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Introduction is about 600 words, covering the aims of the research and provide an adequate background, avoiding a detailed literature survey or a summary of the results. **Materials and Methods** should emphasize on the procedures and data analysis. **Results and Discussion** should be written as a series of connecting sentences, however, for a manuscript with long discussion should be divided into subtitles. Thorough discussion represents the causal effect mainly explains why and how the results of the research were taken place, and do not only re-express the mentioned results in the form of sentences. **Concluding** sentence should be given at the end of the discussion. **Acknowledgements** are expressed in a brief; all sources of institutional, private and corporate financial support for the work must be fully acknowledged, and any potential conflicts of interest are noted.

Figures and Tables of a maximum of three pages should be clearly presented. The title of a picture is written down below the picture, while the title of a table is written above the table. Colored figures can only be accepted if the information in the manuscript can lose without those images; the chart is preferred to use black and white images. The author could consign any picture or photo for the front cover, although it does not print in the manuscript. All images property of others should be mentioned the source. Author is suggested referring to Wikipedia for international boundaries and Google Earth for satellite imagery. If not specifically mentioned, it is assumed to refer to these sources. **There is no appendix**, all data or data analysis is incorporated into Results and Discussions. For broad data, it can be displayed on the website as a supplement.

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Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from the internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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Dictyosporium matherense sp. nov.: A new-fangled cheirosporous fungal species described from the Western Ghats of India

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Abstract. *Dubey R. 2022.* Dictyosporium matherense *sp. nov.: A new-fangled cheirosporous fungal species described from the Western Ghats of India. Asian J For 6: 1-8.* A new species of *Dictyosporium* from forest areas of Matheran, Western Ghats of India, is described and illustrated. This new-fangled cheirosporous species is characterized by large conidia being cheiroid, digitate, variable shape, having 600-3000 individual cells arranged in 15-80 rows consisting of widening apical ends with tightly appressed prolongations/arms which produce hyaline, rounded appendages which latter on produces 8-20 hyaline, long, and hypha-like septate appendages. The isolate was identified based on asexual morphs and, to some extent, stands close to *D. palmae, D. digitatum,* and *D. stellatum* but remarkably differs from all in size of conidia. To our understanding, the present taxon has turned out to be a hitherto unreported species. The morphological character of all accepted species of *Dictyosporium* is also presented.

Keywords: Ascomycetes**,** asexual-morphs**,** cheirosporous, Matheran, taxonomy

INTRODUCTION

Matheran means forest on the forehead of the mountains and is located in the Western Ghats of India at an elevation of around 800 m above sea level. It is an eco-sensitive region declared by the Ministry of Environment, Forest and Climate Change, Government of India, and is the only automobile-free hill station in Asia. During the mycological exploration of Matheran and other fungi, an interesting conidial fungus was collected from the stem of an unknown plant, which was undoubtedly similar to the genus *Dictyosporium* established by Corda (1836).

The genus *Dictyosporium* is characterized by colonies that are usually in the form of compact sporodochia or rarely effuse, with mostly immersed mycelium. Conidiophores are micronematous or absent, but conidiogenous cells, which arise directly from hyphae and cells constituting the conidiomata, are discrete and doliiform or subspherical. Conidia are dematiaceous, holoblastic, solitary, multiseptate, cheiroid with multiple columns of cells, closely branched from the base, without the arms separating, in most species flattened in one plane, and they secede rhexolytically (Damon 1952; Ellis 1971; Sutton 1985). A few *Dictyosporium* species have conidia with appendages generally thin-walled, hyaline, and may be clavate, cylindrical, and filiform or globose in shape (van Emden 1975; Bhat and Sutton 1985; Tzean and Chen 1989; Chen et al. 1991). The teleomorph is characterized by dark brown, subglobose superficial ascomata, bitunicate cylindrical asci and hyaline, and fusiform uniseptate ascospores with or without a sheath. *Dictyosporium* species have been grown in vitro and can sporulate in culture (von Arx 1981; Matsushima 1975, 1980, 1981, 1993; Tzean and Chen 1989; Chen et al.1991).

The cheirosporous *Dictyosporium* has been reported worldwide from dead wood and plant litter in terrestrial and aquatic habitats (Hyde and Goh 1998; Ho et al. 2002; Pinnoi et al. 2006; Pinruan et al. 2007). Based on molecular phylogenetic analysis, *Dictyosporium* is placed under Pleosporales (Tsui et al. 2006; Crous et al. 2009; Liu et al. 2015; Tanaka et al. 2015). Tsui et al. (2006) considered that the genus is closely related to the family of Massarinaceae (Pleosporales) based on phylogenetic analysis using small ribosomal subunit and large ribosomal subunit sequence data. Tanaka et al. (2015) and Boonmee et al. (2016) have long-established the phylogenetic placement of *Dictyosporium* in Dictyosporiaceae (Massarineae, Pleosporales) along with other genera, such as *Aquaticheirospora*, *Gregarithecium*, *Diplococcium*, *Pseudocoleophoma*, *Paraconiothyrium*, *Dendryphiella*, *Digitodesmium,* and *Pseudodictyosporium.* Later on, *Cheirosporium*, *Vikalpa*, *Dictyocheirospora*, *Jalapriya*, *Aquadictospora*, and *Neodendryphiella* were placed under Dictyosporiaceae (Yang et al. 2018; Hyde et al. 2020). Goh et al. (1999) reviewed the genus *Dictyosporium* and accepted 22 species, and dichotomous keys were provided for *Dictyosporium* species (Cai et al. 2003b; Crous et al. 2009; Whitton et al. 2012; Silva et al. 2015). However, until 2015, only 48 species were accepted under the genus (Whitton et al. 2012; Prasher and Verma 2015, and Silva et al. 2015).

During 2015-2017, nine more new species were established under the genus, namely *D. araucariae* S.S. Silva, R.F. Castaneda & Gusmao; *D. hydei* I.B. Prasher & R.K. Verma; *D. indicum* I.B. Prasher & R.K. Verma; *D. olivaceosporum* Kaz. Tanaka, K. Hiray., Boonmee & K.D. Hyde; *D. palmae* Abdel-Aziz; *D. pseudomusae* Kaz. Tanaka, G. Sato & K. Hiray; *D. sexualis* Boonmee & K.D.

Hyde; *D. splendidum* Alves-Barb., Malosso & R.F. Castañeda, and *D. wuyiense* Y. Zhang & G.Z. Zhao were newly introduced to the genus (Prasher and Verma 2015; Tanaka et al. 2015; Abdel-Aziz 2016; Boonmee et al. 2016; da Silva et al. 2016; Alves-Barbosa et al. 2017; Zhang et al. 2017). Furthermore, additional nine new species were established after 2017 under the genus, namely *D. appendiculatum* Tibpromma & K.D. Hyde; *D. guttulatum* Tibpromma & K.D. Hyde; *D. krabiense* Tibpromma &. Hyde; *D. hongkongensis* Tibpromma & K.D. Hyde; *Dictyosporium pandanicola* Tibpromma & K.D. Hyde; *Dictyosporium tratense* J. Yang & K.D. Hyde; *D. tubulatum* J. Yang, K.D. Hyde & Z.Y. Liu; *D. marinum* Dayarathne & E.B.G. Jones; *D. muriformis* N.G. Liu, K.D. Hyde & J.K. Liu. Currently, 13 species of *Dictyosporium* have been re-assigned to other genera (Boonmee et al. 2016; Yang et al. 2018), and 53 species are accepted under the genus (Table 2 & 3). In addition, Wijayawardene et al. (2017) provided information on the availability of cultures and references to accessible sequence data of the genus.

MATERIALS AND METHODS

Samples of fallen stems infested with fungi were collected from the ground, placed in a paper bag, taken to the laboratory, and treated as per the protocol provided by Castaneda-Ruiz (2005). Colonies were taken from the surface of the wood with a needle and transferred to a drop of lactophenol [lactic acid 20 %, glycerol 40 %, phenol 20 %, distilled water 20 % (v/v)] on a slide. Finally, the slides were sealed with Dibutylphthalate Polystrene Xylene (DPX). All Micrographs were captured using (OLYMPUS CX41 aided with Digi-CAM) microscope. All microscopic characters were determined based on measurements of 25 mature conidia mounted in lactophenol, and measurements of the fungal structures were taken from the microscope. According to the manufacturer's protocol, scanning electron microscopic images were captured using a Zeiss scanning electron microscope EVO 18-12 -97 (Zeiss, Germany). The holotype and Isotypes are deposited in the Fungal Herbarium of Botanical Survey of India, WRC, Pune, India.

RESULTS AND DISCUSSION

***Dictyosporium matherense* sp.nov. Rashmi Dubey**
(Figures 2 & 3) Mycobank: MB840295.

Saprobic on the unknown fallen stem. Sexual morph: undetermined. Asexual morph: mycelium light brown, verrucose, 2.5−4 µm thick, septate. Conidiomata on the natural substrate sporodochial, loose, scattered, shining black, 1-10 mm in length. Conidiophores are inconspicuous or absent. Conidiogenous cells are monoblastic, determinate, brown in color, sub-globose to ovate, thin-walled, 8-10 × 6–7.5 µm. Conidia are solitary, holoblastic, light reddish to dark brown, smooth, complanate, cheirosporous, mostly digitate or very variable in shape, viz. V/Yshaped or multifigured or feathery, widened apical end with tightly appressed prolongations/arms, round to tapered base, 172-271 x 68-244 µm (x = 207 x 160, n = 25), consisting cylindrical, elongated, 5–7 µm tall, 2.5–4 µm wide, 600-3000 individual cells arranged in 15-80 rows, each row with 40-50 cells, tips of some rows are armed with jelly-like, hyaline, rounded appendages which latter on produces 8-20 hyaline, long, hypha-like septate appendages which are up to 50 µm long and 3-4 µm thick.

Material Examined: — India, Maharashtra, Matheran, 18°59'08.2"N 73°15'41.2"E, on dry stem litter, 4.11.2017, Rashmi Dubey, BSI (W.C.) 205598 (Holotype), 205599 (isotype) deposited in Botanical Survey of India, Western Regional Centre, Pune, Maharashtra, India.

Etymology: species named after the place of collection 'Matheran' in Maharashtra, India.

Additional material/cultures examined: — Culture has grown on Potato Dextrose Agar (PDA) medium and Malt Extract Agar medium (MEA) under different light and dark conditions. Vegetative hyphae grew on medium for 7 days but did not sporulate, and the culture died.

Distribution - Only known from the type locality in forest areas of Matheran in the Western Ghats, Maharashtra, India, at an altitude of 800 m asl. Along with type, the species of *Monodictys* spp. and *Pithomyces* spp. were found to be associated.

Taxonomic notes

As per Index fungorum (2021), a total of 82 species were recognized under the *Dictyosporium,* of which 16 species were found doubtful or excluded by Goh et al. 1999 (Table 1), 13 species were re-assigned to other genera, namely *Dictyocheirospora*, *Jalapriya,* and *Vikalpa* (Table 2) and presently 53 species are accepted under the genus (Table 3). Therefore, the present collection undoubtedly falls in the category of *Dictyosporium* based on morphological features.

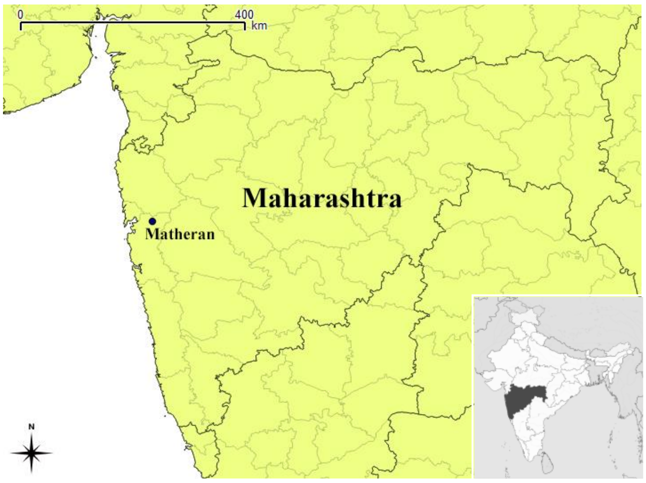

Figure1. Map of Maharashtra State (yellow) showing the GPS location of the collection site (dot)

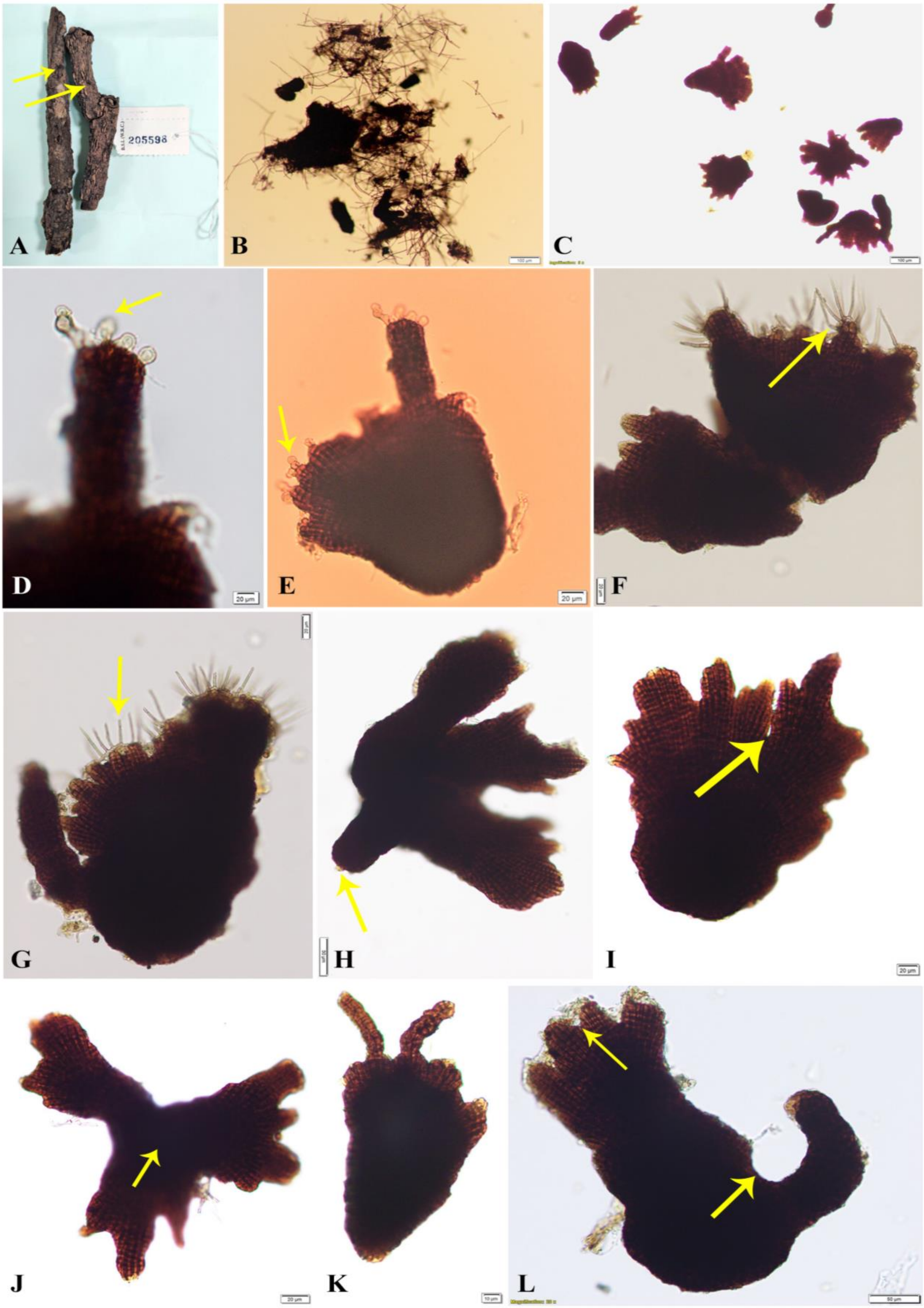

Figure 2. *Dictyosporium matherense* sp.nov. (A) black colonies on the host surface (arrow), (B) colonies with mycelium and sporodochia, (C) conidia, (D-E) tip of conidia armed with hyaline rounded appendages colonies (arrow), (F-G) tip of conidia armed with hyaline hyphae like appendages (arrow), (H) conidia with conidiogenous cell (arrow), (I) digitate conidia with deep constrictions (arrow), (J) feather-like conidia, (K) V-shaped, (L) palm-like conidia

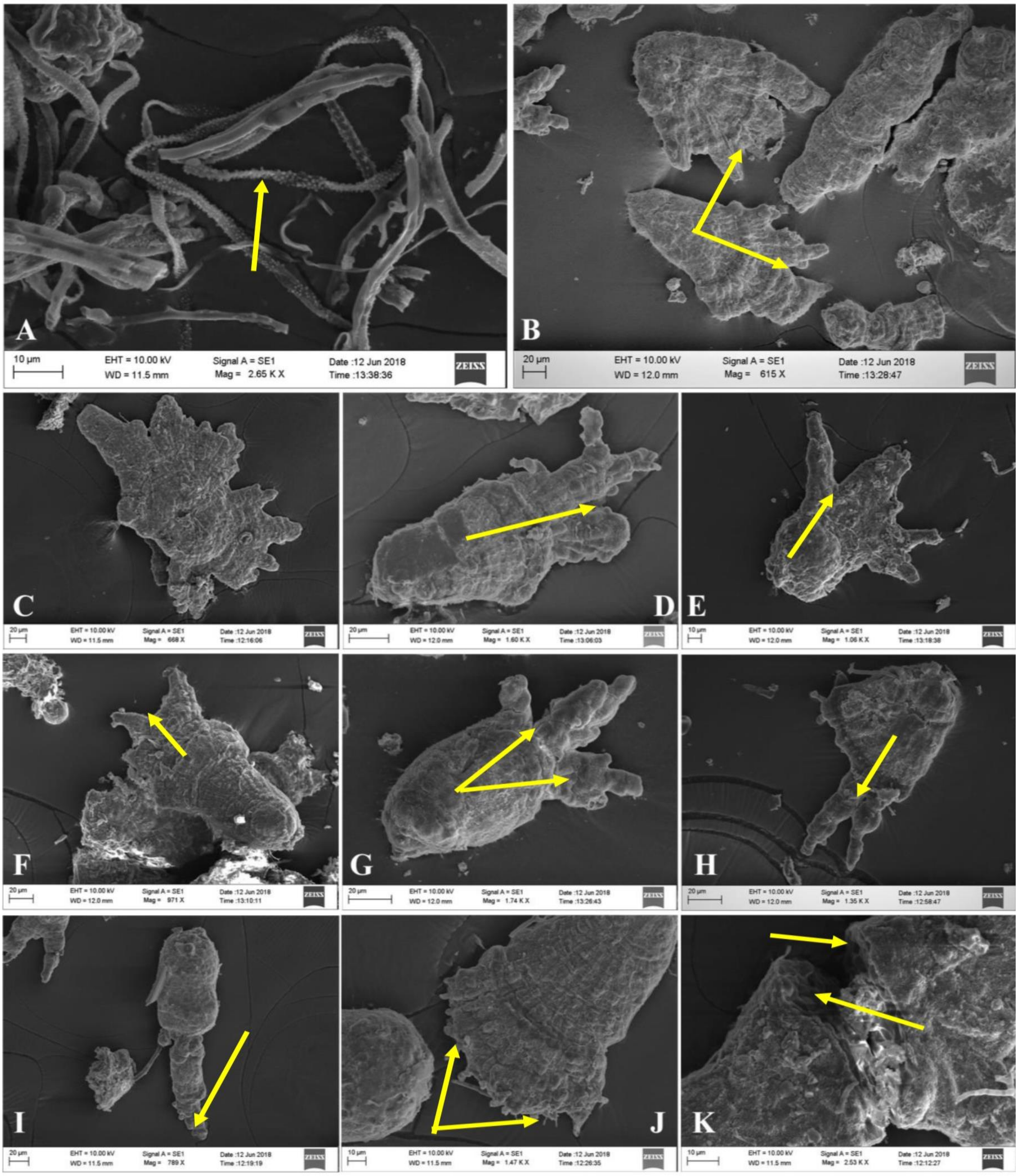

Figure 3. Scanning Electron Microscopic images of *Dictyosporium matherense* sp.nov. (A) verrucose mycelium (arrow), (B) digitate conidia (arrow), (C) discoid conidia, (D-H) conidia having prolongations/arms with deep constrictions (arrow), (I) figure-like conidia (arrow), (J) widen apical end of conidia armed with rounded hyaline conidia (arrow), (K) broken conidia showing internal cells (arrow)

Table 1. List of doubtful/excluded species under *Dictyosporium*

Doubtful/excluded species of *Dictyosporium* sp. (Goh et al. 1999)
D. binatum (Sacc.) S. Hughes 1958, *D. boydii* A.L. Sm. & Ramsb. 1915, *D. castaneum* Gonz. Frag. 1924, *D.circinatum* Cooke & Harkn., 1884, *D. crustaceum* (P. Karst.) S. Hughes 1958, *D. hymenaearum* Bat. & J.L. Bezerra 1960, *D. intermedium* Subram. 1971, *D. minus* Sacc. 1918, *D. minus* (Sacc.) Damon [as 'minor'], 1952, *D. opacum* Cooke & Harkn. 1884, *D. pelagicum* (Linder) G.C. Hughes ex E.B.G. Jones 1963, *D. prolificum* Damon 1952, *D. secalinum* Delacr. 1891, *D. solanii* A.D. Sharma, Munjal & Jandaik 1983, *D. verrucosum* Tzean & J.L. Chen (1989), *D. yerbae* Speg. 1909.

Table 2. List of *Dictyosporium* species transferred to other genera (Boonmee et al. 2016; Yang et al. 2018)

Former species name	**Accepted species**
Dictyosporium australiensis B. Sutton 1985	*Vikalpa australiensis* (B. Sutton) D'souza, Boonmee & K.D. Hyde 2016
Dictyosporium freycinetiae McKenzie 2008	*Vikalpa freycinetiae* (McKenzie) D'souza, Boonmee & K.D. Hyde 2016
Dictyosporium giganticum Goh & K.D. Hyde 1999	*Dictyocheirospora gigantica* (Goh & K.D. Hyde) D'souza, Boonmee & K.D. Hyde 2016
Dictyosporium heptasporum (Garov.) Damon 1952	*Dictyocheirospora heptaspora* (Garov) D'souza, Boonmee & K.D. Hyde 2016
Dictyosporium hydei Prasher & R.K. Verma 2014	*Dictyocheirospora hydei* (I.B. Prasher & R.K. Verma) J. Yang & K.D. Hyde, in Yang, Liu, Hyde, Jones & Liu 2018
Dictyosporium indicum I.B. Prasher & R.K. Verma 2015	*Dictyocheirospora indica* (I.B. Prasher & R.K. Verma) J. Yang & K.D. Hyde 2018
Dictyosporium inflatum (Matsush.) Kirschner R, Pang KL, Gareth Jones EB 2013	*Jalapriya inflata* (B. Sutton) D'souza, Boonmee & K.D. Hyde 2016
Dictyosporium micronesiacum Matsush 1981	*Vikalpa micronesiaca* (Matsush.) D'souza, Boonmee & K.D. Hyde 2016
Dictyosporium musae Photita 2002	*Dictyocheirospora* musae (Photita) J. Yang, K.D. Hyde & Z.Y. Liu, 2018
Dictyosporium pseudomusae Kaz. Tanaka, G. Sato & K. Hiray 2015	*Dictyocheirospora pseudomusae* (Kaz. Tanaka, G. Sato & K. Hiray.) Kaz. Tanaka, K. Hiray, Boonmee & K.D. Hyde 2016
Dictyosporium subramanianii B. Sutton 1985	*Dictyocheirospora subramanianii* (B. Sutton) D'souza, Boonmee & K.D. Hyde 2016
Dictyosporium toruloides (Corda) Guég 1905	*Jalapriya toruloides* (Corda) M.J. D'souza, Hong Y. Su, Z.L. Luo & K.D. Hyde 2016
Dictyosporium tetraploides L. Cai & K.D. Hyde, in Cai, Zhang, McKenzie & Hyde (2003)	*Dictyocheirospora tetraploides* (L. Cai & K.D. Hyde) J. Yang & K.D. Hyde, in Yang, Liu, Hyde, Jones & Liu 2018

The present collection differs from other species in having large conidia, V to Y shaped or multifigured or feathery, and widened apical ends with tightly appressed prolongations/arms. Each conidium possesses 600-3000 individual cells arranged in 15-80 rows, each row with 40-50 cells; tips of some rows are armed with jelly-like, hyaline, rounded appendages, which latter on produce 8-20 hyaline, long, hypha-like septate 50 µm long and 3-4 µm thick appendages. As evident, no such significant features are observed in other species of *Dictyosporium*; therefore, the present collection deserves the rank of a noble species and is described here as a new species (Table 3).

Although 53 species are accepted under the genus *Dictyosporium* (Table 3), no infrageneric classification is available for the genus. *D. matherense* shows a close affinity to *D. palmae, D. digitatum,* and *D. stellatum* in having a large size of conidia. However, the new collection is morphologically distinct from them in their conidial morphology. *D. matherense* differs from *D. palmae* by having longer and broader conidia (172-271 x 68-244 µm vs. 75−15 × 18−32 µm) and having larger no. of cell rows (15-80 vs. 4−6) for D. *matherense* and *D. palmae* respectively. *D. matherense* differs from *D. digitatum* by having longer and narrower conidia (172-271 x 68-244 µm × vs. 46.5−88 × 26−46 µm) and a large no. of cell rows (15-80 vs. 5–7 rows) for *D. matherense* and *D. digitatum* respectively. *D. matherense* differs from *D. stellatum* by having longer and broader conidia *(*172-271 x 68-244 µm vs. 50–175 × 27.5–52.5 µm) and having larger no. of cell rows (15-80 vs. 5–7) for *D. matherense* and *D. stellatum* respectively. Apical hyaline, hypha-like appendages are found in *D. matherense and D. palmae,* and *D. digitatum* but are absent in *D. stellatum.* We could not match this collection with any other; therefore, we established this collection as a novel species based on morphological differences.

