Environment and Ecology 39 (1) : 143—151, January—March 2021
ISSN 0970-0420

Tree Species Diversity and Carbon Stock of Tropical Moist Deciduous Forest in Nagaland, Northeast India

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Received 28 November 2020, Accepted 10 December 2020, Published on 8 January 2021

ABSTRACT

The study was conducted to understand the soil properties, tree diversity and carbon stock of a forest community of Nagaland University campus, a site located in the topical moist region of Northeast India. The allometric equations were employed to calculate the tree biomass. Soil analysis showed a significant positive association ($p \geq 0.05$) among the majority of soil parameters. A total of 15 tree species belonging to 13 families with a tree density of 800 individual ha^{-1} and a total basal area 11.02 m^2 ha^{-1} have been documented. The values of different diversity indices (i.e. Shannon- Index, H' =2.58 ; Simpson Index, D=0.81 ; Pielou's Evenness Index, J = 0.81 ; Margalef = 3.80 and alpha diversity = 8.53) indicated high tree diversity with high tree species richness and community evenness. Further, *Schima wallichi* (IVI = 60) emerged as the most important tree species followed by *Quercus accutissima*. The highest biomass was recorded in *Schima wallichi* (4.11 t ha^{-1}) trailed by *Quercus accutissima* (2.17 t ha^{-1}). The total carbon stock of NU campus was estimated at 4.79 t ha^{-1}. Results showed that forest communities with high species richness and even composition are important for carbon sequestration and therefore, conservation and management of natural forests is imperative to combat global climate change problems.

Keywords : Soil properties, Carbon stock, Species richness, Tree diversity.

INTRODUCTION

Globally, about 4.06 billion hectares of the land-mass is recorded under forest cover with around 60% of total plants found in the tropical forests (FAO and UNEP 2020). The majority of tropical forests fall within the boundaries of developing countries, where, forests are now being converted into other land-use types to fulfill the requirements of energy and space for developmental activities causing a reduction in forest area-forest cover and alteration in climate (Sharma *et al.* 2018). An increase in atmospheric carbon dioxide (CO_2) has greatly influenced the climate around the globe, which is evident froman increase in temperature, strange precipitation patterns and sea-level rise (Garg *et al.* 2015, Upadhyay *et al.* 2019). The level of atmospheric CO_2 has significantly increased from 280 parts per million (ppm) in 1750 to 406 ppm in early 2017 (NOAA 2017). With atmospheric concentration of ~ 400 ppm, CO_2 has become the major green house gas responsible for global warming and significantly increasing the Earth's average temperature at a rate of 0.17ºC per decade. Forest ecosystems have a huge potential

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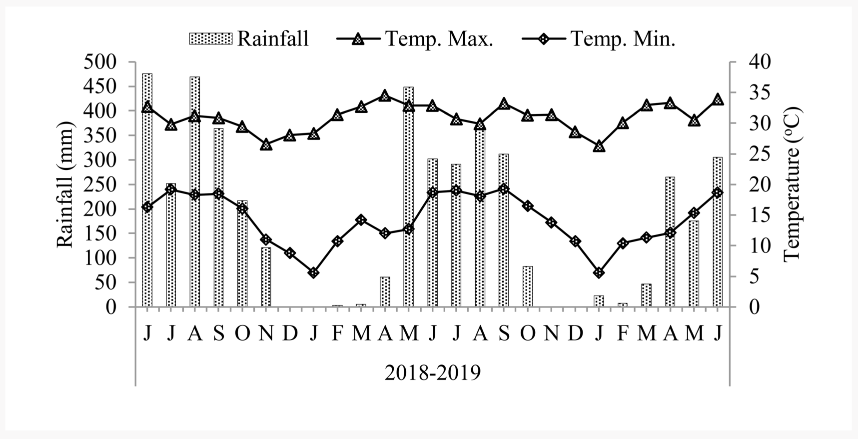

Fig. 1. Monthly climatic representation of Annual Temperature (ºC), Rainfall (mm), Humidity (%) for the year 2018-2019 of NU campus, Zunheboto District, Nagaland.

for carbon sequestration and play a crucial role in carbon cycling through their vegetation and soil, but also act as a source of CO_2 emission following human activities or natural phenomenon (Sharma *et al.* 2010, Mitchard 2018). Tropical forests accumulate more than 50% (247 Gt carbon) of total carbon (471 ± 93 Gt) stored in the forests world wide (West *et al.* 2014, Saatchi *et al.* 2011). The above ground pool of tropical forests carbon stock accounts for about 193 Gt (Saatchi *et al.* 2011, Khadanga and Jayakumar 2020), whereas, below ground C pool varies from 684–724 Pg C in the top 30 cm, 1462–1548 Pg C in the top 100 cm and 2376–2456 Pg C in the top 200 cm (Batjes 2014).

