Regular Article
pISSN: 2288-9744, eISSN: 2288-9752
Journal of Forest and Environmental Science
Vol. 34, No. 1, pp. 31-45, February, 2018
https://doi.org/10.7747/JFES.2018.34.1.31

JFES
Journal of Forest and Environmental Science

Tree Diversity, Distribution and Population Structure of a Riparian Forest from Certain Zones along the Dikhu River in Nagaland, India

Devlin Leishangthem and Maibam Romeo Singh*
Centre for Biodiversity Studies, Department of Botany, Nagaland University, Lumami-798627, Nagaland, India

Abstract

At present the biodiversity of the riparian forest is under threat due to various anthropogenic pressures. Hence study was conducted along the three unprotected zones of riparian forest in Dikhu river, Nagaland, north-east India in order to compared the diversity, distribution and population structure of riparian trees. In each zone 100×100 m^2 plot were marked and subdivided into 20 plots of 10×10 m^2. 10 plots on each side of the river were taken randomly covering 0.02 ha. Only tree with dbh ≥10 cm and dbh above 1.5 m above ground level were recorded as individual species. A total of 29 tree species belonging to 18 families were recorded from the three zones of the river. Tree species richness was highest at the middle zone (19) followed by upper (14) and lower zone (7). The most abundant species and family recorded at upper, middle and lower zones were Melia azaderach of Euphorbiaceae (380 stems ha^{-1}), Terminalia chebula of Euphorbiaceae (432.5 stems ha^{-1}) and Duabanga grandiflora of Lythraceae (365 stems ha^{-1}) respectively. The ranges of diversity indices observed in the three zones were: Shannon-Wiener index (1.25-0.73), Simpson diversity index (0.42-0.93), Evenness index (0.47-0.37) and Index of co-dominance (0.75-0.94). Rest of other indices were also estimated and compared. Distribution of trees shows the contagious pattern common in the upper and middle zones and regular in the lower zone. The girth size class analysis demonstrated that the riparian forest is in less mature succession stage. This study emphasize the need for management and conservation of riparian forest by developing policy to declare the riparian zone as protected area to prevent further degradation and loss of biodiversity from these unregulated zones along the river.

Key Words: riparian trees, unprotected zone, tropical forest, Eastern Himalaya, Dikhu river

Introduction

Riparian plant communities along the rivers are dynamic, species rich (Nilsson 1991) and sensitive to anthropogenic interference (Malanson 1993) resulting disturbance adapted communities. Plant communities in these systems are likely to be affected both by longitudinal i.e. upstream-downstream (Vannotte et al. 1980; Noss 1983) and transversal i.e. stream-floodplain or floodplain-basin (Newbold et al. 198l) linkages for species recruitment and diversity. The spatial heterogeneity resulting from geomorphological processes is viewed as one of the major causes of high species richness (Ferreira and Stohlgren 1999). As a consequence of the shifting mosaic of landforms and communities resulting from natural disturbance (Whittaker 1977), high levels of species richness are usually found along rivers. Studies on species richness patterns in river corridors indicated that total species richness in a river is

Received: September 14, 2017. Revised: December 4, 2017. Accepted: January 22, 2018.

Corresponding author: Maibam Romeo Singh
Centre for Biodiversity Studies,Department of Botany, Nagaland University, Lumami-798627, Nagaland, India
Tel: 91-9612211169, Fax: +91-0369-2268248, E-mail: romeomaibam@gmail.com

maximum in the middle reaches (Vannotte et al. 1980). Species richness patterns in the riparian corridor change in response to the dynamics of flood disturbance (Renofalt et al. 2005) but regular moderate flooding is required to sustain high levels of diversity in riparian ecosystems (Naiman and Decamps 1997). Tree species diversity is an important aspect of forest ecosystem diversity (Rennolls and Laumonier 2000; Tchouto et al. 2006) and is also fundamental to tropical forest biodiversity (Evariste et al. 2010). The rapid inventory of tree species that provides information on diversity will represent an important tool to enhance our ability to maximize biodiversity conservation that results from deforestation and degradation (Baraloto et al. 2013). Tree species diversity in tropical forests differs greatly from location to location mainly due to variation in biogeography, habitat and disturbance (Neumann and Starlinger 2001; Padalia et al. 2004). Plant diversity changes are compared in conjunction with human impacts. Certain changes are easy to predict, at least qualitatively. Population sizes when reduced may have deleterious consequences (Sukumar et al. 1992). Human activities have been drastically transformed the major rivers of Asia such as Indus, Ganges and Yangtze (Dudgeon 2000) and are now categorized as threatened ecosystems (Johnsingh and Joshua 1989; Dudgeon 1992) due to the loss of species richness. In India, the phytodiversity of riparian forests are under threat due to anthropogenic disturbances such as deforestation, overgrazing and land reclamation (Gopal 1988). The Ganga river has lost 80% of its original forest cover in its basin (Smakhtin et al. 2007). Riparian forests adjoining stream and river banks have been almost entirely eliminated outside the protected areas (Gadgil 2004). Moreover, there has been no quantitative estimation of riparian diversity in Indian rivers. In India, few quantitative plant biodiversity inventories were investigated in riparian forests of Chalakkudy river (Bachan 2003); Valapattanam river (Sreedharan 2005) of Kerala and Cauvery river of Tamil Nadu (Sunil et al. 2010) and Meenachil river basin in Kerala (Vargashe 2014). Dikhu river is the important river of Nagaland, a state in the north-east corner of India bordering the Indo-Myanmar biodiversity hotspot which is under the eastern Himalayan region. The riparian forest along the Dikhu river remains relatively unprotected from poor agricultural practices by way of shifting cultivation, residential and commercial construction, rock quarrying, forest fire, fodder collection for feeding animals and logging. These result in accelerating both onsite and offsite degradation due to erosion, runoff, nutrient losses, siltation, loss of bio-diversity and disruption in watershed hydrology causing fragmentation of riparian forest. The objectives of this paper was to compare the community composition, species diversity, distribution and tree population structure from three unprotected zones of riparian forest in Dikhu river. Understanding the knowledge of species diversity is a useful tool in plant ecology and forestry to compare the composition of different species. Quantitative analysis of trees from riparian forest will provide a valuable information for riparian forest assessment and improve our knowledge by the identification of ecologically, useful species as well as species of special concern, thus identifying conservation efforts for sustainability of riparian forest biodiversity.

Materials and Methods

Study areas

The study was conducted in the three unprotected zones of riparian forest along Dikhu river, Nagaland, India. Nagaland has a total geographical area of 16,579 sq. km and extends between 25°6′ N to 27°4′ N Latitude and 93°20′ E to 95°15′E Longitude. The state enjoys sub-tropical to warm temperate monsoonic types of climate with an annual mean rainfall of approximately 2,600 mm. The Dikhu river is one of the most prominent rivers of Nagaland which passes mainly to Zunheboto, Tuensang, Longleng, Mokokchung and Mon districts of the state and flows across the Mokokchung and the Longleng districts. The Dikhu river is one of the tributaries of Brahmaputra. It originates from Nuroto Hill area in Zunheboto district, flow further northward and leaves the hill near Naginimora and finally joined with the Brahmaputra River in Assam. The river has a total length of about 160 km. The three zones were selected for the present study and designated as 1. Upper zones, Lumami (Latitude 26°12′57.2″ and Longitude 094°29′ 45.5″) with an elevation of 960 m above 'm a.s.l.' in Zunhebotto district 2. Middle zones, Chare (Latitude 26°17′ 58.00″ and Longitude 094°35′26.8″) with an elevation of 566 m above 'm a.s.l.' in Tuensang district and 3. Lower zones, Yachem (Latitude 26°29′51.5″ and Longitude

094°41′40.00″) with an elevation of 292.6 m above 'm a.s.l.' in Longleng district (Fig. 1). In all the three zones through observation the level of disturbance is much more in the lower zone compared to rest of other zones. The lower zone being located near the residential area and passing highway, it is much prone to anthropogenic activities like logging, rock quarrying, farming and plantation practices. However, upper and middle zone are not much affected as they are located in the interior portion of the riparian forest but logging is taking place in these zones.