Table 3. Comparison of *Dictyosporium matherense* sp.nov. with 53 accepted species of the genus *Dictyosporium*

Species	Conidial size (µm)	No. of rows	Cells per conidium	Cells per row	Conidial vesicles appendages	References
D. acroinflatum	28–52×23–35	4–8	39–68	5–13	0	Whitton et al. (2012)
D. alatum	26–32×15–25	5	26-37	4-6	0–2	van Emden (1975)
D. amoenum	20–30×12–15	4	24-28	5-7	4-5	Silva et al. (2015)
D. appendiculatum	30–40×12–25	4-5	30-40	6-8	1–3	Tibpromma et al. (2018)
D. aquaticum	60–85×20–30	5-6	66-82	13-16	5	Liu et al. (2015)
D. araucariae	12–27×14–24	4–6	15-27	3-6	4-(5)-6	Silva et al. (2016)
D. biseriale	22–30×9–10	2	10–17	5–8	0	Hu et al. (2010)
D. brahmaswaroopii	17–24×12.5–19	3–5	9–21	3–5	0	Mehrotra (1990)
D. bulbosum	27–46×11–30	5-6	12-48	6-10	1–2	Tzean and Chen (1989)
D. campaniforme	22–40×20–30	4–8	20–60	5–9	0	Matsushima (1975)
D. canisporum	27–47×20–25	4-5	20-44	5-9	2	Cai et al. (2003a)
D. cocophilum Bat. 1951	53–76×19–22	7	70-100	10–14	0	Batista (1951)
D. digitatum J.L.	47–77×22–39	5–7	65-90	7-13	4-5	Chen et al. (1991)
D. dkagarwalii	30–40×9.5–11.5	2–3	19–37	6–13	0	Manoharachary et al. (2007)
D. elegans Corda 1836,	40–80×24–31	5	51–96	9–13	0	Goh et al. (1999)
D. foliicola	34–56×20–38	5–7	37–60	3–14	0	Kirk and Spooner (1984)
D. gauntii	40–50×18–25	4–6	40-50	8-10	1	Goh et al. (1999)
D. guttulatum	30–40×16–23	4-5	40-44	9-10	1-2	Tibpromma et al. (2018)
D. hongkongensis	28–41×18–26	4-5	16-30	4-6	0	Tibpromma et al. (2018)
D. hughesii	33–50×23–32	7	45-50	7-8	1	McKenzie (2010)
D. krabiense	14–17×15–20	4–5	16-30	4-6	1-2	Tibpromma et al. (2018)
D. lakefuxianense	15–22 × 10–16.5	3	9–13	Middle 3(–4); outside two rows 4–5	0	Cai et al. (2003b)
D. matherense sp. nov.	172-271×68- 244	15-80	600-3000	40-50	hypha-like septate appendages	*Present study*
D. manglietiae	22–28×12.5–18	3	16-18	5-6	1	Kodsueb et al. (2006)
D. marinum	34–50×22–28	4-5	35-40		0	Dayarathne et al. (2020)
D. meiosporum	17–28×6–8.5 3–4	3-4	4-16	4-7	0	Liu et al. (2015)
D. muriformis	20–30×11–14.5	3-5	14-27	3-8	0	Hyde et al. (2020)
D. nigroapice	28–41×15–20	4	20-32	7-8	2	Goh et al. (1999)
D. oblongum	30–50×12–30	3–6	22–46	9–11	0	Goh et al. (1999)
D. olivaceosporum	32–42(–44)×20–28	5-6	28-43	6-7	2-4	Boonmee et al. (2016)
D. palmae	75–165×15–33	3-6	95–144	17–26	Hyaline appendages on the tip	Abdel-Aziz (2016)
D. pandani	22–48×14–28	4–5	29–49	4–10	0	Whitton et al. (2012)
D. pandanicola	30–50×15–33	5-6	34-62	6-8	0	Tibpromma et al. (2018)
D. polystichum	26–34×23–34	7–9	33–40	3–6	0	Damon (1952)
D. rhopalostylidis	28–48×20–29	5-6	5–6	30–40(48)	0	McKenzie (2010)
D. schizostachyfolium	15–17×11–12	4	13–16	2–4	0	Goh et al. (1999)
D. sexuale	Only teleomorph forms known					Boonmee et al. (2016)
D. sinense	50–130×20–35	4–7	50–93	7–15	0	Zhang (2009)
D. splendidum	22–29×11–14	2-3	16-27	8-9	2-3	Alves-Barbosa et al. (2017)
D. stellatum	50–175×27.5–52	5–7	(59–)110–165(–180)	14–33	0	Crous et al. (2011)
D. strelitziae	(30–)40–46(–55)×(20–)21–23(–25)	4–6	28-66	7–11	1–2	Crous et al. (2009)
D. taishanense	27–43×15–30	(3–)5(–7)	24–55	4–9	0	Zhao and Zhang (2003)
D. tetraseriale	24–40×14–20	4	24-38	7-9	2	Goh et al. (1999)
D. tetrasporum	23.5–40×16–21.5	4	12–27	5–7*	0	Cai and Hyde (2007)
D. thailandicum	15–35×15–21	5	28-32	6-9	0–2	Liu et al. (2015)
D. tnlakhanpalii	80–120×25–36	(4–)6(–8)	90–100+*	16–22*	0	Manoharachary et al. (2007)
D. tratense	40-57×20-36	4-6	39-68	9-11	Sometimes 1-2	Yang et al. (2018)
D. triramosum	40–60×10–13.5	(2–)3	26–30	9–10	0	Arambarri et al. (2001)
D. triseriale	26–32×16–18	3	15–21	5–7	0	Goh et al. (1999)
D. tubulatum	25–38×14–22	4 (-5)	28-30	7-8	2-3	Yang et al. (2018)
D. wuyiense	Type -1 33–52×27–43 Type -2 42–70×20–33	4– (5)–6	28	8-12	0–3	Zhang et al. (2017)
D. yunnanense	25–45×22–38	(5–)6(–7)	19–47 *	5–9	0	Cai et al. (2003b)
D. zeylanicum	26–40×13–25	5	28–34*	4–8*	0	Goh et al. (1999)
D. zhejiangense	25–35×17–24	(4–)5	22-33	4-6	1–3	Wongsawes et al. (2009)

Note: *After Whitton *et al.* (2012)

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Discovery of a rare stiped puffball *Calostoma junghuhnii* in Neora Valley National Park, India: A new record for West Bengal, India

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Abstract. *Majumdar S, Rai BS, Rai A, Ghosh U, Bhattacharyya S, Bose A, Goswami N, Chakraborty D, Sarkar J, Mukherjee S, Acharya K, Pradhan P. 2022. Discovery of a rare stiped puffball Calostoma junghuhnii in Neora Valley National Park, India: A new record for West Bengal, India. Asian J For 6: 9-14.* The varied topography, soil, and climate of West Bengal, India, make conducive conditions for nurturing the magnificent diversity of macrofungi and their habitats. During an exploration of macro-fungal diversity in Neora Valley National Park, West Bengal, India, in 2021, basidiocarps of *Calostoma* (Calostomataceae) were collected and photographed, along with macro-morphological and ecological notes were taken. The specimens were identified through macro and micro-morphological characters following standard literature. Amplified description of *Calostoma junghuhnii* (Schltdl. & Müll. Berol.) Massee, along with necessary figures and photographs, is presented in this paper. A literature survey revealed that *C. junghuhnii* is a new record for West Bengal. The outcome of the present study would enrich data related to the macro-fungal diversity in the state of West Bengal, India.

Keywords: Annual biodiversity assessment camps, Basidiomycota, Calostomataceae, Neora Valley National Park, UNESCO

INTRODUCTION

Neora Valley National Park (NVNP), under the jurisdiction of Gorumara Wild Life Division, Jalpaiguri, West Bengal, India, comprises around 160 km^2 of pristine late-successional forest with a rich repository of biodiversity in the Eastern Himalayan landscape. That place was one of the components of Global Biodiversity Hotspots (Myers et al. 2000). Besides, NVNP has been included in the tentative list of UNESCO World Heritage Sites due to its superlative natural phenomena or areas of exceptional natural beauty, aesthetic importance, and significant natural habitats for in-situ conservation of biological diversity, including those containing threatened species of outstanding universal value from the point of view of science or conservation (UNESCO 2022).

The altitudinal gradient of NVNP is 180 m to 3200 m, incorporating various forest habitat types such as Subtropical Mixed Broadleaf Forests, Lower Temperate Evergreen Forests, Upper Temperate Mixed Broadleaf Forests, and Rhododendron Forest. Besides being a catchment area for tributaries of the Teesta and Jaldhaka Rivers, NVNP nurtures rich biodiversity through its virgin terrain and spatial continuum with some of the national (Pangolakha Wildlife Sanctuary in Sikkim) and the international (Toorsa Strict Reserve of Bhutan) protected areas.

The temperate forests in NVNP are found at elevations where moisture tends to condense and spectacularly remains in the air during the warm moist season. It is one of the species-rich but less explored temperate forests worldwide. These forests are dominated by evergreen broadleaved trees like *Quercus* in the lower reaches from about 2000-2500 m and mixed conifers like *Taxus*, *Tsuga*, and winter deciduous broadleaved species *Acer*, *Betula*, and *Magnolia* in the upper reaches. In addition, the drier south-facing slopes support extensive stands of arboreal *Rhododendrons.* Besides fauna, these forests support a rich diversity of epiphytic, parasitic, ectomycorrhizal, and mycoheterotrophic plants and diverse members of macrofungi and myxomycota (Pradhan 2015; Yonzone 2019; Ghosh et al. 2021).

Regarding biodiversity surveys, Dr. D. Brandis, the then Inspector General of Forests, India (1862), was the first to highlight the importance of conservation of the forest area under NVNP jurisdiction; even Dr. Brandis's proposal was crucial to frame NVNP's existence which came to effect in December 1992. The NVNP, since then, has been explored by organizations of repute like the Botanical Survey of India and the Zoological Survey of

India. Still, the first major systematic study on NVNP was conducted during 2019-2021 through a series of Annual Biodiversity Assessment Camps (ABACs), organized by O/o CCF Wildlife North, Directorate of Forests, Government of West Bengal, with the participation of more than 20 experts on various biodiversity components.

Macrofungi – the group of fungi with visible reproductive structures are an important component of biodiversity in the natural ecosystem. Among multifarious functions, they are the primary agents of decomposition, ectomycorrhizal partnerships with host trees, as well as hardwood, and insecticide parasitism. Macrofungi that produce dust-like spores inside their globose peridial fruitbodies and the spores are released by mature fruitbodies on bursting or external impact in the form of cloud or smoke are informally called gasteroid fungi or puffball fungi. *Calostoma* is a gasteroid genus of 30 species of macrofungi in the suborder Sclerodermatineae (Mycobank 2022). They have a worldwide distribution, including eastern North America, Asia, and Australasia (Massee 1888; Kobayasi 1962). Their somewhat beautifully netted ornamentation of the exoperidium and the presence of bright-colored ostioles resembling human lips wearing lip color have garnered the cognomen of "prettymouths" (World Heritage Encyclopedia 2021). In addition, they are reported to be ectomycorrhizal with the members of Fagaceae (Wilson et al. 2012) and play an important role in the sustenance of temperate deciduous forests.

During the field study of the 5th ABAC (March 2021), specimens of *Calostoma junghuhnii* (Schltdl. & Müll. Berol.) Massee was found between the stretch of the Public Health Engineering (PHE) protection camp and the Alubari protection camp, whose descriptive notes were presented in the present paper.

MATERIALS AND METHODS

Collections were made on 12 March 2021, during the 5th Annual Biodiversity Assessment Camp at Neora Valley National Park, West Bengal, India, en route to the Alubari protection camp from the PHE protection camp. During fieldwork, digital photographs of the samples were taken in their habitat, and their macro-morphological and habitat features were noted. In addition, during the work tenure, a standard identifying protocol, color photographs, and macro-morphological features of each specimen were taken in the field. Next, each collection was wrapped with tissue paper and kept in separate boxes to avoid contamination/ spore mixing. Finally, the collected specimens were carefully withered (separately) in a hot air drier until the moisture was minimal.

Light microscopic features were observed with a Dewinter Smart microscope from thin handmade sections of the dried basidiocarps by staining with Congo Red. In addition, basidiospores were observed in KOH, Melzer's reagent, Congo Red, and Cresyl Blue. Light microscopic photographs were taken with the rear camera of MI A2 mounted upon a microscope bracket clip. Scanning Electron Microscopic studies were conducted in the Centre for Research in Nanoscience and Nanotechnology, University of Calcutta, Kolkata using a Zeiss EVO-MA10 Scanning Electron Microscope.

Forty measurements of basidiospores were taken from each sample to calculate the dimensions of basidiospores. Basidiospore (L & B), Spore ornamentation, and spore wall dimensions include (lowest observed value) 5th percentile value-95th percentile value (highest observed value) following Tulloss and Yang (2021). Mean values are followed by ± standard deviation. Basidiospore Length/breadth ratio denotes the Q value. The mean Q value (Qm) was measured by dividing the sum of the Q value by the total number of spores observed.

Specimens were identified using published literature (Kobayasi 1962, 1965; Chen and Yeh 1975; Massee 1888; Miller and Cotter 1988; Das 2009). Kornerup and Wanscher (1978) were followed for color terminology, while hex color code was used especially for the color of the Ostiole. The voucher specimens were preserved following Pradhan et al. (2015) and were deposited in the Calcutta University Herbarium (CUH), Kolkata, India.

RESULTS AND DISCUSSION

Calostoma junghuhnii (Schltdl. & Müll. Berol.) Massee (Figures 1 and 2)

Basidiomycota, Calostomataceae

Macroscopic observations

Fruitbody gastroid with distinct stipe; solitary or in the group. Exoperidium globose to sub-globose, 9-17 mm × 8.48-16.33 mm, ground color 5A4-5B4, to 8D6 in eroded areas, especially towards Ostiole. With tetra-pentagonal lattice-like reticulations, reticulations are more prominent in the upper 2/3rd exoperidium, smaller warts are present throughout the reticulation ridges, and warts at the center of reticulation are larger and more dehiscent than warts of reticulation ridges. Ostiole burnt sienna-cinnabar (#ea6d56 -#e2604d), with 5-6 sutures, initially covered with warts. Warts 1A4, sometimes with a tint of 29B8-29C8 due to adhesion of bryophytes, pyramidal, more specifically turtle shell-shaped, upper ½ of larger warts with 6C4 coloration. Mesoperidium was not observed. Endoperidium globose, attached to the exoperidium at Ostiole only. Base gelatinous, rhizoidal, 10E7-10D8, moist, made of mycelial interwoven strands, 20-24 mm long, 17-20 mm broad, tapered towards exoperidium attachment in some specimens, while in others swollen in the middle and tapered towards both apex and base.

Microscopic observations

Warts are composed of a hyaline gelatinous matrix, with intermittent hyphae of two types (i) broad, thin-walled congo red (-) hyphae, 12.95-16.49 µm broad (Figure 2A), (ii) slender, filamentous, branched with clamp connections, congo red (+) 3.53-4.71 µm broad (Figure 2B), both hyaline in KOH. Ostiole composed of a hyaline gelatinous matrix with (i) hyaline, branched intermittent hyphae, with swollen base, 3.53-3.77 µm broad (Figure 2C), (ii) hexagonal rose-colored (#de8877-#9c161d) cells, 9.42-

23.55 × 6.59-17.66 µm in size (Figure 2D-F), sometimes with the central vacuole, surface radial, ridges arising from the six angles meeting at the central point. Exoperidium is composed of a hyaline gelatinous matrix (Figure 2G), with intermittent 3.06-3.53 µm broad branched, septate, congo red (+) hyphae with clamp connections (Figure 2H); hyphal granules present in intermitted hyphae but not prominent like that of the stipe. Endoperidium is composed of a hyaline gelatinous matrix, with (i) intermittent hyaline branched, septate hyphae, branches arising near the septum, clamp connections present, hyphal granules absent (Figure 2J), (ii) capillitial threads translucent 3D4-4D4 in color, filamentous, with elongated-curved to elliptical cells 11.30-25.91 µm long × 4.47-4.71 µm broad (Figure 2K). Stipe hyphae are composed of a hyaline gelatinous matrix, with intermittent 3.53-4.71 µm broad, branched hyphae, septate with clamp connections, and brownish granular content (incrustations), septa few, many intermittent hyphae connected in 'H' shape (Figure 2I). Basidiospores (Figure 2L-P) whitish in mass, basidiospore dimension (without ornamentation) (8.54) 9.16-14.48 (16.64) µm × (8.48) 8.81-13.36 (16.33) µm, L_{mean} = 11.73±1.50 µm, B_{mean} = 11.38±1.39 µm, Q = (1) 1.01-1.09 (1.10), Q_{av} = 1.03±0.03, globose to partly subglobose, aguttulate, inamyloid, hyaline to partly refractive in KOH, cyanophilous with Cresyl Blue, metachromatic reaction absent, spore wall more congophilous than ornamentation. Spore ornamentation warty, warts mostly pyramidal, (0.73) 1.01-4.06 (4.22) µm high, mean ornamentation height = 2.88±1 µm, made of 18-30 hyaline longitudinal strands (coremium) arising from spore wall, conjoint at apex, apex obtuse, the base of warts nearly ovate. Spore wall thick when immature, spore wall thickness = (0.46) 0.57-1.69 (1.76) µm, mean spore wall thickness = 1.17±0.34 µm, a wall with the uneven inner wall when a spore is immature and even in mature spores.

Known distribution

Nepal, India, S.E. China, Bhutan, Java, Taiwan, Japan, East Indies (Balfour-Browne 1955; Chen and Yeh 1975; Massee 1888; Miller and Cotter 1988; Das 2009).

Material examined

India, West Bengal, Kalimpong District, Neora Valley National Park, Upper Neora Range, Towards Alubari, 27.10545º N and 88.71894º E, elevation 2446 m., Basidiocarps ectomycorrhizal, growing solitary-caespitosely at the floor of a mixed stand of *Quercus lineata* Blume and *Quercus lamellosa* Sm., 12 March 2021, S. Majumdar, P. Pradhan, B.S. Rai, A. Rai, (Calcutta University Herbarium, CUH AM728).

Figure 1. Fruitbodies of *Calostoma junghuhnii* recorded from Neora Valley National Park, India

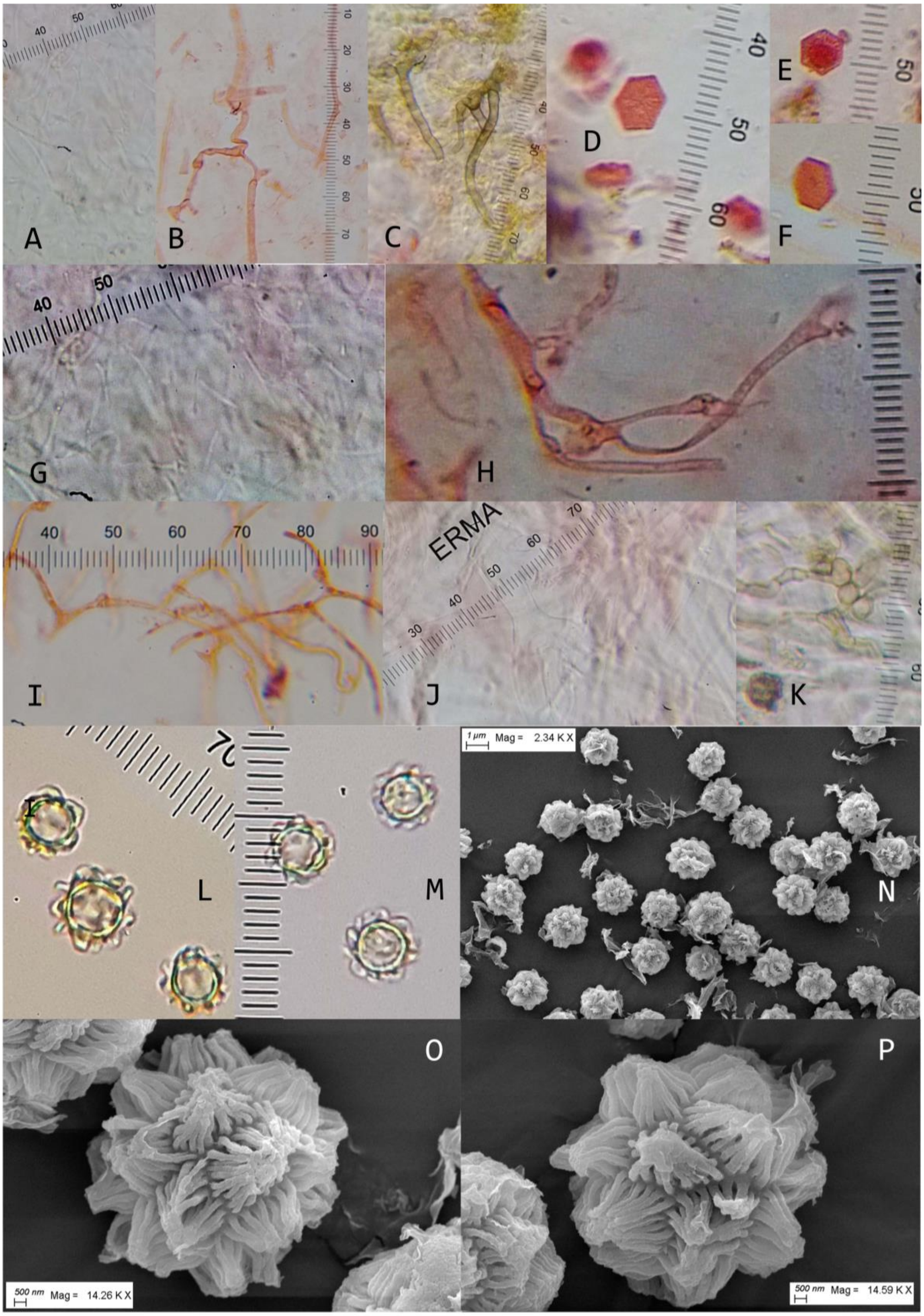

Figure 2. *Calostoma junghuhnii*. Warts (A & B): A = hyaline gelatinous hyphae, B = slender, filamentous, branched hyphae; Ostiole (C-F): C = hyaline, branched hyphae in gelatinous matrix, D,E,F = hexagonal #de8877 - #9c161d coloured cells; Exoperidium (G & H): G = Hyaline gelatinous matrix of exoperidium, H = branched hyphae of exoperidium with clamp connections; Stipe (I): I = branched incrustation hyphae on gelatinous matrix with clamp connections; Endoperidium (J & K): J = Hyaline cells of endoperidium, K = Capillitial threads; Basidiospores (L-P): L-M = micrographs of basidiospores from light microscope; N-P = micrographs of basidiospores from Scanning Electron Microscope. Scale Bar One Optical Division (A-M) = 2.355 µm; Scale Bar (N) = 1 µm; Scale Bar (O-P) = 500 nm

Discussion

West Bengal is an Indian state possessing diverse phytogeographical realms, spreading through its Coastal, Lateritic, Gangetic, and Terai-dooars to Eastern Himalayan montane-subalpine regions. These wide arrays of geomorphology, climatic variations, and vegetation structure make luxuriant conditions for the thriving of a mosaic of life forms, including macrofungi (Pradhan et al. 2012, 2013, 2016; Dutta et al., 2013). Some notable gastroid macrofungi reported from West Bengal are *Calvatia cyathiformis* (Bosc) Morgan, *Lycoperdon perlatum* Pers., *L. pyriforme* Willd., *L. pratense* Pers., *Tulostoma chudaei* Pat from the family Agaricaceae; *Astraeus hygrometricus* (Pers.) Morgan from the family Diplocystaceae; *Geastrum triplex* Jungh. and *G. saccatum* Fr. from the family Geastraceae; *Pisolithus arrhizus* (Scop.) Rauschert, *Scleroderma cepa* Pers. and *S. macrorhizon* Wallr. from Sclerodermataceae; however, there was no earlier record from the family Calostomataceae in West Bengal, India (Pradhan et al. 2011, 2012; Chakraborty et al. 2012, 2013; Dutta et al. 2013; Roy et al. 2014). Among the gastroid macrofungi of West Bengal, the notable ectomycorrhizal partner of *Shorea robusta* Gaertn. (Dipterocarpaceae) forests are *A. hygrometricus*, while *P. arrhizus* is associated with the plantations of *Eucalyptus globulus* Labill. (Myrtaceae) and *Acacia auriculiformis* Benth. (Fabaceae) (Pradhan et al. 2013).

Genus *Calostoma* was established by Desvaux in 1809 and had priority over the synonym *Mitremyces* Nees 1817 (Baseia et al. 2006). *Calostoma* is characterized by typically gelatinous cord-like stipe (pseudo-stipe) and peridium with apical Ostiole. Based on spore morphology, Massee (1888) provisionally grouped *Calostoma* into the western world species with elliptical-oblong spores and the eastern world species with spherical (globose to sub-globose) spores. However, the idea of this artificial segregation of *Calostoma* into western world species and eastern world species has been doubted, as *Calostoma lutescens* (Schwein.) Burnap, a globose-spored species, was reported from the U.S. (Burnap 1897) and as well from Sri Lanka (Massee 1888), while, *Calostoma ravenelii* (Berk.) Massee (Western world species) and *Calostoma japonicum* Henn., both of which have elliptical-oblong spores were reported from Japan (Minakata 1903); further, very recently broadly ellipsoidal *Calostoma sinocinnabarinum* N.K. Zeng, Chang Xu & Zhi Q. Liang was discovered in Central and Eastern China (Xu et al. 2022).

In the Indian sub-continent, the reported species of *Calostoma* are *C. junghuhnii* (Nepal; Bhutan; Sikkim; West Bengal [*from the present study*]), *Calostoma viride* (Berk.) Massee (West Bengal [from Tonglu and Sinchel]); and *C. lutescens*, *C. berkeleyi* Massee, *C. insigne* (Berk.) Massee in Sri Lanka (Massee 1888). The *C. junghuhnii* has been known in the Himalayan region since 1854 (Berkeley 1854), and the first color photograph of *C. junghuhnii* from the Himalayan region (Nepal) was taken by Prof. Hiroshi Hara during the Himalayan Botanical Expedition conducted by the University of Tokyo during 1960 and 1963 (Kobayasi 1965). One striking specimen from Prof. H. Hara's collections from Sikkim was *C. junghuhnii* (collected from Chola 1828.8-2438.4 m), and Kobayasi (1965), during the study of the specimen, mentioned it to appear close to the Kuchibenitake (*C. japonicum*). However, the spores of the sample from Sikkim were found to be spherical rather than ellipsoid, as in Kuchibenitake. The *C. junghuhnii* is distinguished from all other species in the genus by its distinctive exoperidial warts, bright orange-red ostiole/stoma with convergent, pointed teeth, and bluntly warted/tuberculose, globose spores that are 12.5-18 µm in diameter (Massee 1888; Miller and Cotter 1988).

The *C. viride* is a dull green species reported from the Tonglo and Sinchel areas of Darjeeling, which was collected by Sir J.D. Hooker and studied by Berkeley (Massee 1888). Perhaps it is endemic and very rare. The Stark dull green color of the fruit body makes *C. viride* different from *C. junghuhnii*. The *C. lutescens* is similar to *C. junghuhnii* regarding ochraceous exoperidium and globose spores. However, the latter has somewhat larger coarsely tuberculose spores with cinnamon-brown endoperidium and mostly intact exoperidium. In comparison, the former has smaller verrucose spores (7-9 µm), which resemble pitted under Scanning Electron Microscope with yellowish endoperidium and form a collar-like base at maturity due to the separation of exoperidium from endoperidium (Castro-Mendoza et al. 1983). The globose spores of *C. berkeleyi* are minutely verruculose and smaller (7-9 µm) than that of *C. junghuhnii*, which has tuberculate globose spores; further, *C. insigne*, though having creamy white fruitbody and globose spores of the size 14-17 µm, rather have coarsely spinulose spores instead of tuberculose spores (Massee 1888).

Phylogenetically some studies have placed *C. junghuhnii* close to other Asian species like *Calostoma areolatum* Y.H. Ma, B. Zhang & Y. Li, *Calostoma oriruber* Massee [as *'orirubra'*] and *C. sarasinii* Lim (Wilson et al. 2012; Phosri et al. 2014; Liu et al. 2018). Spores of *C. areolatum* are larger (15.5-18.2 µm), and irregularly verruculose separates it from *C. junghuhnii*. The *C. junghuhnii* is close to *C. orirubra* for spore size (14-17~18 µm) and the exoperidium breaking into areas and drying more or less as scales on the endoperidium; however, the former has pale ochraceous exoperidium with a greenish tinge, while exoperidium of the latter is brown (Massee 1888). The spores of *C. junghuhnii* are non-truncate, and exoperidium is pale ochraceous, while *C. sarasinii* spores are partially truncated (Boedjin 1938; Lim 1969), and the exoperidium surface is creamy in color (Wilson and Hibbet 2006).

Habitat-wise, the altitudinal range of *C. junghuhnii* varies from 2380 m in Chipling, Nuwakot District Nepal (Miller and Cotter 1988); 2438.4 m in Sikkim (Massee 1888); 2446 m in the present study; 2500 m in S.E. Tibet (Balfour-Browne 1955); ca. 2700 m in Halhale, Nepal (Kobayasi 1965) and 3000 m in Bakkhim, Sikkim (Kobayasi 1965). It prefers the damp soil of montane dense primary forests mainly composed of hardwoods (Chen and Yeh 1975). In the Central Himalaya (Bagmati Zone, Nuwakot District, Nepal), *C. junghuhnii* is reported to be associated with *Quercus semecarpifolia* Sm. (Miller and Cotter 1988). In Eastern Himalaya (Sikkim), it is reported to be associated with *Lithocarpus* (Das 2009), while from the present study in Neora Valley National Park, India, it is known to be associated with a mixed stand of *Q. lineata* and *Q. lamellosa*.