Tropical forests sequester about 46% carbon in vegetation and 11% in soil (Brown and Lugo 1982) and both above and below ground carbon sinks significantly influence the global carbon balance (Ketterings *et al.* 2001). North-East India is extensively rich in floral and faunal biodiversity with a high degree of endemism, constitutes parts of 2 of 35 biodiversity hotspots in the world and encompasses about 7% of the total geographical area of the country. Indo-Burma is one of the biodiversity hotspots covers ~ 2 million km 2 are a of Tropical Asia (Sharma *et al.* 2018). As part of the Indo-Burma biodiversity hotspot, Nagaland ranked fifth in terms of forest cover (75.31%) in the country and houses rich flora and fauna. Increasing anthropogenic pressure, needs for infrastructural development and natural calamities viz., wild fires, floods, land slide causing changes in land use land cover (LULC) and resulting in deforestation and degradation of forests (Ritse *et al.* 2020). Forest disturbances followed by fragmentation of habitats and genetic pools create a direct and indirect impact on soil organic carbon (SOC) and other soil nutrients (Smith 2008, Grilli 2012). This study hypothesizes that forest disturbances impact the tree species diversity and soil characteristics in a forest community. To prove the hypothesis, a study was conducted to assess the forest tree diversity, soil characteristics and above ground carbon stock in Nagaland University (NU) Campus, a disturbed forest site.

MATERIALS AND METHODS

Study site

The study was conducted at NU campus in Lumami village of Zunhebo to district (94º09' E, 25º 72' N) and located 40 km away from Mokokchung District head quarters (Fig. 1). The study site is located in Nagaland, a Northeast Indian state with a geographical area of 16,579 km^2 constituting 0.50% of the total geographical area of the country. Barak is considered a major river among several others flowing through the state. State experience monsoonal climate with-average rainfall varying from about 1,800 mm to about 2,500 mm and the average annual temperature ranges between 21ºC to 40ºC. Lumami falls under a humid sub-tropical climate (Cwa) with the warm temperature and heavy rains during summers and cool winters. The area receives a total annual rainfall of 2039 mm with a mean annual temperature of 18.6ºC. January and July are the coldest and hottest months of the year, respectively. Soils are generally acidic, rich in organic carbon but poor in available phosphorus and potash content. The Forest of the study site is characterized by mixed deciduous and evergreen vegetation (Wapongnungsang *et al.* 2018).

Floristic data collection

The experiment was conducted in 5 different locations using 5 random quadrates of 10×10 m size at each location. Individuals of all tree species were identified and recorded. Tree height was measured using a clinometer and single-pole method. Diameter at Breast Height (DBH) was recorded for all trees from all quadrats using diameter tape. Quantitative parameters such as density, frequency, abundance and their relative values were determined using methods suggested by Muller-Dombios and Ellenberg (1974), Mishra (1968). R package "vegan" was used for vegetation analysis.

Estimation of above ground tree biomass and carbon stock

Above ground tree biomass was estimated using a model developed by Chave *et al.* (2005). The following equation was used for the estimation of biomass:

$$M = 0.059 \times (\rho D^2 H).$$

Where, M is the above ground biomass (kg), H is the height of the trees (meter), D is the diameter at breast height in cm and ρ is the wood density (gm/cm^3). The specific gravity values of trees were taken from the global wood density database (Zanne *et al.* 2009). The carbon stock of standing trees was calculated by multiplying the total biomass with a constant factor of 0.55 (Winrock 1997).

