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Plant Community Composition and Carbon Stocks of a Community Reserve Forest in North-East India

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Abstract: Anthropogenic activities are altering the structure and functioning of forests and their services to society. However, we know little about the degree to which such activities are changing the health of forests through edge effects in fragmented forests in different regions of the world. The present study was carried out in Minkong Community Reserve Forest of Nagaland (North-east India) with the aim to determine the effects of anthropogenic activities on floristic composition and diversity, population structure, and biomass and carbon (C) stocks in the core zone (CZ) and buffer zone (BZ) of the forest. We established 15 plots of 0.04 ha each in the two forest zones. We identified 31 trees, 18 shrubs, and 22 herbs in the CZ, and 22 trees, 25 shrubs, and 24 herbs in the BZ; tree species diversity was greater in the CZ whereas the diversity of shrubs and herbs was greater in the BZ. The values for tree density and basal area in the CZ and BZ were 303 and 197 individuals ha^{-1} and 32.6 and 22.2 m^2 ha^{-1}, respectively; in contrast, the shrub and herb density increased in the BZ (4470 and 50,200 individuals ha^{-1}) compared to that of the CZ (2530 and 35,500 individuals ha^{-1}). The total stand biomass (including that below-ground) was 327 Mg ha^{-1} in the CZ and 224 Mg ha^{-1} in the BZ. Similarly, the total ecosystem C stocks in the CZ and BZ were 224 Mg C ha^{-1} and 173 Mg C ha^{-1}, indicating that the overall ecosystem C pool including soil in the CZ was approximately 30% greater than the BZ. These results show how fragmentation and anthropogenic disturbance can reduce forest diversity and C stocks and that community forest management can play a role in conserving biodiversity and act as an ecosystem management tool to mitigate climate change.

Keywords: carbon; community forestry; diversity; Minkong; Nagaland; species composition

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1. Introduction

Globally, forests play vital roles in conserving biodiversity, biogeochemical cycling including storing a large amount of carbon (C) in the vegetation and soil, and sustaining peoples' livelihoods [1]. Tropical forests contribute significantly to the global terrestrial C stocks and harbour half of the world's biodiversity whilst supporting human populations by providing a wide range of goods and services. However, these forests are regularly over-exploited leading to the loss of forest cover (>10 million ha year^{-1}), thereby losing their potential for ecological service provision [2,3]. Tropical forests, with appropriate management, can provide economic benefits through ecotourism, non-wood forest products, a sustainable timber source, and also through emerging C financing mechanisms [4,5]. Tropical moist forests are characterized by the high density of understory trees, high species diversity, and a high degree of endemism [6]. Habitat fragmentation due to anthropogenic activities (e.g., agriculture, road construction, urbanization, etc.) has become one of the most pervasive and conspicuous forms of disturbance in tropical rain forests [7–9]. Studies on tropical forest fragmentation have shown edge effects to influence changes in the abiotic environment impacting upon forest structure and composition. Studies on a range of tropical forests reported the influence of fragmentation on ecosystem processes resulting in increasing biomass loss, tree mortality rates, and ultimately changes to the population structure of the forest [10–13].

Community forestry plays an important role in forest conservation, where the local people are involved in the management and protection of the forest [14,15]. Community forestry is practiced over the world but it is mainly dominant in Asia and has had a long history in India [16]. The Indian state of Nagaland, geographically located in the north-east of the country within the Himalaya and Indo-Burma biodiversity hotspots, is endowed with diverse vegetation cover that supports the predominantly tribal communities in their livelihoods. The constitution of India has provided special customary rights to the population of the state for the traditional use of natural resources, and thus over 85% of the natural habitats are owned by individuals or clans through the co-ordination of village councils and other traditional institutions [17]. Since most of the economic activities in rural areas are dependent on natural resources, the over-exploitation of forest resources in recent years is posing a threat to the region's biodiversity.

Minkong Community Reserve Forest is managed by local communities within a mountainous region of Mokokchung district in the state of Nagaland surrounded by three villages, namely, Chuchuyimpang, Longmisa, and Sungratsu. The forest, which is owned by the local communities, is traditionally managed by laying down certain customary laws such as restricting the cutting of trees, gathering of natural resources, or hunting of wild animals from the forest without permission from the local village councils. Heavy fines are levied upon the defaulters to act as a deterrent and help protect the forest.

In this study, we look at the floristic and structural attributes of a community-conserved sub-tropical humid forest and we hypothesize that human disturbance reduces species diversity and C stocks. We also examine the role of edge effects through not only biophysical disturbances but also increased human interference on the forest composition. Therefore, the present study aims to: (i) assess the vegetation community composition (trees, shrubs, and herbs), diversity, and species distribution patterns; (ii) estimate tree biomass and ecosystem C stocks; and (iii) determine how these differ between the core zone and buffer zone of the Minkong Community Reserve Forest of Nagaland in North-east India.

2. Materials and Methods

2.1. Study Area

The study was located in Minkong Community Reserve Forest, having a total area of 2.75 km^2 located at 26°21′ N and 94°33′ E and about 1400 m above mean sea level in Mokokchung district, Nagaland, North-east India (Figure 1). The vegetation is sub-tropical evergreen forest [18]. The forest area, which was initially owned by the state government until the 1980s, was handed over to the surrounding village communities which later declared it a Community Reserve Forest with the aim to conserve and protect the biodiversity inhabiting it due to the high level of anthropogenic disturbance at that time. About 40% of the forest area is considered secondary/fallow forests from shifting cultivation practices by the Naga agriculturalists. While the core zone (CZ) is situated in the centre of the reserve forest without any disturbance, the buffer zone (BZ) surrounds this zone and is located about 2 km from the human settlements. The forest soil has, on average, a pH of 5.8 [19] and 3.4% soil organic carbon (SOC) [20].