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Vegetation structure and carbon stock potential in the community-managed forest of the Mid-Western Hilly Region, Nepal

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Abstract. *Rawal K, Subedi PB. 2022. Vegetation structure and carbon stock potential in the community-managed forest of the Mid-Western Hilly Region, Nepal. Asian J For 6: 15-21.* Community forests (CF) play a crucial role in sustainable development and accumulate carbon to mitigate global climate change. The objective of this study was to evaluate the plant diversity, regeneration status, and carbon stock potential of two community-managed *Shorea robusta*-dominated forests in Nepal's Dailekh District, namely Bayeldhunga Pahapu CF and Bayeldhunga CF. A total of 76 sample plots were studied using a systematic sampling intensity of 0.5%. The density of species in the developmental phase was used to determine the forest's regeneration condition. Allometric equations were used to calculate the aboveground carbon store of tree species. *Shorea robusta* Gaertn. was the foremost species regarding regeneration and carbon storage in the studied forest areas, with high regeneration conditions. The seedlings, saplings, and trees in the Bayeldhunga Pahapu CF exceeded those in the Bayeldhunga CF. In both study areas, J-shaped reverse population curves were observed. This study provided details on tree species' regeneration condition, structure, proportions, and carbon sequestration capacity, which is critical for community forest management and conservation. The analysis showed that by altering the structure and proportions of community forests, community management has boosted the carbon storage of forests and enhanced forest productivity.

Keywords: Allometric equation, carbon sequestration, population curve, regeneration structure

INTRODUCTION

Forest ecosystems play a vital role in the overall carbon cycle and climate change and trap and store a considerable quantity of carbon over time (Magar and Shrestha, 2015; Nugroho et al., 2022). Forests comprise around 31% of the world's terrestrial surface and are projected to store 289 Gt of carbon biomass (FAO 2010), greater than the quantity of carbon in the atmosphere. However, between 2005 and 2010, the tropical forest experienced a worldwide reduction in its area, with an annualized rate of 0.5 Gt of carbon reserves in forest biomass (FAO 2010). Furthermore, in the 1990s, deforestation, recognized as a key source of biological diversity loss, contributed around 5.8 GtCO2/year to world greenhouse gas emissions (Karousakis 2007). Thus, today's forest ecosystem has the challenge of devising effective strategies and techniques for enhancing forest regeneration conditions and restoring abandoned areas (Chand et al., 2018). Deforestation prevention is, therefore, a generally acknowledged acceptable mitigation strategy for mitigating climate change in the short term (Karki et al. 2017), and it is gaining traction across scientific communities and carbon negotiation mechanisms like REDD+ (reduced emissions from deforestation and forest degradation).

Regeneration is an essential component for the existence and survival of species in a community. Research has shown the impact of the devolved management of forests in Nepal as a representative picture of forest regeneration and conservation (Sharma et al., 2020; Joshi, 2021). The existence of distinct age groups of seedlings, saplings, and trees characterizes a forest's regeneration and production capacity (Karki et al., 2017), which subsequently aids in understanding the state of tree communities, regeneration, and variety for conservation purposes (Chazdon et al. 2020). Environmental variables, soil quality, human pressures, and management techniques influence species regeneration. They may also be used to see if forest management results in increased productivity and the preservation of forest biodiversity (Joshi et al., 2019). The severity of management interventions differs in forest regeneration complexities and species composition, highlighting the importance of continuous inspection and assessment of silvicultural initiatives to facilitate optimal forest management on regeneration structure and composition, along with species diversity (Pathak et al. 2017).

Nepal is considered the pioneer country in designing and promoting Community Forest (CF) management strategy (Pandey et al. 2012), in which land is handed to Community Forest Users Groups (CFUGs). The decentralization of ownership of forest resources from the state to communities is portrayed in this management system, which symbolizes a paradigm change in Nepal's forestry industry (Karky and Skutsch 2010). Community forests have been reported to operate as a carbon sink, accumulating around 20% of Nepal's total carbon stored. Forest carbon storage and dynamics are particularly crucial, especially in developing countries such as Nepal. Nepal's forest contributes around 176.95 t/ha of carbon stock, with tree constituent accounting for 61.53%, forest soil accounting for 37.80%, and litter and detritus accounting for 0.67%. Carbon stock did not distinguish substantially based on species richness or litter cover, but it does tend to influence over management duration time (Joshi 2021). Beginning with establishing the REDD mechanism, the carbon sequestration capability of forests has been actively investigated and debated worldwide. Because community forestry is seen as a viable forest management initiative in Nepal, the governments and forestry-related non-governmental agencies want to include it in the REDD program (Chakma and Gautam 2019). That necessitates the assessment of the forest carbon stored in community forests. Quantifying carbon stock generates CF's carbon credit potential and assists CFUGs in understanding the role of CF in the earth's climate regulation, eventually motivating users to enhance forest management and conservation (Aryal et al., 2013). Therefore, we analyzed the regeneration condition of Nepalese community forests and their carbon-accumulation capacity, allowing us to understand better the impacts of forest management and silvicultural activities on the fundamental health and prosperity of the forests. Thus, this work uses a comparative study focused on two community-managed forests (CFs) in the Mid-Western Hilly area to address the mechanisms responsible for regeneration and carbon build-up, which is under-represented in the previous literature.

MATERIALS AND METHODS

Study area

The study area was Bayaldhungaa Pahapu (Ward no.9) and Bayaldhungaa (Ward no. 6) community forests (CF) of Aathbis municipality of Dailekh District, Nepal. Dailekh District is located in the Karnali Province of the hilly part of Nepal (28°50'15"N; 81°42'28"E) (Figure 1). The district's elevation is steep, ranging from upper tropical (544 m asl) to subalpine (up to 4168 m asl). The average annual rainfall is 185.07 mm, and the temperature ranges from 20 to 35ºC.

Bayaldhungaa Pahapu CF covers an area of 229.42 ha at 1600-2700 m asl, whereas Bayaldhungaa CF covers an area of 489.62 ha at 1600-2800 m asl. Therefore, according to the geographical condition and species composition, community forest user groups (CF manuals) partitioned the entire forest area into separate blocks. That way, Bayaldhungaa Pahapu CF was divided into three blocks and Bayaldhungaa CF into four blocks.

The study area has a natural forest where we can find broadleaved tree species. Both CF consists of a dominant natural species, Sal (*Shorea robusta* Gaertn.), and other associate species, such as Kafal (*Myrica esculenta* Buch.-Ham. ex D.Don) and Lali gurans (*Rhododendron arboreum* Sm.).

The field study was carried out during the dormant stage of the plant, i.e., the winter season (January-February 2021).

Forest sampling design and measurement

The community forests were mapped by using GPS and Arc Map 10.8 software. A sum of 76 rectangular sample plots (25 in Bayaldhunga Pahapu and 51 in Bayaldhunga CF), each of 500 m^2, were established using systematic sampling of the intensity of 0.5% in both community forests.

In every sample plot, four rectangular plots with measurements of 5m*2m, 5m*5m, 10m*10m, and 50m*10m were used for sampling seedlings (Height<1m), saplings (Height≥1m, DBH <10cm), poles (10cm≤DBH <30cm), and trees (DBH≥30cm), respectively. In addition, regenerations (seedlings and saplings) were recorded in the field (MoFSC 2010) to calculate density. For example, in a 12.62 m^2 plot, the height of every tree was recorded with a Silva clinometer, and the diameter at breast height (DBH) of every tree inside the sample plot was recorded with a diameter tape.

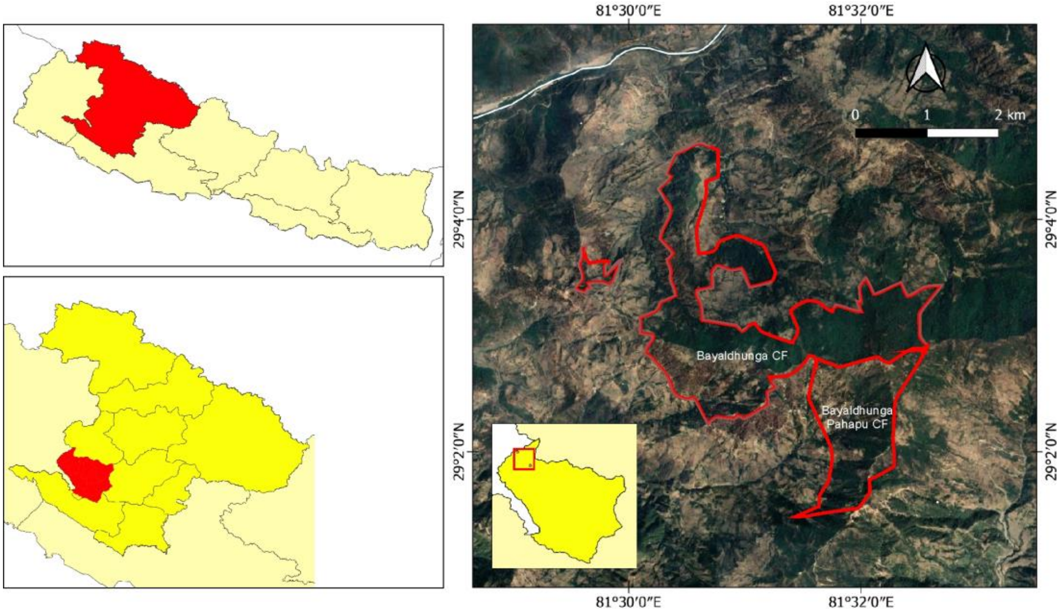

Figure 1. Map of the study area in the Dailekh District, Nepal

Quantitative analysis

Regeneration density

The number of total saplings and trees was calculated using the number of individuals gathered during the carbon stock inventory, with saplings described as those with a DBH of lesser than 10 cm and trees described as those with a DBH of greater than 10 cm (Måren et al. 2015; Chand et al. 2018). Individuals with DBH 1 cm (height within 15 cm and 137 cm) were called seedlings (Måren et al. 2015) and were assessed in 76 sample plots employing 2m*5m measurements. Finally, each sample plot's seedlings, saplings, poles, and trees were counted, and the final numbers were added, averaged, and noted for density calculations. The following equation was used to compute density:

$$Density\left(\frac{no}{ha}\right)=\frac{Total\ number\ of\ individuals\ in\ each\ life\ form}{Total\ no.of\ sample\ plots\ studied*area\ of\ each\ plot(m^2)}*10000$$

Similarly, the density of particular species was calculated by the given below equation:

$$Density\left(\frac{no}{ha}\right)=\frac{Total\ number\ of\ individuals\ of\ each\ species\ in\ each\ life\ form}{Total\ no.of\ plots\ studied*area\ of\ each\ plot(m^2)}*10000$$

Community attributes (Importance Value Index)

The density, frequency, and basal area of species of trees were estimated for quantitative analysis (Zobel et al. 1987). The Importance Value Index (IVI) notion was devised to convey any species' dominance and ecological accomplishment with a particular single value. It was computed to estimate the significance of every species in the plant communities by introducing additional relative values of the three variables: density, frequency, and basal area (Curtice 1959).

$$I.V.I = RD + RF + RBA$$

Where, I.V.I. = Importance Value Index, RD = Relative Density, RF = Relative Frequency, and RBA = Relative Basal Area.

Aboveground tree biomass and carbon estimation

A non-destructive approach was applied in this study to estimate biomass. The following allometric equation was used to compute the aboveground tree biomass (AGTB) (Chave et al. 2005).

$$AGTB = 0.0509 * D^2 * WD * H$$

Where, D = Tree diameter at breast height (cm), WD = Wood specific density (kgm^{-3}), H = Tree height (m) for trees (DBH $\geq$ 10 cm) (Chave et al. 2005).

Carbon stock of species

Individual tree species' summed carbon stocks in community forests were estimated by summing the overall density values of the entire forest for that particular species. Then, the proportionate amount of carbon stock for each ha of all species available in the forest was divided by the aggregate of carbon stock of a particular species in the same forest to calculate the percent proportion of carbon stock of particular tree species in a forest (Joshi and Singh 2020). The given equation calculated it:

$$Carbon\ stock\ of\ tree\ species\ \%=\frac{Sum\ of\ carbon\ stock\ of\ a\ particular\ tree\ species(ha)}{Sum\ of\ carbon\ stochk\ of\ all\ tree\ species(ha)}*100$$

Statistical analysis

To determine the significance of the differences among CFs, species, and related interactions, a two-way analysis of variance (ANOVA) test was used. The CF scale was used to quantify carbon stocks. In contrast, three analytical replications of each CF were used to quantify the species-wise net carbon stock among the similar variety in community forests. Replications were allocated randomly to generate an equal number of replications of both CFs, to solve a challenge with the uneven number of plots for species and CFs. SPSS software and Microsoft Excel (2010) were used for statistical analysis. The standard error (± SE) followed all the mean values.

RESULTS AND DISCUSSION

Quantitative analysis

Regeneration status of species in CF

Compared to Bayaldhunga CF, the regeneration condition of the Bayaldhunga Pahapu CF was significant. Bayaldhunga Pahapu CF had seedlings of 11 species from the 25 sample plots investigated, whereas Bayaldhunga CF had seedlings of 14 species from the 51 sample plots. In Bayaldhunga Pahapu CF, the maximum number of seedlings was *S. robusta*, followed by *Alnus nepalensis* D.Don, and *Pyrus pashia* Buch.-Ham. ex D.Don, and *Persea duthiei* (King ex Hook.fil.) Kosterm. Similarly, in Bayaldhunga CF, the maximum number of seedlings was *S. robusta*, followed by *P. duthiei*, *A. nepalensis*, and *Quercus semecarpifolia* Sm. In comparing both CFs, *S. robusta* was the most prominent in both the seedling and sapling stages. The total seedlings in Bayaldhunga Pahapu and Bayaldhunga CF were calculated to be 5,840 and 4,903 ind.ha^{-1}, respectively (Table 1). Similarly, the total sapling number was higher in Bayaldhunga Pahapu CF than in Bayaldhunga CF, calculating 1,712 and 1,412 ha^{-1}, respectively.

Therefore, Bayaldhunga Pahapu CF had a better regeneration condition than Bayaldhunga CF (Table 1). Similarly, Sal (*S. robusta*) seedlings and saplings were more consistent and abundant in the Bayaldhunga Pahapu community forest, which had a greater density and periodicity than the Bayaldhunga community forest. Therefore, it suggests that the dispersion of Sal (*S. robusta*) seedlings and saplings is consistent and that the forest composition and structure are unlikely to alter in the coming years.

DBH distributions

When comparing the two community forests, it was reported that Bayaldhunga CF contributed most of the trees' overall diameter categories (from DBH>10cm). In Bayaldhunga Pahapu and Bayaldhunga CFs, there were 47 and 88 individuals in the diameter class (10-20) cm, accordingly. On the other hand, trees with a diameter of more than 50 cm were the lowest represented in both CFs (Figure 2).

Forest structure

Seedlings had a higher density in saplings and trees across both CFs. The presence of large numbers of seedlings on the community understory indicates that the forest site has significant regeneration potential (Figure 3).

Community attributes (Importance Value Index)

From the entire sample plots of both community forests, 18 tree species were identified and documented. However, in Bayaldhunga Pahapu CF, 12 species with a total of 144 trees were identified and analyzed. Similarly, in Bayaldhunga CF, 16 tree species were identified and measured, totaling 278 trees. Hence, Bayaldhunga Pahapu CF had a greater tree density (355 ind.ha^{-1}) than Bayaldhunga CF (325 ind.ha^{-1}) (Table 2). The *S. robusta* was the most prominent tree species in the Bayaldhunga Pahapu and Bayaldhunga community forests, with IVI values of 101.30 and 90.35, respectively. *Aesculus indica* (Colebr. ex Cambess.) On the other hand, hook. (1.85) and *Quercus leucotrichophora* A.Camus (1.52) had the lowest IVI in Bayaldhunga Pahapu and Bayaldhunga community forests, respectively (Joshi et al. 2019).

Biomass and carbon estimation

Aboveground tree biomass (AGTB) and carbon stock

Mean AGTB and carbon stock in Bayaldhunga Pahapu CF were 126.69 t.ha^{-1} and 59.54611098 t.ha^{-1}, respectively. Similarly, the AGTB and carbon stock in Bayaldhunga CF were 110.3504368 ± 43.05 t.ha^{-1} and 51.8647053 t.ha^{-1}, respectively. Hence, net AGTB and carbon stock in Bayaldhunga Pahapu CF were higher than in Bayaldhunga CF (Figure 4). This result might be attributed due to the presence of large-sized trees, which have larger biomass content (Joshi and Singh 2020).

Contribution of tree species in carbon stock

In the case of the layer of the tree, *S. robusta* had the maximum carbon stock contribution to both community forests contributing 29.94301 t.ha^{-1} (50.28542%) in Bayaldhunga Pahapu CF and 38.95303 t.ha^{-1} (75.10508%) in Bayaldhunga CF. The *S. robusta* was followed by *Michelia champaca* L. (11.48415 t.ha^{-1}) and *A. nepalensis* (5.421748 t.ha^{-1}) in Bayaldhunga Pahapu and Bayaldhunga community forests (Table 3). The least carbon stock was calculated in *Juglans regia* L. (0.3631702784 t.ha^{-1}) and *Quercus lanata* Sm. (0.65669209152 t.ha^{-1}) of Bayaldhunga Pahapu and Bayaldhunga community forests. Some other tree species likewise represented a significantly larger percentage of carbon stock in both community forests (Table 3).

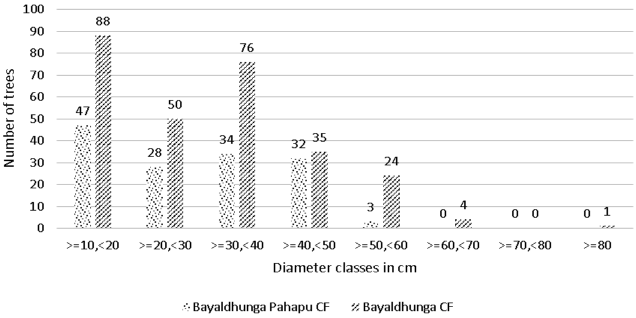

Figure 2. Distribution of DBH in Bayaldhunga Pahapu and Bayaldhunga CFs, Dailekh District, Nepal

Table 1. Overview of particular species seedlings and saplings regeneration status in Bayaldhunga Pahapu and Bayaldhunga CFs, Dailekh District, Nepal

Species	**Bayaldhunga Pahapu CF**				**Bayaldhunga CF**			
	Individuals ha^(-1)		**Proportion (%)**		**Individuals ha^(-1)**		**Proportion (%)**	
	Seedlings	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**	**Seedlings**	**Saplings**
Shorea robusta	1360	384	23.3677	22.42991	902	243	18.3969	17.20963
Alnus nepalensis	880	256	15.12027	14.95327	667	173	13.60392	12.25212
Persea duthiei	600	208	10.30928	12.14953	824	235	16.80604	16.64306
Michelia champaca	480	208	8.247423	12.14953	0	0	0	0
Pyrus pashia	640	144	10.99656	8.411215	196	47	3.997553	3.328612
Quercus semecarpifolia	520	160	8.934708	9.345794	510	133	10.40179	9.419263
Lyonia ovalifolia	520	160	8.934708	9.345794	216	47	4.405466	3.328612
Juglans regia	160	48	2.749141	2.803738	0	0	0	0
Daphniphyllum himalense	360	96	6.185567	5.607477	0	0	0	0
Aesculus indica	120	16	2.061856	0.934579	78	24	1.590863	1.699717
Quercus floribunda	200	32	3.436426	1.869159	176	71	3.589639	5.028329
Rhododendron arboreum	0	0	0	0	510	165	10.40179	11.68555
Brassaiopsis glomerulata	0	0	0	0	137	71	2.794208	5.028329
Persea odoratissima	0	0	0	0	157	39	3.202121	2.76204
Quercus lamellosa	0	0	0	0	137	31	2.794208	2.195467
Myrica esculenta	0	0	0	0	275	94	5.608811	6.657224
Ficus religiosa	0	0	0	0	118	39	2.40669	2.76204
Quercus lanata	0	0	0	0	0	0	0	0
Total	5840	1712	100.3436	100	4903	1412	100	100

The mean carbon stock of common species in both CFs ranged from 1.38 to 34.44 t.ha^{-1} (Table 4). The highest mean value was recorded in *S. robusta* (34.44 t.ha^{-1}), followed by *A. nepalensis* (6 t.ha^{-1}), *Q. semecarpifolia* (3.36 t.ha^{-1}), *M. esculenta* (2.915178 t.ha^{-1}), *Daphniphyllum himalense* (Benth.) Müll.Arg. (2.400733 t.ha^{-1}), and minimum in *Quercus floribunda* Lindl. ex A.Camus (1.38 t.ha^{-1}).

Table 2. Importance Value Index (IVI) of tree species

Species name	Bayaldhunga Pahapu CF	Bayaldhunga CF
Shorea robusta	101.05	94.3
Alnus nepalensis	62.09	46.91
Persea duthiei	18.05	37.35
Michelia champaca	21.31	0
Pyrus pashia	13.91	5.90
Quercus semecarpifolia	32.06	18.31
Lyonia ovalifolia	14.90	6.34
Juglans regia	5.59	0
Daphniphyllum himalense	11.22	5.08
Aesculus indica	1.85	5.38
Quercus floribunda	7.16	8.63
Rhododendron arboreum	0	23.46
Brassaiopsis glomerulata	0	6.40
Persea odoratissima	0	12.49
Quercus lamellosa	0	6.06
Myrica esculenta	10.74	15.72
Ficus religiosa	0	6.20
Quercus lanata	0	1.38

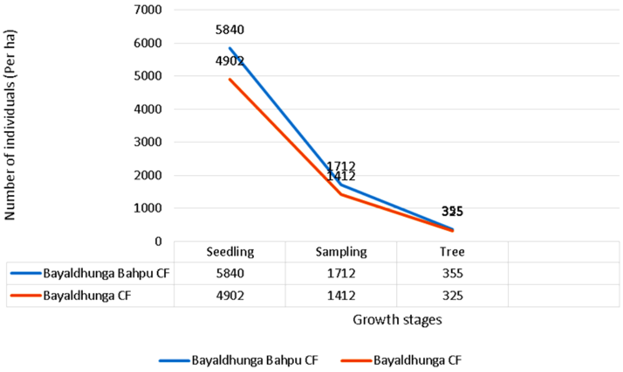

Figure 3. Inverse J-shaped curve indicating the immature condition of community forests

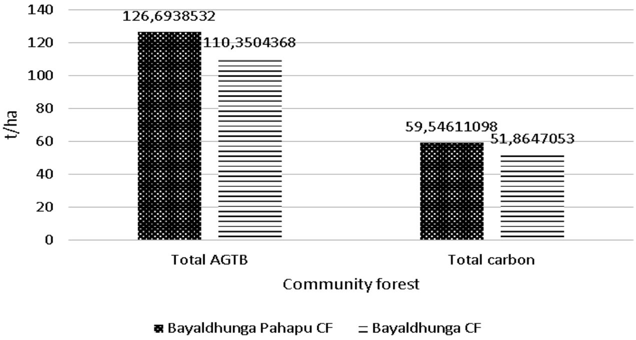

Figure 4. Total AGTB accumulation and carbon stock in Bayaldhunga Pahapu and Bayaldhunga CFs, Dailekh District, Nepal

Table 3. The percentage share of species contribution on carbon stock of Bayaldhunga Pahapu and Bayaldhunga CFs, Dailekh District, Nepal

Bayaldhunga Pahapu CF			Bayaldhunga CF		
Species name	**Carbon stock ta/ha**	**C (%)**	**Species name**	**Carbon stock ta/ha**	**C (%)**
Shorea robusta	29.94301	49.39274	*Shorea robusta*	38.95303	65.81616
Michelia champaca	11.48415	18.94376	*Alnus nepalensis*	5.421748	9.160741
Alnus nepalensis	6.584624	10.86172	*Persea duthiei*	2.329855	3.936589
Quercus semecarpifolia	5.821574	9.603024	*Myrica esculenta*	2.118139	3.578869
Myrica esculenta	3.712218	6.123519	*Rhododendron arboreum*	1.968236	3.325588
Quercus floribunda	1.637367	2.700931	*Persea odoratissima*	1.882466	3.180669
Daphniphyllum himalense	0.793708	1.309267	*Daphniphyllum himalense*	1.462981	2.471895
Juglans regia	0.36317	0.59907	*Quercus floribunda*	1.131694	1.912143
Lyonia ovalifolia	0.282483	0.465972	*Quercus semecarpifolia*	0.906719	1.532018
			Aesculus indica	0.708447	1.197012
			Quercus lamellosa	0.6694	1.131038
			Quercus lanata	0.656692	1.109566
			Ficus religiosa	0.552334	0.93324
			Brassaiopsis glomerulata	0.422855	0.714468
Total	60.6223	100	Total	59.1846	99.99999

Table 4. Mean carbon stock by common species in Bayaldhunga Pahapu and Bayaldhunga CFs, Dailekh District, Nepal

Common species	Bayaldhunga Pahapu CF	Bayaldhunga CF	Mean
Shorea robusta	29.94301257	38.95303	34.44802
Alnus nepalensis	6.584623888	5.421748	6.003186
Quercus semecarpifolia	5.821574226	0.906719	3.364146
Myrica esculenta	3.71221787	2.118139	2.915178
Quercus floribunda	1.637366674	1.131694	1.38453
Daphniphyllum himalense	1.68873984	3.112726	2.400733
Mean	8.231255844	8.607343	

Table 5. Two-way ANOVA test between the common tree species of Bayaldhunga Pahapu and Bayaldhunga CFs, Dailekh District, Nepal

Source of variation	SS	Df	MS	F	P-value	F crit
Species	1683.11597	5	336.62319	30.725751	0.00092607	5.05032906
CF	0.18795277	1	0.1879528	0.0171557	0.90089835	6.60789097
Error	54.7786773	5	10.955735			
Total	1738.0826	11				

Note: Where,* $p< 0.05$ is considered statistically significant. Total species-wise carbon stock in both Bayaldhunga Pahapu CF and Bayaldhunga CF statistically showed a significant difference in the total quantity of carbon storage in both community forests (p 0.05)

Discussion

Regeneration and other attributes

Compared to Bayaldhunga CF, the number of total seedlings, saplings, and tree density was greater in Bayaldhunga Pahapu CF. That is because the canopy cover and ground vegetation cover of Bayaldhunga Pahapu CF were greater than Bayaldhunga CF. Sal (*S. robusta*) has dominated both community forests' seedling and sapling layers. The higher density of Sal species (seedlings and saplings) may be attributed to the impact of low canopy cover in community forests, which enabled ample sunlight to reach the understory and generated an environment suitable for the plentiful establishment of Sal species seedlings and saplings (Joshi and Singh 2020). The regeneration capacity of light-demanding species like Sal is assisted by a large canopy gap proportion (low canopy cover) (Sapkota et al. 2009). Therefore, the number and density of seedlings and saplings reflect a CF's regenerating ability (Pallardy 2010). In both community forests, the total number of individuals declined from the early regeneration period to the later development phases.

The current study on forest regeneration conditions indicates a trend comparable to that of Kandel (2007). The entire chart was inverse J-shaped, indicating the community forests' juvenile condition (Chauhan et al. 2008) and also indicative of sustainable regeneration (Acharya et al. 2015) (See Figure 3).

Community attributes

The *S. robusta* has the highest Importance Value Index (IVI) in both Bayeldhunga Pahapu and Bayeldhunga CFs, with values of 101.30, and 90.34, respectively. A species' high IVI value indicated dominance, ecological success, good regeneration power, and higher ecological intensity (Shameem and Kangroo 2011), implying that S. robusta was the most significant and dominating tree species across both communities' forests. As a result of significant forest deterioration or disturbance activities, historically dominating species like *S. robusta* with the other companion species as a dominant characters during their recruitment stage have vanished (Onaindia et al. 2004).

Sal forest and carbon stock

The carbon sequestration of trees fluctuates with the forest's successional stage, and its capacity is determined by the forest type, age, tree size, density, and stand quality (Joshi and Singh 2020). The carbon absorbed by plants is deposited as biomass as the age of the forest increases.