Soil sampling and analysis

Composited soil samples of about 100–150 g were collected from the upper soil (0–10 cm) layer of all five sampling sites. Soil samples were packed into polythene bags and brought to the laboratory. Soil samples were divided into two parts one part a fresh to determine soil moisture, available nitrogen (NO -N and NH -N) and microbial carbon (MBC). The other part was air-dried to analyze soil carbon (SC), total nitrogen (TN), available phosphorus (P_{avail}), available potassium (K_{avail}) and pH. Bulk density (BD, g cm^{-3}) was calculated using a metallic tube of known inner volume to determine the dry weight of a unit volume of soil. Soil pH was measured in a soil-water suspension (1:2.5 w/v H O) through a digital pH meter. Gravimetric soil moisture was estimated employing the method suggested by Anderson and Ingram (1993). SC and N were determined by Heraeus CHN-O-S Rapid Auto-analyzer applying Sulphanilamide ($C_6H_8N_2O_2S$) standard. Molybdo-blue color method (Allen *et al.* 1974) was employed for estimating bicarbonate P_{avail}. Further, K_{avail} and MBC were determined using flame photometer and chloroform fumigation method (Vance *et al.* 1987), respectively. Statistical analysis was carried out using SPSS version.

RESULTS AND DISCUSSION

Physico-chemical and biological properties of soil

High soil moisture (33%) is thought to be related to transpirational losses subsided by canopy thickness and coincide with the reported range (25% to 35%) by previous studies (Lalnunzira 2017) from hilly regions of Northeast India. SC (1.7%) was also in agreement with the previous report (0.9–2.3%) by Wapongnungsang *et al.* (2018). The amount of SOC decreases during habitat fragmentation and land-use change (Xiangmin *et al.* 2014), but increases with successional stages, where soil microbes enrich the soil with SOC and nutrients through the decomposition of litter organic matters and dead roots (Lalnunzira and Tripathi 2018). The soil was found to be (pH 4.0) acidic, a peculiar characteristic of the hilly region caused by the addition of cations during organic litter decomposition (Wapongnung sang *et al.* 2017, 2018). A decrease in the availability of soil nutrients in the upper layers (0–10 cm) attributes to

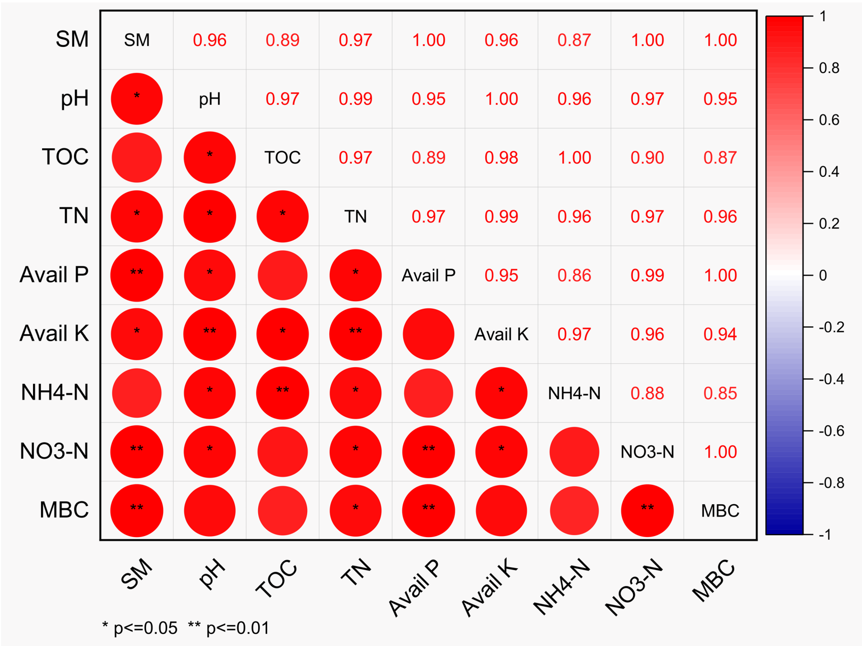

Fig. 2. Correlation of soil parameters at NU campus.

leaching losses caused by heavy rainfall and also results in the rapid growth of weeds (Wapongnungsang 2018). Soil MBC level (476 ug^{-1} g^{-1}) in the study site was comparable with the recent findings (408-576 ug^{-1} g^{-1}). SOC is responsible for increment in MBC and linked with greater accumulation of organic matter in this region (Lalnunzira and Tripathi 2018) (Table 1).