2.2. Vegetation Sampling

For a detailed quantitative analysis of vegetation, the forest was divided into two zones—the core zone (CZ) in the centre of the reserve forest without disturbance and the buffer zone (BZ) present towards the periphery. Tracts of the forest were selected in each zone for the measurement of species diversity and C stocks. In each zone, 15 quadrats each measuring 20 m × 20 m (0.04 ha) were laid randomly for tree species (DBH $\geq$ 10 cm). Within each 20 m × 20 m plot were nested two 5 m × 5 m subplots for shrubs and four 1 m × 1 m subplots for herbs (including epiphytes, lithophytes, and climbers). The plant species were photographed and identified, and herbarium vouchers were prepared following

Jain and Rao [21]. Vouchers were deposited in the Herbarium, School of Agricultural Sciences and Rural Development, Nagaland University, Medziphema, Nagaland, India. Plant community attributes such as frequency, density, and basal area were analyzed. The importance value index (IVI) of each individual species was calculated to study the dominance of the species. Tree species were classified into different diameter classes to study the population structure of the forest. The Shannon–Weiner diversity index [22] of each lifeform in each quadrat and Sørensen's similarity index [23] between the CZ and BZ for each of the lifeforms were also calculated. Comparisons between the two zones were made with t-tests using Minitab 19.2, whilst a detrended correspondence analysis ordination was conducted on the three groups of lifeforms (i.e., trees, shrubs, and herbs) using Canoco 5.15 [24].

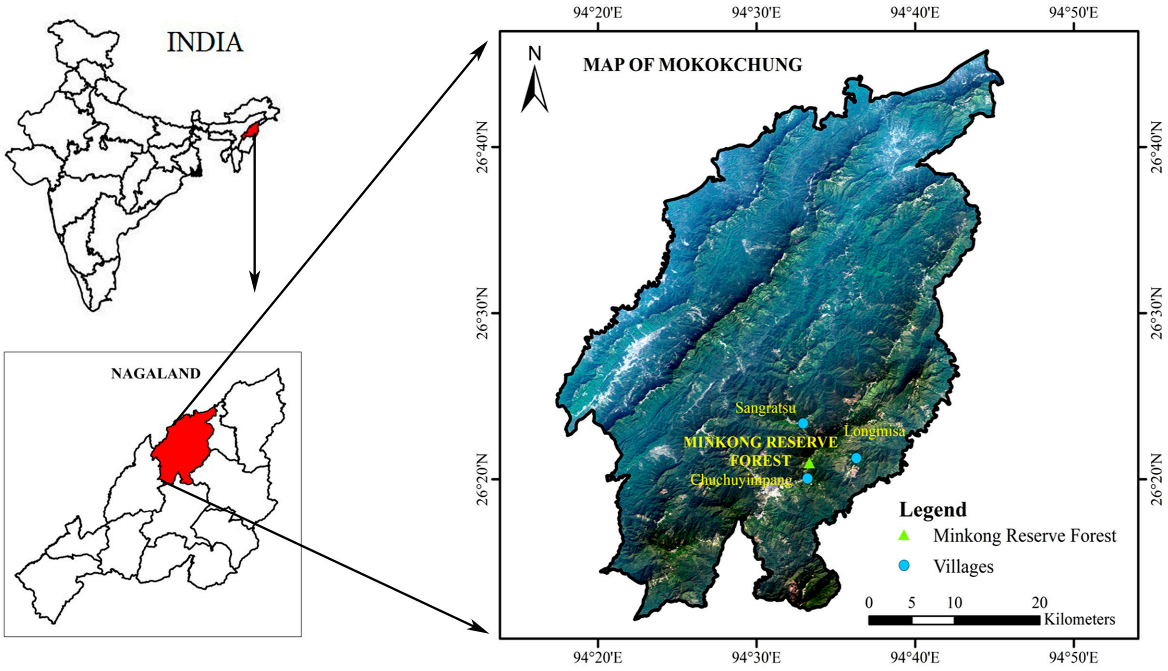

Figure 1. Map of the study site and villages surrounding the Minkong Community Reserve Forest, Mokokchung district, Nagaland, India.

2.3. Soil Sampling and Analysis

Soil samples were collected from two random locations from each 0.1 ha sampling plot at two depths (0 to 25 cm and 25 to 50 cm). Soil samples collected from five sampling plots were composited to represent one sample with a total of three samples from 15 sampling plots of 0.04 ha from each of the two zones. Soil bulk density was determined using a stainless-steel tube of known inner volume within which soils were oven-dried at 40 °C to constant weight and then passed through a sieve of 2 mm. Soil organic carbon (SOC) was analyzed using the method of Walkley and Black [25].

2.4. Estimation of Plant Biomass and Carbon Stock

Total above-ground biomass of trees (AGB_{est}) was estimated using the allometric equation developed from trees in North-east India by Nath et al. [26]:

$$AGB_{est} = 0.32\ (D^2 \times H\delta)^{0.75} \times 1.34 \tag{1}$$

where D is the DBH, H denotes the height of the tree, and δ is wood-specific gravity obtained from the ICRAF database [27].