Many trees surveyed in community forests had a DBH of less than 20 cm. Thus, if forests are well-stocked, trees store carbon at a significant rate between of ages of 10, 20, and 30, according to Johnson and Coburn (2010). For example, at the age of 30 years, forests with productivity ranging from extremely low to high typically store 200-520 tons of carbon dioxide (CO_2). So, the community forests analyzed may have the ability to sequester more carbon. Carbon sequestration is influenced by the yearly growth rate of forests, which is positively related to age. Because mature trees grow slower than new trees, aged forests with more than mature stands have a large carbon store but a poor carbon sequestration rate. Among the community forests investigated, Bayaldhunga Pahapu CF had a greater tree biomass stock than Bayaldhunga CF. The aboveground tree biomass and carbon stock in Bayaldhunga Pahapu CF were 126.69 $t.ha^{-1}$ and 59.546 $t.ha^{-1}$, respectively, which was higher than in Bayaldhunga CF (biomass 119.34 $t.ha^{-1}$, and carbon 51.86 $t.ha^{-1}$, respectively). The FRA report 2014 indicates that the sum of carbon stock from the forest of the Terai region is 89.18 $t.ha^{-1}$; Sal was the biggest provider of carbon stock in the tree layer with 49.392% (29.943 $t.ha^{-1}$), and 65.816% (38.953 $t.ha^{-1}$) in both Bayaldhunga Pahapu and Bayaldhunga CFs, respectively, according to our study. Sal species contributed 95% and 86% of carbon stock in both study areas, respectively, following the trends seen in Gorkha's Sal-dominated two CFs, where Sal contributed 95% and 86% of C-stock (Neupane and Sharma 2014).

In conclusion, the carbon storage of forests increased as the tenure of sustainable forest management increased. In contrast, the density of seedlings, saplings, as well as trees in the analyzed CFs was in the sequence seedlings > saplings > trees. As a result, the concept that community-managed forest biomass C-stock grows with management tenure and community-managed forests exhibit strong regeneration status has been accepted. Bayaldhunga Pahapu CF had more seedlings, saplings, and trees than Bayaldhunga community forests. Sal seedlings and saplings had a higher total number (density) than other related species in both Community Forests. The *S. robusta* was the most common species, contributing significantly to both community forests' carbon stocks (49.392% in Bayaldhunga Pahapu CF and 65.816% in Bayaldhunga CF). Other species, such as *M. champaca, A. nepalensis, Q. semecarpifolia,* and *M. esculenta,* made substantial contributions. Community forest management had a beneficial impact on forest regeneration and carbon stock, indicating that carbon capture and storage have a favorable effect on biodiversity, which leads to increased forest productivity. Both community forests, however, require extra steps to increase tree richness. Thus, this study strongly promotes implementing sustainable management approaches, such as those employed in management and conservation. These community-managed forests should also be evaluated for participation in the REDD+ system to benefit from carbon credits, which will help to improve forest conditions and local livelihoods.

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Tree diversity and vegetation structure of the tropical evergreen forests of the southern slopes of Meghalaya, North East India

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Abstract. *Tynsong H, Dkhar M, Tiwari BK. 2022. Tree diversity and vegetation structure of the tropical evergreen forests of the southern slopes of Meghalaya, North East India. Asian J For 6: 22-33.* In the tropical evergreen forests of the southern slopes of Meghalaya, North East India, we examined the plant species diversity and community structure of woody plant species. The forests chosen for this study represent the area's primary vegetation. We counted a total number of 6016 individual trees belonging to 146 species, 95 genera, and 56 families from three 1-ha plots. The Shannon-Wiener Index (H') of the tree species in the three forest stands ranged from 3.74 to 3.95, the dominance of Simpson's index from 0.02 to 0.04, the evenness index from 0.68 to 0.83, and Margalef index range from 23.07 to 27.39. The density of woody species ranged from 1944 to 2100 trees ha^{-1} (mean 2005 ± 48.01). The dominant families based on Importance Value Index (IVI), number of species, genera and individuals were Fagaceae (IVI = 205.29, species= 11, genera= 4 and number of individuals= 1184), Lauraceae (IVI = 139.42, species= 22, genera= 9 and Individual= 882) and Euphorbiaceae (IVI = 68.39, species= 17, genera= 8 and Individual=478). Arecaceae represented by *Arenga pinnata* (Wurmb) Merr. and *Caryota* sp. and Pandanaceae, represented by *Pandanus odoratissimus* Blume, were the only monocot families, and Pinaceae, the sole gymnospermic family, represented by *Pinus kesiya* Royle ex Gordon. This study offers valuable knowledge about the species diversity and community structure of trees which is a prerequisite for efficient management and protection of the forests conserved by the local village communities primarily for ecosystem services.

Keywords: Diversity, species richness, tropical evergreen forests, village community forests

INTRODUCTION

The tropical forests cover an area of over seven percent of the total land surface (Gentry 1982; Richards 1996) and are often referred to be one of the highest species-rich terrestrial ecosystems harboring an enormous portion of the earth's biodiversity (Apguaua et al. 2015; Gandiwa et al. 2016). However, worldwide most tropical forests are highly threatened by anthropogenic activities (Curran et al. 2004; Sahu et al. 2010; Majumdar and Datta 2015). Large patches of forests are being deforested each year, resulting in rapid loss of biodiversity at an accelerated rate that may eventually end in the collapse of some ecosystems (Kharkwal et al., 2005; Panda et al., 2013; Mutiso et al., 2015). It is estimated that 177,000 km^2 of forests and woodlands are cleared annually to form space for farming or to reap timber trees for fuel and wood products and also believed that the earth has lost about half of its forests in 8,000 years and over 3% of forests have been clear-felled since the 1990s alone (WWF 2017). The natural forests are being converted into plantation forests, mainly timber, to meet the ever-increasing human population's needs (Pandey and Shukla 1999). The present generation largely depends on managed forests for wild plant resources, as few natural forests are left (Bhuyan et al. 2003).

Forest is an association of plants dominated by trees of various sizes and other components, such as shrubs and herbs, which occupy different strata (Zhang et al., 2017). The tree diversity determines the biodiversity of a forest as all resources, as well as habitats for almost all other forest plants, are provided by trees (Li et al. 2003 Armenteras et al. 2009; Neumann and Starlinger 2001). In forest ecosystems, the tree species diversity greatly varies from place to place, mainly because of variations in geographic space, geological time, surrounding ecosystems, and disturbance (Whitmore 1998; Sundarapandian and Karoor 2013). Vegetation analysis of the forest ecosystem helps ecologists/conservationists to understand the community structure (Sahu et al. 2019) and the regeneration potential of the species, which are useful in forest management, species conservation (Borogayary et al. 2017), and ecosystem services (Palit et al. 2012). Furthermore, understanding forest dynamics will help conserve the species composition, reduce financial inputs and control the growth, composition/structure, and quality of the forests (Bhat et al. 2000), and conserve plant diversity (Murali et al. 1996). Species diversity is a crucial component of forest ecosystems because it reflects the general health of a specific forest and provides useful information for conserving trees, shrubs, herbs, and other organisms within the forest ecosystem (Roy et al., 2004; Sharma and Kant, 2014).

Eastern Himalayas and Northeast India's forests are rich in plant species and estimated to harbor about 5000 endemic species (Olson et al. 1998). According to Takhtajan (1988), the region is the center of origin of some angiosperms. Meghalaya, a constituent of the Indo-Burma biodiversity hot spot, harbors 3128 species of angiosperms, including 1237 endemic species and fifty-three vulnerable plant species (Khan et al. 1997). The species richness of tropical forests in the Eastern Himalayas and Northeast India was first investigated by taxonomists like Hooker (1872-1897), Kanjilal et al. (1934-1940), Rao and Panigrahi (1961), Rao (1977), and Balakrishnan (1981-1983). Lately, several researchers like Rao et al. (1990), Bhuyan et al. (2003), Saikia et al. (2017), and others have also carried out various studies to understand the ecology of the forest communities and also to quantify plant diversity in the region. The biodiversity of the natural forests of Meghalaya has been studied by workers like Upadhaya et al. (2003), Jamir and Pandey (2003), Tripathi et al. (2006), Jamir et al. (2006), Kumar et al. (2006), Lakadong and Barik (2006), Tynsong (2009), Tynsong and Tiwari (2011) and Tripathi and Shanker (2014). Meghalaya has six principal forest types viz., tropical evergreen forest, tropical moist mixed deciduous forest, Sal forest, subtropical pine forest, sub-tropical mixed broadleaved forest, and sub-tropical oak-dominated forest (Tripathi and Shanker 2014). Through literature reviews, we found out that there is still a lack of research on the plant diversity of the tropical evergreen forest of Meghalaya. The objective of this study was to inventory the tree diversity and community structure of tropical evergreen forests of southern Meghalaya, which is necessary for the management and protection of the local Village Community Forests.

MATERIALS AND METHODS

Study area

The State of Meghalaya, India, lies between 24°02′ and 26°07′ N latitude and 89°48′ and 92°51′ E longitude, with a total geographic area of 22429 km^2 and an altitude ranging from 100 to 1965 m above sea level. It's bordered on the North-West, North, and East by Assam, while Bangladesh borders the South and South-West. The forests within the state of Meghalaya are broadly grouped into (i) government-managed forests comprising reserve forests, national parks, and wildlife sanctuaries controlled and managed by, and subject to, Indian union or state laws and (ii) Autonomous District Council forests which include what locally named as *Law Shnong* (village forest), *Law Adong* (restricted village forest), *Law Kyntang* (sacred forest), *Law Ri-Sumar* (private forest on community land), *Law Ri-Kynti* (private forest on private land), *Law Raid* (forests belonging to a bunch of villages) and *Law Kur* (clan forest) (Tiwari et al. 2010). The forests controlled and managed by the government are barely 1112 km^2 area or 12% of the recorded forest area, and the remaining 88% of the forest in the state (8372 km^2) is managed by the three Autonomous District Councils of the state (Tiwari et al. 2010).

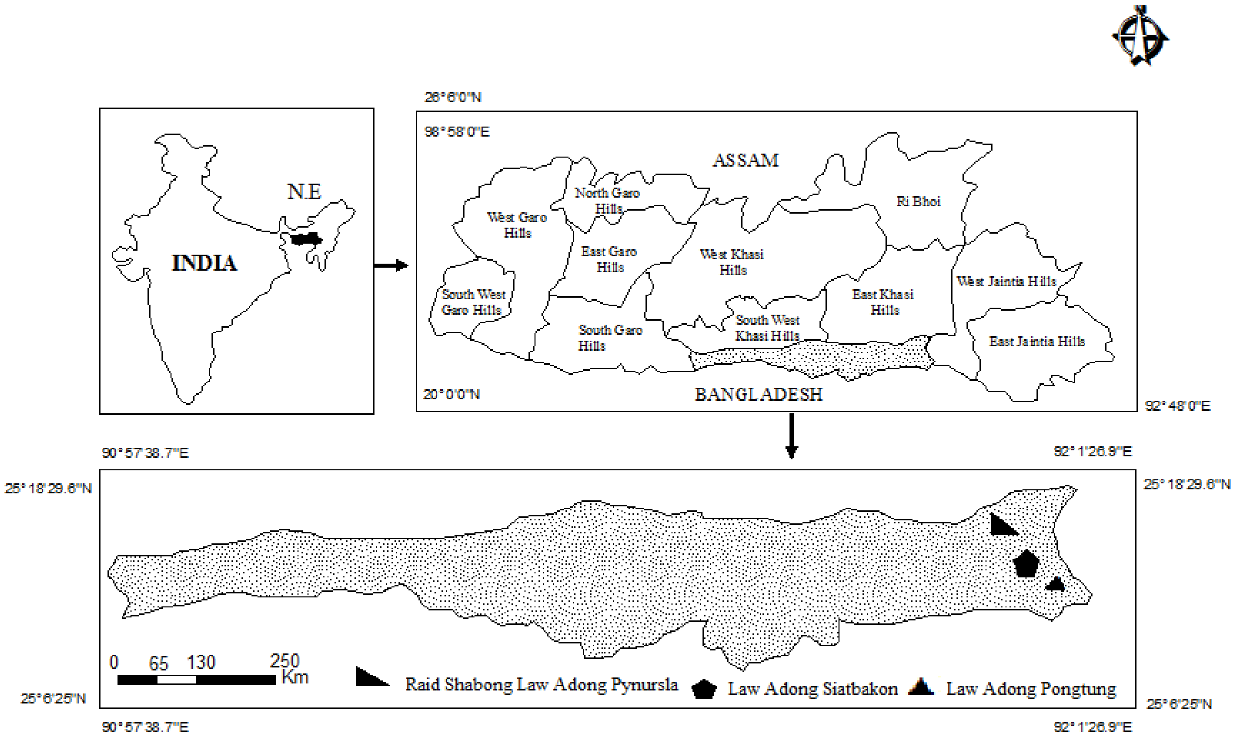

Figure 1. Location of the study area in Meghalaya, India

The plant diversity survey was conducted in the three natural forests (Village Community Forests) with mature stands viz., Raid Shabong Law Adong Pynursla (RSLP), Law Adong Siatbakon (LAS), and Law Adong Pongtung (LAP) of southern slopes of Meghalaya, North East India (Figure 1). The RSLP is located in Pynursla Village (latitude 25018' N, longitude 91054' E, altitude 1200 m asl), LAS in Siatbakon village (latitude $25^0$16' N, longitude $91^0$56' E, altitude 1003 m asl) and LAP in Pongtung Village (latitude 25014' N, longitude 91057' E, altitude 776.1m asl). All three forests are affected by human interference, such as encroachment for house construction and the widening of existing roads.

The mean annual maximum and minimum temperatures of south Meghalaya are 23ºC and 13ºC, respectively, and the mean annual rainfall is 11565 mm (Tynsong and Tiwari 2010). Southern Meghalaya is rugged and undulating hilly terrain, and the slope angle varies between 10º and 40º (Tynsong et al. 2018). The region has many rivers and rivulets, which drain into the plains of Bangladesh (Tynsong and Tiwari 2010). At times, narrow and deep river valleys separate one hill range from the other. As a result, the population density is sparse. Horticulture, cash crops (broom grass, betel leaf, and areca nut), and limited fisheries are the principal occupations of the people. Agriculture is restricted to some small valleys where mainly tuber crops are grown. The important products of the region include orange, betel leaf, betel nut, jackfruit, bay leaf, edible seed, honey, and broom grass (Tynsong et al., 2012). The War Khasi people inhabit the region, a tribal community with a long forest conservation tradition. People collect, process, and market a huge quantity of non-timber forest products (NTFPs) and medicinal and aromatic plants (MAPs) like *Piper peepuloides*, *Cinnamomum tamala*, *Phrynium capitatum*, bamboo, mushrooms, nuts, tubers, wild honey, worms, insects and wild fruits and leafy vegetables from the forests (Tynsong et al. 2012).

Data collection

Extensive field surveys were carried out for plant diversity studies, and data were collected once every season from January 2006 to October 2008. Species composition and vegetation structure of RSLP, LAS, and LAP were determined by randomly placing 100 quadrats per site of 10 m × 10 m for the tree (dbh ≥15 cm). The total sample area for each study site was 1 ha, as Sykes and Horrills (1977) suggested for the rugged and undulating hilly terrain. Tree species with >15 cm diameter at breast height (dbh) were individually counted, measured, and numbered in each plot (100 m^2 plot). The density and frequency of tree species per site per plot were also estimated. The height of stems of each tree species was recorded by rough estimation in all plots, and they were grouped into four height classes [Under-canopy (< 8 m height), Sub-canopy (8-15 m height), canopy (15-30 m height) and emergent (>30 m height)]. The representative species were collected and identified with the help of regional floras (Balakhrishnan 1981-1983; Kanjilal et al. 1934-1940). The herbaria specimens housed in the Botanical Survey of India, Eastern Circle, were consulted to confirm the identification. The nomenclature of the species follows the regional flora (Balakrishnan 1981-1983; Haridasan and Rao 1985-1987; Kanjilal et al. 1934-1940). The voucher specimens were processed following Jain and Rao (1976).

Data analysis

The frequency, density, basal cover, dominance, abundance, and importance value index (IVI) of the species were determined according to Misra (1968) and Mueller-Dombois and Ellenberg (1974). The individuals were allocated into six dbh classes: (i) 15-25 cm, (ii) 25-35 cm, (iii) 35-45 cm, (iv) 45-55 cm, (v) 55-65 cm and (vi) > 65 cm to understand the population structure of species in the area. The IVI of tree species was determined as the sum of relative frequency, relative density, and relative dominance (Curtis and McIntosh 1950). The data were also used to compute the community indices.

Diversity index (H')

The species diversity index was calculated following Shannon and Wiener (1963) by using equation (1):

$\mathbf{H'} = - \sum (pi)(lnpi)$ (Eq.1)

Where pi = ni/N, N is the total individuals of all species; ni is the number of species.

Dominance index (Cd)

The species dominance was calculated following the index by Simpson (1949) using equation (2):

$\mathbf{Cd} = \sum (ni/N)^2$ (Eq. 2)

Where, ni = number of individuals of ith species and N = total number of individuals of all the species.

Evenness index (E)

The equitability or evenness refers to the degree of the relative dominance of each species in that area. It was calculated according to Pielou (1975) by using equation (3):

$\mathbf{E}: {}^{-}\sum (ni/N) \log_e (ni/N)/ \log_e S$ (Eq. 3)

Where, ni = IVI of each species, N = total IVI, and S = number of species

Basal area (BA)

BA of each overstory tree was calculated using equation (4):

$\mathbf{BA} = \pi D_2$ (Eq. 4).

Where: BA: basal area (m^2ha^{-1}); D: diameter at breast height (cm); and π: pi (3.142)

Species richness index (R)

The species richness index was calculated following Margalef (1968) using equation (5):

$R=S_1/\log N$ (Eq. 5)

Where: S is the number of species and N is the number of individuals.

Whitford's index (W)

Whitford's index was calculated following Whitford (1948) to study the horizontal distribution pattern of species in the community using equation (6):

W= Abundance (A)/Frequency (F) (Eq. 6)

Where, A/F ratio = <0.025 signifies regular distribution, 0.025-0.05 random distribution and >0.05 clumped distribution

RESULTS AND DISCUSSION

Species richness and diversity

We counted a total number of 6,016 individual trees belonging to 146 species from a 3 ha area of 1 ha area in each plot (138 identified up to species level and 8 up to genus), 95 genera, and 56 families from three 1 ha plots within the tropical evergreen forests of southern Meghalaya. The species richness of the tree species within the three forest stands is given in Table 1. A total of 30 species (20.54%) were common species in all the forest stands, 31 species (21.23%) were found only in RSLP, 15 species (10.27%) only in LAS, and 24 species (16.44%) only in LAP. The similarity index between RSLP and LAS was 56.96%, RSLP and LAP 46.42%, and LAS and LAP was 50.98%. All the tree species encountered were native (Table S1). The diversity of the tree species within the three forest stands calculated using Shannon-Wiener Index (H') showed that the highest was in forest stand LAP (3.95) while there's a slight decrease in Shannon-Wiener Index (H') for LAS (3.87) and RSLP (3.74). The dominance of Simpson's index started from 0.02 (LAS and LAP) to 0.04 (RSLP). The evenness index was highest at stand LAS (0.83) and lowest at stand LAP (0.68), while the Margalef index was highest in stand RSLP (27.39) and lowest in stand LAS (23.07) (Table 1A).

Stratification

The three forest stands of southern Meghalaya showed three distinct layers viz., canopy layer composed of the huge tree (15-30 m height), sub-canopy composed of the middle-sized tree (8-15 m height), and under-canopy composed of small trees (<8 m height). The most common tree species within the canopy layer were *Betula alnoides, Engelhardtia spicata, Lithocarpus fenestratus*, *Syzygium tetragonum,* etc., sub-canopy composed of *Aglaia perviridis, Callicarpa vestita, Glochidion khasicum,* and *Styrax serrulatum* while under canopy composed of *Ardisia floribunda, Erythroxylum kunthianum,* and *Eurya acuminata*. Further, 35 (38.46%) in stand RSLP, 33 (43.42%) in LAS, and 28 (35.44%) in LAP species were canopy trees (≥15 m height). On the other hand, at sub-canopy layer 42 (46.15%) in stand RSLP, 31 (40.78%) in LAS, and 31 (39.24%) in LAP species (8-15 m height), and the rest were under-canopy trees (<8 m height) (Table 1B).

Frequency

Analysis of Raunkier's frequency classes revealed that 63-75% of the tree species in all the stands belonged to Raunkier's frequency class A, while the remainder were distributed in B, C, D, and E classes (Figure 2). The *S. tetragonum, Ficus* sp., *Garcinia spicata,* and *Castanopsis hystrix* in RSLP, *S. tetragonum, Sarcosperma griffithii, Lithocarpus elegans,* and *L. fenestratus* in LAS and *L. elegans, Quercus lanceofolia* and *Litsea elongata* in LAP were the foremost frequently found tree species within the three forest stands. All the tree species showed a contagious distribution pattern in all the forest stands.

Table 1. Composition, diversity, and community characteristics of tree species (dbh ≥15 cm) in 1 ha area of three different sites of southern Meghalaya, India

Variable	RSLP	LAS	LAP	Mean (±SD)
Community characteristic				
No. of species	93	77	79	83 (±5.03)
No. of genera	70	61	62	64 (±2.33)
No. of family	39	38	41	39 (±2.18)
Density (ha^{-1})	2100	1972	1944	2005 (±48.01)
Basal area (m^2/ha)	68.05	52.26	64.84	61.72 (±4.82)
Shannon	3.74	3.87	3.95	3.85 (±0.06)
Simpson	0.04	0.02	0.02	0.03 (±0.01)
Evenness	0.78	0.83	0.68	0.76 (±0.04)
Margalef	27.39	23.07	24.02	24.83 (±1.31)
Sampling size (ha)	1	1	1	1 (±0)
Stratification				
Emerging (> 30 m height)	0	0	0	0
Canopy (15 - 30 m height)	35	33	28	32 (±2.08)
Sub-canopy (8 - 15 m height)	42	31	31	35 (±3.66)
Under-canopy (< 8 m height)	16	13	20	16 (±2.40)

Note: RSLP: Raid Shabong Law Adong Pynursla, LAS: Law Adong Siatbakon, LAP: Law Adong Pongtung

Density and stand basal area

The mean stand density of three forest stands was 2005 (±48.01) individuals/ha. The highest stand density was observed in RSLP with 2,100 individuals/ha, whereas the lowest stand density was observed in LAP with 1944 individuals/ha (Table 1). In RSLP, *Ficus* sp. (196 stem/ha), *S. tetragonum* (194 stem/ha), and *C. hystrix* (136 stem/ha) had the highest density and accounted for 25.05% of tree density in this forest stand. In LAS, *L. fenestratus* (169 stem/ha), *L. elegans* (133 stem/ha), and *S. griffithii* (104 stem/ha) accounted for 20.58% of tree density. In LAP, *L. elegans* (131 stem/ha), *Machilus bombycina* (118 stem/ha), and *Wenderhardia tinctoria* (83 stem/ha) had the highest density and accounted for about 17.07%) (Table 2). The basal area recorded was highest in RSLP stand with 68.05 (m^2/ha), followed by LAP at 64.84 (m^2/ha) and lowest in LAS at 52.26 (m^2/ha) (Table 1A).

Size class distribution

The distribution of density in different dbh classes was 83.38% to 92.95% in the 15-25 cm dbh class, 4.86% to 14.40% in 25-35 cm dbh class, 0.33% to 0.96% in 35 to 45 cm dbh class, 0.61% to 1.13% in 45-55 cm dbh class, 0% to 0.56% in 55-65 cm dbh class and 0.61% to 1.86% in >66 cm dbh class. Tree species richness, as well as diversity, decreased with increasing girth classes (Figure 3). That shows that the regeneration rate was good and fresh recruits survived in good numbers. The number of species per unit area (density) within the community was examined by measuring some tree species in 100 m2 plots to check the distribution of species richness. The species density per 100 m2 ranged from 12-44 in the three forest stands. The species distribution in all three forest stands followed a normal distribution (Figure 4).

Species area curves

The species-area curves for LAS and LAP were very similar. After a gradual increase in the species number with an increase in area, they reached an asymptote at 0.6-0.7 ha for LAS and LAP, while RSLP reached an asymptote at 0.7-0.8 ha. About 60-70% of the species were found in a 0.5 ha area for LAS as well as LAP and in a 0.6 ha for RSLP, while 89-90% of the species were encountered in 0.7 to 0.8 ha for LAS and LAP, while RSLP at 0.8 ha (Figure 5). Plots of a cumulative number of tree species against sampling size (ha) showed that RSLP is slightly more diverse than LAS and LAP for a given sampling size.

Dominance and distribution pattern

The pattern of dominance distribution in all three forest stands was similar, with a standard log distribution pattern, signifying high equality and low dominance of species (Figure 6). In RSLP, *Oroxylum indicum* (IVI= 28.75) and *S. tetragonum* (IVI= 23.63), in LAS, *L. fenestratus* (IVI=40.66) and *L. elegans* (IVI= 30.80) and in LAP, *L. elegans* (IVI= 21.05) and *M. bombycina* (IVI= 17.98) were dominant and co-dominant species respectively (Table 2). In RSLP and LAP, all plant species (100%) and LAS (93.51%) in the forest had a contagious/clumped distribution pattern, with only a few species in LAS having random distribution. Higher contagious distribution revealed that the species were found in patches which were further supported by the frequency distribution pattern, with most species having a low frequency.