Vegetation analysis and identification of Species

The phytosociological studies of trees from three zones along the river were conducted during the period of 2014 to 2015. The vegetation was analyzed by random sampling to obtain the most representative composition of the samples. In each zone 100×100 m^2 plots were marked and subdivided randomly into 20 plots of 10×10 m^2 sizes. 10 plots on each side of the river were taken randomly covering 0.02 ha. Tree density, basal area and girth class were estimated from 0.2 ha area and extrapolated on per hectare basis. In each quadrate, the circumference at breast height (dbh at 1.37 m above ground level) of each tree (>10 cm dbh) was measured and individuals with dbh <10 cm were recorded as individual tree (Pande et al. 1988). The plant specimens collected during field study were processed for herbarium preservation and identified with the help of literatures (Bentham and Hooker 1862-1883; Prain 1903; Kanjilal et al. 1934; Kanjilal et al. 1936; Kanjilal et al. 1938; Kanjilal et al. 1940; Bor 1940; Guha Bakshi 1984; Bennet 1987). Herbarium specimen were deposited and preserved in the Department of Botany, Nagaland University, Lumami Campus.

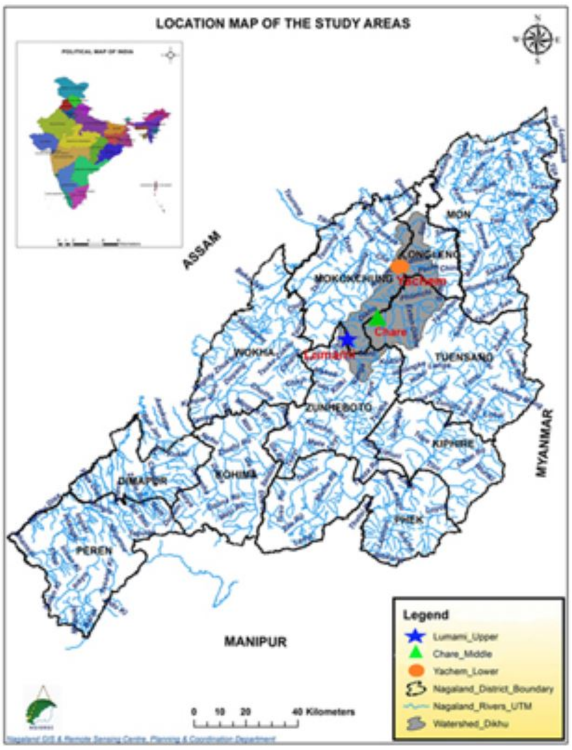

Fig. 1. Location map of the study areas showing the upper, middle and lower zones of Dikhu river in Nagaland, India.

Data Analysis

Standard methods of Curtis and Mclntosh (1950) and Mueller-Dombois and Ellenberg (1974) have been adopted to analyze the density, frequency and abundance. For calculation of frequency, density and abundance the following formulae have been used.

$$\text{Density} = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of quadrates studied}}$$

$$\text{Relative density (\%)} = \frac{\text{Number of individuals of a species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Frequency} = \frac{\text{Number of sampling units species occur}}{\text{Total number of sampling units}} \times 10$$

$$\text{Relative frequency (\%)} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \times 100$$

$$\text{Abundance} = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of quadrates in which the species occured}}$$

$$\text{Relative Basal Area (\%)} = \frac{\text{Basal area of a species}}{\text{Basal area of all the species}} \times 100$$

Basal area of trees was calculated by using the formula:

$$\text{Basal area} = \frac{C^2}{4\pi}$$

where, C= Girth breast height

IVI of each species was calculated by summing the RF, RD and RBA values following Curtis (1959). Abundance to Frequency ratio (A/F) of each species was calculated to study the population dispersion pattern. The ranges of values for determining dispersion pattern were: regular (<0.025), random (0.025-0.05) and contiguous (>0.05) given by Cottam and Curtis (1956). Population structure of tree species was analyzed across ten girth classes.

Measurement of biodiversity indices

The formulae used in the calculation of various biodiversity indices were:

1. Concentration of dominance was measured by using the formula given by Simpson's (1949).

$Cd = \sum(ni/N)^2$

where, ni=Proportion of individuals belonging to the ith species

N=Total number of individuals

2. Shannon and Wiener Index (1963)

It is also called species diversity index. This index is based on information theory and improves upon the Simpson's by giving more importance to the rare species.

$H = -\sum (ni/N) \log (ni/N)$

ni=Total number of individuals belonging to its species

N=Total number of individuals in the sample.

3. Simpson's Diversity Index (D) given by Simpson's (1949) as

$$D = \frac{\sum ni\,(ni-1)}{N\,(N-1)}$$

4. Simpson's Index of Diversity (1949)=1-D

5. Simpson's Reciprocal Index elaborated from Simpson (1949)=1/D

6. Species heterogeneity is defined as the reciprocal of Simpson's index or under root of concentration of dominance (Cd), was also determined as:

$$\text{Species heterogeneity} = \frac{1}{\sqrt{Cd}}$$

7. Hill's diversity Index

$N_1 = e^H$, Where H=Shannon-Weiner's index

$N_2 = 1/D$, Where D=Simpson's index

8. Margalef's richness index (1958)

R=S-1/ln N

where, S=Total no. of species

N=Total no. of individual of all species.

9. Evenness Index given by Pielou (1969)=H/ln S

10. $E_4 = \frac{n2}{n1}$

11. $E_5 = \frac{n2-1}{n1-1}$

12. Menhinick's richness index was calculated by using the formulae given by Menhinick (1964) as, $DI = \frac{S}{\sqrt{N}}$

where, S=No. of species

N=No. of total species

13. Similarity Index (Sorenson 1948) was also calculated by using the formula;

$S = \frac{2C}{A+B}$,

wheres, S=Similarity Index

A=No. of species at a site

B=No. of species at another site

C=No. of species common to both the sites.

14. Dissimilarity Index (Sorenson, 1948)=1-S

where, S=Similarity Index

Results and Discussion

Species composition and distribution of trees

Table 1 shows the composition and distribution of tree species in riparian forest at upper, middle and lower zone of Dikhu river. A total of 29 tree species belonging to 18 families were recorded from the three zones of the river. The species richness was highest at the middle zone (19) followed by upper (14) and lower zone (7). At upper zone, a total of 627 tree individual representing 14 species belonging to 9 families were identified within the 0.2 ha area plot whereas at middle zone, a total of 840 individual trees belonging to 12 families were identified and at lower zone, 175 individual trees belonging to 6 families were recorded. Total stand density and basal area recorded from three zones were: 3,132.5 trees ha^{-1} and 261.48 m^2 ha^{-1} at upper zone, 4,200 trees ha^{-1} and 378.48 m^2 ha^{-1} at middle zone and 872.5 trees ha^{-1} and 5.6 m^2 ha^{-1} at lower zone. High species richness means greater diversity and which leads to a higher community stability (MaAcrthur 1955). Iqbal et al. (2012) reported 31 tree species around Khok river of Garhwal Himalaya, India. Sunil et al. (2016) recorded a total of 177 tree species from the riparian forest along the river Cauvery. Species composition varies widely according to the frequency of river disturbances (Oliveira-Filho et al. 1994; Metzger et al. 1997). This spatial heterogeneity resulting from geomorphological processes is viewed as one of the major causes of species richness (Gould and Walker 1997; Ferreira and Stohlgren 1999). Even though the degree of disturbance in the riparian forests of Dikhu river

Table 1. Composition and distribution of tree in riparian forest at upper, middle and lower zone of Dikhu river