Below-ground biomass was estimated using the allometric equation developed by Cairns et al. [28]:

$$BGB_{est} = \exp\left[-1.085 + 0.9256 \times ln\ (AGB)\right] \tag{2}$$

The vegetation C stock was estimated assuming 45.6% C content of dry biomass [29]. Total above-ground biomass of shrubs was estimated using equation developed by Ali et al. [30]:

$$\text{AGB} = \exp\,(-3.5 + 1.65 \times ln\,(\text{CD}) + 0.842 \times ln\,(\text{H}) \tag{3}$$

where CD is the collar diameter and H denotes the height of the shrub.

The forest floor mass was collected by laying a quadrat of 50 cm × 50 cm in each sampling plot of 0.04 ha. Litter was collected twice in a year (dry and wet seasons) and the mean litter mass of the two seasons was presented. Herb biomass was estimated using the harvest plot method on the basis of fresh/dry weight. All the above- and below-ground vegetation was harvested inside the herb plot after which roots were separated from the shoots and the fresh weight was recorded in the field. About 100 g of a fresh sample of roots and shoots of the herbs was then oven-dried (60 °C) to constant weight. Soil organic carbon (SOC) stock (0 to 50 cm) was estimated as the product of the SOC content, bulk density, and soil depth.

$$\text{SOC stock (Mg C ha}^{-1}) = \text{SOC} \times \text{BD} \times \text{SD} \times 100 \tag{4}$$

where SOC is soil organic carbon content (%), BD is bulk density (g cm^3), and SD is soil depth in metres (m). The total ecosystem C stock was calculated by summing total vegetation C stock and SOC stock.

3. Results

The present study showed that species composition varied significantly between the CZ and BZ with the DCA ordinations showing a clear separation of the plots (Figure 2). The total number of tree species recorded in the CZ was 31, which was reduced to 22 species in the BZ. However, the total species richness of shrub and herb species was greater (25 and 24 species) in the BZ and lower (18 and 22 species) in the CZ (Table 1). The dominant families of trees, shrubs, and herbs were: Lauraceae and Moraceae, Rosaceae and Urticaceae, and Leguminosae and Zingiberaceae, respectively. Structural attributes also varied between the two zones. The tree density and basal area were greater (303 individuals ha^{-1} and 32.6 m^2 ha^{-1}) in the CZ which declined to 197 individuals^{-1} ha^{-1} and 22.2 m^2 ha^{-1} in the BZ. However, the density of shrub and herb species increased (4470 and 50,200 individuals^{-1} ha^{-1}) in the BZ compared to the CZ (2530 and 35,500 individuals^{-1} ha^{-1}) (Table 1).

Table 1. Structural attributes and diversity (mean ± standard error) of trees, shrubs, and herbs in core and buffer zones of Minkong Community Reserve Forest, Nagaland, India.

Parameter		Core Zone	Buffer Zone	*p*-Value
No. of species	Trees	9.47 ± 0.98	6.33 ± 0.55	0.01
	Shrubs	7.60 ± 0.60	12.1 ± 0.70	<0.001
	Herbs	6.60 ± 0.43	10.5 ± 0.85	0.001
Density (ind. ha^{-1})	Trees	303 ± 2.20	197 ± 1.10	0.01
	Shrubs	2530 ± 21.5	4470 ± 14.8	<0.001
	Herbs	35,500 ± 132	50,200 ± 267	0.004
Basal area (m^2 ha^{-1})	Trees	32.6 ± 5.71	22.2 ± 4.30	0.09
Shannon–Wiener diversity index (*H′*)	Trees	2.11 ± 0.10	0.72 ± 0.10	0.01
	Shrubs	1.85 ± 0.10	2.39 ± 0.05	<0.001
	Herbs	1.73 ± 0.06	2.19 ± 0.07	<0.001

The Shannon's diversity index (*H′*) for tree species was greater (2.11) in the CZ and lower (0.72) in the BZ, whereas the *H′* for shrub and herb species showed the opposite pattern (Table 1). Based on IVI values, the most important tree species in the CZ were *Betula alnoides* (15.4), *Choerospondias axillaris* (15.3), *Garcinia pedunculata* (15.3), and *Lithocarpus pachyphyllus* (15.0). On the other hand, the most important tree species in the BZ were: *Lithocarpus elegans* (31.6), *Morus macroura* var. *macroura* (22.4), and *Castanopsis indica* (20.5)

(Table 2). The most important shrub species in the CZ were *Clerodendrum glandulosum* (21.7), *Eriosolena involucrata* (16.9), *Millettia pachycarpa* (15.7), and *Boehmeria japonica* (15.5); in contrast, *Osbeckia nepalensis* (13.7), *Dendrocnide sinuata* (11.3), and *Rubus lucens* (11.3) were the most important species in the BZ (Table 2). Moreover, the most important herb species in the CZ were *Girardinia diversifolia* (22.3), *Smilax aspera* (17.6), and *Commelina benghalensis* (16.1); in the BZ, *Commelina benghalensis* (12.6) was the most important species, along with *Curculigo orchioides* (12.6) *Hellenia speciosa* (12.4), and *Gomphostemma strobilinum* (12.1) (Table 2). The dominance–diversity curves followed a log-normal distribution pattern which indicates that different plant life forms (trees, shrubs, and herbs) showed high equitability and low dominance of species in both zones (Figure 3). The greatest similarity (Sørenson) (73%) between the CZ and BZ was recorded for the herb community, followed by shrubs (46%) and trees (26%); the overall community had 47% similarity between the two zones.