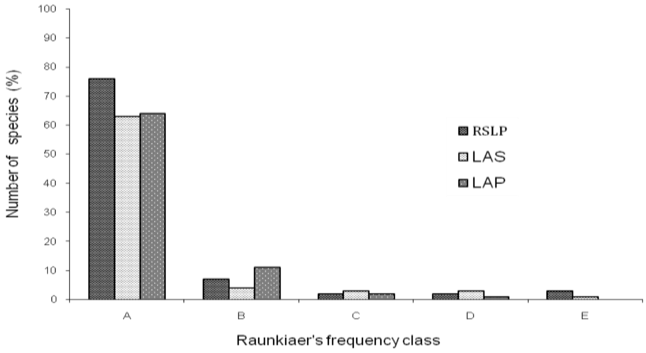

Figure 2. Distribution of tree species in the three forest stands of south Meghalaya, India (RSLP: Raid Shabong Law Adong Pynursla, LASI: LAW Adong Siatbakon, LAP: LAW Adong Pongtung)

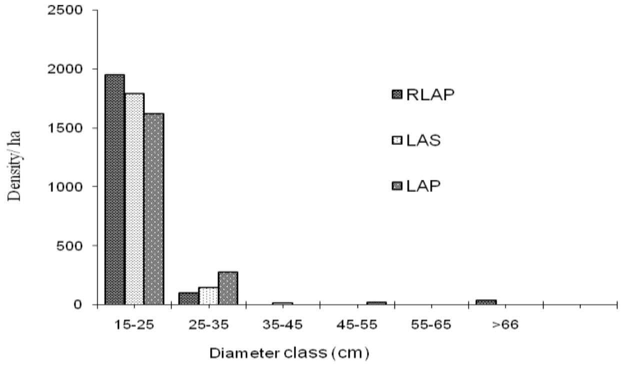

Figure 3. Density-diameter distribution of tree species in the three forest stands of south Meghalaya, India (RSLP: Raid Shabong Law Adong Pynursla, LASI: LAW Adong Siatbakon, LAP: LAW Adong Pongtung)

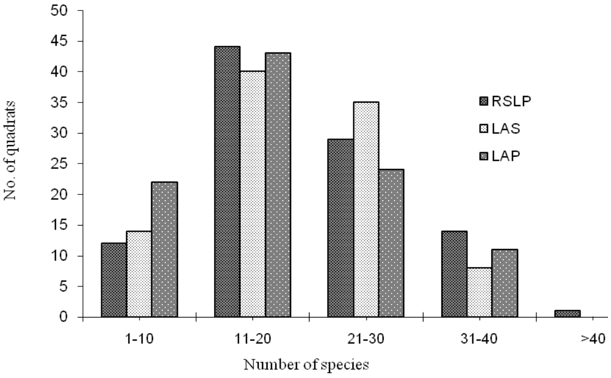

Figure 4. Number of tree species per quadrat (100 m^2) in the three forest stands of Meghalaya, India (RSLP: Raid Shabong Law Adong Pynursla, LASI: LAW Adong Siatbakon, LAP: LAW Adong Pongtung)

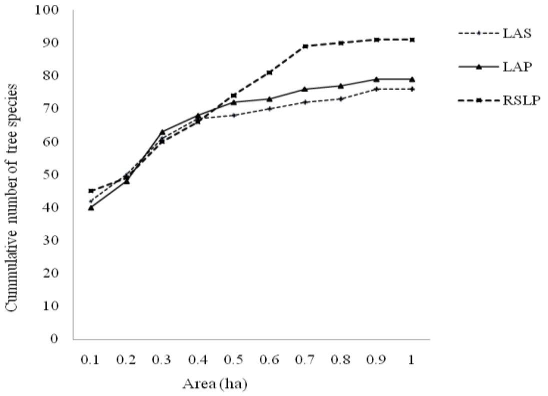

Figure 5. Species area curve of tree species in the three forest stands of Meghalaya, India (RSLP: Raid Shabong Law Adong Pynursla, LASI: LAW Adong Siatbakon, LAP: LAW Adong Pongtung)

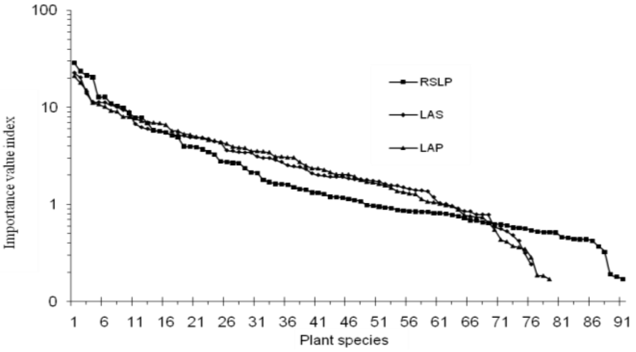

Figure 6. Species area curve of tree species in the three forest stands of Meghalaya, India (RSLP: Raid Shabong Law Adong Pynursla, LASI: LAW Adong Siatbakon, LAP: LAW Adong Pongtung)

Population density

The population density of the enumerated 6,016 tree species varied across the three stands. In RSLP *Oroxyrum indicum* (IVI = 28.75, Density= 37 ha^{-1} and Basal area= 16.55 m^2/ha), *S. tetragonum* (IVI= 23.63, Density= 194 ha^{-1} and Basal area = 4.40 m^2/ha) and *Ficus* sp. (IVI= 21.34, Density= 196 ha^{-1} and Basal area= 3.47 m^2/ha); in LAS *L. fenestratus* (IVI= 40.66, Density= 169 ha^{-1} and Basal area= 4.96 m^2/ha), *L. elegans* (IVI= 30.8, Density= 133 ha^{-1} and Basal area= 4.29 m^2/ha) and *S. griffithii* (IVI= 16.18, Density= 104 ha^{-1}and Basal area= 1.55 m^2/ha) and LAP *L. elegans* (IVI= 21.05, Density= 118 ha^{-1}and Basal area= 3.88 m^2/ha), *M. bombycina* (IVI= 17.98, Density= 131 ha^{-1}and Basal area= 7.94 m^2/ha), *Phoebe cooperiana* (IVI = 15, Density= 74 ha^{-1}and Basal area = 0.12 m^2/ha) are the most important species in term of IVI, Density and Basal area. The name, Importance value index (IVI), Density (D), and Basal area (BA) of the 10 most important species in three forest stands encountered during the study period are given in Table 2. The identified tree species within the three forest stands belonged to 56 plant families. Dominant families based on Importance value index, number of species, genera and individuals includes Fagaceae (IVI= 205.29, species= 11, genera= 4 and Individual= 1,184), Lauraceae (IVI = 139.42, species= 22, genera= 9 and Individual= 882) and Euphorbiaceae (IVI= 68.39, species= 17, genera= 8 and Individual= 478). Arecaceae, represented by *Arenga pinnata* recorded in LAP and *Caryota* sp., and Pandanaceae, represented by *Pandanus odoratissimus* recorded in LAS, were the only monocot families, and Pinaceae, the sole gymnospermic family, represented by *Pinus kesiya* recorded in LAS. Detail of tree families recorded in three 1 ha plots within the tropical evergreen forests of south Meghalaya, including importance value index, the number of species, genera, and individuals, is given in Table 3.

Discussion

Tropical evergreen forests of the southern slopes of Meghalaya are multi-layer forest communities made up of big, medium, and small trees divided into three distinct layers. The canopy, sub-canopy, and under-canopy layers were composed of large (15-30 m tall), medium (8-15 m tall), and small (<8 m tall) trees, respectively. The high species abundance of sub-canopy and sub-canopy layers (61.54%) is attributed to the presence of individuals of canopy species who are either young or whose development has been stopped due to the heavy shade of the overhead canopy (Jamir et al. 2006).

Table 2. Importance value index (IVI), Density (D ha^{-1}), and basal area (BA m^2/ha) of the 10 most important species in three 1 ha plots of southern slopes of Meghalaya, India

Species	RSLP			Species	LAS			Species	LAP		
	IVI	D	BA		IVI	D	BA		IVI	D	BA
Oroxyrum indicum	28.75	37	16.55	*Lithocarpus fenestratu*	40.66	169	4.96	*Lithocarpus elegans*	21.05	118	3.88
Syzygium tetragonum	23.63	194	4.40	*Lithocarpus elegans*	30.8	133	4.29	*Machilus bombycina*	17.98	131	7.94
Ficus sp.	21.34	196	3.47	*Sarcosperma griffithii*	16.18	104	1.55	*Phoebe cooperiana*	15	74	0.12
Castanopsis hystrix	20.4	136	6.06	*Syzygium tetragonum*	12.5	89	1.25	*Knema andamanica*	11.65	74	0.54
Garcinia spicata	12.82	93	1.31	*Machilus bombycina*	12.35	79	1.61	*Wenderhardia tinctoria*	10.76	83	1.80
Lithocarpus elegans	12.82	101	2.11	*Schima wallichii*	11.56	62	2.94	*Antidesma khasianum*	10.26	77	0.50
Macropanax undulatus	10.99	50	4.19	*Quercus lanceifolia*	10.51	66	1.84	*Arenga pinnata*	9.44	81	1.89
Machilus bombycina	10.39	61	2.74	*Castanopsis hystrix*	10.48	56	2.12	*Schima wallichii*	9.05	78	0.91
Sarcosperma griffithii	9.88	81	1.29	*Helicia erratica*	8.76	52	1.02	*Erythroxylum kunthianum*	8	22	0.06
Erythroxylum kunthianum	8.77	134	0.41	*Castenea sativa*	8.5	48	2.52	*Itea macrophylla*	7.98	61	0.17

Note: RSLP: Raid Shabong Law Adong Pynursla, LAS: Law Adong Siatbakon and LAP: Law Adong Pongtung

Table 3. Dominant families based on importance value index (IVI), number of species, genera, and individuals in three 1 ha plots of southern slopes of Meghalaya, India

Family	IVI	Species	Genera	Individual
Fabaceae	229.32	16	9	522
Lauraceae	139.42	22	9	815
Phyllanthaceae	48.12	10	5	149
Myrtaceae	38.87	1	1	223
Moraceae	35.32	7	1	45
Theaceae	34.45	5	3	285
Bignoniaceae	31.59	2	2	134
Erythroxylaceae	29.55	1	1	22
Rubiaceae	28.46	5	5	309
Sapotaceae	27.37	3	2	117
Euphorbiaceae	22.32	8	5	371
Iteaceae	21.94	1	1	122
Clusiaceae	21.2	5	1	68
Myristicaceae	15.84	5	1	37
Magnoliaceae	13.87	2	1	17
Primulaceae	13.45	1	1	1
Elaeocarpaceae	12.94	1	1	16
Proteaceae	12.34	1	1	3
Sterculiaceae	10.91	3	2	170
Myricaceae	9.45	2	1	39
Arecaceae	9.44	2	1	57
Styraceae	9.13	1	1	144
Juglandaceae	8.76	1	1	19
Meliaceae	7.12	4	4	336
Rutaceae	6.55	1	1	7
Symplocaceae	6.15	2	1	256
Ebenaceae	5.88	1	1	17
Sapindaceae	5.76	3	2	84
Ehretiaceae	5.42	1	1	20
Daphniphyllaceae	5.25	1	1	32
Vitaceae	5.22	1	1	4
Actinidiaceae	3.44	1	1	103
Oleaceae	3.25	1	1	4
Lythraceae	2.45	1	1	7
Aquifoliaceae	2.33	1	1	26
Lamiaceae	2.04	1	1	3
Ericaceae	1.99	1	1	37
Araliaceae	1.58	4	4	514
Anacardiaceae	1.55	2	2	79
Pandanaceae	1.45	1	1	38
Burseraceae	1.3	1	1	21
Betulaceae	1.15	2	2	18
Cyatheaceae	0.93	1	1	98
Vaccinaceae	0.92	1	1	181
Simaroubaceae	0.9	1	1	16
Hamamelidaceae	0.84	1	1	1
Apocynaceae	0.7	2	2	326
Urticaceae	0.65	1	1	1
Achariaceae	0.43	1	1	3
Dilleniaceae	0.36	1	1	2
Celastraceae	0.19	1	1	81
Pinaceae	0.16	1	1	16
Total	900	146	95	6016

Upadhaya et al. (2003) reported similar observations from the two sub-tropical humid forests in Jaintia Hills, Meghalaya, and Quigley and Platt (2003) from nine seasonally deciduous forests in America. A total of 146 tree species were recorded in the study area (in 3 ha, for trees ≥15 cm gbh). However, the number of tree species identified in this study was found to be lower than that documented by several workers in other tropical forests. For instance, Condit et al. (1996) reported 683 species (in 50 ha) in the Pasoh Forest Reserve of Malaysia. Lieberman et al. (1996) reported 561 species (in 23.4 ha) along an elevation gradient of Costa Rica. Condit et al. (1996) reported 229 species (in 50 ha) in Barro Colorado Island, Panama. Ayyappan and Parthasarathy (1999) recorded 148 species (in 30 ha) in Varagalaiar tropical evergreen forest in Western Ghats, India, and Kumar et al. (2006) recorded 165 species (35 ha) in the tropical forest of Garo Hills, Meghalaya. However, tree species recorded in southern Meghalaya are much greater than the 63 species (50 ha) recorded in the deciduous forest of Mudumalai, south India (Condit et al. 1996), 103 species (in 28 ha) encountered in the Western Ghats, India (Pascal and Pelissier 1996) and 40 species (in 0.16 ha) in tropical wet evergreen forest in Bangladesh (Feroz et al. 2016).

The species richness in each forest stand of south Meghalaya ranged from 77 to 93 species ha^{-1}, with a mean of 83(±5.03) species ha^{-1}. That may be considered moderate as compared to species richness in neo-tropical forests, which ranges from 20 species ha^{-1} in the Varzea forest of Rio Xingu, Brazil (Campbell et al. 1992) to 307 species ha^{-1} in the Amazonian Equator (Valencia et al. 1994) and other tropical forests where it ranged from 26 species ha^{-1} in Kolli hills of India (Chittibabu and Parthasarathy 2000) to 231 species ha^{-1} in Brunei Darussalam of Southeast Asia (Poulsen et al. 1996) and 76 species ha^{-1} recorded in evergreen tropical forests, Meghalaya (Tripathi and Tripathi 2010). However, it may be considered as considerably higher when compared to other sites in southern and central Western Ghats, viz., 30 species ha^{-1} in Nelliampathy (Chandrashekara and Ramakrishnan 1994), 57 species ha^{-1} in Mylodai forest of Courtallum (Parthasarathy and Karthikeyan 1997), 60 species ha^{-1} recorded in the wet temperate forest of Fakim Wildlife Sanctuary, Nagaland, India (Ao et al. 2020), and 75 species ha^{-1} recorded in the tropical dry deciduous forest of the Eastern Ghats, India (Gandhi and Sundarapandian 2020).

Species diversity indices are computed to understand the diversity and abundance of tree species in different ecosystems for comparison, and the higher the value, the greater the species richness (Naidu and Kumar 2016). The higher values of the diversity indices imply that the forest exhibits high diversity and abundance of tree species (Adekunle et al., 2013). Shannon-Weiner values for tree species diversity in the present study ranged from 3.74-3.95 (mean 3.85±0.06), which is comparable to that of Varagalaiar tropical evergreen forest of Western Ghats, India 3.93 (Ayyappan and Parthasarathy 1999), tropical forests in Eastern Ghats of Andhra Pradesh, India 3.76-3.96 (Naidu and Kumar 2016), tropical forest of Garo Hills, Meghalaya 3.78-4.27 (Kumar et al. 2006), evergreen and sub-tropical forests, Meghalaya 4.2-4.21(Tripathi and Tripathi 2010), betel leaf agroforest, Meghalaya 4.1 (Tynsong and Tiwari 2010) and wet temperate forest of Fakim Wildlife Sanctuary, Nagaland, India 3.9 (Ao et al.

2020). However, Shannon-Weiner values in this study are much higher than that of the areca nut agroforest of Meghalaya 3.3 (Tynsong and Tiwari 2010), sacred groves of the Jaintia hills, Meghalaya 3.42-3.55 (Upadhaya et al. 2003) and Khasi hill sal forest, 3.39 (Tripathi and Shanker 2014). The Margalef index ranged from 23.07-27.39 (mean 24.83±1.31), which falls within the range of 4.54-23.41 for tropical forests reported by earlier workers (Mishra et al. 2005; Sathish et al. 2013). Based on the number of species recorded per hectare and species diversity indices, sub-tropical evergreen forests of southern Meghalaya may be considered a high diversity and abundance of tree species. Ayyappan and Parthasarathy (1999) stated that one of the most important features of the tropical forest is the richness of species. Estimating species richness is a valuable tool in plant and forest ecology to compare the species composition of different forest ecosystems (Naidu and Kumar 2016). Huang et al. (2003) opined that the forest structure and composition significantly influence species diversity. Changes in forest species diversity are often caused by anthropogenic activity, which can harm the forest ecosystem (Sukumar et al. 1992).

The density distribution of woody species in the forests of the southern slopes of Meghalaya ranged from 1,944 to 2,100 trees ha^{-1}; (mean 2,005±48.01) which is similar to a Himalayan temperate forest with 1,570-1,785 stem ha^{-1} in the montane forests of Garhwal Himalaya (Bhandari and Tiwari 1997), 2,090-2,100 stem ha^{-1} recorded in Dolpa District of Mid-West Nepal (Kunwar and Sharma 2004), tropical wet evergreen forests in the Western Ghats, India 1,875 stem ha^{-1} (Giriraj et al. 2008) and Ades forest, Oromia Regional State, West Hararghe Zone, Ethiopia 1,453 stem ha^{-1} (Atomsa and Dibbisa 2019). However, the density of tree species recorded in the present study was found to be much higher than that of evergreen forests of the Andaman Islands of 1,137 trees ha^{-1}, semi-evergreen forests of the Andaman Islands 1,027 trees ha^{-1} (Padalia et al. 2004), tropical forests rainforest remnants of Australian rainforests 94 stem ha^{-1} (Fox et al. 1997), Central Himalaya tropical forests 92 stem ha^{-1} (Khera et al. 2001), Northern forest-Sananna ecotone of Ghana 88 stem ha^{-1} (Attua and Pabi 2013) and evergreen tropical forests, Meghalaya 1,023 stem ha^{-1} and semi-tropical forests of Meghalaya 838 stem ha^{-1} (Tripathi and Tripathi 2010). Other tropical forests such as those of Bolivia (649 trees ha^{-1}) (Boom 1986), Costa Rica (448-617 stem ha^{-1}) (Heaney and Proctor 1990), and Lowland tropical forests in Kurupukari, Guayana (716 to1,440 stem ha^{-1}) (Johnston and Gilman 1995) are also lower in tree density compare to the current study. The total density in several other tropical forests ranged from 5.5 to 18 trees ha^{-1} (Visalakshi 1995), and temperate forests ranged from 3.2 to 21 trees ha^{-1} (Debel and Day 1977; Ralhan et al. 1982; Saxena and Singh 1982).

The total Basal area of trees recorded on the southern slopes of Meghalaya ranged from 52.26 to 68.05 m^2/ha (mean 61.72±4.82). The *O. indicum* contributed the highest basal area with 16.55 m^2/ha, followed by *M. bombycina* (7.94 m^2/ha), *C. hystrix* (6.06 m^2/ha), and *L. fenestratus* (4.96 m^2/ha). A similar study conducted by various workers showed that in the tropical forest of Western Ghats, India, the Basal area ranges from 24.2-75.3 m^2/ha (Subashree et al. 2020), tropical moist deciduous forest of Saptasajya Hill range, Eastern Ghats, India 22.21-46.73 m^2/ha (Sahu et al. 2019), tropical forest of Baratang Island, India, 94.18 m^2/ha (Mane et al. 2019). The basal area of trees in this study is much higher than tropical dry evergreen forests of southern India, where it ranges from 10.79-20.44 m^2/ha (Parthasarathy and Sethi 1997), Miombo woodlands, Tanzania range: 3.9-16.7 m^2/ha (Backeus et al. 2006), New Caledonia range: 47-49.5 m^2/ha (Jaffre and Veillon 1990) and evergreen tropical forests, Meghalaya 33.3 m^2/ha and semi-tropical forests, Meghalaya 49.5 m^2/ha (Tripathi and Tripathi 2010). The emergent layer comprising very tall trees is absent in the studied forests, which may be due to the nutrient-poor soil of studied forests (Visalakshi 1995; Upadhaya et al. 2003).

The presence of a higher number of smaller trees than large ones is perceived as an indicator of a regenerating forest (Bhat et al., 2011). The present study showed a decline in the species richness and density with the increasing diameter class, suggesting a 'reverse J-shaped' curve feature, which in turn indicates strong regeneration status of the forest (Ganesh et al. 1996; Varghese and Balasubramanyan 1999; Bhat et al. 2011; Joglekar et al. 2015; Mohandass et al. 2016). Regeneration in the forest ecosystem is a critical mechanism for the species' survival (Khumbongmayum et al., 2005). Swamy et al. (2010) stated that tropical forests have a great intrinsic self-maintenance capacity, although many have lost this ability in recent years due to anthropogenic disturbances. Chauhan et al. (2010) considered that the distribution of species in a forest depends on the regeneration in space and time of the species that make up the ecosystem. Species diversity, heterogeneity, and dynamic community organization are one of the most perceptible characteristics of tropical and subtropical forests (Tripathi and Tripathi 2010). Two forest stands, RSLP and LAP (100%) and LAS (93.51%), had a contagious/clumped pattern of distribution which could be attributed to insufficient seed dispersal (Richards 1996), topography, and soil factors (Currie 1991). Since most of the species were contagiously distributed and frequency class A was dominant, the forest can be termed highly heterogeneous and patchy in terms of species distribution. Poore (1968), Ashton (1969), and Herwitz (1981) identified tropical rain forests as highly patchy communities primarily because of the species' gap formation and dispersal mechanism of the species. Hubbell (1979) found that the dry tropical forest was either clumped or scattered at random, with uncommon species clumping more than common species. Whitmore (1990) has also recorded patchy ground flora distribution in most tropical rainforests. The dominance of families like Fagaceae, Lauraceae, Euphorbiaceae, Myrtaceae, and Rubiaceae in the study area is similar to the tropical rain forests of Pasoh reserve forests in Malaysia, tropical wet evergreen forests, Western Ghats (Giriraj et al. 2008), the wet temperate forest of Nagaland (Ao et al. 2020) and sub-tropical forests/sacred forests in Meghalaya (Manokaran et al. 1990; Mishra et al. 2004; Tripathi and Khongjee 2010; Tripathi et al. 2010).

Table 4. Vegetation characteristics of various tropical forests located in the tropics

Forest type	Location	Sample area (ha)	DBH (cm)	Species richness (no.)	Diversity index (H')	Density (Tree/ha)	Basal area (m^2/ha)	References
Tropical evergreen	**Southern Meghalaya**	**1**	**≥ 15**	**83**	**3.85**	**2005**	**61.72**	**This study**
Tropical Forests	Eastern Ghats, India	4	≥ 15	129	3.86	601	23.31	Naidu and Kumar (2016)
Sub-tropical Evergreen	Meghalaya	1	≥ 15	76	4.2	1023	33.3	Tripathi and Tripathi (2010)
Subtropical Semi-Evergreen	Meghalaya	1	≥ 15	77	4.21	838	49.5	Tripathi and Tripathi (2010)
Sal Forest	Ri-Bhoi, Meghalaya	5.2	≥10	111	3.39	747	15.54	Tripathi and Shankar (2014)
Tropical Semi- evergreen	Bangladesh	2	≥10	66	-	384	48.05	Biswas and Misbahuzzaman (2008)
Tropical Evergreen	Andaman Island, India	4	≥17	264	2.05	1137	44.8	Padalia et al. (2004)
Tropical Semi-Evergreen	Andaman Island, India	4	≥17	231	1.99	1027	33.76	Padalia et al. (2004)

Note: (-) indicates data absent

One of the unique features of the sub-tropical evergreen forests of southern Meghalaya is the presence of Fagaceae as one of the dominant families with 11 species. Though it was difficult to explain the causes of high species richness in the forests of southern Meghalaya, it seemed that high rainfall, unique topographic condition, and protection over a long period may have played a major role in making the community highly complex and rich in diversity of plants. As a result, tree density and basal area are higher in our studied area, but species richness and plant diversity are significantly lower compared to some tropical forests (Table 4).

In conclusion, the present study shows that the sub-tropical evergreen forests of the southern slopes of Meghalaya show near similarity in terms of species richness with the tropical dry deciduous forests of Eastern Ghats, India, and evergreen tropical forests of Meghalaya in terms of species diversity indices; with the tropical forest of Garo Hills, tropical evergreen forest the Western Ghats and tropical forests in the Eastern Ghats, in term of tree density; with tropical wet evergreen forests of the Western Ghats, montane forests of Garhwal Himalaya and community forests of Dolpa district, mid-west Nepal and in term of the basal area with the tropical forest of the Western Ghats, tropical moist deciduous forest of Saptasajya Hill range, Eastern Ghats and tropical forest of Baratang Island, India. An increase in the disturbance in the form of human encroachment into the forest area would jeopardize the robustness of the forest structure and further threaten the forests of the southern slopes of Meghalaya. This study offers valuable knowledge about tree species' density, distribution, and population structure, which is a prerequisite for efficient management and protection of the forests conserved by the local village communities primarily for ecosystem services.

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Table S1. Plant species, their families, frequency, density (individual ha^{-1}) and IVI recorded in sub-tropical forests of southern slopes of Meghalaya, India

Plant species	Family	Frequency			Density			IVI		
		RSLP	LAS	LAP	RSLP	LAS	LAP	RSLP	LAS	LAP
Acer negundo L.	Sapindaceae	4	3	-	6	4	-	0.97	0.48	-
Acer oblongum Wall. ex DC.	Sapindaceae	3	-	-	3	-	-	0.52	-	-
Actinodaphne angustifolia Nees.	Lauraceae	3	3	3	4	6	5	0.78	0.61	0.74
Actinodaphne obovata (Nees.) Bl.	Lauraceae	4	4	3	6	7	4	0.95	0.77	0.76
Adenanthera pavonina L.	Fabaceae	1	-	18	3	-	54	0.45	-	6.6
Aesculus assamica Griff.	Sapindaceae	-	7	8	-	12	14	-	1.55	2.24
Albizia stipulata (DC.) Boivin	Fabaceae	2	-	3	2	-	12	0.46	-	2.37
Alstonia scholaris (L.) R.Br.	Apocynaceae	2	-	-	2	-	-	0.46	-	-
Amoora rohituka (Roxb.) Wight & Arn.	Meliaceae	-	6	8	-	11	8	-	1.76	1.4
Antidesma diandrum (Roxb.) B.Heyne ex Roth	Phyllanthaceae	2	-	-	3	-	-	0.44	-	-
Antidesma khasianum Hk.f.	Phyllanthaceae	1		7	1	-	77	0.18	-	10.26
Aporosa octandra (Buch.-Ham. ex D.Don) Vickery.	Phyllanthaceae	3	11	-	6	18	-	0.81	2.35	-
Aralia sp.	Araliaceae	3	-	-	4	-	-	0.57	-	1
Ardisia floribunda Roem. & Schult.	Primulaceae	18	16	30	33	42	37	3.98	4.55	4.87
Arenga pinnata (Wurmb) Merr.	Arecaceae	-	-	18	-	-	81	-	-	9.44
Baccaurea sapida (Roxb.) Muell.	Phyllanthaceae	-	24	25	-	46	19	-	5.52	2.52
Beilschmiedia sp.	Lauraceae	2	-	-	2	-	-	0.66	-	-
Betula alnoides Buch.-Ham. ex D.Don.	Betulaceae	2	-	-	3	-	-	0.61	-	-
Bridelia montana (Roxb.) Willd.	Phyllanthaceae	3	-	-	6	-	-	0.76	-	-
Bridelia retusa (L.) A.Juss.	Phyllanthaceae	-	-	10	-	-	48	-	-	6.85
Callicarpa vestita Wall. ex C.B.Clarke.	Lamiaceae	-	-	22	-	-	7		-	1.02
Camellia caduca C.B.Clarke ex Brandis	Theaceae	9	-	-	69	-	-	5.12	-	-
Camellia caudata Wall.	Theaceae	3	-	-	8	-	-	0.85	-	-
Canthium glabrum Blume.	Rubiaceae	3	6	4	3	9	9	0.54	1.17	4.55
Carpinus viminea Wall. ex Lindl.	Betulaceae	2	-	-	4	-	-	0.53	-	-
Caryota mitis Lour.	Arecaceae	4	-	-	17	-	-	1.32	-	-
Caryota urens L.	Arecaceae	-	2	6	-	8	12	-	0.66	1.7
Castanea sativa Mill.	Fagaceae	-	19	-	-	48	-	-	8.5	-
Castanopsis hystrix Hook.f. & Thomson ex A.DC.	Fagaceae	45	34	8	136	56	6	20.4	10.48	1.07
Castanopsis indica (Roxb. ex Lindl.) A.DC.	Fagaceae	5	-	-	9	-	-	1.62	-	-
Castanopsis tribuloides (Sm.) A.DC.	Fagaceae	-	-	5	-	-	45	-	-	6.99
Cedrela toona Roxb. ex Rottler & Willd.	Meliaceae	2	-	-	2	-	-	0.52	-	-
Chrysophyllum roxburghii G.Don.	Sapotaceae	-	5	-	-	11	-	-	0.96	-
Cinnamomum bejolghota (Buch.-Ham.) Sweet.	Lauraceae	5	-	7	12	-	27	2.11	-	3.54
Cinnamomum camphora (L.) J.Presl.	Lauraceae	25	9	15	53	14	28	7.83	1.71	4.22
Cinnamomum caudatum Nees.	Lauraceae	3	-	-	7	-	-	0.8	-	-
Cinnamomum cecidodaphne Meisn.	Lauraceae	4	-	-	8	-	-	1.2	-	-
Cinnamomum tamala (Buch.-Ham.) T.Nees & Eberm.	Lauraceae	19	21	27	31	34	13	5.52	4.86	2.15
Cinnamomum wightii Meisn.	Lauraceae	12	-	-	25	-	-	3.91	-	-
Citrus latipes (Swingle.)Tanaka.	Rutaceae	17	6	14	22	7	7	3.27	1.05	0.75
Coffea khasiana Hook.f.	Rubiaceae	4	-	3	14	-	24	1.27	-	2.36
Croton caudatus Geiseler.	Euphorbiaceae	-	2	6	-	5	19	-	0.37	3.54
Cryptocarya amygdalina Nees	Lauraceae	9	12	-	14	20	-	2.15	2.76	-
Cyathea gigantea (Wall. ex Hook.) Holttum.	Cyatheaceae	3	-	-	10	-	-	0.93	-	-
Daphniphyllum himalayense Müll.Arg.	Daphniphyllaceae	6	5	-	10	19	-	1.8	1.72	-
Debregeasia longifolia (Burm.f.) Wedd.	Urticaceae	3	-	-	4	-	-	0.58	-	-
Derris robusta Benth.	Fabaceae	-	12	11	-	58	41	-	5.82	5.72
Dillenia pentagyna Roxb.	Dilleniaceae	-	-	23	-	-	1	-	-	0.17
Diospyros kaki L.f.	Ebenaceae	-	8	1	-	12	6	-	1.54	1.37
Drimycarpus racemosus Hook.f.	Anacardiaceae	3	-	6	4	-	6	0.73	-	0.74
Duabanga grandiflora (Roxb. Ex DC.) Walp.	Lythraceae	-	6	-	-	15	-	-	2.45	-
Ehretia acuminata (DC.) R.Br.	Ehretiaceae	9	7	-	26	11	-	2.78	1.32	-
Elaeocarpus lanceifolius Roxb.	Elaeocarpaceae	15	11	4	27	13	17	3.7	2.58	2.04
Engelhardtia spicata Bl.	Juglandaceae	25	5	-	46	9	-	7.82	0.94	-
Erythroxylum kunthianum A.St.-Hil.	Erythroxylaceae	16	7	5	134	25	22	8.77	2.39	8
Eurya acuminata Wall.	Theaceae	4	8	11	18	14	5	1.51	1.64	1.05
Exbucklandia populnea (R.Br. ex Griff.) R.W.Br.	Hamamelidaceae	3	-	-	6	-	-	0.84	-	-
Ficus cunia Buch.-Ham. ex Roxb.	Moraceae	-	-	11	-	-	13	-	-	1.94
Ficus foveolata Pittier ex Tamayo.	Moraceae	-	4	-	-	14	-	-	1.21	-
Ficus gibbosa Blume.	Moraceae	2	-	-	16	-	-	1.17	-	-
Ficus hirta Vahl.	Moraceae	-	5	-	-	7	-	-	0.82	-
Ficus roxburghii Wall.	Moraceae	-	-	9	-	-	8	-	-	1.34

