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Rice field in Maros Karst Area, Indonesia; photo by CIFOR-ICRAF

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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.

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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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Ecological change detection in PT. Semen Gresik Rembang, Indonesia (limestone mining) activities between 2016 to 2022

ULFI HANUM[1], DIANTI[1], ROSI NUR SAFITRI[1], VANIA MAHARANI RIZKY PRATIWI[1], WAHYU GILANG HERMAWAN[1], MUHAMMAD INDRAWAN[1], AHMAD DWI SETYAWAN[1,2,♥]
[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com
[2]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

Manuscript received: 18 November 2023. Revision accepted: 3 July 2024.

Abstract. *Hanum U, Dianti, Safitri RN, Pratiwi VMR, Hermawan WG, Indrawan M, Setyawan AD. 2024. Ecological change detection in PT. Semen Gresik Rembang, Indonesia (limestone mining) activities between 2016 to 2022. Intl J Trop Drylands 8: 59-68.* Limestone mining, such as at the PT. Semen Gresik Rembang (Persero) Tbk in Rembang District, East Java Province, Indonesia, impacts long-term environmental changes. One way to minimize environmental impacts due to mining activities is through remote sensing and Geographic Information Systems (GIS) to determine the dynamics of landscape management. This study aims to assess ecological changes due to the cement industry or limestone mining activities in Rembang between 2016 to 2022, the assessment was carried out by considering the dynamics of land use-land cover (LULC), and measuring the emergence of water bodies and the dynamics of vegetation productivity. The data used includes Landsat 7 ETM+ satellite image data in 2016 and three Landsat 8 OLI/ TIRS satellite image data in 2018, 2020, and 2022 with a 30 m spatial resolution. Therefore, satellite image data is collected before image processing, including correction, band merging, and cropping. The maximum likelihood image classification technique was used to analyze the dynamics of land use, land cover, and the growth of water bodies. Changes in vegetation productivity were analyzed with NDVI. In the LULC analysis, an accuracy test has been conducted with satisfactory results of more than 0.81. In the occurrence of water bodies with LULC analysis, it is known that there is a possible occurrence of water bodies in the form of ex-mining ponds. During the vulnerable years of 2016 to 2022, it is known that the area of the water body increased by 5.26 hectares. The vegetation productivity results show that those area's productivity is improving; the increase in water body cover is associated with decreased vegetation land cover by 18.58 hectares and open land cover by 8.71 hectares. The increase in mining land coverage between 2016 and 2022 is 38.07 hectares; meanwhile, the increase in built-up land area from 2016 to 2022 also increased by 15.88 hectares. Thus, remote sensing and GIS can be used to determine the dynamics of landscape management in an area.

Keywords: Land cover change, maximum likelihood classification, NDVI, remote sensing, vegetation productivity

INTRODUCTION

Indonesia possesses abundant natural resources that are crucial for human existence. These resources can be classified into two categories: renewable and non-renewable natural resources (Astuti and Simandjuntak 2018). Renewable natural resources are resources that can be replenished at a relatively fast rate, either through natural processes or human-made technology. Non-renewables are natural resources that can be regenerated, but the process takes a significant amount of time (Pongtuluran 2015). Raw materials and minerals, including metals, coal, and karst rock, are examples of non-renewable natural resources (Risal et al. 2017).

Activities in the utilization of non-renewable natural resources are mining activities (As'ari et al. 2019). Mining is one of the natural resource utilization activities that support the country's economic development due to its role as a resource provider that is indispensable for the economic growth of a country (Ericsson and Löf et al. 2019). Along with the times, the demand for mining products in the future is increasing (Tabelin et al. 2021). This has led to the growth of mining companies in Indonesia because it has a huge attraction for investors (Sutomo et al. 2020).