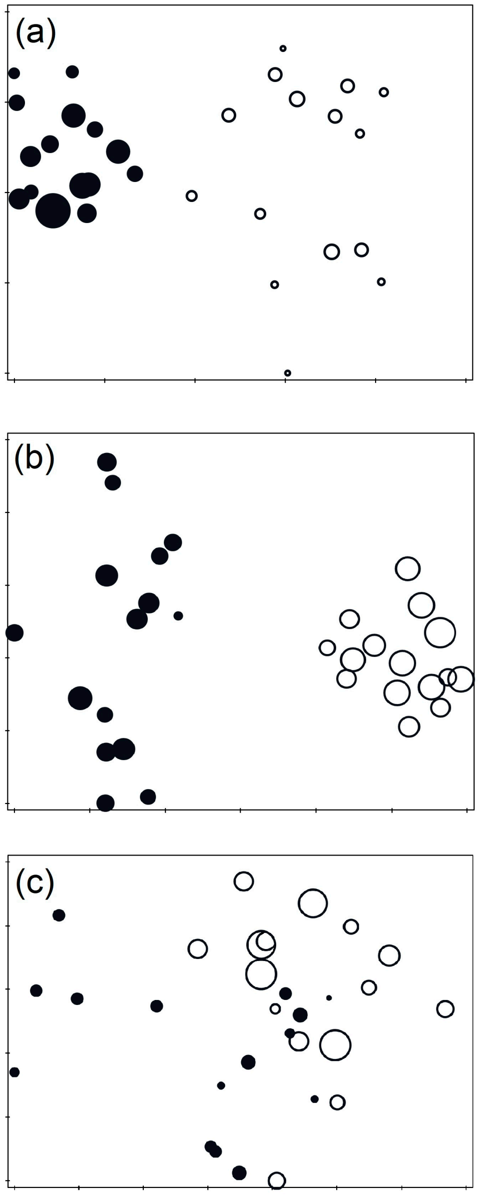

Figure 2. Detrended correspondence analysis ordination of (**a**) tree, (**b**) shrub, and (**c**) herb species in the core (filled circles) and buffer (open circles) zones in Minkong Community Forest Reserve, Nagaland, India. The comparative size of the circles represents the species richness of each plot.

Table 2. Density (individuals ha^{-1}), basal area (m^2 ha^{-1}), and important value index (IVI) of trees, shrubs, and herbs in core and buffer zone of Minkong Community Reserve Forest, Nagaland, India.

Species	Family	Core Zone			Buffer Zone		
		Density	Basal Area	IVI	Density	Basal Area	IVI
Trees							
Acer thomsonii Miq.	Sapindaceae	13.3	1.16	13.6			
Actinodaphne obovata (Nees) Blume	Lauraceae				6.67	0.52	8.94
Aglaia spectabilis (Miq.) S.S.Jain & S.Bennet	Meliaceae	8.33	0.81	8.05			
Alnus nepalensis D.Don	Betulaceae	10.0	1.86	12.5			
Bauhinia purpurea L.	Fabaceae				8.33	0.66	11.5
Beilschmiedia roxburghiana Nees	Lauraceae				8.33	0.55	9.92
Betula alnoides Buch.-Ham. ex. D.Don	Betulaceae	10.0	2.54	15.4			
Bischofia javanica Blume	Phyllanthaceae	11.7	1.44	11.8	8.33	0.81	13.2
Brassaiopsis hainla (Buch.-Ham.) Seem.	Araliaceae	3.33	0.36	3.61			
Callicarpa arborea Roxb.	Lamiaceae	8.33	0.69	7.71			
Castanopsis indica (Roxb. ex Lindl.) A.DC.	Fagaceae	15.0	1.05	12.4	10.0	2.72	20.5
Castanopsis tribuloides (Sm.) A.DC.	Fagaceae				8.33	0.49	9.64
Cephalotaxus griffithii Hook.f.	Taxaceae	11.7	1.29	9.21			
Choerospondias axillaris (Roxb.) B.L.Burtt & A.W.Hill	Anacardiaceae	15.0	1.30	15.3			
Cinnamomum sulphuratum Nees	Lauraceae	10.0	0.44	8.20			
Cinnamomum verum J.Presl.	Lauraceae	15.0	0.74	10.8	6.67	0.32	6.95
Dalrympelea pomifera Roxb.	Staphyleaceae				10.0	0.74	12.7
Elaeocarpus tectorius (Lour.) Poir.	Elaeocarpaceae	11.7	1.31	11.4			
Engelhardia spicata Lechen ex Blume	Juglandaceae				8.33	0.70	12.7
Eurya cerasifolia (D.Don) Kobuski	Pentaphylacaceae				8.33	0.48	10.7
Ficus hispida L.f.	Moraceae	5.00	0.37	4.90	8.33	0.20	9.41
Ficus neriifolia Sm.	Moraceae				5.00	0.25	6.85
Ficus semicordata Buch.-Ham. ex Sm.	Moraceae	16.7	0.87	13.8	3.33	0.20	4.71
Garcinia pedunculata Roxb. ex Buch.-Ham.	Clusiaceae	16.7	1.58	15.3			
Grewia serrulata DC.	Malvaceae	3.33	0.31	3.48			
Hovenia dulcis Thunb.	Rhamnaceae	8.33	1.03	8.73			
Ilex sp.	Aquifoliaceae	3.33	0.10	2.83			
Ilex dipyrena Wall.	Aquifoliaceae				10.0	1.13	15.5
Juglans regia L.	Juglandaceae	11.7	1.49	12.7			
Lithocarpus elegans (Blume) Hatus. ex Soepadmo	Fagaceae	10.0	1.90	12.0	16.7	3.01	31.6
Lithocarpus pachyphyllus (Kurz) Rehder	Fagaceae	16.7	1.02	15.0			
Macaranga denticulata (Blume) Müll.Arg.	Euphorbiaceae				11.7	0.75	15.7
Macropanax dispermus (Blume) Kuntze	Araliaceae	10.0	0.96	8.38			
Mallotus nepalensis Müll.Arg.	Euphorbiaceae	8.33	0.45	6.24			
Morus macroura var. *macroura* Miq.	Moraceae				13.3	2.28	22.4
Myrica esculenta Buch.-Ham. ex D.Don	Myricaceae	6.67	0.44	6.37			
Oreocnide integrifolia (Gaudich.) Miq.	Urticaceae	3.33	0.20	3.13			
Prunus napaulensis (Ser.) Steud.	Rosaceae				5.00	2.04	14.9
Quercus lamellosa Sm.	Fagaceae	5.00	2.52	11.5			
Quercus serrata Murray	Fagaceae	13.3	1.11	11.3	8.33	0.83	12.2
Sloanea dasycarpa (Benth.) Hemsl.	Elaeocarpaceae				11.7	0.62	16.2
Sterculia lanceolata var. *coccinea* (Jack) Phengklai	Sterculiaceae				11.7	0.71	15.5
Terminalia myriocarpa Van Heurck & Müll.Arg.	Combretaceae	10.0	1.33	10.2			
Toona ciliata M.Roem.	Meliaceae	5.00	1.66	8.16			
Trema cannabina Lour.	Cannabaceae	6.67	0.30	5.94			
Xerospermum noronhianum (Blume) Blume	Sapindaceae				8.33	2.21	18.5
Shrubs							
Abutilon indicum (L.) Sweet	Malvaceae				120		3.78
Agapetes macrantha (Hook.) Benth. & Hook.f.	Ericaceae				160		6.86
Amomum dealbatum Roxb.	Zingiberaceae				147		8.20
Boehmeria japonica (L.f.) Miq.	Urticaceae	213		15.5	200		10.5