Correlation among soil parameters in the study site of NU campus

A strong positive correlation was observed among all soil parameters. Most of the soil parameters showed a significant positive association ($p \geq 0.05$) with each other. Further, an insignificant positive correlation of NH_4-N was also observed with NO_3-N and MBC (Fig. 2). This may be because of the dependence of microbes on litter accumulation for their biological activity on the forest floor (Saplalrinliana 2016, Yang *et al.* 2010). Moreover, MBC showed a significant positive relationship with other nutrients in the study site (Fig. 2). This reflects that microbial populations

Table 1. Soil physico-chemical and biological properties in NU campus.

Site	SM (%)	pH	TOC (%)	TN (%)	Avail P (mg kg^{-1})	Avail K (kg ha^{-1})	NH_4-N (mg kg^{-1})	NO_3-N (mg kg^{-1})	MBC (ug^{-1} g^{-1})
Plot 1	24	3.5	0.9	0.06	4.4	245	36.4	29.4	408.3
Plot 2	31	4	0.96	0.08	7.5	278	48.54	36.78	475.6
Plot 3	35	4.3	2	0.09	8.9	285	51	38.7	487
Plot 4	46	4.6	2.3	0.11	14.3	301	54.4	46.3	576
Plot 5	28	3.9	1.7	0.08	6.3	268	47.5	– 32.4	431
Overall (NU campus)	32.8	4.06 ± 0.19	1.572 ± 0.28	0.084 ± 0.01	8.28 ± 1.68	275.4 ± 9.31	47.568 ± 3.03	36.716 ± 2.90	475.58 ± 28.92

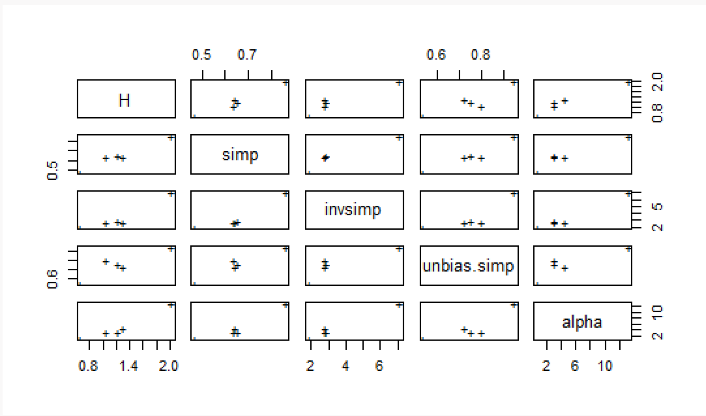

Fig. 3. Biodiversity indices recorded in different plots.

establish just after the processes of habitat fragmentation such as leaching, erosion and removal of vegetation and become stable at a later stage where other factors like N play an important role at the later stage of distribution and development (Lalnunzira 2017, Saplalrinliana 2016).

Vegetation analysis

A total of 15 tree species belonging to 13 families were recorded from the study area. Fagaceae emerged as the dominant family (3) followed by Moraceae (2). The number of woody species recording less in this study could be due to the plantation practice and removal of trees within and around the campus. Previous researchers have reported 75 tree species in Hollongapar Gibbon Wildlife Sanctuary, Assam (Sarkar and Devi 2014) and also reported 83 species in semi-evergreen and 84 species in the evergreen forest of Andaman island (Rasingam and Parthasarathy 2009). However, the less number of tree species recorded at the study site may be due to the forest disturbance and smaller size of the study area. The *S. wallichi* with the highest Important Value Index (IVI 60) was recorded as most important tree species followed by *Q. accutissima* (30). The least IVI was recorded in case of *A. heterophyllus, C. tribuloids, S. cochichinansis*, *Garuga floribunda* var *gamblei.*

The tree density (800 indv. ha^{-1}) of study site was higher than recorded (750 ha^{-1}) in Hollongapar Gibbon Wildlife Sanctuary (Sarkar and Devi 2014) and lower than (966 trees ha^{-1}) recorded at Nongkhyllem wildlife sanctuary in Meghalaya (Baishya *et al.*

Table 2. Phyto-sociological indices recorded at NU campus.