One of the mining companies in Indonesia is PT. Semen Gresik Rembang (Persero) Tbk, a state-owned company that produces various types of cement and strongly desires to mine karst rocks as raw material for cement (Hidayatullah et al. 2016; Dharmawan et al. 2020). The increasing demand for cement raw materials has encouraged this company to build a new cement plant in Rembang District, Central Java (Wasito and Syaikhudin 2020). Mining activities pose a high risk to the environment, both the biological, physical and social environments (Mohsin et al. 2021; Haddaway et al. 2022). Mining activities impact environmental changes, such as geological changes, namely soil movement, collisions with mining cavities, aquifer deformation, and other negative impacts (Simion et al. 2021). Karst areas will be vulnerable to rocks collapsing due to natural conditions. Failure to exercise caution and disregard for the environmental fragility might result in the destabilization of karst rocks by the utilization of excessive vibrations in mining operations (Wei et al. 2023). Karst mining has the potential to diminish the amount of water and cause contamination of groundwater in karst water systems (Fang and Fu 2011). These alterations will have long-term repercussions on the ecosystem, including degradation of flora, creation of sinkholes, soil erosion, flooding, and contamination of soil and water. Even after restoration, if not done appropriately, these harmful impacts will persist (Agboola et al. 2020). According to the Law of the Republic of Indonesia Number 32 of 2009 Article 1 Number 16 (UU RI No. 32/2009; Wicaksono 2022), concerning Environmental Protection and Management described that "Environmental destruction is people's action who cause direct or indirect in the biological, physical, and/or chemical properties changes of the environment that exceeds the standard criteria for environmental damage."

Dynamic landscape management is a method that can be employed to reduce the environmental effects of mining activities (Saining et al. 2023). Landscape management is a comprehensive endeavor that involves organizing and utilizing the environment's upkeep, conservation, regulation, and enhancement to create a landscape that is advantageous to both humans and other organisms (Arroyo-Rodríguez et al. 2020). An effective method for monitoring short-term changes in the landscape involves evaluating the fluctuations in water bodies and vegetation over a period of time. These changes can yield significant data on enduring geological phenomena such as land subsidence, sinkhole development, and water table dynamics, as well as their environmental consequences (Padmanaban et al. 2017). Assessing the geological changes in active mining and reclamation regions is significantly influenced by changes in vegetation productivity (Vorovencii 2021).

The Geographic Information System (GIS) techniques and remote sensing are the monitoring tools to assess landscape dynamics, both long-term and short-term (Erener 2011; Ranjan et al. 2022; Li et al. 2024). This technique is highly efficient compared to other techniques because it does not require expensive equipment and shortens research time and data processing (Orimoloye and Ololade 2020). Landsat 8 images with 30 m resolution are excellent for monitoring the health of vegetation in mining areas (Erener 2011). Multispectral satellite imagery in this technique allows for detecting landscape changes over time (Wijaya 2015). This technique can also be used in monitoring and assessing mining impacts on the landscape and environment and associated geological changes and vegetation productivity dynamics. The Normalized Water Body Difference Index (MNDWI) and Normalized Difference Vegetation Indeks (NDVI) time series are used to identify and monitor rehabilitation progress and inform reclamation success (Erener 2011). The accuracy value in monitoring land use/land cover dynamics using this technique is overall above 91.55% (Owolabi 2020). This research aims to assess the dynamics of Land Use and Land Cover (LULC) in 2016, 2018, 2020, and 2022 in the mining activity and reclaimed area, measure the occurrence and growth of water bodies, and assess vegetation productivity dynamics of PT. Semen Gresik Rembang, Indonesia.

MATERIALS AND METHODS

Study area

The study area is Gunem and Bulu Sub-districts, Rembang District, Central Java, Indonesia, i.e. the limestone mining site of PT. Semen Gresik Rembang, Indonesia. The mine reclamation area is located between 6°51'49.64"S-111°27'59".33"E and 6°51'59.74"S-111°28'15.44"E with a total area of approximately 3.78 km^2 (Figure 1).