Table 2. *Cont.*

Species	Family	Core Zone			Buffer Zone		
		Density	**Basal Area**	**IVI**	**Density**	**Basal Area**	**IVI**
Breynia retusa (Dennst.) Alston	Phyllanthaceae				173		6.61
Calamus rotang L.	Arecaceae	93.3		7.22			
Camellia oleifera C.Abel	Theaceae				173		7.16
Chromolaena odorata (L.) R.M.King & H.Rob.	Asteraceae	160		9.85	240		9.20
Clerodendrum glandulosum Lindl.	Lamiaceae	280		21.7	107		4.57
Crotalaria juncea L.	Fabaceae	120		8.28			
Croton caudatus Geiseler	Euphorbiaceae	147		12.0			
Debregeasia longifolia (Burm.f.) Wedd.	Urticaceae				173		7.71
Dendrocnide sinuata (Blume) Chew.	Urticaceae	133		10.6	227		11.6
Deutzia compacta Craib	Hydrangeaceae	80.0		7.58			
Eriosolena involucrata (Wall.) Tiegh.	Thymelaeaceae	160		16.9			
Grona heterocarpos (L.) H.Ohashi & K.Ohashi	Fabaceae				213		9.69
Hibiscus sabdariffa L.	Malvaceae				93.3		4.28
Leucosceptrum canum Sm.	Lamiaceae	187		11.8	200		8.30
Maesa indica (Roxb.) Sweet	Primulaceae	147		9.33			
Melastoma malabathricum L.	Melastomataceae	120		11.8	240		9.75
Millettia pachycarpa Benth.	Fabaceae	173		15.7			
Mussaenda roxburghii Hook.f.	Rubiaceae	93.3		8.99	227		9.45
Neillia thyrsiflora D.Don	Rosaceae				133		7.36
Osbeckia nepalensis Hook.	Melastomataceae				293		13.7
Oxalis acetosella L.	Oxalidaceae				133		5.72
Oxyspora paniculata (D.Don) DC.	Melastomataceae				200		8.30
Rhaphiolepis bengalensis (Roxb.) B.B.Liu & J.Wen	Rosaceae	93.3		8.11	173		7.71
Rubus ellipticus Sm.	Rosaceae				213		9.69
Rubus efferatus Craib	Rosaceae	40.0		4.23	133		5.72
Rubus lucens Focke	Rosaceae				187		11.3
Securinega sp.	Phyllanthaceae				240		9.75
Senegalia pennata (L.) Maslin	Fabaceae	120		10.1	66.7		3.13
Uraria oblonga (Wall. ex Benth.) H.Ohashi & K.Ohashi	Fabaceae	173		10.4			
Herbs							
Arisaema concinnum Schott	Araceae	667		3.80	2170		10.7
Bidens pilosa L.	Asteraceae	1330		7.60	1670		6.49
Commelina benghalensis L.	Commelinaceae	4000		16.1	3170		12.6
Curculigo orchioides Gaertn.	Hypoxidaceae				2500		12.6
Cymbidium aloifolium (L.) Sw.	Orchidaceae	1830		9.97	2170		8.75
Dendrobium lituiflorum Lindl.	Orchidaceae				2330		11.0
Dioscorea glabra Roxb.	Dioscoreaceae	100		4.74	2500		10.1
Drymaria cordata (L.) Willd. ex Schult.	Caryophyllaceae	1670		7.58			
Elatostema sessile J.R.Forst. & G.Forst.	Urticaceae	2330		12.3	1170		4.86
Entada rheedei Spreng.	Fabaceae	1170		5.21	1000		5.16
Erythropalum scandens Blume	Olacaceae	833		3.31			
Fagopyrum cymosum (Trevir.) Meisn.	Polygonaceae				2670		9.11
Fragaria nilgerrensis Schltdl. ex J.Gay	Rosaceae	1670		7.58	2330		8.45
Girardinia diversifolia (Link) Friis	Urticaceae	4170		22.3	2170		6.85
Gnetum latifolium Blume	Gnetaceae	1500		9.99	1830		6.19
Gomphostemma strobilinum Wall. ex Benth.	Lamiaceae	1670		9.50	3830		12.1
Hedychium coronarium J.Koenig	Zingiberaceae				1330		6.45
Hellenia speciosa (J.Koenig) S.R.Dutta	Costaceae	1500		12.9	3670		12.4
Mucuna macrocarpa Wall.	Fabaceae	1330		8.56	2330		10.4
Oxalis corniculata L.	Oxalidaceae	833		5.23			
Papilionanthe teres (Roxb.) Schltr.	Orchidaceae	1500		13.8			
Phanera vahlii (Wight & Arn.) Benth.	Fabaceae	2000		12.4	1330		4.56
Poranopsis paniculata (Roxb.) Roberty	Convolvulaceae	2330		9.46	2830		10.1