Species name	Family	Upper zone	Middle zone	Lower zone
1 *Antides mabunius* (L.) Spreng.	Euphorbiaceae	Δ	+	Δ
2 *Bischofia javanica* Blume	Euphorbiaceae	Δ	+	Δ
3 *Bombax ceiba* L.	Malvaceae	Δ	+	+
4 *Colona floribunda* (Wall. ex Kurz) Craib	Malvaceae	Δ	+	Δ
5 *Diospyros kaki* Thunb.	Ebenaceae	Δ	+	Δ
6 *Diospyros lanceifolia* Roxb.	Ebenaceae	Δ	+	Δ
7 *Duabanga grandiflora* (DC.) Walp.	Lythraceae	Δ	Δ	+
8 *Evodia fraxinifolia* (Hook.) Benth.	Rutaceae	Δ	+	Δ
9 *Ficus hispida* L. f.	Moraceae	+	Δ	Δ
10 *Ficus semicordata* Buch.-Ham. ex Sm.	Moraceae	+	+	+
11 *Garcinia cowa* Roxb. ex Choisy	Clusiaceae	Δ	+	Δ
12 *Glochidion* sp.	Euphorbiaceae	Δ	+	Δ
13 *Guidonia vareca* (Roxb.) Baill. ex Kurz	Ulmaceae	+	Δ	Δ
14 *Itea macrophylla* Wall.	Iteacaeae	+	Δ	+
15 *Knema erratica* (Hook. F. & Thomson) J. Sinclair	Myristicaceae	Δ	+	Δ
16 *Macaranga denticulata* (Blume) Müll.Arg.	Euphorbiaceae	+	Δ	Δ
17 *Macaranga indica* Wight	Euphorbiaceae	+	+	+
18 *Macropana xundulatus* (Wall. ex G.Don) Seem.	Araliaceae	+	Δ	Δ
19 *Mallotus ferrugineus* (Roxb.) Müll. Arg.	Euphorbiaceae	+	+	Δ
20 *Melia azedarach* L.	Meliaceae	+	Δ	Δ
21 *Parkia timoriana* (DC.) Merr.	Fabaceae	Δ	+	Δ
22 *Phoebe lanceolata* (Nees) Nees	Lauraceae	+	Δ	Δ
23 *Quercus acutissima* Carruth.	Fagaceae	Δ	+	Δ
24 *Rhus chinensis* Mill.	Anarcardiaceae	+	Δ	Δ
25 *Sapium eugeniifolium* Buch.-Ham. ex Hook.f.	Euphorbiaceae	+	+	Δ
26 *Saurauia punduana* Wall.	Actinidiaceae	Δ	+	Δ
27 *Terminalia chebula* Retz.	Combretaceae	Δ	+	+
28 *Terminalia myriocarpa* Van Heurck & Müll. Arg.	Combretaceae	+	Δ	+
29 *Trevesia palmata* (Roxb. ex Lindl.) Vis.	Araliaceae	+	+	Δ
Total		14	19	7

+, presence; Δ, absence.

has not been analyzed, the anthropogenic stress and the intermittent small scale folds were prevalent at upper and lower zones. However, the disturbance is not among the most important factors that affect species diversity (Mackey and Currie 2001) but variation in species richness and composition also related to natural site variations like elevation, slope and mean annual precipitation (Wyant and Ellis 1990). It was recorded that the maximum environment heterogeneity occurs in midcourse resulting highest species richness and habitat diversity (Vannotte et al. 1980; Tabacchi 1990). The riparian forest of Dikhu river harbors diverse riparian trees with high species richness. Species richness in a forest depends on climatic, edaphic and biotic factors (Ayappan and Parthasarathy 1999).

Based on the IVI obtained, *Melia azaderach* had the highest IVI (32.95) followed by the *Macaranga indica* and *Macaranga denticulata* (27.26) and lowest in *Itea macrophylla* (15.34) at upper zone (Table 2). At middle zone, *Terminalia chebula* had the highest IVI (32.05) followed by *Sapium eugeniifolium* (23.92), *Macaranga indica* (22.11) and *Diospyros kaki* has the lowest (10.42) IVI (Table 3) whereas at the lower zone *Duabanga grandiflora* had the highest IVI (110.47) followed by *Ficus semicordata* (58.52), *Itea macrophylla* (32.03) whereas *Bombax ceiba* had the lowest IVI (21.40) as shown in Table 4. At the upper zone, Euphorbiaceae family occupied the highest (4) followed by Araliaceae (2), Moraceae (2), Meliaceae (1), Lauraceae (1), Anarcardiaceae (1), Combretaceae (1), Iteacaeae (1), Ulmaceae (1). At the middle zone, Euphorbiaceae family has also occupied the maximum (6) followed by Malvaceae (2), Ebenaceae (2), Combretaceae (1), Fagaceae (1), Actinidiaceae (1), Myristicaceae (1), Araliaceae (1), Rutaceae (1), Fabaceae (1), Moraceae (1) and Clusiaceae (1). Whereas, at the lower zone Combretaceae family obtained the highest (2), followed by Lythraceae, Moraceae, Iteacaeae, Euphorbiaceae and Malvaceae family having 1 number in each of the family (Table 1). Thus from the IVI values, *Melia azaderach*, *Terminalia chebula* and *Duabanga grandiflora* were found to be the most dominant tree species occurred at upper, middle and lower zones respectively. IVI value of any species indicates the dominant of species in a mixed population and it gives a total picture of the social structure of species in a community and can be used to form an association of dominant species (Parthasarathy and Karthikeyan 1997). In the present study, it was found that Euphorbiaceae family was dominant at upper and middle zones whereas Lythraceae was dominant at lower zone. The predominant of Fabaceae, Combretaceae and Euphorbiaceae families in riparian zone was confirmed by Fousseni et al. (2011). The dominance of tree families Euphorbiaceae,

Table 2. Quantitative analysis of tree at upper zone (Lumami) in riparian forest of Dikhu river

Scientific name	Density	F	RD	RF	RBA	BA	IVI	Abundance	A/F ratio	DP
Ficus hispida	267.5	62.5	8.54	6.54	4.74	12.39	19.82	4.28	0.07	Contagious
Ficus semicordata	205	47.5	6.54	4.97	4.44	11.61	15.96	4.32	0.09	Contagious
Guidonia vareca	175	75	5.59	7.85	4.25	11.11	17.69	2.33	0.03	Random
Itea macrophylla	195	62.5	6.23	6.54	2.57	6.71	15.34	3.12	0.05	Contagious
Macaranga denticulate	260	72.5	8.30	7.59	11.37	29.72	27.26	3.59	0.05	Contagious
Macaranga indica	295	70	9.42	7.33	11.24	29.40	27.99	4.21	0.06	Contagious
Macropana xundulatus	177.5	70	5.67	7.33	4.39	11.48	17.39	2.54	0.04	Random
Mallotus ferrugineus	242.5	65	7.74	6.81	7.30	19.09	21.85	3.73	0.06	Contagious
Melia azedarach	380	82.5	12.13	8.64	12.18	31.86	32.95	4.61	0.06	Contagious
Phoebe lanceolata	152.5	72.5	4.87	7.59	10.35	27.06	22.81	2.10	0.03	Random
Rhus chinensis	137.5	60	4.39	6.28	11.00	28.77	21.67	2.29	0.04	Random
Sapium eugeniifolium	257.5	77.5	8.22	8.12	2.73	7.13	19.06	3.32	0.04	Random
Terminalia myriocarpa	212.5	70	6.78	7.33	2.50	6.55	16.62	3.04	0.04	Random
Trevesia palmata	175	67.5	5.59	7.07	10.94	28.60	23.59	2.59	0.04	Random
	3,132.5									

D, density (trees ha^{-1}); F, frequency; RD, relative density (%); RF, relative frequency (%); RBA, relative basal area (%); BA, basal area (m^2 ha^{-1}); IVI, importance value index; A, abundance; A/F ratio; DP, distribution pattern.