Site	Shannon-Wiener Index (H′)	Inv simp	Simp	Unbias simp	Margalef Index	Pielou's Evenness Index (J)	Alpha
Plot 1	0.66	1.88	0.47	0.54	0.48	0.95	0.86
Plot 2	1.21	2.91	0.66	0.75	1.44	0.88	3.18
Plot 3	1.30	2.79	0.64	0.72	1.82	0.81	4.63
Plot 4	2.02	7.12	0.86	0.95	2.92	0.97	13.19
Plot 5	1.05	2.78	0.64	0.80	1.24	0.96	3.17
Overall (NU campus)	2.20	5.34	0.81	0.83	3.80	0.81	8.53

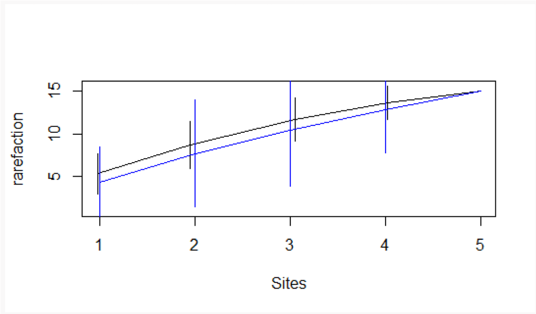

Fig. 4. Species-area and species-individual curves (Blue= Species accumulation, Black = Accumulation of individuals).

2009). The total tree basal area recorded (11m^{2}ha^{-1}) at the study site was less as compared to other studies conducted at Fakim Wildlife Sanctuary (42.8 m^{2}ha^{-1}) and Nongkhyllem Wildlife Sanctuary of Meghalaya (73 m^2 ha^{-1}) (Baishya *et al.* 2009). The disparity in tree density and basal area of different forest stands might be attributed to shifting in topography, successional stage, species composition and structure and level of disturbance (Swamy *et al.* 2000, Devi *et al.* 2018).

The overall value of the Shannon-Weiner (H') Index (2.20) observed at the study site was in the range (0.67–4.86) recorded for the tropical forest of the Indian sub-continent (Parthasarathy *et al.* 1992, Vishalakshi 1995, Panda *et al.* 2013). The high value of H' reflects that the forest has diversified flora and managed properly by allowing the growth of ample trees of lower girth class to boost natural regeneration (Devi *et al.* 2018). Simpson Index of diversity (0.81) (Table 2) at the present study site was also comparable with previous studies (0.03-0.92) of Kushwaha and Nandy (2012), Deb and Sundriyal (2011) in different Indian tropical regions. The Evenness Index indicates consistency in species distribution in the region. Species Evenness Index was recorded at 0.81, which is in agreement with the range (0.81–0.89) documented by Tynsong and Tiwari (2011) from the tropical ecosystem of Meghalaya. The Margalef Richness Index (3.80) at the present study was almost comparable to the range reported (4-23) by Kumar *et al.* (2010).

Among plots, the highest values of diversity indices (Table 2, Fig. 3) and species accumulation (Fig. 4) were recorded in plot 4 followed by plots 3, 2 and 5. Similarly, the higher values of all soil parameters were recorded from plots 3 and 4, whereas, negative changes in soil parameters were observed at more disturbed sites with low biodiversity values. This indicated that species diversity and soil parameters are directly related to each other and disturbance affects both negatively.

Increasing anthropogenic activities like shifting

Table 3. IVI, ABG and carbon stock at NU Campus.

Name of species	Family	IVI	Above ground tree biomass (ABTB) (t/ha)	Litter biomass (LB) (t/ha)	Carbon stock (t/ha)
Albizia thompsonii	Fabaceae	22.78	0.50	0.093	0.03
Artocarpus heterophyllus	Moraceae	13.89	0.30	0.045	0.16
Castanopsis tribuloids	Fagaceae	13.89	0.40	0.044	0.22
Dalbergia stipulacea	Liguminosae	15.74	0.22	0.045	0.12
Emblica officinalis	Euphorbiaceae	13.89	0.31	0.044	0.17
Ficus elastic	Moraceae	15.74	0.16	0.045	0.08
Osmanthus oleinae	Oleaceae	15.74	0.11	0.045	0.06
Pinus roxburghii	Pinaceae	15.74	0.11	0.046	0.06
Quercus accutissima	Fagaceae	30.15	2.17	0.13	0.94
Quercus variabilis	Fagaceae	22.78	0.87	0.090	0.37
Schima wallichi	Theaceae	60.35	4.11	0.17	0.9
Sphenodesme pentandra	Verbenaceae	15.74	0.85	0.044	0.46
Sterculia villosa	Malvaceae	15.74	0.05	0.046	0.02
Symplocos cochichinansis	Symplocaceae	13.89	0.38	0.045	0.21
Garuga floribunda var *gamblei*	Burceraceae	13.89	0.18	0.044	0.99
		300	10.72	0.97	4.79