Ficus sp.	Moraceae	62	13	-	196	27	-	21.34	3.15	-
Garcinia morella (Gaertn.) Desr.	Clusiaceae	-	-	7	-	-	3	-	-	0.51
Garcinia lanceifolia Roxb.	Clusiaceae	-	7	5	-	13	11	-	1.73	1.48
Garcinia paniculata Roxb.	Clusiaceae	-	13	-	-	17	-	-	2.42	-
Garcinia pedunculata Roxb.	Clusiaceae	4	-	-	7		-	0.86	-	-
Garcinia spicata (Wight & Arn.) Hook.f.	Clusiaceae	58	5	-	93	15	-	12.82	1.38	-
Garuga pinnata Roxb.	Burseraceae	-	4	-	-	6	-	-	0.65	-
Glochidion khasicum (Müll.Arg.) Hook.f.	Phyllanthaceae	22	6	2	44	13	30	5.81	1.37	3.94
Glochidion lanceolarium (Roxb.) Voigt.	Phyllanthaceae	5	-	-	6	-	-	1.11	-	-
Glochidion sp.	Phyllanthaceae	-	-	16	-	-	4	-	-	0.55
Glochidion thomsoni (Muell-Arg.) Hk.f.	Phyllanthaceae	-	-	2	-	-	37	-	-	5.69
Gynocardia odorata R.Br.	Achariaceae	-	-	20	-	-	2	-		0.43
Helicia erratica Hk.f.	Proteaceae	4	40	2	9	52	7	1.08	8.76	1.27
Hyptianthera stricta (Roxb. ex Schult.) Wight & Arn.	Rubiaceae	1	-	-	2	-	-	2.67	-	-
icus elastica Roxb. ex Hornem.	Moraceae	-	-	3	-	-	25	-	-	4.35
Ilex sulcata Wall.	Aquifoliaceae	2	-	6	3	-	8	0.64	-	1.69
Itea macrophylla Wall. ex Roxb.	Iteaceae	5	7	4	8	21	61	1.14	2.42	7.98
Knema andamanica (Warb.) W.J.de Wilde.	Myristicaceae	1	-	27	22	-	74	1.42	-	11.65
Knema angustifolia (Roxb.) Warb.	Myristicaceae	-	-	29	-	-	1	-	-	0.19
Knema latifolia (Roxb.) Warb.	Myristicaceae	4	-	-	5	-	-	0.85	-	-
Knema linifolia (Roxb.) Warb.	Myristicaceae	-	8	-	-	10	-	-	1.4	-
Knema sp.	Myristicaceae	-	2	-	-	3	-	-	0.33	-
Leea umbraculifera C.D.Clarke.	Vitaceae	-	-	1	-	-	40	-	-	5.22
Ligustrum robustum (Roxb.) Blume.	Oleaceae	5	8	18	7	8	6	1.44	1.3	0.96
Lindera caudata (Nees) Hook.f.	Lauraceae	3	-	4	9	-	131	0.88	-	17.98
Lindera latifolia Hook.f.	Lauraceae	-	-	48	-	-	50	-	-	7.25
Lindera pulcherrima Benth.	Lauraceae	-	-	30	-	-	12	-	-	2.03
Lithocarpus elegans (Bl.) Hatus ex Soep.	Fagaceae	44	48	7	101	133	118	12.82	30.8	21.05
Lithocarpus fenestratus Rehder.	Fagaceae	-	41	-	-	169	-	-	40.66	-
Litsea citrata Blume.	Lauraceae	3	8	-	3	11	-	0.51	1.53	-
Litsea elongata (Nees ex Wall.) Benth. & Hook.f.	Lauraceae	-	-	25	-	-	38	-	-	6.95
Litsea leiantha Hook.f.	Lauraceae	-	3	17	-	6	4		0.6	2.45
Litsea semecarpifolia (Wall. ex Nees) Hook.f.	Lauraceae	2	4	-	3	7	-	0.57	0.7	-
Macaranga denticulata Muell. Arg.	Euphorbiaceae	4	-	-	4	-	-	0.68	-	-
Macaranga indica Wight.	Euphorbiaceae	-	9	-	-	14	-	-	1.74	-
Macaranga peltata Muell. Arg.	Euphorbiaceae	4	-	-	16	-	-	1.63	-	-
Machilus bombycina King ex Hook.f.	Lauraceae	31	38	3	61	79	4	10.39	12.35	0.78
Machilus khasyana Meissn.	Lauraceae	6	-	-	11	-	-	1.6	-	-
Macropanax undulatus (Wall.ex D.Don) Seem.	Araliaceae	22	-	3	50	-	4	10.99	-	0.36
Magnolia pterocarpa Roxb.	Magnoliaceae	4	2	2	5	4	55	0.99	0.39	5.3
Magnolia sp.	Magnoliaceae	10	14	-	14	41	-	2.68	4.51	-
Mallotus ferrugineus (Roxb.) Müll.Arg.	Euphorbiaceae	3	-	14	3	-	1	0.63	-	0.28
Melia azedarach L.	Meliaceae	-	-	1	-	-	5	-	-	0.98
Microtropis discolor (Wall.) Wall.	Celastraceae	1	-	-	1	-	-	0.19	-	-
Myrica esculenta Buch-Ham.ex D.Don.	Myricaceae	20	9	-	50	11	-	6.91	1.61	-
Myrica nagi Thunb.	Myricaceae	-	4	-	-	7	-	-	0.81	-
Neolitsea sp.	Lauraceae	1	-	-	3	-	-	0.37	-	-
Oroxylum indicum Vent.	Bignoniaceae	24	14	5	37	25	5	28.75	3.82	1.72
Ostodes paniculata Blume.	Euphorbiaceae	-	2	-	-	3	-	-	0.33	-
Pandanus odoratissimus Blume.	Pandanaceae	-	5	-	-	13	-	-	1.39	-
Parkia roxburghii G.Don.	Fabaceae	-	-	1	-	-	1	-	-	0.19
Pentapanax umbellatus Seem.	Araliaceae	2	-		3	-	-	0.44	-	-
Phoebe cooperiana P. C. Kanjilal & Das.	Lauraceae	-	17	5	-	24	74	-	3.61	15
Phoebe lanceolata (Nees) Nees.	Lauraceae	-	9	18	-	17	15	-	2.02	3.82
Picrasma javanica Blume.	Simaroubaceae	3	-	-	8	-	-	0.81	-	-
Pinus kesiya Royle ex Gordon.	Pinaceae	-	1	-	-	1	-	-	0.16	-
Quercus dealbata Hook.f. & Thomson.	Fagaceae	8	8	35	25	24	47	3.94	3.06	7.7
Quercus dilatata Royle.	Fagaceae	6	12	-	13	46	-	1.7	5.5	-
Quercus lanceifolia Roxb.	Fagaceae	10	29	-	37	66	-	3.47	10.51	-
Quercus sp.	Fagaceae	-	-	10	-	-	24	-	-	3.51
Quercus sp.	Fagaceae	5	16	25	9	52	20	1.2	6.77	3.54
Randia dumetorum (Retz.) Poir.	Rubiaceae	-	-	13	-	-	2	-	-	0.37
Rhododendron arboreum Sm.	Ericaceae	2	1	-	3	3	-	0.42	0.65	-
Rhus acuminata DC.	Anacardiaceae	1	-	-	2	-	-	0.62	-	-
Sapium baccatum Roxb.	Euphorbiaceae	2	6	-	3	13	-	0.44	2.07	-
Sapium insigne (Royle) Trimen.	Euphorbiaceae	22	7	14	31	9	24	5.7	1.31	4.6
Saraca indica L.	Fabaceae	-	9	2	-	16	1	-	2.24	0.18

Sarcosperma griffithii Hook.f. ex C.B.Clarke.	Sapotaceae	37	51	18	81	104	2	9.88	16.18	0.35
Saurauia punduana Wall.	Actinidiaceae	-	-	1	-	-	22	-	-	3.44
Schima khasiana Dyer.	Theaceae	3	-	-	4	-	-	0.69	-	-
Schima wallichii Choisy.	Theaceae	13	22	2	15	62	78	2.66	11.66	9.05
Sterculia colorata Roxb.	Sterculiaceae	-	-	17	-	-	7	-	-	1.57
Sterculia roxburghii Wall.	Sterculiaceae	1	3	-	1	6	-	0.17	0.54	-
Sterculia villosa Roxb.	Sterculiaceae	6	16	26	7	34	19	1.33	4.2	3.1
Stereospermum chelonoides (L.f.) DC.	Bignoniaceae	2	4	7	3	9	14	0.84	0.65	1.79
Styrax serrulatum Roxb.	Styraceae	21	14	15	43	30	6	4.88	3.12	1.13
Symplocos ramosissima Wall.	Symplocaceae	-	7	7	-	12	8	-	1.54	0.88
Symplocos sp.	Symplocaceae	-	-	5	-	-	16	-	-	3.11
Toona ciliata Roem.	Meliaceae	-	12	-	-	19	-	-	2.46	-
Trevesia palmata (Roxb.) Vis.	Araliaceae	11	27	3	15	37	25	2.36	6.02	3.05
Vaccinium donianum Wight.	Vaccinaceae	4	-	-	8	-	-	0.92	-	-
Wendlandia tinctoria (Roxb.) DC.	Rubiaceae	1	18	7	3	36	83	0.33	4.44	10.76
Wrightia tomentosa Roem. & Schult.	Apocynaceae	-	-	9	-	-	22	-	-	2.74
Syzygium tetragonum (Wight) Wall. ex Walp.	Myrtaceae	71	42	34	194	89	23	23.63	12.5	3.84
Total		-	-	-	2100	1972	1944	300	300	300

Note: - : indicates absence

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Impact of climate variability, farmers adaptation and coping strategies on coffee production in highlands of Kigoma District, Tanzania

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Abstract. *Msuya AM, Mahonge CP. 2022. Impact on coffee production of climate variability, farmers adaptation and coping strategies in highlands of Kigoma District, Tanzania. Asian J For 6: 34-42.* Worldwide, climate change and variability have raised concerns about potential changes to crop yields and production systems. This study concerns climate variability's effects on coffee production among smallholder farmers in the highland zone of the Kigoma District, the western part of Tanzania. This study specifically aimed to determine how climatic variability affected coffee production and the strategies taken to cope with the problem. Also, this study determined farmers" perceptions of climatic change and variability. The coffee production and rainfall data for thirty years (1981-2010) were used. Also, to study the trend relationship between climate change and agricultural production. Data were collected using household surveys, interviews, focus group discussions, documentary reviews, and field observations. The sampling unit was the household; 120 respondents were selected from 5 villages. First, a purposive sampling technique was employed to study wards and villages, and then 5 villages from 2 wards were selected. In each village, 24 households producing coffee were randomly selected from the village register to 120 respondents. Then, correlation analysis was used to examine the relationship between rainfall variability and coffee production in the area. In contrast, to study the effect of rainfall variability/change on coffee production, a simple linear regression was used. Both coffee production and rainfall showed a decreasing trend. However, the correlation between both trends was insignificant at a 5% probability level. Moreover, it can be concluded that coffee production was not much influenced by rainfall, given the weak correlation between rainfall and coffee production and the decreasing trend for both. Still, other factors, like a shortage of agricultural inputs such as fertilizers and pesticides, must influence coffee production in the study area.

Keywords: Climate change, coffee, purposive sampling, variability

INTRODUCTION

The first World Climate Change Conference to discuss climate change's real impacts on agriculture and other development sectors took place in 1979 in Geneva (Koo 2011). Decision makers from Federal and Regional governments, experts from research institutions and universities, practitioners from private sectors, and civil society organizations came together for plenary discussions and expert presentations on the impacts. Climate change and variability are already significantly impacting the agriculture sector, an important activity in the developing world, dominated by rain-fed crop production, and households' food security is particularly vulnerable. Hulme (1996) also stated that rain-fed agriculture is an important economic activity in the developing world. Globally, 80% of the total physical agricultural land on which 62% of the world's staple food is practiced rain-fed agriculture (FAO 2005; Bhattacharya 2008).

In recent years, several studies conducted in Tanzania have documented that climate change and variability significantly impact agriculture production. The second most vulnerable to climate change identified by NAPA (2006) was the agricultural sector. Therefore the first National Action Plan on Climate Change, which contained removal by sinks of greenhouse gases and inventory of emissions by source, helps farmers adapt to new agricultural technologies and practices. Humans depend more on agriculture for their livelihood than other economic activities. That is particularly true for small farmers in Kigoma District, whose economic well-being and food security depend primarily on farming, which has been growing coffee for over 20 years as the sole cash crop.

However, in the last 10 years, coffee production has faced severe difficulties resulting in low-yielding trees. Climate change and variability contribute to such conditions; in response, farmers have been undertaking various coping mechanisms. According to Low (2005), among farmers, several coping mechanisms include actions that agriculture agencies do not formally recognize. The coping and adaptation mechanism implications may have both negative and positive effects on coffee production.

In Tanzania, like many other African countries, the agriculture sector accounts for about half of the national income and three-quarters of product exports. In addition, it employs about 80% of the population (NAPA 2006). However, this sector in Tanzania is mostly dependent on rainwater, making it vulnerable to climate change and variability. Climate change affects the most important agricultural inputs, rainwater, and temperature (Deschenes and Greenstone 2006). Therefore, a change in rainfall has been considered to affect agriculture production in many parts of the country. A recent analysis of rainfall trends over 20 meteorological stations indicates a decrease in 13

(61.9%), whereas an increase in 7 stations (33.33%) (New et al. 2006). Furthermore, some analysis has shown decreasing annual rainfall at an average rate of 2.8 mm per month (3.3%) for a decade. The southernmost of Tanzania shows the greatest annual decreases have occurred (Mwandosya et al. 1998).

Coffee is a vulnerable crop that needs special climatic conditions to thrive and give a good harvest. Robusta and Arabica coffee varieties require agroecological areas with hot-wet or hot-temperate climates with temperatures varying between 15 and 25ºC and frequent rains of about 1,000 mm or moreper annum with two months of a dry spell (Muya 2008). Arabica coffee, common in Kigoma District, is more tolerant to low temperatures than the Robusta and sometimes could withstand temperatures below 5ºC without damage. However, the prolonged temperatures exceeding 30ºC and rains variability than the required amount are disastrous to both coffee varieties (Muya 2008). According to Rosenzweig (1996), heavy rainfall, excessive soil moisture, and flooding disrupt crop production. Also, rising temperatures could reduce and staggered flowering, different berry growths, and difficulties in managing disease and pests, lengthening the harvest and processing seasons and compromising quality. Many studies on climate change and the coffee industry (ITC 2010), indigenous knowledge in seasonal rainfall prediction in Tanzania (Chang'a et al. 2010), and research protocols to assess the impact of climate change and variability in Rural Tanzania agriculture production (Liwenga et al. 2008). However, those studies have little to address the local abilities to adapt to climate variability and its impact on Kigoma District.

Therefore, this study aimed to investigate how climate change and variability have contributed to low coffee production, which farmers have been coping with in the highlands zone of Kigoma District, Tanzania.

MATERIALS AND METHODS

Description of the study area

The research was conducted in Kigoma District, Tanzania. This area is located at about 5° S and 30° E. The district is bordered on the north by Burundi and the Kagera District, on the east by Geita County and Tabora County, on the south by Katavi District, and the west by Lake Tanganyika, which forms the border with the Democratic Republic of Congo. The total area is 45,066 m^2, of which 37,037 m^2 is land, and 8,029 m^2 is water. Figure 1 shows the study area (National Census 2012).

There were about 427,024 people in the Kigoma district; the population density was 42.4 (rural) and 1,127.0 (urban) persons per square kilometer, according to the National Census (2012). Most residents depend on agriculture for their livelihood, and a few people engaged in other activities like beekeeping, lumbering, and fishing.

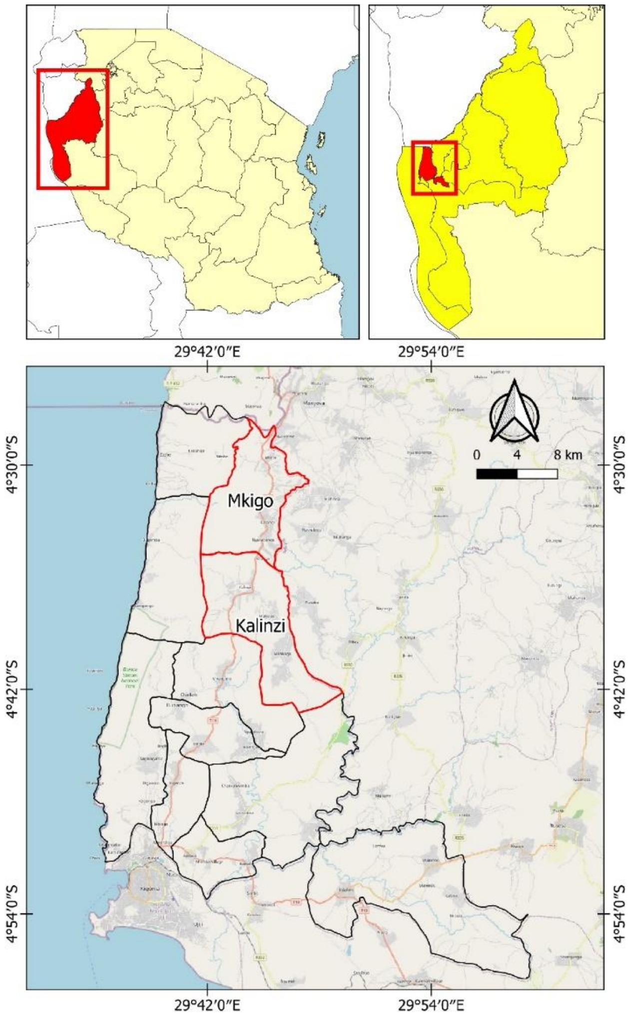

Figure 1. Map showing the study area, Kigoma District, Tanzania

Kigoma District experiences diverse climatic conditions, with annual rainfall between 600 mm and 1,600 mm, mostly distributed around and along the lake and in the highlands zone. The rainy season is in January, February, March, April, November, and December, with the most rainfall. The rainfall pattern is unimodal, with the rainy season lasting from October to May, with a short dry spell of 2-3 weeks in January or February, then a prolonged dry season. Precipitation allows a wide range of crops to be grown and is reliable for double-planting short-season crops. Lowland areas are warm for most of the year. The mean daily temperature ranges between 25ºC in December and January to 28ºC in September. Temperature varies inversely with altitude. Therefore, the lowland zone tends to be warmer than the highlands zone.

Research design

The study used a cross-sectional design, allowing in-depth data collection at one point in time from different groups of respondents (Bailey 1998). The study targeted farmers in the Kigoma District's highland zone who grow coffee. The sampling unit was the household, whereby 120 respondents were selected from 5 villages. A purposive sampling technique was employed to get the study villages and wards because not all wards produce coffee. Therefore, two wards and five villages were purposively selected. Furthermore, from the village register, 24 households producing coffee were randomly selected in each village to make a total of 120 respondents.

Preliminary visits

A reconnaissance survey was conducted to familiarize ourselves with the research site and gather general information. The main purpose was to introduce the research and the researchers to the community. So often, it takes a long time for the communities to become comfortable with strangers. They may be unwilling to answer questions because they are doubtful, then the doubt will decrease as the communities become familiar with the researcher.

Data collection methods

The household surveys and interview methods were used to collect primary data; the documentary method was used for secondary data, and this study collected qualitative and quantitative data. In gathering socio-economic data, semi-structured, closed-ended, and open-ended questionnaires were used to get information from the households. In addition, individual interviews were also carried out to get information from the farmers within the targeted households.

The questions that capture the trends in coffee crop production, climate change, and variability were used to identify changes and farmers' perceptions. Questionnaires were also administered to get information on coping and adaptation strategies to climate change and variability. In addition, the key informants were administered a checklist of questions to key informants. Conversely, secondary data on rainfall, coffee production, and temperature over 30 years (1981-2010) were collected from the district agriculture office, metrological stations, and water engineers district through documentary review. These methods are intended to collect information about climate variability's effects on coffee production and farmers' coping strategies.

Data analysis

Data from the respondents were verified and compiled, were then coded and summarized, then analyzed using Excel computer programs and the Statistical Package for Social Science (SPSS). The results were then presented using frequencies, graphs, and tables. Descriptive statistics, including frequency distribution, were computed. In addition, cross-tabulation was done to make the comparison. Furthermore, data from checklists and the researcher "s diary were analyzed by the content analysis technique, mainly transcribing information recorded in the notebooks, then clustering information into sub-themes.

RESULTS AND DISCUSSION

The major findings of the study were presented and discussed in this chapter. The first part presents the population's socio-economic characteristics of the samples, including age, marital status, education, sex, and occupation. The second part presents the rainfall trends and coffee production; the third part describes the relation between rainfall and coffee production trends; the fourth part concerns information on the local community's perception of climate variability and their adaptation and coping strategies in the highland of Kigoma District.

Socio-economic characteristics of the coffee farmers involved in the study

Socio-economic characteristics such as sex, family size, age, marital status, and education are critical to farm decisions and performance regarding climate change and variability. Respondents" education level helps in understanding the general requirements of farming and their application in the right season, while age reflects experience in farming. Marital status and sex determine farmers' responsibilities in crop production. In addition, family size gives a good labor determination on production. Table 1 shows the study area socio-economic characteristics of the sample population, whereby less than 60% of the heads of household were aged between 50 and 60 years, 35% were aged between 61 and 70 years, 3% were aged between 71 and 80 years, and 2% were aged above 80 years. About 75% of the respondents are inhabitants, and 25% are migrants, particularly from Rwanda and Burundi, neighboring countries. About 90% of the sample population resided for more than 30 years.

The sampled populations show how they are well familiar with the study area. Moreover, the household heads were 80% male, while female-headed were 20%. Regarding marital status, 92% of the respondents were married, while 6% were widows or divorced. Regarding respondents' education, about 90% had a primary school, while the others (10%) had either secondary or no formal education. Finally, regarding household size, most households had an average of 6-8 members.

Table 1. Socio-economic characteristics of the respondents (n=120) in the highland zone of Kigoma District, Tanzania

Socio-economic characteristic	Freq.	% of response
Age		
Respondents between 50 and 60	72	60
Respondents between 61 and 70	42	35
Respondents between 71 and 80	04	3
Respondents above 80	02	2
Sex		
Male	96	80
Female	24	20
Marital status		
Married	111	92
Single	02	2
Widowed	05	4
Divorced	02	2
Level of education		
Primary school education	108	90
Secondary school education	02	2
Non-formal education	10	8
Economic activities		
Coffee crop production	72	60
Both coffee crop and livestock production	42	35
Business	06	5

Trends in coffee production

Several District agricultural office documents and a report from Rumako Cooperative Union, which collects and sells all the coffee production in the Kigoma region, showed a decreasing coffee production trend over 30 years (1981-2010). The data show the maximum total annual coffee production was 736 tons in 1982, then by 687 tons in 1985 and 683 tons in 1988. It shows a considerable decrease except for a few years with an improvement in production. Figure 2 illustrates the decline of coffee production in the highland of the Kigoma District.

The Kigoma average annual coffee production for 5 years showed a decreasing trend; for example, the average coffee production from 1981 to 1985 was 676.8 tons, while the average from 1986 to 1990 was 493.8 tons.

As such, coffee productivity declined by an average of 183 tons from 1981 to 1990, data results are closely similar to farmers" perceptions of production trends. When asked about production trends, most farmers (91%) revealed that production had declined over 30 years. The average production between 1991 and 1995 was 500.8 tons, while the average production between 1996 and 2000 was 291.4 tons. In contrast, average production for the last decade, from 2001 to 2010, indicated an increase of 139.6 tons, a non-significant. The report from the International coffee organization (ICO 2006) showed that coffee production has decreased from 1,126.5 to 869.6 thousand tons annually in Africa. The production has decreased in 16 countries members of the international coffee organization but has increased in 9 countries. The coffee production trend in Kigoma following the ICO report shows a declining trend in all African countries.

Three-quarters of the farmers (75%) associated declining coffee production with non-climatic factors, such as the absence of agricultural inputs and inadequate extension services. Their views closely agree with the correlation analysis of rainfall variability and coffee production results in the study area. The coffee production trend assessment in the Kigoma District from 1981 to 2010 appears that production was good from 1981-1995 compared to the succeeding years from 1996.

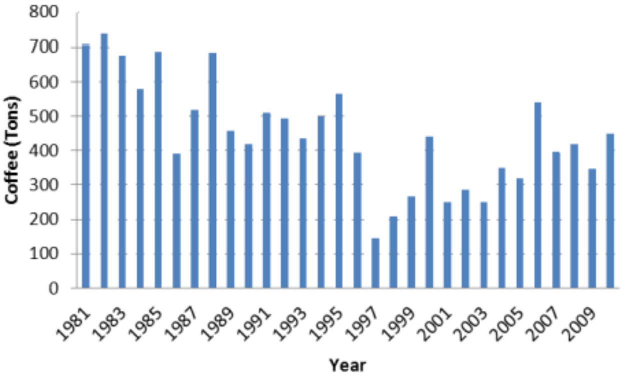

Figure 2. Coffee production trend in the Kigoma District highland, Tanzania (1981-2010)

Trends in rainfall

The rainy season in Kigoma is from October to May, and the dry season occurs from June to September. The warmest month happened in August, and the coolest month was November. Conversely, March is the wettest month, and July is the driest month. The meteorological data showed a declining trend for the last 30 years for rainfall during the rainy season between October to May, from 1981 to 2010.

Trend analysis of rainfall data (Figure 3) indicates a small variation in inter-annual rainfall. However, despite small variations in inter-annual rainfall, overall rainfall amount decreased over the years. Geographically, this area has an altitude of between 1,500 and 1,700 meters above sea level, characterized by total annual rainfall ranging from 1,000-1,600 mm. Over the thirty years (1981-2010), in 2005, 742 mm was the lowest rainfall, while the highest rainfall was 1,173 mm in 1982 ever recorded. Even though data showed that between 1981and 2010, only 11 years experienced annual rainfall of more than 1,000 mm, while 19 years experienced rainfall of less than 1,000 mm. That illustrates the fact that rainfall is less in the area.