Table 2. *Cont.*

Species	Family	Core Zone			Buffer Zone		
		Density	Basal Area	IVI	Density	Basal Area	IVI
Saccharum longesetosum (Andersson) V.Naray. ex Bor	Poaceae				1000		3.89
Smilax aspera L.	Smilacaceae	2170		17.6	1170		5.49
Spatholobus parviflorus (Roxb. ex G.Don) Kuntze	Fabaceae				2330		11.6
Tetrastigma eucostaphylum (Dennst.) Alston	Vitaceae				667		2.59
Tinospora sinensis (Lour.) Merr.	Menispermaceae				2000		7.78

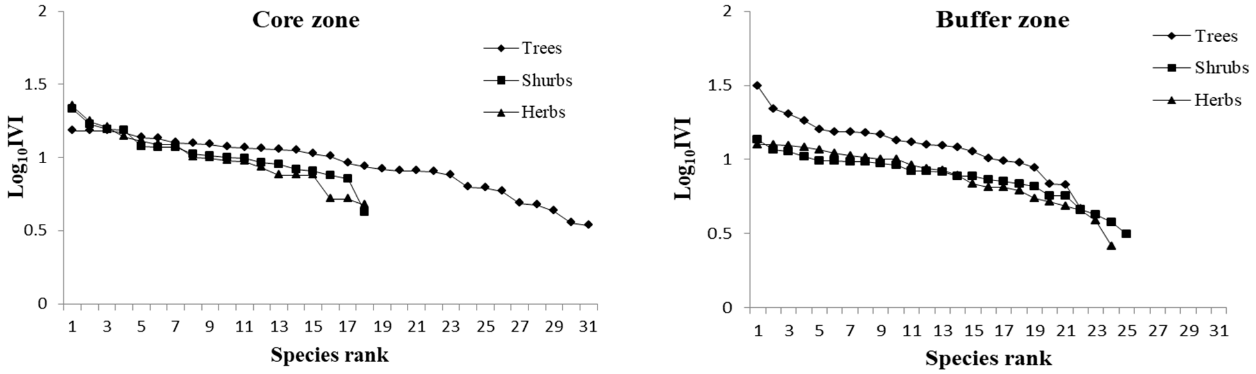

Figure 3. Dominance–diversity curve for trees, shrubs, and herbs in core (**left**) and buffer (**right**) zones in Minkong Community Forest Reserve, Nagaland, India.

While tree density and basal area were lower in the BZ as compared to the CZ (Table 1), the tree density and basal area showed the greatest occurrences in the 10 to 20 cm DBH range in both zones (Figure 4) with the number of individuals declining with increasing DBH in both zones; there were proportionally fewer trees in the 20 to 30 DBH class in the BZ compared to the CZ. The overall plant biomass and C stock were greater in the CZ than in the BZ. Out of the total biomass (327 Mg ha^{-1}) in the CZ, the tree biomass contributed 98% and the remaining was contributed by shrub, herb, and floor mass. Similarly, of the total biomass (224 Mg ha^{-1}) in the BZ, trees contributed 97%. The overall distribution of tree biomass among different girth classes showed the greatest biomass in the trees of 10 to 30 cm DBH which contributed 79% in the CZ and 71% in the BZ. The maximum tree biomass of 50% and 58% was contributed by the 10 to 20 cm diameter class in the CZ and BZ, respectively (Figure 5).