cultivation, changes in LULC for developmental activities, collection of fuel-wood for household energy and harvesting of timber for construction causing the disturbance in natural forest stands and imposing threat to biodiversity in this region (Devi *et al*. 2018, Wapongnungsang *et al.* 2018).

Above ground biomass (ABG) and carbon stock in NU campus of Lumami village

The maximum above ground biomass was recorded in *S. wallichi* (4.11 tha^{-1}) followed by *Q. accutissima* (2.17 tha^{-1}) (Table 3) with a total of 10.72 t ha^{-1} AGB at NU campus. The results showed a huge gap with ABG recorded in a relatively undisturbed site of Hmuifang forest (635 t ha^{-1}) of Mizoram (Sharma *et al.* 2018). Similarly, the total carbon stock of NU campus was computed at 4.79 t ha^{-1}, which is much lower than reported by previous studies from Garhwal Himalayas: 129–533 t ha^{-1} (Sharma *et al.* 2010), Peninsular Malaysia: 550 t ha^{-1} (Iverson *et al.* 1994) and Manipur: 530.72 – 623.24 t ha^{-1} (Waikhom *et al.* 2018). The observed difference in the values of ABG and carbon stock from other areas is believed to be due to differences in sampling distribution, sampling size of the area, variation in species distribution, climate, geographical location and most importantly the level of disturbance.

CONCLUSION

The study showed a high correlation in soil parameters but values of soil physico-chemical properties varying from plot to plot due to the level of disturbance and composition of flora. The analysis shows that soil properties have a direct influence on floristic diversity and vice-versa. The changes in values of diversity indices and soil properties for different plots are thought to be due to the level disturbance created by on going development activities in the NU campus. It is concluded that forest disturbances created by anthropogenic activities are a major cause of depreciation in floristic diversity and soil properties for a particular site. The lower values of ABG and carbon stock further indicated the problem of forest disturbance in the areas as it affects the species composition and accumulation of biomass in forest and soil. Since, tropical forests are important sites for biodiversity, carbon sequestration and climate regulation, it is suggested to minimize the level of disturbance at such forests to realize their maximum potential in combating the problem of biodiversity conservation, global warming and climate change.

ACKNOWLEDGEMENT

The authors like to express special gratitude to Dr. Mayur (Headi/c) and M. Sc. students of Department of Forest Science, Nagaland University for their kind assistance. Further, the authors are also thankful to the District Administration of Zunheboto for providing daily and monthly climatic data for the year 2018–2019.

REFERENCES

Allen S.E., Grimshaw, Parkinson H.M., Quarnby A.C. (1974) Chemical analysis of Anderson J.M. and Ingram I.S.I. (1993) Tropical Soil Biology and Fertility - A Handbook of Methods. 2nd edn. CAB International, Wallingford, UK. Ecological Baishya material (Oxford : Blackwell).

R. Barik, SK. Upadhaya K. (2009) Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in Northeast India.Trop. Ecol. 50 : 295—304.

Batjes NH (2014) Total carbon and nitrogen in the soils of the world. *Europ J Soil Sci* 65 : 10—21.

Brown S, Lugo AE (1982) The storage and production of organic matter in tropical forests and their role in the global carbon cycle. *Biotropical* 14 : 61—187.

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure JP, Nelson BW, Ogawa H, Puig H, Riera B, Yamakura T (2005) Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia* 145 : 87—89.

Deb P, Sundriyal RC (2011) Vegetation dynamics of an old-growth lowland tropical rain forest in Northeast India: Species composition and stand heterogeneity. *Int J Biodiver Conserv* 3 : 405—430.

Devi NL, Singha D, Tripathi SK (2018) Tree species composition and diversity in tropical moist forests of Mizoram, Northeast India. *J Ind Ecol* 45 (3) : 454—461.