Outside the traditional rain season, rainfall also occurred in June 1995 and July 1998 at a highly significant rate. These months traditionally fall under the dry season, which suggests splitting the season into short and long rains. The total amount of rainfall, however, at the onset of the rain season recorded in October 1981-1995 was 1,451.8 mm, while for 1995-2010 was 1,005.3 mm.

Based on the data, the number of rain days decreased from one year to another. Furthermore, starting from the 1990s, significant changes in the onset of rains tended to be delayed, with short rainfall duration associated with heavy storms. Also, rainfall was too high at the onset of rain in October 1997 compared to October of other rain seasons over thirty years. That was also reflected in local people" s perceptions; they mentioned the extreme flood event to have occurred in 1997, a clear shift in weather patterns attributed to climate variability. Anomalies graphs (Figure 4) indicate rainfall variability from January to December (1981-2010) over thirty years.

In the same way, the trends analysis of rainfall from 20 meteorological stations in Kigoma Highland District indicates a decrease for 13 stations (61.9%) and an increase for 7 stations (33.33%) (Mwandosya 1998). In Tanzania, analysis shows that areas with a unimodal rainfall pattern will experience a decrease of 5% - 15%, and a bimodal pattern will experience a decrease of 5% - 45% (Munish et al. 2006). Moreover, the IPCC report (2007) showed a decline in rainfall trend in the study area, which also showed the forecasted increasing warming in most of western Tanzania. Similarly, the International Institute for Environment and Development (IIED) also forecasted a rise in temperature between 2 and 4ºC and a decline in rainfall over western Tanzania (IIED 2009).

When asked about their views on rainfall trends, most farmers (95%) perceived an increase in temperature and rainfall change, which illustrates that drought is common in the area. However, further data verify that over 30 years (1981-2010), the last 15 years (1995 to 2010) received a minimum rainfall amount that was not experienced for the first 15 years from 1981 to 1995.

Relationship between rainfall and coffee production

The numerical data for rainfall collected at the meteorological stations were tested against data collected from District agricultural office on coffee production. The analysis of correlation was used to examine the relationship between rainfall variability and coffee production in the area. In contrast, to analyze the effect of the independent variable (amount of rainfall in millimeters) on the dependent variable (amount of coffee in tons), a simple linear regression was used. Statistically, the analysis showed a weak relationship between the amounts of coffee in tons produced and the amount of rainfall in millimeters from 1981 to 2010. The scatter plot (Figure 5) elaborates more on the relationship between the two variables.

The relationship between the amount of rainfall in millimeters and the amount of coffee in tons produced was statistically insignificant at a 5% level (p = 0.275). That indicates that coffee production was not much influenced by rainfall. Still, other factors must influence coffee production in the study area, like a shortage of agricultural inputs such as fertilizers and pesticides. Table 2 shows the results of the correlation analysis between the amount of coffee in tons and the amount of rainfall in millimeters.

On the other hand, a simple linear regression model was used to see the effect of an independent variable (amount of rainfall in millimeters) on a dependent variable (amount of coffee in tons). The regression analysis shows that the amount of rainfall can explain only 4.2% of total variations in coffee production. In contrast, the other 95.8% can be explained by other factors, meaning that the amount of rainfall has insignificantly impacted the amount of coffee produced (Table 3).

From Table 3 above, the result indicates that coffee production would be 192.276 tons if there were no rainfall. Conversely, the results show that if rainfall increases by a unit (1 mm), coffee production will rise by 0.263 tons, which also indicates the regression coefficients (192.276 and 0.263) all have an insignificant effect on the amount of coffee (p-values are 0.413 and 0.275, respectively). That implied that as much as rainfall is required to give a satisfactory production, on the other side, production might increase at a non-significant rate. For example, the Rainfall amount recorded in 1986/1987 was 1,139 mm, while the coffee production recorded in the same period was 392 tons. Therefore, farmers expected more production but needed help in this situation. The same experience appeared in 1990/1991, 1996/1997, and 2001/2002. Three-quarters of the respondents (75%) agreed that the yearly decrease in coffee production was mostly because of non-climatic factors, although rainfall plays a small part.

According to the data from the Kigoma District agriculture office and Kigoma weather station, annual rainfall and coffee production (1981-2010) show a decreasing trend. Some years have high rainfall but low production, while others have low production but high rainfall. Those indicate that coffee production in the area depends not only on rainfall; but other factors, such as shortage of agricultural inputs like fertilizers and pesticides, influencing coffee production in the study area.

Table 2. Correlation analysis between the amount of coffee in tons and the amount of rainfall in millimeters

		Amount of coffee	Amount of rain
Amount of coffee (tons)	Pearson correlation	1	.206
	significant (2- tailed)		.275
	N	30	

Table 3. The relationship between coffee production and climate variability in Kigoma District, Tanzania-Regression analysis

	Unstandardized Coefficients		Standardized Coefficient		P value
Model	**B**	**SE**	**Beta**	**t**	**Significant**
Constant	192.276	231.153		.832	.413
Amount of rain	.263	.236	.206	1.113	.275

Note: Dependent variable: the amount of coffee

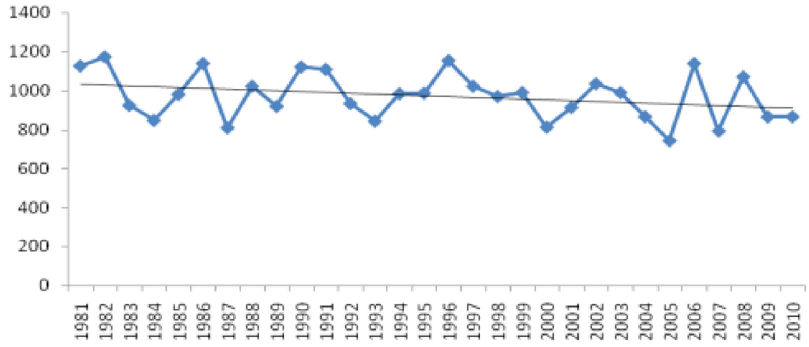

Figure 3. Annual rainfall trend in Kigoma District, Tanzania (1981-2010)

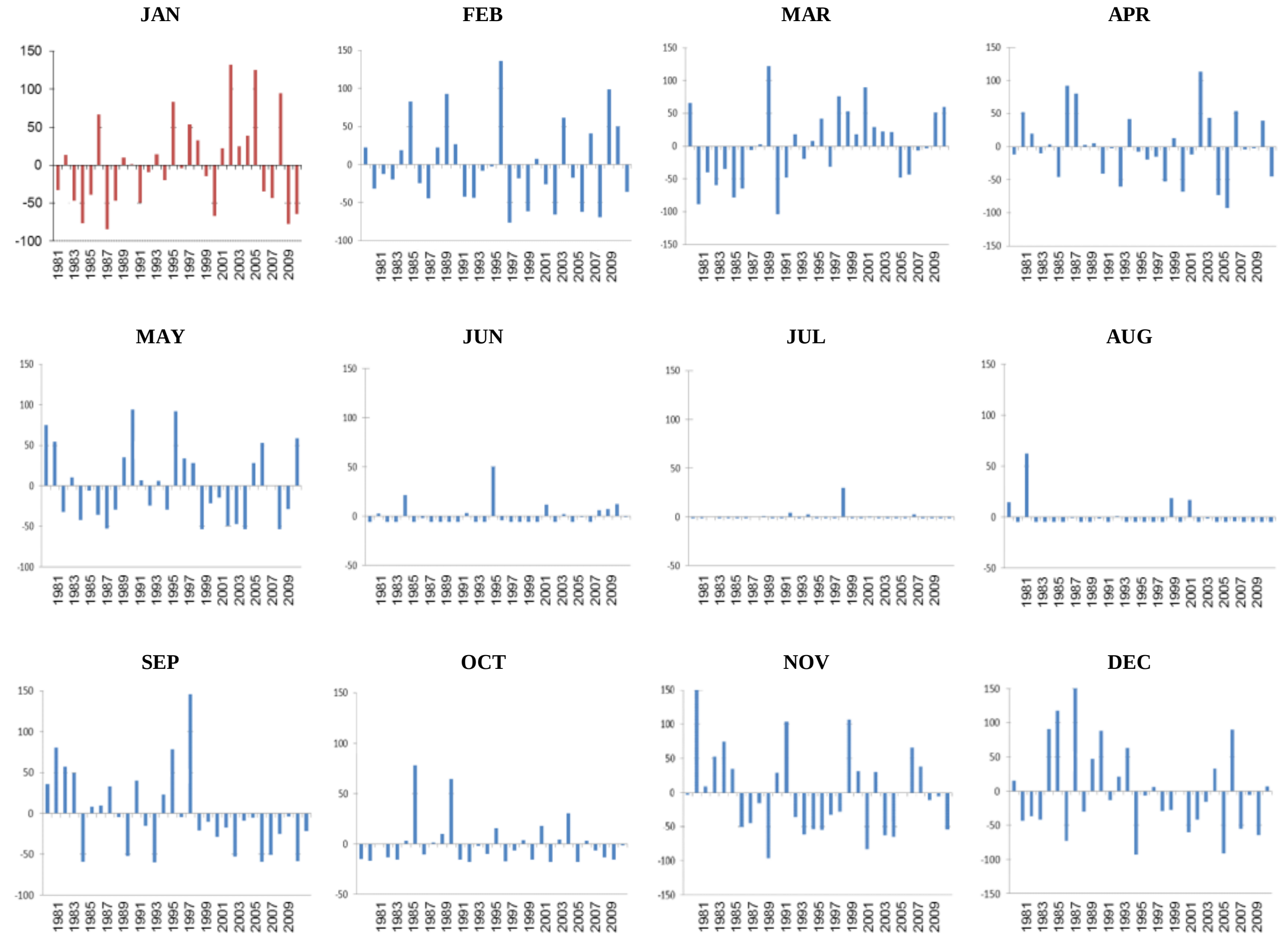

Figure 4. Anomalies for rain in Kigoma District, Tanzania (1981-2010)

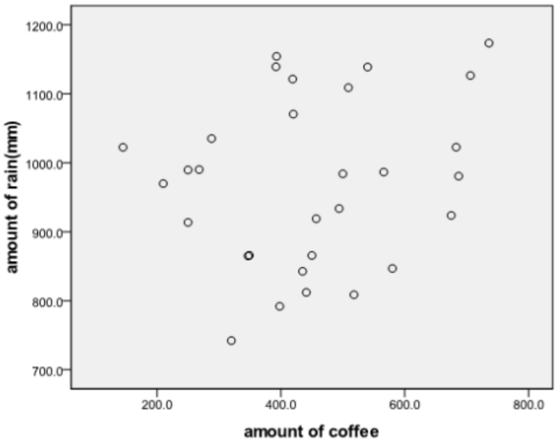

Figure 5. Scatter plot to demonstrate the amount of coffee in tons versus the amount of rainfall in millimeters

Farmer's perception of climate change and variability

Various stakeholders perceive climate change differently, even within the same level. For example, the household interviews revealed that farmers had a different understanding of climate variability. Over half (55%) explained climate variability due to a shifting rainfall as an extended dry season. Many respondents (33%) understood climate variability as decreases in rainfall, while the rest, 14 respondents (12%), defined climate variability as rainfall change and an increase in temperature; the temperature to be hotter today than in the past days perceived as climate variability.

Conversely, when asked about the causes of climate variability, most respondents (95%) mentioned the degradation of water sources and deforestation as the major factors of climate change. Other factors mentioned included bush fire and overgrazing (3%). Only a smaller number of respondents (2%) perceived climate change and variability due to breaking traditional rules laid down by their forefathers. They claimed that a rainmaker could solve drought during their time. Farmers" perceptions of changes in rainfall variability and temperature are closely similar to empirical results from the rainfall and temperature trends analysis using the data obtained from the Kigoma meteorological station.

Trend analysis of rainfall data (Figure 3) indicates that total annual rainfall has decreased over the years. A more pronounced decrease was from 1,173 mm in 1982 to 742 mm in 2005. Farmers" perceptions of rainfall trends in the area are also closely similar to the IPCC report (2007), which forecasted increasing warming in most of western Tanzania. A similar result from the International Institute for Environment and Development (IIED) forecasting that temperature will rise between 2 and 4ºC and decline in rainfall over western Tanzania (IIED 2009).

According to the respondents, the area was becoming warmer over the last 15 years, from September to December. The majority (95%) declared that the onset of rainfall had changed because rainfall used to be at the beginning of October. Still, nowadays, rains start in the middle of October or the beginning of November. Maddison's (2006) reports were similar, whereby many farmers in 11 African countries mentioned that precipitation had declined and temperatures had increased. Majule et al. (2008) also reported similar results. Other respondents' views were regarding the absence or drying of some water sources like natural springs, rivers, and natural water-hole in the area, implying rainfall amount changes. The respondents" views were also closely similar to the empirical analysis that showed drought occurrences in most of Tanzania between 1983 and 1992 (URT 1998).

Hatibu et al. (2000) analysis revealed that more than 33% of disasters in Tanzania over 100 years were related to drought. Interviews conducted in the study area included farmers" awareness assessment of years where drought has been observed. Most farmers mentioned 1974, 1979, 1982, 1983, 1992, 1996, and 1999 as the most severe drought periods and heavy rainfall of 1997 and 1998. However, some farmers needed help to recollect the dates of past droughts. In all drought periods, the farmers' main problem experienced was the absence of rainfall, which was related to a water shortage in the areas.

Coping and adaptation strategies

Farmers were asked about management practices in coffee production (coping and adaptive strategies) to reduce the risk and vulnerability under climate variability. Coping strategies are the actual responses that are considered short-term responses to the crisis in livelihood systems in the face of unwelcome situations (Boko and Niang 2007). Adaptive strategies are how a sector or a region responds to changes in their livelihood through either planned or autonomous adaptation (Smit and Skinner 2002). Most (95%) of the farmers interviewed knew the connection between climate variability and coffee production. However, only some have developed coping and adaptation measures that help them address climate change's short-term and long-term impacts and variability. A total of 53% of interviewed households adopted a range of practices in response to perceived climate change. The common practices included switching to non-farming activities (7%), engaging in casual labor (5%), rainwater harvesting (9%), mulching to reduce evaporation (4%), receiving the credit from the coffee cooperatives union (3%), planting hedge and shade tree to mitigate increased temperature because direct sun rays impact (5%), contouring/terracing to avoid soil erosion and to improve soil fertility (15%). Other responses included changing fertilizer application (2%) and planting trees (3%). On the contrary, 47% of the farmers responded to weather changes that they did not experience serious farming problems. Therefore, during extreme weather events, they did not take any coping or adaptation strategies. Table 4 shows the farmers in the Kigoma District's coping and adaptation strategies and practices.

Coping strategies

Coping strategies against low production experienced during extreme weather events, as depicted in Table 5, include switching to non-farming activities to extend household income, engaging in causal labor, and receiving the credit from the coffee cooperatives union. However, in most cases, the extreme weather events in the area did not impact coffee production because the main strategy during low production was switching to non-farm activities, according to some respondents.

Adaptation strategies

The farmers in the study area responded to the impacts associated with climate change and variability by implementing different adaptation measures to cope with the expected and unexpected rainfall variability. The strategies are mainly related to the adaptation of local people to the surrounding environment and local production systems. Therefore, the strategies to cope with changes and variations in rainfall differ depending on the farmers' knowledge and economic status. The adaptation strategies include rainwater harvesting, improving soil fertility, mulching to reduce evaporation, and terracing/contouring to avoid erosion. Other strategies include planting hedges and shading trees to mitigate increased solar brilliance, reducing temperature variations, and helping retain moisture. Respondents indicated that rainwater harvesting is effective and widely used as a coping mechanism to rainfall and water resource variability in the study area. The rainwater harvesting technique includes the construction of a water reservoir and the digging of shallow basins to collect run-off water.

Adaptation strategies have been advocated to potentially increase productivity in the face of climate change and variability. Majule et al. (2008) clearly indicated some adaptation measures that are more appropriate to address short-term impacts due to climate variability, with measures that are primarily used to address variability in the farming community. The IPCC and TAR (2001) also distinguish several types of adaptations that farmers in most African countries mostly use. Agricultural systems' adaptation to climate conditions is well documented (CAST 1992; Easterling et al. 1993; Kaiser et al. 1993). Moreover, good farming practices help to conserve soil and water and, in doing so, also make it easier to adapt to climate variability while at the same time lessening its impact. Studies on climate change (Boko and Niang 2007) suggest that coping and adaptation strategies to climate variability should be sustainable and environmentally friendly. A survey from these studies indicates that farmers in rural areas use temporary solutions that sometimes result in habitat changes and affect the surrounding environment.

Table 4. Farmers' perception of climate change and variability

	Frequencies	% of response
Farmers' perceptions on the definition of climate change and variability		
Climate variability as extended dry season due to shifting rainfall	70	58
Climate variability as decreases in rainfall	50	42
Farmers' perceptions on causes of Climate change and variability		
Deforestation and degradation of water resources is the primary factor of climate change and variability	114	95
Overgrazing and bush fire as the causes of climate change and variability	4	3
Climate change and variability as a result of breaking traditional rules laid down by forefathers	2	2

Table 5. Farmers' coping and adaptation strategies in the Kigoma District, Tanzania

Coping strategies	%	Adaptation strategies	%
Switching to non-farming activities	7	Rainwater harvesting	9
Engage in casual labor	5	Mulching to reduce evaporation	4
Cooperatives union credit erosion	3	Terracing/contouring to avoid	15
Reducing temperature variations	2	Tree planting	5

In conclusion, the global concern about climate change and its implication on agriculture, the most vulnerable sector to climate change, prompted the present study on assessing weather and coffee production trends in the Kigoma Highland District. The study has revealed that coffee production and rainfall in the area have decreased over 30 periods (1981-2010), and farmers are aware that agriculture production has decreased over time. At the same time, the climate has continuously been adversely changing over time. Data shows that rainfall has decreased over 30 years while temperatures have increased.

Consequently, farmers have developed and adopted coping strategies to combat drought and desertification in the area. Therefore, although rainfall and coffee production has been decreasing over the thirty years, this study concludes that; the decline in coffee production in the highland zone of the Kigoma District is not strongly attributed to the decline of rainfall and its variability. However, while the decline could be attributed to other factors, temperature, dry spells, and rainfall trends indicate that the study area is vulnerable to climate change and variability impacts.

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The impact of bushfires on animal abundance and diversity across land tenures in Miombo woodlands, Tanzania

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Abstract. *Matimbwi L, Madoffe SS. 2022. The impact of bushfires on animal abundance and diversity across land tenures in Miombo woodlands, Tanzania. Asian J For 6: 43-51.* Southern Africa is dominated by Miombo forests (woodlands), the world's largest savanna. The purpose of this research was to examine how bushfires affect mammalian populations in Miombo woodlands under various forest tenure systems. The data was gathered through household questionnaires, a probing question checklist for key informants, participant observation, Participatory Rural Appraisal (PRA) methods, and a field inventory. We enlisted the aid of the local communities in our analysis of the PRA data we collected. Quantitative and qualitative data and information were subjected to content and structural-functional analysis. Quantitative data was examined using Statistical Package for the Social Sciences (SPSS) software. Microsoft Excel was used to examine inventory data on animal stocks. The average number of mammals collected from each forest tenure system was compared using Analysis of Variance (ANOVA) to see if there were statistically significant variations. The variety of mammal species in various forest tenure systems was measured using the Shannon-Wiener Index (H). Based on the findings, agricultural activities (44.5%), charcoal production (21.1%), and wildlife hunting (18.9%) accounted for the vast majority of bushfires in Miombo woods. It was thought that illegal logging and honey collection were the only contributing factors. Mammal populations tend to be most significant in Central Governmental Forest Reserves, then in those of the Local Government, and finally in those of the Village Government. Mildly burned sections in the Central Governmental Forest Reserve had a diversity index of 3.2. In contrast, those in the Local Government Forest Reserve and the Village Forest Reserve had indices of 2.0. There was little difference in the diversity index values of the Central Governmental Forest Reserve (2.0) and the Village Forest Reserve (2.0) for moderately burned blocks and the Local Government Forest Reserve (1.6) for unburned blocks. The Central Governmental Forest Reserve had a diversity value of 1.5 for the severely burned blocks, the Village Governmental Forest Reserve had a value of 1.4, and the Local Government Forest Reserve had a value of 1.2. Like other mammals with a low fire escape rate, bushfires hit the rock hyrax particularly hard. As a result, it is suggested that the current management regimes of Local Government Authorities be strengthened to ensure enhanced local community participation with more effective law enforcement measures to save the woods from deterioration. Similarly, communities should be given access to financing and encouragement to pursue income-generating activities to lessen their reliance on Miombo woodlands.

Keywords: Africa, fires, forest, mammals, woodlands

INTRODUCTION

Forests covered an estimated 38.8 million ha (41% of the total land area) on the Tanzanian mainland in 2011 (FAO 2011a). The combined acreage of all wild and cultivated woods is called "forested." The Miombo woodlands are some of the world's largest unbroken savannas (Desanker et al. 1997). Even though current data on the provision of products and services is underestimated due to the lack of recording of other forest products, apart from timber, such as wild fruits, vegetables, herbs, thatch grasses, and other services such as catchments and biodiversity values, the contribution of these forests to the national economy is very high (URT 2002). MNRT (1998) estimates that more than 75 million Africans call the Miombo ecoregion home and that the woodlands there are directly responsible for the well-being of more than 40 million.

The Miombo is crucial to local economies but is at risk from bushfires (Chidumuyo 2002). Large and tiny organisms can be lost in forests threatened, and a decrease in forest productivity could be caused by fire (Gleason et al. 2013; Prasetya et al. 2017; Dickman and McDonald 2020; Prestes et al. 2020; Schwartz et al. 2020,2021; Feng et al. 2021), which is a constant danger in natural and artificial forests. Most Miombo woodland species see a decline in numbers during and immediately following fires. Many creatures and vegetation perish as individuals due to fire or suffocation. Others may survive the fire but may not fare as well due to a lack of food and shelter (UNEP/SARDC 2009). Of course, some mammals make it through fires, and, like plants, they have a wide variety of strategies for adaptation (Davies 2011). It's commonly believed that fire is bad for plants and animals, yet it can also positively affect specific ecosystems.

The only feasible method of decreasing fuels in forests and woodlands is the low-fire-intensity burning of litter and undergrowth during pleasant weather conditions (Viklund 2011). Mechanically removing litter and undergrowth is one alternative strategy that has been proposed, but it is neither practical nor cost-efficient. Fire can help with land management by reducing fuel loads before they become a problem. Tasks linked to clearing brush and trimming trees, such as keeping trails clear. Fire buffers can be quite helpful in preventing and mitigating the damage caused by natural bushfires (Stephens 2010). The seeds of some plants can only be dispersed if exposed to high temperatures or smoke. It indicates that fires are essential to the survival of some plant species and their ability to reproduce (Davies 2011).

Wildfires significantly impact the economies of many eastern and southern African countries, including Tanzania. Although the lack of long-term fire monitoring programs currently hinders attempts to estimate the spatial distribution and size of wildfires in Tanzania, the limited number of available information sources suggests that fire is a pervasive phenomenon. Around 12% of Tanzania's land was lost to fires every year between 2001 and 2007 (Archibald et al. 2010), placing the country fourth in the Southern African Development Community (SADC). About 65,000 hectares (ha) of forests and other forested areas are lost annually to forest fires (MNRT 2009). More than seventy-five percent of these fires happen in Miombo woodlands, followed by forest plantations (20%) and nature reserves (5%) (MNRT 2009).

Tanzania's forests are administered by three fire management authorities: the national, provincial, and community levels (MNRT 2009). The current study is to create data that could aid management decisions by determining the impact of bushfires on animals in Miombo woodlands under different forest tenure regimes, such as those administered by the Central, Local, and Village Government Authorities.

It is generally accepted that the increased frequency of bushfires in the Miombo woodland of Kilombero District, Tanzania, can be attributed to the influx of cattle herders and farmers from other areas searching for pastures and farming land. Due to its ability to alter the post-fire microclimate and the activity of soil biota, fire has both detrimental and beneficial direct effects on conservation. There is a vast range of variation across organisms in their reactions to and resilience against fire (Zohlo 2005).

The objectives of this research are (i) to identify the factors that contribute to the occurrence and severity of bushfires across a range of Miombo woodland tenure types, (ii) to determine how bushfires have affected the kind and number of mammals in the research areas, (iii) to assess and report on the performance of fire management techniques used in each of the study forests.

MATERIALS AND METHODS

Study area

Location

Three Miombo woodland reserves in Kilombero District, Tanzania, were selected for this research. Ihanga FR (under the District council) is located between longitude 080 25" South and longitude 36020" East, and Itundufura FR (under the Village government) is located between longitude 08018" south and latitude 360 06" East. Nyanganje FR (under the Central government) is located between 07° 56′ and 8° 4′ South and longitude 36° 39′ and 36° 50′ East, approximately 15 km north-east of Ifakara town. The district covers 14,918 square kilometers and is located at an elevation of between 300 and 1,700 meters.

Climate

In the Kilombero District, annual average rainfall typically ranges from 1200 to 1850 millimeters. The district experiences a bimodal rainfall pattern with lengthy wet seasons from March to May and short rainy seasons from October to December, with average daily temperatures between 26°C and 32°C.

Flora and fauna

In most cases, environmental factors, such as soil conditions and dynamic events like fire, determine the species mix of an area (Frost 1996). For example, tree species include *Brachystegia boehmii, Brachystegia bussei, Julbernardia globiflora, Brachystegia spiciformis, Pseudolachnostylis maprouneifolia, Pterocarpus angolensis,* and *Dalbergia melanoxylon* can be found in the Miombo woodland (Backe'us et al. Besides those mentioned above, the same woodland area in Kilombero District is home to a wide variety of other animals, including elephants (*Loxodonta africana*), buffaloes (*Syncerus caffer*), lions (*Panthera leo*), spotted hyenas (*Crocuta crocuta*), rock hyraxes (*Procavia johnstoni*), greater kudus (*Tragelaphus streps*) (Frontier Tanzania 2003).

Human population and economic activities

According to the population and housing census of 2012, Kilombero District had a population of 321,611 people, of which 169,397 were males and 162,214 were females. The growth rate is 3.4% above the National annual average of 2.1%. The main ethnic groups are Wapogoro, Wandamba, Wabena, Wambunga, and several others in small proportions. On the other hand, the main economic activities conducted by the majority of the local people include crop farming, livestock keeping, and petty trading.

Methods

Reconnaissance survey

It was essential to perform a reconnaissance study of the area before beginning the actual data-gathering procedure to pre-test the data collection gear and make any necessary adjustments to ensure they were suitable for the local conditions.

Data collection

A variety of sources, including the Kilombero District Catchment Project Office, Kilombero District Council Officials, the villagers of Kiberege, Lungongole, and Ihanga who live near the forest, and Non-Governmental Organizations, were consulted to compile the biophysical and socio-economic data used in this study. In addition, different secondary sources were tapped for more data.

Biophysical data

Field inventories were used to compare forest reserves managed by different levels of government, including the

Nyanganje Forest Reserve, the Ihanga Forest Reserve, and the Itundufura Forest Reserve, to determine differences in mammal species composition and distribution. Two local experts who understood Kilombero's fauna and I made up the survey team. The district game officer was also on board. All forest tenures were split into thirds, with each block subjected to varying degrees of fire suppression and distinct categories: minimal damage, moderate damage, and severe damage. Less than a quarter of the former's semi-evergreen forest was destroyed in fires. Open Miombo and grasslands predominated in the severely burned area, while closed Miombo prevailed in the moderately burned area, with between 25 and 50% of its area burned. Villagers' accounts of past wildfire patterns, reports from the District Forest Officer and District Game Officer, and our observations from the field all contributed to pinpointing these locations.