Table 3. Quantitative analysis of tree at middle zone (Chare) in riparian forest of Dikhu river

Scientific name	Density	F	RD	RF	RBA	BA	IVI	Abundance	A/F ratio	DP
Antides mabunius	237.5	55	5.65	4.68	6.04	22.87	16.38	4.32	0.08	Contagious
Bischofia javanica	112.5	55	2.68	4.68	5.81	21.98	13.17	2.05	0.04	Random
Bombax ceiba	102.5	47.5	2.44	4.04	8.39	31.76	14.87	2.16	0.05	Contagious
Colona floribunda	245	55	5.83	4.68	1.22	4.61	11.73	4.45	0.08	Contagious
Diospyros kaki	182.5	62.5	4.35	5.32	0.76	2.87	10.42	2.92	0.05	Contagious
Diospyros lanceifolia	197.5	47.5	4.70	4.04	1.82	6.87	10.56	4.16	0.09	Contagious
Evodia fraxinifolia	247.5	72.5	5.89	6.17	0.66	2.48	12.72	3.41	0.05	Contagious
Ficus semicordata	180	60	4.29	5.11	2.78	10.52	12.17	3.00	0.05	Contagious
Garcinia cowa	155	62.5	3.69	5.32	2.38	9.02	11.39	2.48	0.04	Random
Glochidion sp.	225	50	5.36	4.26	5.55	21.02	15.17	4.50	0.09	Contagious
Knema erratica	257.5	57.5	6.13	4.89	3.17	11.99	14.19	4.48	0.08	Contagious
Macaranga indica	275	55	6.55	4.68	10.88	41.19	22.11	5.00	0.09	Contagious
Mallotus ferrugineus	220	77.5	5.24	6.60	4.04	15.31	15.88	2.84	0.04	Random
Parkia timoriana	125	67.5	2.98	5.74	3.99	15.10	12.71	1.85	0.03	Random
Quercus acutissima	242.5	65	5.77	5.53	9.06	34.30	20.37	3.73	0.06	Contagious
Sapium eugeniifolium	260	70	6.19	5.96	11.77	44.56	23.92	3.71	0.05	Contagious
Saurauia punduana	325	60	7.74	5.11	3.34	12.64	16.18	5.42	0.09	Contagious
Terminalia chebula	432.5	77.5	10.30	6.60	15.16	57.37	32.05	5.58	0.07	Contagious
Trevesia palmata	177.5	77.5	4.23	6.60	3.18	12.04	14.00	2.29	0.03	Random
	4,200									

D, density (trees ha^{-1}); F, frequency; RD, relative density (%); RF, relative frequency (%); RBA, relative basal area (%); BA, basal area (m^2 ha^{-1}); IVI, importance value index; A, abundance; A/F ratio; DP, distribution pattern.

Table 4. Quantitative analysis of tree at lower zone (Yachem) in riparian forest of Dikhu river

Scientific name	Density	F	RD	RF	RBA	BA	IVI	Abundance	A/F ratio	DP
Bombax ceiba	57.5	62.5	6.13	13.66	1.61	0.09	21.40	0.92	0.01	Regular
Duabanga grandiflora	365	67.5	38.93	14.75	56.79	3.18	110.47	5.41	0.08	Contagious
Ficus semicordata	153.5	67.5	16.27	14.75	27.50	1.54	58.52	2.26	0.03	Random
Itea macrophylla	44	70	11.73	15.30	5.00	0.28	32.03	1.57	0.02	Regular
Macaranga indica	80	60	8.53	13.11	2.50	0.14	24.15	1.33	0.02	Regular
Terminalia chebula	80	65	8.53	14.21	2.86	0.16	25.60	1.23	0.02	Regular
Terminalia myriocarpa	92.5	65	9.87	14.21	3.75	0.21	27.82	1.42	0.02	Regular
	872.5									

D, density (trees ha^{-1}); F, frequency; RD, relative density (%); RF, relative frequency (%); RBA, relative basal area (%); BA, basal area (m^2 ha^{-1}); IVI, importance value index; A, abundance; A/F ratio; DP, distribution pattern.

Araliaceae, Moraceae, Meliaceae, Lauraceae, Anarcardiaceae, Combretaceae, Iteacaea, Ulmaceae, Malvaceae, Ebenaceae, Fagaceae, Actinidiaceae, Myristicaceae, Rutaceae, Fabaceae, Clusiaceae and Lythraceae in the riparian forest of Dikhu river indicates the types of the tropical forest. There is no riparian tree data to cite the comparison from India except the work of Chalakkudy river basin (Bachan 2003) and Meenachil river basin (Varghese 2014). Fig. 2 depicts dominance diversity (D-d) curve of the tree species from the three zones of Dikhu riparian forest in relation to their availability of suitable niche. Whittaker (1969) pointed out that resource apportionments in a community have often been interpreted from (D-d) curve. The (D-d) curve under present investigation approached to log normal distribution model of Preston (1948) with less number of tree in high IVI range. Dominance diversity relationships form

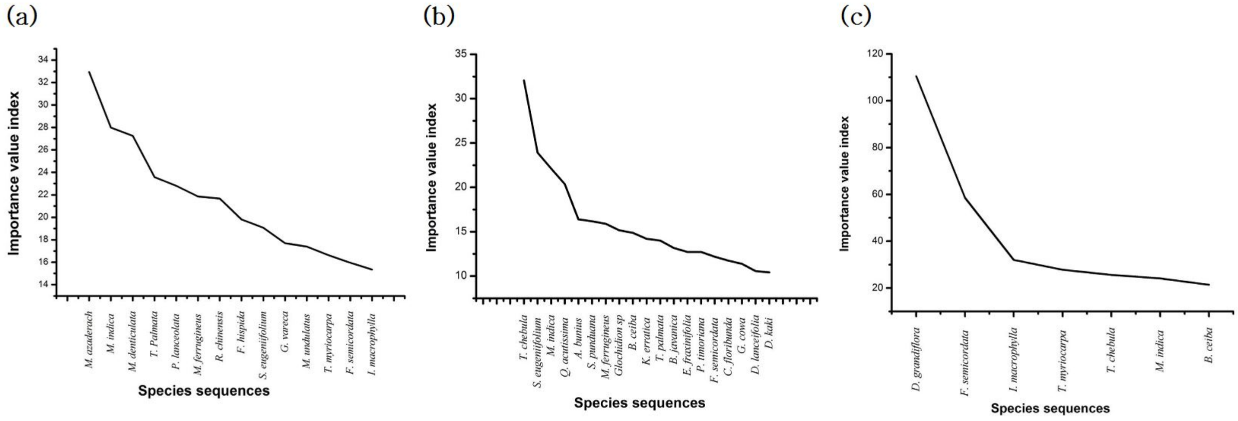

Fig. 2. (a) Dominance diversity curve for riparian tree species at upper zone. (b) Dominance diversity curve for riparian tree species at middle zone. (c) Dominance diversity curve for riparian tree species at lower zone.

a continuous progression from dominant to intermediate to rare species. These curves are believed to expressed different pattern of competition and value differentiation in communities and thus have varied forms. Lognormal hypothesis assumes that the importance of species is governed by the interaction between a large numbers of factor determining successes in the niche hyperspace (Whittakker 1970). In connection to this, Whittakker (1965) noted that the log-normal series describes the partitioning of realized niche space among various species and is the consequence of evolution of particular species diversity along the niche parameters which they exploit.

Distribution pattern

The Abundance to frequency ratio ranged from 0.03 to 0.09 at upper zone, 0.03 to 0.09 at middle zone and 0.01 to 0.08 at lower zone. At the upper zone, 7 species contributing 50% were recorded the contagious pattern of distribution followed by value of 50% for random distribution pattern by 7 species. At middle zone, out of 19 species recorded, 14 species show the contagious pattern of distribution contributing 73.69% and remaining 5 species show random distribution pattern contributing 26.31%. At lower zone, out of 7 tree species recorded, 5 species were recorded to be show regular pattern of distribution (71.42%) followed by contagious pattern (14.29%) by *Duabanga grandiflora* and random pattern of distribution (14.29%) by *Ficus semicordata* as mentioned in Table 1-3. The distribution pattern analysis shows species dispersion across a span of time at any given site. The patterns of distribution solely depend on both the physico-chemical natures of the environment as well as on the biological peculiarities of the organisms themselves. According to Odum (1971), contiguous distribution is common in nature and formed as a result of small but significant variations in the ambient environmental conditions. The author also noted that random distribution is found in very uniform environments only, and regular distribution occurs where severe competition exists between individuals. The above statement supports the findings of the present study. The analysis of distribution pattern along the three zones indicate that contiguous distribution pattern was the most common followed by random pattern except in lower zone, the pattern of species distribution was dominated by regular. Several workers (Ralhan et al. 1982; Majumdar and Datta 2015) have reported similar distribution pattern in the forest vegetation of India. Variation in the distribution pattern among zones and vegetation composition are associated with micro-environmental and biotic factors (Singhal and Soni 1989).

