 to <2 m, followed by 529 seedlings in height class 0 to <1 m from natural forest of Sitakunda, Chittagong. It may be due to field data collection after 4 months of regeneration or high rate of mortality of seedling in dry soil condition or human disturbances. Moraceae, Mimosaceae, Verbenaceae, Dipterocarpceae and Fagaceae were found as dominant families probably because of higher regeneration potential and the seed dispersal capability of their species and favorable conditions for regenerating in CWS.

A. wallichi, *G. nervosa*, *S. fruticosum*, *L. polystachya* and *D. alatus* were found as dominant regeneration species because of their profuse seed production.

The diversity indices of the present study indicates better generation in CWS in comparison to species diversity index (0.01), species richness index (4.92), Shannon–Winner index (3.62), Shannon's maximum diversity index (3.69), species evenness index (2.26), Simpson index (0.03) and dominance of Simpson index (0.97) reported by Rahman *et al.* (2011) from biodiversity conservation areas of Northeastern Bangladesh.

Conclusion

The present investigation provides authentic information on natural regeneration status of CWS. Values of diversity indices indicate rich plant species diversity and existence of complex ecosystem functions in the Sanctuary. The IVI values reveal ecologically the most important tree species in the forest and those to be prioritized for conservation. The height class distribution and coppice regeneration indicate occurrences of illegal removal of trees from the forest. Although their natural regeneration was coming up, seedling cutting particularly by fuel wood collectors and betel leaf cultivators imposes threats on new recruitments. Finally, it can be concluded that although the condition of the forest is poor, there is still some hope as shown by the rich number of regeneration. If it is possible to protect the sanctuary in the current state with effective measures of diverting the forest-dependent people toward non-forest-related livelihood alternatives or reducing dependency on the forest, there is a greater possibility of this forest to develop into a better-quality forest in future.

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