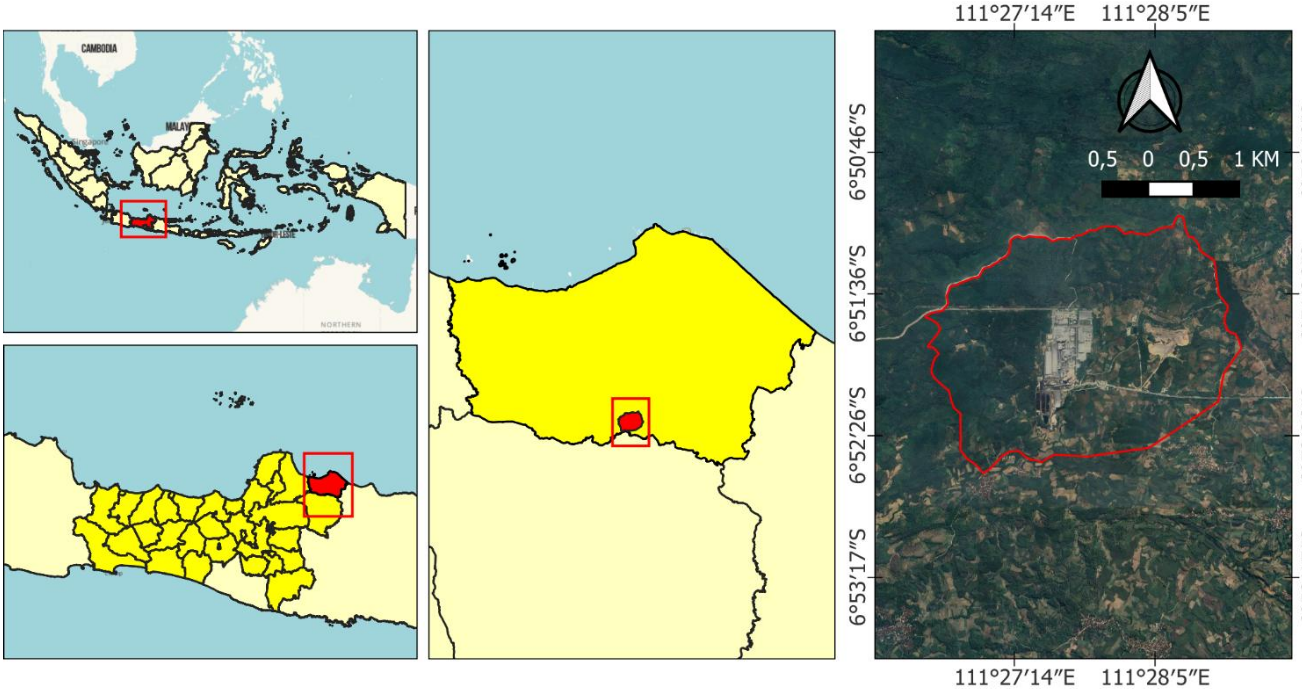

Figure 1. Site location of PT. Semen Gresik Rembang Factory in Rembang District, Central Java, Indonesia

This mining site was selected because the site carried out by PT. Semen Gresik Rembang was only opened in 2017. This can be seen in the satellite imagery on Google Earth, where land changes began to appear in 2017 and developed until 2022. Therefore, satellite data was collected from 2016 to 2022 to compare environmental conditions before and after the site's development. This research area includes the ownership area of the PT. Semen Gresik Rembang and the green belt areas located around the factory area. Therefore, from October to November 2023, data was processed using Landsat 8 and Landsat 7 images in 2016, 2018, 2020, and 2022. Figure 2 is a picture of the condition of the mining area at the study site, and the image is obtained from Google (Penamerahputih.com 2017; Nasional.tempo.co 2017).