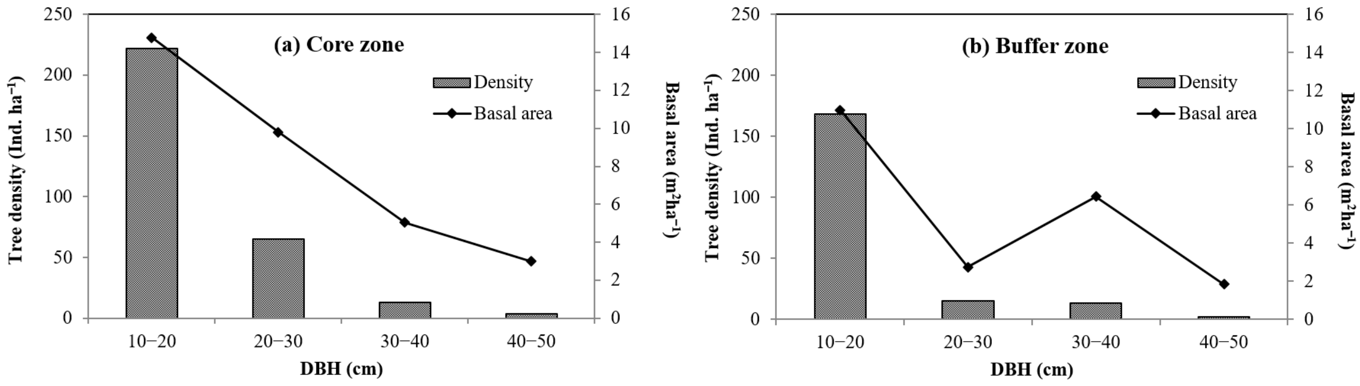

Figure 4. Contribution of tree stand density and basal area based on diameter class distributions in the core (**a**) and buffer (**b**) zones in Minkong Community Forest Reserve, Nagaland, India.

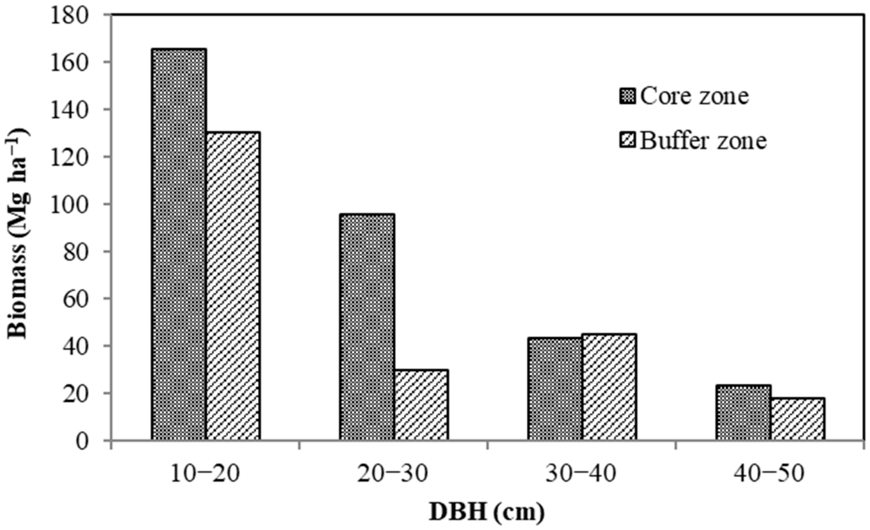

Figure 5. Tree biomass distribution in various DBH classes for the core and buffer zones in Minkong Community Forest Reserve, Nagaland, India.

The total C contributed by different tree species to AGB C varied between the species and was directly associated with the tree basal area. In the CZ, the contribution of major tree species (i.e., *Betula alnoides, Bischofia javanica, Cephalotaxus grifithii, Lithocarpus elegans, Quercus lamellosa, Terminalia myriocarpa,* and *Toona ciliata*) was around 40% of the total AGB and C stocks, with a similar contribution of major tree species (i.e., *Castanopsis indica, Ilex dipyrena, Lithocarpus elegans, Prunus nepaulensis, Quercus serrata,* and *Xerospermum noronhianum*) in the BZ. The total tree biomass (AGB + BGB) was estimated at 322 Mg ha^{-1} and 218 Mg ha^{-1} in the CZ and BZ, respectively (Table 3). The total understory biomass (shrubs + herbs) was 1.90 and 2.94 Mg ha^{-1} in the CZ and BZ.

Table 3. Total biomass (Mg ha^{-1}) (mean ± standard error) in core and buffer zones of Minkong Community Reserve Forest, Nagaland, India).

Ecosystem Component	Core Zone	Buffer Zone
Above-ground tree biomass	263 ± 8.4	177 ± 11
Below-ground tree biomass	58.7 ± 3.4	40.7 ± 4.1
Shrub biomass	1.20 ± 1.2	2.01 ± 0.3
Herb biomass	0.70 ± 0.6	0.93 ± 0.4
Floor mass	3.3 ± 0.8	3.4 ± 0.5
Total stand biomass	327 ± 13.3	224 ± 18.7

The total SOC stock (0 to 50 cm) was not different between the CZ (75 ± 4.51 Mg C ha^{-1}) and the BZ (71 ± 3.45 Mg C ha^{-1}) (Table 4). The total C stored in all ecosystem compartments, including SOC, showed a sum of 224 Mg C ha^{-1} in CZ and 173 Mg C ha^{-1} in BZ.

Table 4. Distribution of carbon stocks (Mg C ha^{-1}) (mean ± standard error) in different ecosystem compartments of core and buffer zone of Minkong Community Forest Reserve, Nagaland, India.

Ecosystem Compartment	Core Zone	Buffer Zone
Above-ground tree biomass	120 ± 0.31	80.7 ± 0.43
Below-ground tree biomass	26.8 ± 1.45	18.6 ± 2.10
Shrub biomass	0.54 ± 1.16	0.92 ± 0.52
Herb biomass	0.31 ± 1.20	0.42 ± 0.45
Floor mass	1.50 ± 0.12	1.55 ± 0.15
Total biomass carbon	149 ± 3.40	102 ± 1.21
Soil organic carbon	75 ± 4.51	71 ± 3.45