Population structure

Tree density at the middle riparian zone was higher (4,200 trees ha^{-1}) compared to upper (3,132.5 trees ha^{-1}) and lower zone (872.5 tree ha^{-1}). However, the tree density observed in the present study was high compared to 118.6 trees ha^{-1} in Cauvery river and 11.9 trees in 0.01 ha^{-1} reported by Bachan (2003) in Chalakkudy river, Kerala and 660 ha^{-1} reported by Iqbal et al. (2012) in Khok river of

Garhwal Himalaya. Burton et al. (2005) worked in riparian forest of two countries observed the density values between 950 trees ha^{-1} to 1958 trees ha^{-1}. The reason for higher tree density values at the upper and middle zones may be due to *Melia azaderach*, *Terminalia chebula* and *Duabanga grandiflora* are dominant at the upper, middle and lower zone of the riparian forest indicating the deciduous type of forest. They are pioneer species which often initiates a secondary succession in the riparian forest replacing the dominant native riparian species. Upper and middle zone are less affected by anthropogenic activities compared to lower zone. The reason for low tree density in the lower zone may be due to high anthropogenic pressure created by villagers for extraction of fuel wood, collection of fodder for animal feeding and farming practices. Flooding events are primarily responsible for creating its spatial heterogeneity, with the timing of flooding, its duration, frequency and magnitude all identified as influencing the structure and composition of riverine vegetation (Richter et al. 1997; Ward et al. 1999). There is considerable heterogeneity in tree species along the three zones of the river. He and Lagendre (2002) reported species-area relation, which predicts that species richness increases with increasing area. Pausas and Austin (2001) also suggested that over large region, the distribution of species richness is likely to be governed by two or more environmental factors and not by a single factor. Density of tree with smaller girth size is higher than that of the larger girth size (Basyal et al. 2011). The basal area of the trees in the studied zones indicates a high level of human disturbance in lower (10-60 cm gbh) and middle girth classes ($61^{-1}20$ cm gbh) because of selective felling of under storey and upper storey trees for fence-posts, house construction and other agricultural implements according to the information gathered during field work. Such selective elimination of species would affect forest species composition and stand structure, and also a more subtle impact and depends largely on accessibility, which itself is related to topography (Johst et al. 2002). Stem density and species richness have consistently decreased with increasing girth class of tree species from 60 to more than 100 cm girth. The contribution of each species to the overall basal area of the trees showed that *Terminalia chebula* contributed the largest basal area of 57.37 m^2 ha^{-1} at middle zone followed by *Melia azadarach* at upper zone (31.86 m^2 ha^{-1}) and *Duabanga grandiflora* (3.18 m^2 ha^{-1}) at lower zone (Table 2-4). The mean basal area ranged from 0.45 m^2 ha^{-1} (lower zone) -21.29 m^2 ha^{-1} (upper zone). Higher value at upper zone indicates that the riparian forest at this zone are densely populated and exhibit species competition whereas minimum at lower zone might be due to less number of species with few population. Variation in density and basal area of different zones of riparian forest may be attributed by altitudinal variation, species composition, age structure, successional stage of the forest and degree of disturbance (Swamy et al. 2000). The size class distribution of tree has often been use to represent the population structure of forest (Saxena and Singh 1984; Khan et al. 1987). Tree size class distribution can be used as indicator of changes in population structure and species composition (Newbery and Gartlan 1996). Fig. 3 shows that all the three riparian zone were characterized by small and young trees whose girths were mostly ＞11-20, ＞21-30, ＞31-40, ＞41-50, ＞51-60 cm

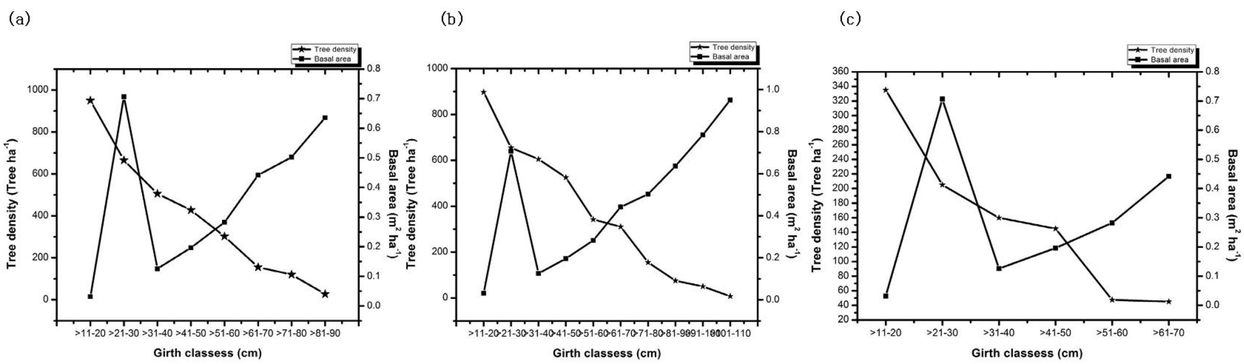

Fig. 3. (a) Tree density (tree ha^{-1}) and basal area (m^2 ha^{-1}) distribution along the girth classes at upper zone. (b) Tree density (tree ha^{-1}) and basal area (m^2 ha^{-1}) distribution along the girth classes at middle zone. (c) Tree density (tree ha^{-1}) and basal area (m^2 ha^{-1}) distribution along the girth classes at lower zone.

though, trees of higher girth were obtained in the middle zone compared to the rest of the zones. Girth class frequency showed reverse J-shaped population curve in our present study which is similar to those reported from forest of north-east India (Mishra et al. 2005; Tynsong and Tiwari 2011), eastern ghats (Kadavul and Parthasarathy 1999; Sahu et al. 2012). The reverse J-shaped population curve of trees suggests an evolving or expanding population, climax or stable type of population in forest ecosystem, indicating that the forest harbors a growing and healthy population (Mishra et al. 2005; Sahu et al. 2012; Sarkar and Devi 2014). The reverse J-shaped GBH-density distribution of trees indicates that the forest sites are disturbed and they are in their successional stages, hence most of the species identified are secondary forest regrowth species.

Diversity indices and their measures

Table 5 show the various diversity indices of riparian tree at the three zones of riparian forest. The highest index of co-dominance (Cd) values recorded was 0.94 at middle zone whereas lowest index obtained was 0.75 at lower zone. The concentration of dominance of the study sites corresponds with the reported value for tropical semi evergreen forest of Manipur (Devi and Yadava 2006). According to Whittaker and Niering (1965), Risser and Rice (1971), Singhal et al. (1986) and Pande et al. (1996), the value of concentration of dominance (Cd) for temperate forests falls within the range of 0.10 to 0.99, however, for tropical forests the average value was 0.06 as reported by Knight (1975). The range of Cd reported for tropical forest of India varies from 0.21 to 0.92. The value reported in present study corresponds well with the reported ranged for tropical forest by several workers (Parthasarathy et al. 1992; Visalakshi 1995).

The highest Shannon's Index H′ was recorded in middle zone (1.25) whereas lowest H′ (0.73) was recorded at lower zone. High value of H′ at the middle zone would be representative of more diverse community. The diversity index (H') for some of the Indian riparian forest were 3.06 (Iqbal et al. 2012), 5.6 (Sunil et al. 2016), 1.43^{-1}.84 (Bachan 2003), 2.19-2.92 (Burton et al. 2005) and 2.43-5.4 (Natta 2000).

Hill diversity numbers (N1 and N2) recorded at three zones were 3.35 and 1.08 at upper zone followed by middle zone (3.50 and 1.06) and 2.07 and 1.31 at lower zone, respectively. Number 2 of Hill diversity index was found to be consistent with the values of Kumar et al. (2004) whereas Number 1 and 2 of Hill diversity indices were found to be very low with the values of Rajkumar and Parthasarathy (2008), Yang et al. (2008) and Adekunle et al. (2013).