FAO, UNEP (2020) The State of the World's Forests (2020).

Forests, biodiversity and people. Rome. https://doi.org/10.4060/ca8642en

Garg A, Mishra V, Dholakia HH (2015) Climate change and India: Adaptation GAP (2015) (No. WP 2015-11-01). Indian Institute of Management Ahmedabad, Research and Publication Department.

Giri Krishna, Buragohain P, Wonwar S, Pradhan B, Gaurav Mishra G, Meena DK (2018) Tree Diversity and Ecosystem Carbon Stock Assessment in Nambor Wildlife Sanctuary, Assam. Proceeding National Academy Science India, Section B Biology Science, DOI 10.1007/s40011-018-01072-8

Grilli G, Urcelay C, Galetto L (2012) Forest fragment and nutrient availability: Complex responses of mycorrhizal fungi in native–exotic hosts. *Pl Ecol* 213 (1) : 155—165.

Iverson LR, Brown S, Prasad A, Mitasova H, Gillespsie AJR, Lugo AE (1994) Use of GIS for estimating potential and actual forest biomass for continental South and Southeast Asia. In: Dale VH (eds). Effects of Land Use Change on Atmospheric CO_2 Concentrations: South and Southeast Asia as a Case Study. Springer-Verlag, New York, pp 67—116.

Ketterings QM, Coe R, van Noordwijk M, Ambagau Y, Palm CA (2001) Reducing uncertainty in the use of allometric biomass equations for predicting above ground tree biomass in mixed secondary forests. *For Ecol Manag* 146 : 199—209.

Khadanga SS, Jayakumar S (2020) Tree biomass and carbon stock: Understanding the role of species richness, elevationand disturbance. *Trop Ecol* 1—14.

Kumar JN, Kumar RN, Bhoi RK , Sajish PR (2010) Tree species diversity and soil nutrient status in three sites of tropical dry deciduous forest of western India. *Trop Ecol* 51 (2) : 273—279.

Kushwaha SPS, Nandy S (2012) Species diversity and community structure in sal (*Shorea robusta*) forests of two different rainfall regimes in West Bengal, India. *Biodiver Conserv* 21 : 1215—1228.

Lalnunzira C (2017) Structural and functional properties of leaf, fine root and soil in secondary successional aforests following stone mining in relation to a reserve forest in Mizoram. PhD thesis Mizoram University.

Lalnunzira C, Tripathi SK (2018) Leaf and root production, decomposition and carbon and nitrogen fluxes during stand development in tropical moist forests, Northeast India. *Soil Res* 56 (3) : 306—317.

Mishra R (1968) Ecology Work Book. Oxford and IBM publishing Co. Calcutta, pp 244.

Mitchard ET (2018) The tropical forest carbon cycle and climate change. *Nature* 559 (7715) : 527—534.

Muller-Dombios DJ, Ellenberg H (1974) Aims and Methods in Vegetation Ecology. John Wiley and Sons, New York.

NOAA (2017) National Oceanic and Atmospheric Administration. Earth System Research Laboratory Global Monitoring Division, https://www.esrl.noaa.gov/gmd/ccgg/trends/. Accessed 13 October 2017.

Panda PC, Mahapatra AK, Acharya PK, Debata AK (2013) Plant diversity in tropical deciduous forests of Eastern Ghats, India : A landscape level assessment. *Int J Biodiver Conserv* 5 : 625—639.

Panda PC, Mahapatra AK, Acharya PK, Debata AK (2013) Plant diversity in tropical deciduous forests of Eastern Ghats, India : A landscape level assessment. *Int J Biodiver Conserv* 5 : 625—639.

Parthasarathy N, Kinbal V, Kumar LP (1992) Plant species diversity and human impact in tropical wet evergreen forests of Southern Western Ghats. Indo-French Workshop on tropical forest ecosystem: Natural Functioning and Anthropogenic Impact. French Institute, Pondicherry.

Rasingam L, Parthasarathy N (2009) Tree species diversity and population structure across major forest formations and disturbance categories in Little Andaman Island, India. *Trop Ecol* 50 : 89—102.

Ritse V, Basumatary H, Kulnu AS, Dutta G, Phukan M M, Hazarika N (2020) Monitoring land use land cover changes in the Eastern Himalayan landscape of Nagaland, Northeast India. *Environm. Monit Assess* 192 (11) : 1—17.