Data collection procedures

Satellite data

The data used in this study includes Landsat 7 Enhanced Thematic Mapper plus (ETM+) satellite image data in 2016 and three Landsat 8 Operational Land Thermal Infrared Sensor (TIRS)/Operational Land Imager (OLI) satellite image data covering the years 2018, 2020, and 2022 with a spatial resolution of 30 m. The clipping of Landsat 8 OLI/TIRS satellite imagery should be consistent every year so that the landscape dynamics can be seen from the higher quality imagery compared to other Landsat satellites (Estoque and Murayama 2015). Furthermore, the satellite imagery utilized in this investigation was chosen based on the minimum proportion of pixel values within a single cloud cover that obscures the land surface in the Landsat data (referred to as Land Cloud Cover) (Zhu and Woodcock 2012). Nevertheless, in 2016, the Landsat 8 OLI/TIRS satellite imagery had the lowest proportion of pixel values affected by cloud cover. Thus, this study employed Landsat 7 ETM+ satellite image data from 2016. Hence, the chosen Landsat satellite photos spanned a duration of four years, allowing for the examination of short-term changes in the terrain. These images were acquired at no cost from the United States Geological Survey (USGS) gateway, as stated by Padmanaban (2012).

Image processing

Prior to analyzing satellite image data, preprocessing of the satellite image data is conducted. The pre-processing of satellite image data involves performing image correction, combining bands, and cropping the image based on the research region. In 2016, the Landsat 7 ETM+ satellite image data had scan line errors. To fix this, the Scan Line Corrector (SLC)-off Gap Landsat 7 tool was used to rectify the faults and create mosaics. Any residual gaps were then adjusted using histogram correction, as described by Chen et al. (2011). The image data utilized in this study underwent image correction by Top-of-Atmosphere (TOA) using QGIS. Furthermore, the process of radiometric correction was conducted to identify and quantify alterations in the landscape. This was achieved by utilizing the characteristics provided in the ETM+ metadata, specifically the Top-of-Atmosphere (TOA) radiance, as described by Chander et al. (2009). The rectified satellite image data was blended by amalgamating bands 1, 2, 3, 4, 5, and 7 to process the image using the highest likelihood approach. The subsequent step involves the segmentation of satellite image data using the Area of Interest (AOI) that has been established according to the specific geographical area of the research location.

Data analysis

Land use and land cover classification and accuracy assessment

Analyzed utilizing image classification techniques, the study examined four years of surface-level landscape processes. Subsequently, the photos from 2016, 2018, 2020, and 2022 were categorized into five distinct Land Use and Land Cover (LULC) classes, as shown in Table 1. The greatest likelihood classification technique was utilized to optimize the proximity of data points (Goslee 2011; Madasa et al. 2021). LULC classification was performed using the maximum likelihood method using ArcGIS software.

Table 1. Land Use and Land Cover (LULC) classification

LULC classes	Land uses involved in the class
Vegetation Land	Forests, gardens, and shrubs
Open Soil	Roads, unirrigated land, and dry land
Built-up Land	Factory building
Water Body	Open water
Mining Land	Mining

Figure 2. Location of PT. Semen Gresik Rembang in Rembang District, Central Java Province, Indonesia

The image classification accuracy was evaluated by comparing the classified LULC map with USGS EROS reference images from 2016 to 2022 of the study area obtained from the Google Earth platform. The accuracy assessment generated 100 randomly scattered points using the ArcGIS tool the Accuracy Assessment Point tool and extracted the values for four different study year periods (Assal et al. 2015). Subsequently, a set of arbitrary values was chosen, specifically obtained from Google Earth, and subsequently compared to the LULC map. In Stehman's (1996) study, the kappa coefficient was used to measure image accuracy. A kappa coefficient value greater than 0.8 implies that the categorized image is highly accurate and comparable to the reference data, as mentioned by Islami et al. (2022).