The following formula obtained the number of plots:

$$N = (TA*Si)/ (Ps*100)$$

Where: N=number of sampling plots, TA=total area of the forest/block, Si=Sampling intensity, and Ps=plot size. Each study forest was given a potential sampling intensity of 0.01%.

Along the transect that followed the outline of each block, strips (plots) 10 m by 30 m were set up. There was an estimated 6-kilometer distance between each transect. Each transect began at a different location, chosen at random and geo-referenced using a GPS for subsequent reevaluation; compass use was optional but helpful. In this study, each plot and transect were placed 200 meters from one another. The locations of the plots within each block were randomized.

Direct field observations of animals and indirect assessments based on feces, footprints, mammal damages, and sounds of different mammals were used to determine the species diversity and abundances in each plot (indices). For the most accurate and detailed population statistics, small mammals like rodents were captured in a live trapping technique (Sherman trap). Peanut butter was used as bait to lure the rodents into the traps. The group silently traversed the transects, tallying the number of mammals and indices on both sides. Expertise and caution were used to keep from counting the same thing twice. Moreover, to get a good average, counting was done along each transect twice daily, in the morning, in the evening, and every other week. Wildlife experts and residents from the surrounding area helped narrow down the possible mammal species. Large quantities of mammal feces and mammal damage made estimating the number of mammals easier. Estimating mammalian populations was based on the correlation between dung quantity and damage severity. The presence of more tracks and/or a noisier environment suggested the presence of more mammals.

Socio-economic data

Villages adjoining the study forests were surveyed to collect socio-economic data. Ihanga, Sagamaganga, and Kiberege were chosen because they are close to protected forests: Ihanga, Nyanganje, and Itundufura. Information was also collected from local government agencies and Non-Governmental Organizations (NGOs) in the Kilombero District. A Participatory Rural Appraisal (PRA) was conducted before the questionnaire survey. Each PRA consisted of seven to eight participants and collected data through focus groups (Lusambo 2009). Discussions in smaller groups were selected to elicit insights from participants of varying ages, genders, and professional backgrounds (Appendix 2). Kessy (1995) suggests using the PRA as a research tool to spark conversations among rural residents about specific subjects of interest.

Household heads in the research villages were given structured questionnaires with both open-ended and closed-ended questions to collect data on factors such as species abundances, causes of bushfires, areas burned, fire occurrence frequencies, control/measures taken, and fire reduction techniques (Appendix 1). In each town, 30 random households were chosen. As long as the features of the research population are adequately removed, a sub-sample size of 30 from a single observation unit is considered appropriate, as stated by Bailey (1994).

Data analysis

Biophysical data

Mammal abundance and diversity data gathered from a field inventory were analyzed using Microsoft Excel software. Mammal populations in forest reserves have been summarized by species and presented in Table 4. In addition, mammal abundances were compared between forest reserves using Analysis of Variance (ANOVA), specifically between the Nyanganje Forest Reserve, the Ihanga Forest, and the Itundufura Forest Reserve.

The number of mammal species in each forest management system was quantified using the Shannon-Wiener Index (H). In most cases, the figure is between 1.5 and 3.5, although it can go as high as 4.5 in rare cases (Kent and Coker 1992). The following formula is used to calculate the index:

$$H' = -\sum_{i=1}^{s} pi * \ln pi$$

Where;

H'' Diversity index

n_i = The number of individuals in species, I = the abundance of species i.

S =The number of species, also called species richness.

pi = Proportion of individual species i^th^ and ln = Natural logarithm

Socio-economic data

There was an effort to use both descriptive and inferential statistics. Cross-tabulation was used to conduct the descriptive statistical analysis, and measures of central tendency (mean and standard deviation) and frequency and percentage distributions were determined. The data were analyzed using Statistical Package for the Social Sciences (SPSS). The socio-economic data gathered from the survey of households' completed questionnaires were coded and converted into an analyzable format.

Qualitative data or information was processed using a content analysis approach. For example, content analysis was used to dissect interviews and focus groups for recurring topics and patterns of conversation. It aided in discerning the respondent's beliefs and perspectives. According to Kajembe (1994), structural-functional analysis involves explaining social facts by how they relate to one another within the social system and the physical environment.

RESULTS AND DISCUSSION

Social characteristics of the respondents

The age distribution, gender, and marital status

Respondents with ages between 31 and 40 made up nearly half (49%) of the total, with those between 18 and 30 years old making up nearly a quarter (22%) of the sample (Table 1). If most respondents are between the ages of 31 and 40, there is a sizable population of young, active people in the area who can help out financially. A person's age influences income-generating endeavors because it influences their level of experience, wealth, and decision-making. In most cases, people over 60 who respond to a survey are not economically active. Therefore they do not engage in activities that could earn them money (Ishengoma 1998). Forest fires may become more common if people engage in economically beneficial activities like farming and hunting.

Men and women have different social roles depending on their gender. It alludes to the nature of their bond and the societal construction of that bond (Balton 1994). The differences in how men and women are expected to act are primarily the result of social conditioning. That influences what they do and how they act inside a given group (Katani 1999). As a result, gender as a social relation significantly affects men's and women's roles in the administration and protection of ecological systems (Balton 1994).

About two-thirds (74.4%) of the participants were male, while about a quarter (25.6%) were female, according to the results (Table 1). It indicates the conventional gender roles in traditional African communities, where men head most households.

A large proportion of responders (84%) were widowed, separated, divorced, or single (16%) (Table 1). It reflects the widespread notion in African societies that a team of two people can accomplish more than one person working alone, and that married couples are more likely to have a more prosperous home than single people (Muywanga 2004). In terms of household composition, however, married and unmarried respondents represent adults.

Level of education, residence duration, and economic activities

As a means of sharing information and fostering new perspectives, education is crucial to a society's economic and social growth. Knowledge and the ability to think for oneself are only some of the many benefits of a good education. It was hypothesized that as education levels rose, more respondents in the study area would adopt the sustainable land use practices advocated by Participatory Forest Management. It is because those with higher levels of education have greater access to the technical information that enables them to participate in innovations than those with lower levels of education. The respondent's time in school was used as a proxy for their degree of education. Table 1 shows that 83% of respondents have completed elementary school, 12% have completed high school, and roughly 4% have never attended school. With an elementary education as their highest level of education, most responders may have some understanding of conservation issues.

In addition, the findings showed that 46% of respondents had been residents of the research area for more than 20 years, followed by 38% for 11-20 years and 17% for ten years or less (Table 1). It suggests that most respondents have a good grasp of the current fire situation and its effects and potential solutions to the problem of forest fires in the area.

Respondents primarily engaged in farming and small business, with a negligible percentage engaged in other economic activities (Table 1). Farmers made up the vast majority (86.7%), followed by those working in related small businesses (5.6%) and those involved in keeping livestock (3.3%). Cattle keepers use Miombo woodlands as grazing pasture for their livestock due to the floristic composition of Miombo woodlands, which has led to deforestation (Abdallah 2001; Kajembe and Kessy 2004). Many Miombo livestock farmers utilize fire to stimulate grass growth for their animals. Similarly, farmers use fire to reduce biomass when setting up farms, and this fire occasionally spreads to neighboring forests, causing damage. According to data collected by the District Forestry Office in 2011 (DNRO 2011), farmers are the primary perpetrators of forest fires in the district, followed by those who keep cattle and pasture animals.

Ethnicity and household size of respondents

Table 2 shows that Ngindo households comprised 19% of the households surveyed, followed by Ngoni families at 12% and Ndamba households at 11%, with the remaining 58% belonging to tribes other than these three. The Ngindo, Ngoni, and Ndamba prefer to live in the heart of a village. In contrast, agro-pastoralists prefer to live on the outskirts, where they can more easily access grazing and farming area and where they can also use fire to make the land more palatable for livestock.

More than half (45.6%) of the homes had six or more persons, which is higher than the national average of five people (URT 2012). Regarding household composition, families with three to five members accounted for 16.7 %. A household's ability to generate revenue and enhance its standard of living is strongly influenced by the size of its family, but large families may hasten the decline of forest ecosystem services.

Table 1. Characteristics of respondents in Ihanga, Kiberege, and Sagamaganga Villages, Kilombero District, Tanzania

Characteristics/ variable	Frequency			%
	Kiberege	Ihanga	Sagamaganga	
Gender				
Male	27	21	19	74.4
Female	14	8	7	25.6
Age group (in years)				
18-30	7	6	7	22.2
31-40	11	30	13	48.9
41-50	5	6	4	16.7
51-60	2	2	1	5.6
Above 60	3	2	1	6.7
Marital status				
Single	3	4	2	10.0
Married	26	30	20	84.4
Divorced	0	2	1	3.3
Widow	2	0	0	2.2
Education level				
Non-formal education	2	1	1	4.4
Primary education	15	40	20	83.3
Secondary education	1	3	7	12.2
Residence duration				
1-10	4	16	14	37.8
11-20	5	5	5	16.7
Above 20	22	11	12	45.6
Occupation				
Farmers	18	25	25	86.7
Petty trade	2	1	2	5.6
Livestock keeping	1	1	1	3.3
Others	2	1	1	4.4

Table 2. Ethnicity and household sizes of respondents

Characteristics/ variable	Frequency	Percentage
Ethnicity		
Ngindo	21.1	19
Ngoni	13.3	12
Ndamba	12.2	11
Other tribes	43.4	58
Size of the household		
1-2	34	37.8
3-5	15	16.7
Above 5	41	45.6

Causes of bushfire in Miombo woodlands

The causes of bushfires in Miombo woodlands are depicted in Figure 1. The top causes include agricultural preparation (44.5%), charcoal manufacturing (21.1%), hunting (10%), cigarette remnants (5.6%), illegal logging (4.4%), local beliefs (4.4%), honey harvesting (1.1%), and miscellaneous causes (8.9%). As a result of the region's strong population growth and low GDP per capita, slash-and-burn agriculture in the Miombo zone is widely practiced for subsistence (Chidumayo 1997; Luoga 2000). These findings corroborate those of FAO (2011b), which found that unchecked human activities, such as the preparation of agricultural fields, are the leading cause of bushfires in Miombo and grassland ecosystems. Wildlife hunters are another vital contributor; they may intentionally light fires to clear regions of biomass or lure game back to places that have been burned so they can easily capture them in the regenerating grass. Wildfires on the Tanzanian mainland can also be caused by honey-seeking and collecting. When gathering honey, some beekeepers set fires to smoke the bees, but they don't always put out the fires afterward, which might cause unintended or accidental fires. In addition, livestock farmers will intentionally burn grasslands to increase forage quality and, in some cases, to get rid of parasites like ticks and tsetse flies.

There is evidence that charcoal production in Miombo woodlands is a significant human activity that degrades forests, especially within a 200-300 km radius of major urban sites. To prevent unintentional fires from pedestrian smokers and arson, forest plantations, game reserves, and national parks may engage in activities such as mining, pit sawing, and controlled burning (regulated biomass burning) at the start of the dry season. Despite this, most fires are set by individuals for the reasons listed above. However, some people do ignite fires only for amusement (cultural beliefs, e.g., *in Tanzania, some tribes believe that if one starts the fire and it ends up gutting and spreading to a large extent, such a person is bound to live a long life*).

Bushfire occurrence and intensities in Miombo woodlands

Instances of wildfires were recorded from 2005 to 2011 in Table 3. The results demonstrated the frequency and intensity of fires vary yearly due to the multiple elements that contribute to bushfires, such as the forest biomass, the causes of fires, and the weather. VFR typically had the fewest fires and the lowest fire intensities, while LGFR typically had the most. The number and strength of CGFR were about average.

The degree to which people felt ownership of their land (as measured by tenure and financial incentives) may have contributed to the number and severity of fires. The Food and Agriculture Organization of the United Nations (2010) states that many factors have a role in whether or not a government decides to implement tenure reform. Changing tenure patterns with more variety is essential to improve circumstances for achieving forest management goals. The goals of saving mammalian populations and diversity are related to Sustainable Forest Management and improved economic consequences.

Results demonstrated statistically significant differences between the means of blaze occurrences in the CGFR and the VFR, with the difference between the two being 0.956 ± 0.337 and 1.556 ± 0.334, respectively ($p < 0.05$), indicating a higher frequency of bushfire occurrences in these forest reserves. Miombo woodlands are home to a wide variety of mammal species, so all forest reserves must work to prevent bushfires. Better strategies for managing wildlife and, by extension, minimizing the negative impact of wildlife on natural resources can be attained by encouraging local and higher governmental authorities to adopt community development plans, enforce regimes to emphasize risk mitigation, and fire-smart principles (British 2010).

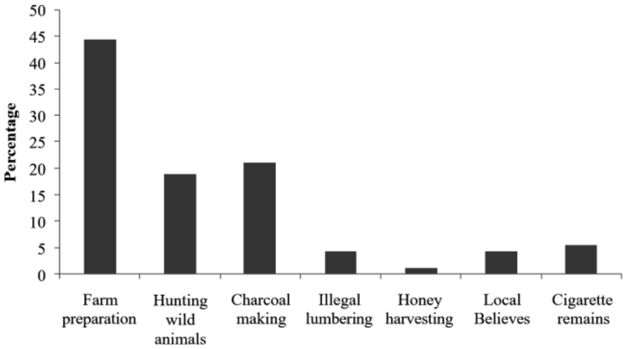

Figure 1. Causes of bushfire in Miombo woodlands

Table 3. Bushfire intensities in Miombo woodlands

Year	management regime	Number of fires occurred	Fire intensity
2005	Nyanganje FR	1	Low
	Ihanga FR	2	Moderate
	Itundufura FR	1	High
2006	Nyanganje FR	2	High
	Ihanga FR	5	High
	Itundufura FR	1	Moderate
2007	Nyanganje FR	3	Moderate
	Ihanga FR	6	High
	Itundufura FR	1	Moderate
2008	Nyanganje FR	1	Low
	Ihanga FR	3	High
	Itundufura FR	2	Moderate
2009	Nyanganje FR	2	High
	Ihanga FR	1	High
	Itundufura FR	1	Moderate
2010	Nyanganje FR	2	High
	Ihanga FR	4	High
	Itundufura FR	2	Low
2011	Nyanganje FR	1	Low
	Ihanga FR	2	High
	Itundufura FR	2	Low

Bushfire management strategies in Miombo woodlands

Even though Miombo woodlands employ a multitude of wildfire control mechanisms to prevent bushfires from occurring, fire still poses a hazard to the survival of mammals there. The use of by-laws (23.3%), conducting bushfire campaigns (6.7%), conducting forest patrols (34.4%), choosing VNRC members to serve as critical implementers of participatory forest management (25.6%), conducting forest patrols (34.4%), and conducting fire management teams (10%) are among these strategies (Figure 2). In addition, the Strategic Bushfire Management Plan (SBMP) outlines the strategies and concrete steps communities, and the government can take to manage bushfires better and lessen the damage. Those damages would cause property, human life, and the environment need to manage now and in the future, including potentially catastrophic events (Corbell 2009). However, 34.4% of respondents to this poll claimed no fire management plans in their villages, while 65.6% said there were fire management procedures in the area. It demonstrates that the local communities near forests do not effectively adopt the policies, which results in poor forest conservation.

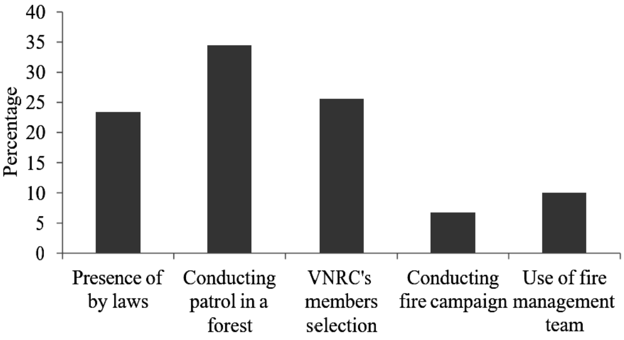

Figure 2. Bushfire management strategies in Miombo woodlands

PFM was used as a fire management strategy in the Miombo woods. The results showed that 63.3% of the households believed PFM significantly reduced the number of fires in the Kilombero Forest Reserves. However, inadequate institutional capacity in terms of technical and professional employees and financial resources, according to FAO (2011c), failed to manage the fires appropriately. In light of this, it is important to promote community involvement, engagement, and collaboration in integrated fire management. About 32.2% of the households said that PFM does not help to reduce fire occurrences, while 4.4% said they knew nothing about PFM (Figure 3).

According to the statistical analysis, there is no statistically significant difference ($p < 0.05$) between the fire suppression tactics used in the forest under the CGFR and LGFR (0.00 ± 0.125) and VFR and CGFR (0.033 ± 0.125), respectively. It demonstrates how different management regimes for forests have varied fire management practices.

Status of mammals due to forest fire

About 71% of respondents claimed that fire-related extinctions of mammal species in the Miombo woodlands had occurred, whereas 29% claimed that mammal species had not changed. Forest fires change the energy, nutritional, and water fluxes between the soil, plants, and atmosphere by reducing plant biomass and litter. These changes could affect the vegetation's productivity and long-term nutrient status, ruining other mammals' habitats (Frost 1996). Additionally, fires cause individual creatures to perish, injure or destroy living tissues, altered growth and reproduction rates, alter resource availability and utilization, and change competitive and other connections between organisms. Mammals are also vanishing because of hunting, and some are escaping from their specialized habitats.

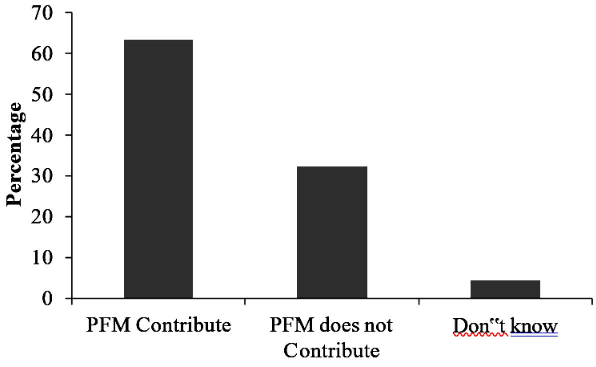

Figure 3. Contribution of PFM in alleviating bushfire problems

Effect of fire regimes on mammal species diversity in different forest tenure

In moderately burned forest blocks, the Shannon Wiener diversity index value was 2.0 under the control of the Central Government (Nyanganje Forest Reserve) and 1.6 under the control of the Village Government Authority (Itundufura Forest Reserve) (Figure 4). For badly burned blocks, the CGFR (Nyanganje Forest Reserve), Village Government Authority (Itundufura Forest Reserve), and Local Government Authority (Ihanga Forest Reserve) had diversity values of 1.5, 1.4, and 1.2, respectively. In the CGFR (Nyanganje Forest Reserve), under VFR (Itundufura Forest Reserve), and Forest Reserve under Local Government Authority (Ihanga Forest Reserve), respectively, the Shannon Wiener index for blocks that had just moderately burned was 3.2, 2.0, and 1.6.

Overall, the Shannon Wiener diversity index values (H) showed that the CGFR had the maximum diversity, followed by the VFR. In contrast, the LGFR had the lowest diversity (Figure 4). These results are consistent with those made by Zahabu (2008), who found that managed forests had a higher species diversity than unmanaged ones. In Tanzania, the woods managed by the Central Government are typically better than those by LGFR. Because of a combination of law enforcement and nearby local populations' participation in forest resources, species variety is more significant in the woods managed by the Central Government. The most significant concern to the Eastern Arc Mountain forests, according to Madoffe and Munishi (2005), is wildfire, which can have a catastrophic impact on biodiversity and water conservation. According to the Shannon Index, there was no discernible difference (p 0.05) in how bushfires affected the mammal species found in forest tenure regimes. The roughly parallel fire regime lines suggest that bushfires in Miombo woodlands under various forest tenures have more or less identical effects on mammals.

Effect of fire regime on mammals abundance under different forest tenure

The number of animal species found in the forests under various tenures is depicted in Figure 5. Mammal abundance is directly impacted by forest tenure and fire management practices. In the mildly burnt site, the distribution of mammals in terms of their numbers per hectare revealed that the numbers were 45, 22, and 20 for CGFR, LGFR, and VFR, respectively. The corresponding CGA, LGA, and VFR numbers for a moderately burned site were 28, 23, and 24. Mammal counts for the severely burned site were 25, 23, and 10 for CGFR, VFR, and LGFR, respectively. Mammal populations in the VFR and LGFR were often substantially lower than those in forests owned by the Central Government. Due to improved habitats in the CGFR as a result of better management, the number may be higher. The Central Government has a consistent budget, more patrols, and better law enforcement (Madoffe and Munishi 2005).

Mammals leave the LGFR for protection because the surrounding communities have significantly encroached on the Local Government forests, and they don't feel safe. In addition, protecting forests overcomes rural poverty and helps to ensure the long-term survival of mammals and the trees that serve as their habitat (Penn 2010). A total of 16 animal species were found in the three studied forests. Table 4 lists the dominant mammal species found, including *Kobus vardoni*, *Madoqua kirki*, *Colobus angolensis sharpie*, *Phacochoerus africanus*, and Rodents. With roughly 43.3% of all species counted, the *Colobus angolensis sharpie* species dominate CGFR, LGFR, and VFR forests.

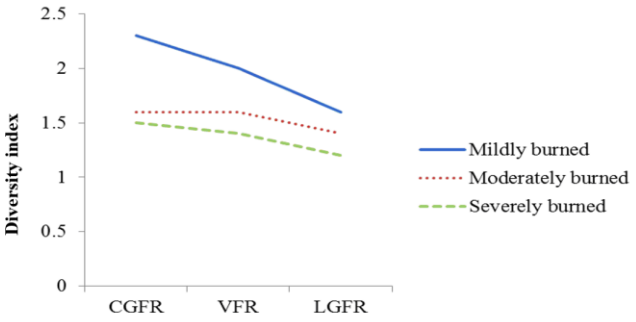

Figure 4. Effect of fire regime on mammal species diversity in different forest tenure, Kilombero District, Tanzania

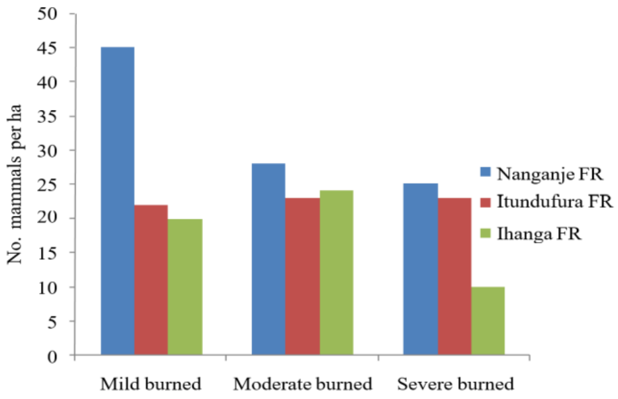

Figure 5. Mammals abundance in forests under different tenure

Table 4. Mammals species in different forest tenure, Kilombero District, Tanzania

Forest tenure, Fire regime	**Common name**	**Scientific name**	**No. of mammals**
CGFR			
Mild	Puku	*Kobus vardoni*	1
	Buffalo	*Syncerus caffer*	5
	Elephant	*Loxodanta africana*	3
	Reedbuck	*Redunca arundinum*	2
	Eland	*Taurotrugus oryx*	1
	Colobus monkeys	*Colobus angolensis sharpie*	12
	Hartebeest	*Alcelaphus bucelaphus lichensteinii*	3
	Sable antelope	*Hippotragus niger*	1
	Waterbuck	*Kobus ellipsiprymnus*	1
	Zebra	*Equus quagga*	1
	Rock hyrax	*Procavia johnstoni*	2
	Dik dik	*Madoqua kirki*	4
	Lion	*Panthera leo*	1
	Warthog	*Phacochoerus africanus*	2
	Rodent	Rodentia (1)	5
	Greater Kudus	*Tragelaphus strepsiceros*	1
Moderate	Elephant	*Loxodanta africana*	2
	Colobus monkeys	*Colobus angolensis sharpie*	5
	Waterbuck	*Kobus ellipsiprymnus*	1
	Rodents	Rodentia (2)	3
	Rock hyrax	*Procavia johnstoni*	2
	Dik dik	*Madoqua kirki*	1
Severely	Elephant	*Loxodonta africana*	2
	Colobus monkeys	*Colobus angolensis sharpie*	37
	Waterbuck	*Kobus ellipsiprymnus*	8
	Rock hyrax	*Procavia johnstoni*	6
	Dik dik	*Madoqua kirki*	4
	Warthog	*Phacochoerus africanus*	6
	Rodents	Rodentia (3)	12
VFR			
Mild	Elephant	*Loxodanta africana*	2
	Reedbuck	*Redunca arundinum*	2
	Colobus monkeys	*Colobus angolensis sharpie*	7
	Hartebeest	*Alcelaphus bucelaphus lichensteinii*	2
	Rock hyrax	*Procavia johnstoni*	2
	Dik dik	*Madoqua kirki*	2
	Lion	*Panthera leo*	1
	Warthog	*Phacochoerus africanus*	2
Moderate	Colobus monkeys	*Colobus angolensis sharpie*	7
	Waterbuck	*Kobus ellipsiprymnus*	3
	Rock hyrax	*Procavia johnstoni*	4
	Dik dik	*Madoqua kirki*	5
	Warthog	*Phacochoerus africanus*	4
Severely burned	Colobus monkeys	*Colobus angolensis sharpie*	12
	Waterbuck	*Kobus ellipsiprymnus*	1
	Dik dik	*Madoqua kirki*	2
	Rodents	Rodentia (4)	4
	Rock hyrax	*Procavia johnstoni*	2
	Warthog	*Phacochoerus africanus*	2
LGFR			
Mild burned	Colobus monkeys	*Colobus angolensis sharpie*	7
	Hartebeest	*Alcelaphus bucelaphus lichensteinii*	4
	Rock hyrax	*Procavia johnstoni*	2
	Dik dik	*Madoqua kirki*	2
	Warthog	*Phacochoerus africanus*	4
	Rodents	Rodentia (5)	9
Moderate	Hartebeest	*Alcelaphus bucelaphus lichensteinii*	2
	Waterbuck	*Kobus ellipsiprymnus*	3
	Warthog	*Phacochoerus africanus*	2
	Rodents	Rodentia (6)	3
Severely	Colobus monkeys	*Colobus angolensis sharpie*	9
	Hartebeest	*Alcelaphus bucelaphus lichensteinii*	3
	Waterbuck	*Kobus ellipsiprymnus*	2
	Rodents		10

The study demonstrated how different forest management systems have very different distributions of animal species. The widespread occurrence of these species may have been caused by wildfires, which are not favorable to their continued existence. Rodents and monkeys, who have strong fire escape rates, were not significantly impacted by fire, although sluggish/slow animals like rock hyrax may have been. Fire may also indirectly affect mammals, especially if it clears out habitats and destroys their food sources and niches. While elephants and giraffes need tall trees or plants to eat on and for shade, some species, like lions, need tall grass to hide from their prey. In contrast, a temperate forest might support green grass growth, which would favorably affect the environment for population expansion.

In conclusion, the study examined the impact of different forest tenure systems on the abundance of animals in Miombo woods. The following conclusions are drawn from the study's results. (i) The study unequivocally shows that agricultural preparation, charcoal production, and wild animal hunting are the primary causes of bushfires in Miombo woodlands. Cigarette ashes, illegal wood harvesting, folklore, and honey gathering also cause some fires. (ii) It was discovered that CGFR had the most diversity of mammals, followed by VFR, while LGFR had the least diversity. Similar numbers of mammals were present in areas that had been burned lightly, moderately, and least in areas that had been severely burned. (iii) The discrepancies in the numbers of mammals found in the various forest regimes can be attributed to differing local community involvement and strict law enforcement. It indicates that conservation is most successful in the CGFR, then the VFR, and least effective in the LGFR. (iv) Several fire control measures, including patrol, PFM, and law enforcement, are used in the research region but only in the CGFR. (v) In addition, social and economic characteristics, particularly the respondents' education level, gender, and length of residency, had a favorable, significant impact on forest conservation, particularly in reducing fire incidences.

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