4. Discussion

Community reserve forests can play an important role in biodiversity conservation and provide socio-ecological benefits for regional populations [14,15,31–33]; however, overexploitation of these forests, combined with ecological edge effects, can considerably affect their structure and function. In the present study, the CZ and BZ of a community reserve forest in North-east India were studied with respect to their species composition, diversity, biomass, and C stocks. The greater tree species richness in the CZ compared to the BZ may be because of the protection provided by the traditional communities [33] and less exploitation, whereas the lower density and species richness of trees in the BZ, being more closely located to human settlements, is likely due to anthropogenic pressures (e.g., extraction of timber and natural resources, forest fire, and agriculture expansion) along with further environmental changes brought about by the opening of the canopy. The diversity indices in the present study showed the changing pattern of the diversity of various lifeforms in the forest community. The tree community was more diverse than the shrub and herb communities, although this could be due to the greater area sampled for trees. High values of the Shannon–Wiener diversity index (H') and low dominance are characteristic features of an old-growth forest [34] which was also supported by our study. Additionally, changes in species composition have been shown at the edges of forest fragments with a move towards more early successional species and a decline in the abundance of old-growth specialists [35]. In the BZ, we found, for example, that *Macaranga denticulata*, a typical secondary forest tree species, was an abundant tree but it was not present in the CZ. In contrast, a greater diversity and density of undergrowth plants (shrubs and herbs) in the BZ may be attributed to a more open canopy due to anthropogenic and natural disturbances allowing more sunlight to reach the forest floor and thus creating favorable microsite conditions enhancing the growth of understory vegetation [36]. The composition of the shrub community in the BZ was clearly distinct from that in the CZ, whereas there was more overlap in the herb community. Similar observations have been reported from other natural undisturbed forests in India [37–40]. This is supported by the similarity measures (Sørenson) which are the most instinctive and common methods for comparing two or more sites with respect to their species overlap [41]. The low similarity between the CZ and BZ may also be because of succession brought about by disturbance, leading to contrasting micro-environmental conditions [42,43]. Different plant life forms (trees, shrubs, and herbs) recorded from the CZ and BZ showed similar characteristics of dominance–diversity curves with high equitability and low dominance of species. The log-normal distribution pattern in both sites indicates high species richness and equitable distribution of natural resources among the species in the forest ecosystem [44,45]. The reduced proportion of trees in the 20 to 30 cm DBH category in the BZ suggests that this size category is preferentially used by the local communities. In other studies of disturbed forest, larger trees are found at lower proportions leading to changes in the slope of a scaling relationship between stem diameter and density [46,47]. Our results present an interesting comparison to this as large trees seem to be retained in the BZ with medium-sized trees appearing to be preferentially removed.

The estimated above-ground biomass for trees in both zones ranged from 177 to 263 Mg ha^{-1} with a mean of 220 Mg ha^{-1} which falls well within the reported range (133 to 262 Mg ha^{-1}) for various natural forests of North-east India [48–55]. Decreased biomass in the BZ may be attributed to lower tree density and size due to various anthropogenic disturbances associated with edge effects [56]. Tree species composition also affects the total biomass and C stock of forests [51,57,58] and the change in species composition in the BZ plots will influence total forest biomass if lighter-wooded species become more dominant. Below-ground biomass contributed about 20% to the total biomass stock in both zones and plays an important role in below-ground C storage; this value is an estimate based on above-ground biomass so it would be valuable to directly measure root biomass in these forests for a more accurate estimate, e.g., [59,60]. Furthermore, in both the zones, tree biomass distribution across diameter classes showed the greatest biomass allocation in smallest classes (10 to 20 cm DBH) which may be due to the occurrence of greater tree density and basal area of the young trees and the lack of particularly large trees due to the montane elevation. A similar study was also conducted in a sacred natural forest of Manipur, North-east India which reported the greatest biomass in the smaller girth class of 30 to 60 cm (equivalent to 10–20 cm DBH) [55]. The greatest familial contribution to total biomass C stocks in both the CZ and BZ was by the Fagaceae, followed by Betulaceae, Sapindaceae, Moraceae, Euphorbiaceae, and Meliaceae, which contributed about 70% of the total biomass among the six families.

There was no difference in the SOC stock between the BZ (71 Mg C ha^{-1}) compared to the CZ (75 Mg C ha^{-1}). It is known that forest conversion to other land-uses such as shifting cultivation or plantations can have a clear effect on SOC stocks with reductions regularly seen [61,62]. It appears that, currently, the low-intensity disturbance in the buffer zone was not severe enough to influence SOC stocks. However, changes in litter input and soil disturbance in the future may influence soil changes, so additional monitoring would be valuable. Determining long-term C sequestration rates and how they may be influenced by disturbance, tree growth, and mortality rates combined with litterfall and other measures of primary production, e.g., [13,59], would be an important next step.

5. Conclusions

We show here that whilst community reserve forests can be valuable for conserving tropical biodiversity, edge effects brought about by human usage of the forest lead to reductions in tree species richness but an increase in shrub and, particularly, herb species richness with a clear impact on the community composition of all three groups of plant life-forms with edge-affected (buffer-zone) plots having a distinct composition to those in the core zone. Total biomass and C stock were both high as compared to other Indian natural forests indicating the high potential of the site to store C in the plant biomass and soil, and the buffer zone can provide similar ecosystem services to that of the core zone if adequate protection is provided. However, the buffer zone can act as an ex situ conservation ground for the valuable local plant species and protect the ecosystem services at a regional level by buffering the human disturbances. We recommend the extension of the buffer zone or the creation of a peripheral zone around Minkong Community Reserve Forest, perhaps in the form of a plantation forest or agroforest, that may help in conserving local species and ecosystem services on a sustained basis. Such an effort may provide livelihood opportunities to the local tribal communities by conserving regional diversity and mitigating climate change.

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