Maximum Menhinick's richness index was found to be recorded at middle zone (0.29) and minimum at lower zone (0.23). The reason for minimum Menhinick's richness index at lower zone may be due to disturbances like logging activity, collection of fodder for animal feeding and plantation. Although riparian areas are largely spared during logging activity because of the regulation on the buffer zone, many plants would be affected particularly due to siltation from runoff water from the area that has been made into footways. Many studies have shown that logging intensity is negatively associated with stem densities and species abundance and richness (Azliza et al. 2012). This was due to targeted removal of large commercial and non-commercial (silvicultural treatments) tree species and an in-

Table 5. Diversity indices of riparian tree at upper, middle and lower zones of Dikhu river

Diversity indices	Upper zone	Middle zone	Lower zone	Average
Species richness (S)	14	19	7	13.33
Concentration of dominance (Cd)	0.92	0.94	0.75	0.87
Shannon-Weiner's diversity index (H′)	1.23	1.25	0.73	1.07
Simpsons diversity index (D)	0.93	0.42	0.76	0.7
Simpsons diversity index of diversity (1-D)	0.07	0.58	0.24	0.3
Simpsons reciprocal index (1/D)	1.07	2.38	4.16	2.54
Species heterogeneity	0.96	0.97	0.86	0.93
Hill's diversity number				
NO (Species richness)	14	19	7	13.33
N1	3.35	3.5	2.07	2.98
N2	1.08	1.06	1.31	1.15
Richness index (R)	1.61	2.16	0.87	1.54
Evenness index (E)	0.47	0.42	0.37	0.42
E4	0.31	0.3	0.63	0.41
E5	0.03	0.02	0.29	0.11
Menhinick's index (D)	0.25	0.29	0.23	0.25

creased mortality soon after logging. The present study was consistent with studies in tropical rain forest (De-graaf 1986) as well as other vegetation (Korning and Baslev 1994).

Similarity indices was found to be maximum between upper and lower zone (0.38) and minimum both between upper and middle zone, middle and lower zone with a value of 0.30 (Table 6). The dissimilarity index value shows the opposite trends of similarity index value in the compared studied zone. Sorensen's similarity index expressed in percentage show low similarity (30.30%) of species composition when compared between upper and middle zone, and obtained high similarity between upper and lower zone (38.09%) followed by middle and lower zone (30.76%) riparian vegetation in the present study. However, a high similarity index in term of species composition was reported for Kenong Forest Park (48%) and Chini watershed forest (40%) in Azliza et al. (2012). According to Chandrashekara and Ramakrishna (1993) the level of distribution and succession ages of forest has effects on species composition.

Simpson's diversity index (D) lies within the ranged: 0.42 (middle zone) -0.93 (upper zone), Simpson's index of diversity (1-D) lies within the range: 0.07 (upper zone) -0.58 (middle zone) and Simpson's reciprocal index (1/D) lies within the range: 1.07 (upper zone) -4.16 (lower zone). The value obtained for Simpson diversity index in present study is less than the value reported by Bachan (2003) which lies within the range 0.94 -1.00 from the riparian vegetation along the middle and lower zones of the Chalakkudy river, Kerala, India. Indicating less number of tree diversity in the studied zones. Sunil et al. (2016) recorded Simpson's index value of 0.96 in riparian vegetation across forest of river Cauvery southern, India. Iqbal et al. (2012) obtained Simpson's index value of 0.08 of trees growing along the Khoh river of Garhwal Himalaya, India, and Varghese (2014) reported the range of 0.12 to 0.67

Table 6. Similarity and Dissimilarity indices of riparian tree at upper, middle and lower zones of Dikhu river

Zone	Middle zone	Lower zone
Upper zone	0.30 (0.7)	0.38 (0.62)
Middle zone		0.30 (0.7)

Values in parentheses indicate dissimilarity indices.

which are lesser than the present value. Simpson index diversity and Simpsons reciprocal index values obtained in the present study i.e. 0.30 and 2.54, respectively are lower than the values reported by Varghese (2014) in his studies on the comparison of riparian species diversity between the main river channel and sub watersheds of Meenachil river basin.

The species evenness (E) was higher at upper zone (0.47) followed by middle (0.42) and lower zone (0.37). E_4 values were found to be maximum at lower zone (0.63) and minimum value of 0.30 was recorded at middle zone. E_5 values recorded its maximum value of 0.29 at lower zone and a minimum value of 0.02 at middle zone. E_4 indicates the ratio of abundant species whereas E_5 indicates the very abundant species in a community. The increase in value of evenness index (Hill's ratio) in general as compared to modified hill ratio seems to be related to the Co-dominance of species and very similar nature of individuals compared to many species. Species evenness is a measure of the relative abundance of species that make up the richness of a forested ecosystem; the maximum evenness was (E=1) obtained when all species in a site have similar population size. Higher the evenness value, more even the species is (Kent and Coker 1992). The high evenness value at lower zone might be due to difference in site condition and disturbance regime in the vegetation types of the riparian corridors. This is in agreement with the report of Naiman et al. (1993) who reported that riparian and adjacent upland vegetation often contrast conspicuously in physical conditions, disturbance regime and vegetation pattern.

Maximum species heterogeneity values were recorded at middle zone (0.97) and minimum at lower zone (0.86). Our values are slightly higher than the values given by Varghese (2014) where he recorded the values of species heterogeneity for riparian trees between 0.40 and 0.83. The present findings are in conformity with the work of numerous riparian ecologists who have noted similar variation in vegetation along river corridors (Carbiener and Schnitzler 1990; Varghese 2014).

Conclusion

This study provides a critical analysis of riparian tree species richness in the riparian forest of Dikhu river.

Although a total of 29 trees species were found from the three zones studied but it provides a diverse family indicating high diversity of the riparian forest. A reverse J-shaped population curve indicates high tree species richness and density in lower girth class which gradually decrease with increase in girth class population size indicating that the riparian forest of Dikhu river is in less mature succession stage. Our observation shows that the riparian forest of Dikhu river harbours rich tree diversity providing habitat and food resources to large number of fauna. However, the anthropogenic activities prevailing in the lower zone like collection of fodder for animals, fuel wood, construction purposes and logging by the local people to meet their requirements imposed threat to the survival and population structure of the species. So, if the present trends of anthropogenic pressure continues, the growth, survival and reproduction potential of the trees species will be affected in near future. Therefore, a proper strategy for the conservation and management of the study site is required to formulate, ensuring a sustainable harvest and utilization of forest resources by the local villagers. This information is also useful for designing management practices of riparian zone to enhance understanding of riparian forest ecology and ecosystem function. It will be interesting to study more representatives of riparian plant communities from other type of forest that exist in India to know more about these plant communities.

Acknowledgements

The first author is thankful to University Grant Commission sponsored SAP-DRS-III, Programme, New Delhi, Government of India for providing financial assistance by appointing as the project fellow. The author also thank the Nagaland GIS & Remote Sensing Centre, Planning & Coordination Department, Nagaland for providing Study area map. We are grateful to the Mr. Santanu Dey, Research Scholar Department of Botany, Nagaland University, for his contribution in identifying the tree species at field.

References

Adekunle VAJ, Olagoke AO, Akinele SO. 2013. Tree species diversity and structure of a Nigerian strict nature reserve. Trop Ecol 54: 275-289.

Ayyappan N, Parthasarathy N. 1999. Biodiversity inventory of trees in a large-scale permanent plot of tropical evergreen forest at Varagalaiar, Anamalais, Western Ghats, India. Biodivers Conserv 8: 1533-1554.

Azliza M, Nazre M, Mohamad-Roslan MK, Shamsul K. 2012. Characterization of riparian plant community in lowland forest of Peninsular Malaysia. Int J Botany 8: 181-191.

Bachan AKH. 2003. Riparian Vegetation Along the Middle and Lower Zones of the Chalakkudy River, Kerala, India. Project 26/2000 Sponsored by Kerala Research Programme of Local Development, CDS, Thiruvananthapuram.