Saatchi SS, Harris NL, Brown S, Lefsky M, Mitchard ETA, Salas W, Zutta BR, Buermann W, Lewis SL, Hagen S, Petrova S, White L, Silman M, More A (2011) Benchmark map of forest car-bon stocks in tropical regions across three conti nents. *Proc Nat Acad Sci USA* 108 : 9899—9904.

Saplalrinliana H, Thakuria D, Changkija S, Hazarika S (2016) Impact of shifting cultivation on litter accumulation and properties of *Jhum* soils of Northeast India: *J Ind Soc Soil Sci* 64 (4) : 1—12.

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 Pl Res* 1 : 26—36.

Sharma CM, Baduni NP, Gairola S, Ghildiyal SK, Sarvesh S (2010) Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India. *For Ecol Manag* 260 (12) : 2170—2179.

Sharma SB, Singh NS, Lalruatfela R (2018) Tree diversity and carbon stock of Hmuifang forest, Mizoram. *Int J Res Bio-Sci* 7 (1) : 87—99.

Smith P (2008) Land use change and soil organic carbon dynamics. *Nutrient Cycling in Agroecosyst* 81 (2) : 169—178.

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. *Biodiver Conserv* 9 : 1643—1669.

Tynsong H, Tiwari BK (2011) Diversity and population characteristics of woody species in natural forests and are canutagro forests of South Meghalaya, Northeast India. *Trop Eco* l.52 : 243—252.

Upadhyay KK, Japang B, Singh NS, Tripathi S K (2019) Status and socio-ecological dimensions of sacred groves in Northeast India. *J Appl Natural Sci* 11 (3) : 590—595.

Vance ED, Brookes PC, Jenkinson DS (1987) An extraction method for measuring soil microbial biomass carbon. *Soil Biol Biochem* 19 : 703—707.

Vishalakshi N (1995) Vegetation analysis of two tropical dry evergreen forest in Southern India. *Trop Ecol* 36 : 117—127.

Waikhom AC, Nath A J, Yadava PS (2018) Above-ground biomass and carbon stock in the largest sacred grove of Manipur, Northeast India. *J For Res* 29 (2) : 425—428.

Wallbrink P, Blake W, Doerr S, Shakesby R, Humphreys G, English P (2005) In : Walling DE Horowitz AJ (eds). Using Tracer Based Sediment Budgets to Assess Redistribution of Soil and Organic Material after Severe Bush Fires, Sediment Budgets. IAHS Publication: Wallingford, UK, pp 223—230.

Wapongnungsang (2018) Impact of fallow periods and treatments on the pattern of recovery of soil fertility and plant productivity in shifting cultivation sites in Aizawl District, Mizoram. PhD thesis. Mizoram University, Mizoram.

Wapongnungsang, Adangnaro, Tripathi SK (2018) Effects different on soil carbon and nitrogen dynamics in Zunheboto District of Nagaland, Northeast India. *J Ind Ecol* 45 (1) : 831—834.

Wapongnungsang, Hauchhum R, Tripathi SK(2017) Litter de composition *Vis-a-Vis* carbon and nitrogen dynamics of *Te phrosia candida* components in different fallow periods following shifting cultivation in Mizoram. *Ind J Ecol* 44 (4) : 791—796.

West TAPP, Vidal E, Putz FE (2014) Forest bio-mass recovery after conventional and reduced-impact logging in Amazonian Brazil. For. Ecol. Manag. 314 : 59—63. https://www.sciencedirect.com/science/article/pii/S0378112713007779.

Winrock (1997) International Institute for Agricultural Department. A guide to monitoring carbon storage in forestry projects.

Xiangmin F, Qingli W, Wangming Z, Wei Z, Yawei W, Lijun N, Limin D (2014) Land use effects on soil organic carbon, microbial biomass and microbial activity in Changbai Mountains of North-East China. *Chinese Geogr Sci* 24 (3) : 297—306.

Yang LY, Wu ST, Zhang LB (2010) Fine root biomass dynamics and carbon storage along a successional gradient in Changbai Mountains, China. *Forestry* 83 : 379—387.

Zanne AE, Lopez-Gonzalez G, Coomes DA, Ilic J, Jansen S, Lewis SL, Chave J (2009) Global wood density database.