Baraloto C, Molto Q, Rabaud S, Herault B, Valencia R, Blanc L, Fine PVA, Thompson J. 2013. Rapid simultaneous estimation of above ground biomass and tree diversity across Neotropical forests: a comparison of field inventory methods. Bitropica 45: 288-298.

Basyal S, Lekhak HD, Devkota A. 2011. Regeneration of *Shorea robusta*. Gaertn in tropical forest of Palpa district, Central Nepal. Sci World 9: 53-56.

Bennet SSR. 1987. Name Changes in Flowering Plants of India and Adjacent Regions. Triseas Publishers, Dehradun, 772 pp.

Bentham G, Hooker JD. 1862-1883. Genera Plantarum. 3 Vols. London.

Bor NL. 1940. Flora of Assam. Vol. 5. Gramineae. Government of Assam, Shillong, 480 pp.

Burton ML, Samuelson LJ, Pan S. 2005. Riparian woody plant diversity and forest structure along an urban-rural gradient. Urban Ecosyst 8: 93-106.

Carbiener R, Schnitzler A. 1990. Evolution of major pattern models and processes of alluvial forest of the Rhine in the rift valley (France/Germany). Vegetatio 88: 115-129.

Chandrashekara UM, Ramakrishnan PS. 1994. Vegetation and gap dynamics of a tropical wet evergreen forest in the Western Ghats of Kerala, India. J Trop Ecol 10: 337-354.

Cottam G, Curtis JT. 1956. The use of distance measures in phytosociological sampling. Ecology 37: 451-460.

Curtis JT, McIntosh RP. 1950. The interrelations of certain analytic and synthetic phytosociological characters. Ecology 31: 434-455.

Curtis JT. 1959. The vegetation of Wisconsin: an ordination of plant communities. University of Wisconsin Press, Madison, Wisc, 657 pp.

de Graaf NR. 1986. A silvicultural system for Natural regeneration of tropical rain forest in Suriname. Ph.D. thesis. Agricultural University, Wageningen, Netherlands.

Devi LS, Yadava PS. 2006. Floristic diversity assessment and vegetation analysis of tropical semievergreen forest of Manipur, north east India. Trop Ecol 47: 89-98.

Dudgeon D. 1992. Endangered ecosystems: a review of the conservation status of tropical Asian rivers. Hydrobiologia 248:

167-191.
Dudgeon D. 2000. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. Annu Rev Ecol Syst 31: 239-263.
Evariste FF, Bernard-Aloys N, Nolé T. 2010 The importance of habitat characteristics for tree diversity in the Mengamé Gorilla Reserve (South Cameroun). Int J Biodivers Conserv 2: 155-165.
Ferreira LV, Stohlgren TJ. 1999. Effects of river level fluctuation on plant species richness, diversity, and distribution in a floodplain forest in Central Amazonia. Oecologia 120: 582-587.
Fousseni F, Yu ZX, Hai ZX, Kperkouma W, Koffi A. 2011. Floristic diversity in most dry and environmentally disturbed areas of northern Togo. Energy Procedia 11: 2127-2132.
Gadgil M. 2004. Karnataka state of environment report and action plan biodiversity sector. ENVIS Technical Report No.16. Indian Institute of Science, Bangalore, 117 pp.
Gopal B. 1988. Wetlands: management and conservation in India. Water Quality Bull 13: 3-6.
Gould WA, Walker MD. 1997. Landscape-scale patterns in plant species richness along an arctic river. Can J Bot 75: 1748-1765.
Guha Bakshi DN. 1984. Flora of Murshidabad District, West Bengal, India. Scientific Publishers, Jodhpur, 440 pp.
He F, Legendre P. 2002. Species diversity patterns derived from species-area models. Ecology 83: 1185-1198.
Iqbal K, Bhat JA, Nazir AP, Negi AK. 2012. Structure and composition estimation of plant species around Khoh river of Garhwal Himalaya, India. J Biodivers Environ Sci 2: 1-11.
Johnsingh AJT, Joshua J. 1989. The threatened gallery forest of the river Tambiraparani, Mundanthurai Wildlife Sanctuary, South India. Biol Conserv 47: 273-280.
Johst K, Brandl R, Eber S. 2002. Metapopulation persistence in-dynamics landscapes: the role of dispersal distance. Oikos 98: 263-270.
Kadavul K, Parthasarathy N. 1999. Plant biodiversity and conservation of tropical semi-evergreen forests in the Shervarayan hills of Eastern Ghats, India. Biodivers Conser 8: 419-437.
Kanjilal UN, Das A, Kanjilal PC, De RN. 1938. Flora of Assam. Vol. 3. Caprifoliaceae to Plantaginaceae. Government of Assam, Shillong, 578 pp.
Kanjilal UN, Kanjilal PC, Das A, Purkayastha C. 1934. Flora of Assam. Vol. 1. Ranunculaceaeto Elaeocarpaceae. Government of Assam, Shillong, 184 pp.
Kanjilal UN, Kanjilal PC, Das A. 1936. Flora of Assam. Vol. 2. Connaraceæ to Cornaceæ. Government of Assam, Shillong, 409 pp.
Kanjilal UN, Kanjilal PC, De RN, Das A. 1940. Flora of Assam. Vol. 4. Nyctaginaceæ to Cycadaceæ. Government of Assam, Shillong, 377 pp.
Kent M, Coker P. 1992. Vegetation description and analysis: a practical approach. Belhaven Press, London, 384 pp.
Khan ML, Rai JPN, Tripathi RS. 1987. Population structure of some tree species in disturbed and protected sub-tropical forests of north-east India. Acta Oecol Oec Appl 8: 247-255.
Knight DH. 1975. A phytosociological analysis of species-rich tropical forest on Barro Colorado Island, Panama. Ecol Monogr 45: 259-284.
Korning J, Basley H. 1994. Growth rates and mortality patterns of tropical lowland tree species and the relation to forest structure in Amazonian Ecuador. J Trop For Sci 10: 151-166.
Kumar M, Sharma CM, Rajwar GS. 2004. A study on the community structure and diversity of a sub-tropical forest of Garhwal Himalayas. Indian For 130: 207-214.
Macarthur R. 1955. Fluctuation of animal population, and a measure of community stability. Ecology 36: 533-536.
Mackey RL, Currie DJ. 2001. The diversity-disturbance relationship: is it generally strong and peaked? Ecology 82: 3479-3492.
Majumdar K, Datta BK. 2015. Cachar tropical semi-evergreen forest type of Northeast India: status of species diversity, distribution and population structure. Proc Int Acad Ecol Environ Sci 5: 104-127.
Malanson GP. 1993. Riparian Landscapes. Cambridge University Press, Cambridge.
Margalef DR. 1958. Information theory in ecology. Gen Syst 3: 36-71.
Menhinick EF. 1964. A comparison of some species-individuals diversity indices applied to samples of field insects. Ecology 45: 859-861.
Metzger JP, Bernacci LC, Goldenberg R. 1997. Pattern of tree species diversity in riparian forest fragments of different widths (SE Brazil). Plant Ecol 133: 135-152.
Mishra BP, Tripathi OP, Laloo RC. 2005. Community characteristics of a climax subtropical humid forest of Meghalaya and population structure of ten important tree species. Trop Ecol 46: 241-251.
Mueller-Dombois D, Ellenberg H. 1974. Aims and Methods of Vegetation Ecology. Wiley, New York, 547 pp.
Naiman RJ, Décamps H, Pollock M. 1993. The role of riparian corridors in maintaining regional biodiversity. Ecol Appl 3: 209-212.
Naiman RJ, Décamps H. 1997. The ecology of interfaces: riparian zones. Annu Rev Ecol Syst 28: 621-658.
Natta AK. 2000. Tree species diversity assessment in riparian forests using remote sensing, geographical information systems and geostatistics (case study of Toui-Kilibo protected forests in Benin). MS thesis. ITC- Forest Science Division, Enschede, The Netherlands, pp 91.
Neumann M, Starlinger F. 2001. The significance of different indices for stand structure and diversity in forests. For Ecol Manage 145: 91-106.
Newbery DM, Gartlan JS. 1996. A structural analysis of rain forests at Korup and Douala-Edea, Cameroon. Proc Royal Soc Edinb 104B: 177-224.
Newbold JD, Elwood JW, O'Neill RV, Van Winkle W. 1981.

Measuring nutrient spiraling in streams. Can J Fish Aquat Sci 38: 860-863.
Nilsson C. 1991. Conservation Management of Riparian Communities. In: Ecological Principles of Nature Conservation (Hansson L, ed). Elsevier Science, Amsterdam, pp 352-372.
Noss F. 1983. A regional landscape approach to maintain diversity. Bioscience 33: 700-707.
Odum EP. 1971. Fundamentals of Ecology. 3rd ed. Philadelphia, Saunders, 574 pp.
Oliveira-Filho AT, Vilela EA, Carvalho DA, Gavilanes ML. 1994. Effects of soils and topography on the distribution of tree species in a tropical riverine forest in south-eastern Brazil. J Trop Ecol 10: 483-508.
Padalia H, Chauhan N, Porwal MC, Roy PS. 2004. Phytosociological observations on tree species diversity of Andaman Islands. Curr Sci 87: 799-806.
Pande PK, Bisht APS, Sharma SC. 1988. Comparative vegetation analysis of some plantation ecosystems. Indian For 114: 379-388.
Pande PK, Negi JDS, Sharma SC. 1996. Plant Species Diversity and Vegetation Analysis in Moist Temperate Himalayan Forests. Abstracted in First Indian Ecological Congress, New Delhi.
Parthasarathy N, Karthikeyan R. 1997. Plant biodiversity inventory and conservation of two tropical dry evergreen forests on the Coromandel Coast, south India. Biodivers Conserv 6: 1063-1083.
Parthasarathy N, Kinhal V, Kumar LP. 1992. Plant species diversity and human impacts in the tropical wet evergreen forests of southern Western Ghats. In Indo-French Workshop on Tropical Forest Ecosystems: Natural Functioning and Anthropogenic Impact. French Institute, Pondicherry.
Pausas JG, Austin MP. 2001. Patterns of plant species richness in relation to different environments: An appraisal. J Veg Sci 12: 153-166.
Pielou EC. 1969. An Introduction to Mathematical Ecology. Wiley-Interscience, New York.
Prain D. 1903. Bengal Plants. Vols. I & II. Botanical Survey of India, Calcutta.
Preston FW. 1948. The commonness, and rarity, of species. Ecology 29: 254-283.
Rajkumar M, Parthasarathy N. 2008. Tree diversity and structure of Andaman Giant Evergreen Forests, India. Taiwania 53: 356-368.
Ralhan PK, Saxena AK, Singh JS. 1982. Analysis of forest vegetation at and around Nainital in Kumaon Himalaya. Proc Indian Natl Sci Acad 348: 121-137.
Rennolls K, Laumonier Y. 2000. Species diversity structure analysis at two sites in the tropical rain forest of Sumatra. J Trop Ecol 16: 253-270.
Renöfält BM, Jansson R, Nilsson C. 2005. Spatial patterns of plant invasiveness in a riparian corridor. Landsc Ecol 20: 165-176.
Risser PG, Rice EL. 1971. Diversity in tree species in Oklahoma upland forests. Ecology 52: 876-880.
Ritcher BD, Baumgartner JV, Wigington R, Braun DP. 1997. How much water does a river need? Freshw Biol 37: 231-249.
Sahu SC, Dhal NK, Mohanty RC. 2012. Tree species diversity, distribution and population structure in a tropical dry deciduous forest of Malyagiri hill ranges, Eastern Ghats, India. Trop Ecol 53: 163-168.
Sarkar M, Devi A. 2014. Assessment of diversity, population structure and regeneration status of tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam, Northeast India. Trop Plant Res 1: 26-36.
Saxena AK, Singh JS. 1984. Tree population structure of certain Himalayan forest associations and implications concerning their future composition. Vegetatio 58: 61-69.
Shannon CE, Wiener W. 1963. The Mathematical Theory of Communities. University of Illinois Press, Urbana, 125 pp.
Simpson EH. 1949. Measurement of diversity. Nature (London) 163: 688.
Singhal RM, Rawat VRS, Kumar P, Sharma SD, Singh HB. 1986. Vegetation analysis of woody species of some forest of chakarta Himalaya, India. Indian For 112: 819-823.
Singhal RM, Soni S. 1989. Quantitative ecological analysis of some woody species of Mussoorie Himalayas (UP). Indian For 115: 327-336.
Smakhtin V, Arunachalam M, Behera S, Chatterjee A, Das S, Gautam P, Joshi GD, Sivaramakrishnan KG, Unni KS. 2007. Developing Procedures for Assessment of Ecological Status of Indian River Basins in the Context of Environmental Water Requirements. Research report 114. International Water Management Institute, Colombo, 34 pp.
Sørensen T. 1948. A method of establishing groups of amplitude in plant society based on similarity of species content. Biol Skr 5: 1-34.
Sreedharan TP. 2005. A Study on the Status of Valapattanam River with Special Reference to Its Ecology and Socio-Cultural Aspects. Kerala Research Programme on Local Level Development, Thiruvananthapuram.
Sukumar R, Dattaraja HS, Suresh HS, Radhakrishnan J, Vasudeva R, Nirmala S, Joshi NV. 1992. Long-term monitoring of vegetation in a tropical deciduous forest in Mudumalai, southern India. Curr Sci 62: 608-616.
Sunil C, Somashekar RK, Nagaraja BC. 2016. Diversity and composition of riparian vegetation across forest and agro-ecosystem landscapes of river Cauvery, southern India. Trop Ecol 57: 343-354.
Swamy PS, Sundarapandian SM, Chandrasekar P, Chandrasekaran S. 2000. Plant species diversity and tree population structure of a humid tropical forest in Tamil Nadu, India. Biodivers Conser 9: 1643-1669.
Tabacchi E, Planty-Tabacchi AM, Décamps O. 1990. Continuity and discontinuity of the riparian vegetation along a fluvial corridor. Landsc Ecol 5: 9-20.

Tchouto MGP, De Boer WF, De Wilde JJFE, Van der Maesen LJG. 2006. Diversity patterns in the flora of the Campo-Ma'an rain forest, Cameroon: Do tree species tell it all? Biodivers Conserv 15: 1353-1374.

Tynsong H, Tiwari BK. 2011. Diversity and population characteristics of woody species in natural forests and arecanut agro-forests of south Meghalaya, Noertheast India. Trop Ecol 52: 243-252.

Vannotte RL, Minshall GW, Cummins KW, Sedell JR, Cushing CE. 1980. The river continuum concept. Can J Fish Aquat Sci 37: 130-137.

Varghese VM. 2015. Comparison of riparian species diversity between the main river channel and subwatersheds of Meenachil River basin, Kerala, Southern India. Braz J Bot 38: 81-98.

Visalakshi N. 1995. Vegetation analysis of two tropical dry evergreen forest in southern India. Trop Ecol 36: 117-127.

Ward JV, Tockner K, Schiemer F. 1999. Biodiversity of floodplain river ecosystems: ecotones and connectivity. Regul Rivers Res Manag 15: 125-139.

Whittaker RH, Niering WA. 1965. Vegetation of the Santa Catalina mountains, Arizona: a gradient analysis of the south slope. Ecology 46: 429-452.

Whittaker RH. 1965. Dominance and diversity in land plant communities: numerical relations of species express the importance of competition in community function and evolution. Science 147: 250-260.

Whittaker RH. 1969. Evolution of diversity in plant communities. Brookhaven Symp Biol 22: 178-196.

Whittaker RH. 1970. Communities and Ecosystems. Macmillan, New York, 162 pp.

Whittaker RH. 1977. Evolution of species diversity in land communities. In: Evolutionary Biology Vol. 10 (Hecht MK, Steere WC, Wallace B, eds). Plenum Press, New York, pp 1-67.

Wyant JG, Ellis JE. 1990. Compositional patterns of riparian woodlands in the Rift Valley of Northern Kenya. Vegetatio 89: 23-37.

Yang Z, Xu S, Ma X, Wang S. 2008. Characterization and acetylation behavior of bamboo pulp. Wood Sci Technol 42: 621-632.