Vegetation productivity

NDVI analysis is used to determine the amount of vegetation productivity at PT. Semen Gresik Rembang during 2016-2022 every 2 years. According to Rouse et al. (1974), the following is the NDVI formula equation:

$$NDVI = \frac{(NIR - R)}{(NIR + R)}$$

Where: NIR: Near Infrared Band value; R: Red band value recorded by Landsat 8 imagery

The NDVI method utilizes the near-infrared band value and red band value to determine the relative density of green vegetation at PT. Semen Gresik Rembang. The NDVI value was categorized into different categories according to the density level. These ranges include non-vegetation (lowest value-0.1), open soil (0.1-0.2), sparse vegetation (0.2-0.4), moderate vegetation (0.4-0.6), and high vegetation (0.6-highest). The ranges are derived from the USGS website (USGS 2018) and have been adapted by the authors. The assessment of vegetation productivity change was conducted in 2016, 2018, 2020, and 2022 utilizing ArcGIS 10.8 software.

RESULTS AND DISCUSSION

Landscape dynamics at the PT. Semen Gresik Rembang in 2016-2022

Figure 3 shows the LULC map of the PT. Semen Gresik Rembang plant area obtained in 2016, 2018, 2020, and 2022 using Maximum Likelihood classification. The area of interest includes land outside their ownership because it is easier to classify landscape dynamics on land around PT. Semen Gresik Rembang Factory. Based on the accuracy test results, an overall accuracy value of more than 80% was obtained for the classified LULC maps for all years with a kappa coefficient average value is 0.84 (Table 2). These values indicate the classified LULC maps have satisfactory accuracy.

The maximum likelihood method in ArcGIS software is used to assess land changes based on spatial analysis after analyzing changes in land size in the PT. Semen Gresik Rembang area. The spatial maps acquired are displayed in Figure 3, while the land class areas are presented in Table 3, providing a comparison of land use and land cover. The land classes examined in this study include vegetative land, open soil, built-up land, water bodies, and mining land. Figure 3 illustrates the comparison of land classes between 2016 and 2022, revealing a noticeable rise in land coverage in built-up areas, aquatic bodies, and mining sites. Table 3 reveals that the land area difference between 2016 and 2022, namely in the built-up land category, exhibits a 15.88 ha rise. The water body classes from 2016 to 2022 indicate a land expansion of 5.26 hectares, while the mining land classes during the same period demonstrate a land expansion of 38.07 hectares. Upon closer examination, it can be noticed that the water body area in the form of ponds increased in 2018 (14.72 hectares) and 2020 (23.98 hectares), but dropped in 2020 (5.26 hectares). Millán et al. (2014) found that as water bodies expand, it leads to a fall in groundwater levels and also causes changes in them. Decreasing groundwater levels can result in collisions with exposed mining structures, infiltration of groundwater, and floods on the surface (Liu and Zhang 2023).

The expansion in land area in the water body and mining land class categories appears to be substantial during the transition from 2016 to 2018, given there were no water bodies or mining land present in these areas in 2016. Subsequently, there was a reduction in land area within the vegetated land and open soil categories. Table 3 reveals that the land area difference between 2016 and 2022 indicates a drop of -18.58 ha in the vegetation land class and a loss of -8.71 ha in the open soil class. The vegetated land underwent substantial changes throughout the years.

Table 2. The image classification accuracy by test matrix value 2016-2022

Years	Accuracy test matrix value	
	User accuracy	Kappa
2016	0.92	0.80
2018	0.92	0.84
2020	0.90	0.81
2022	0.95	0.89

Table 3. Comparison of Land Use and Land Cover (LULC) types during 2016-2022

Classes LULC	Land area (Ha)				Difference (Ha) 2016-2022
	2016	2018	2020	2022	
Vegetation land	495.55	459.50	456.79	476.97	-18.58
Open soil	120.48	142.96	142.19	111.77	-8.71
Built-up Land	48.37	48.93	49.56	64.25	15.88
Water body	-	14.72	23.98	5.26	5.26
Mining land	-	5.36	16.85	38.07	38.07

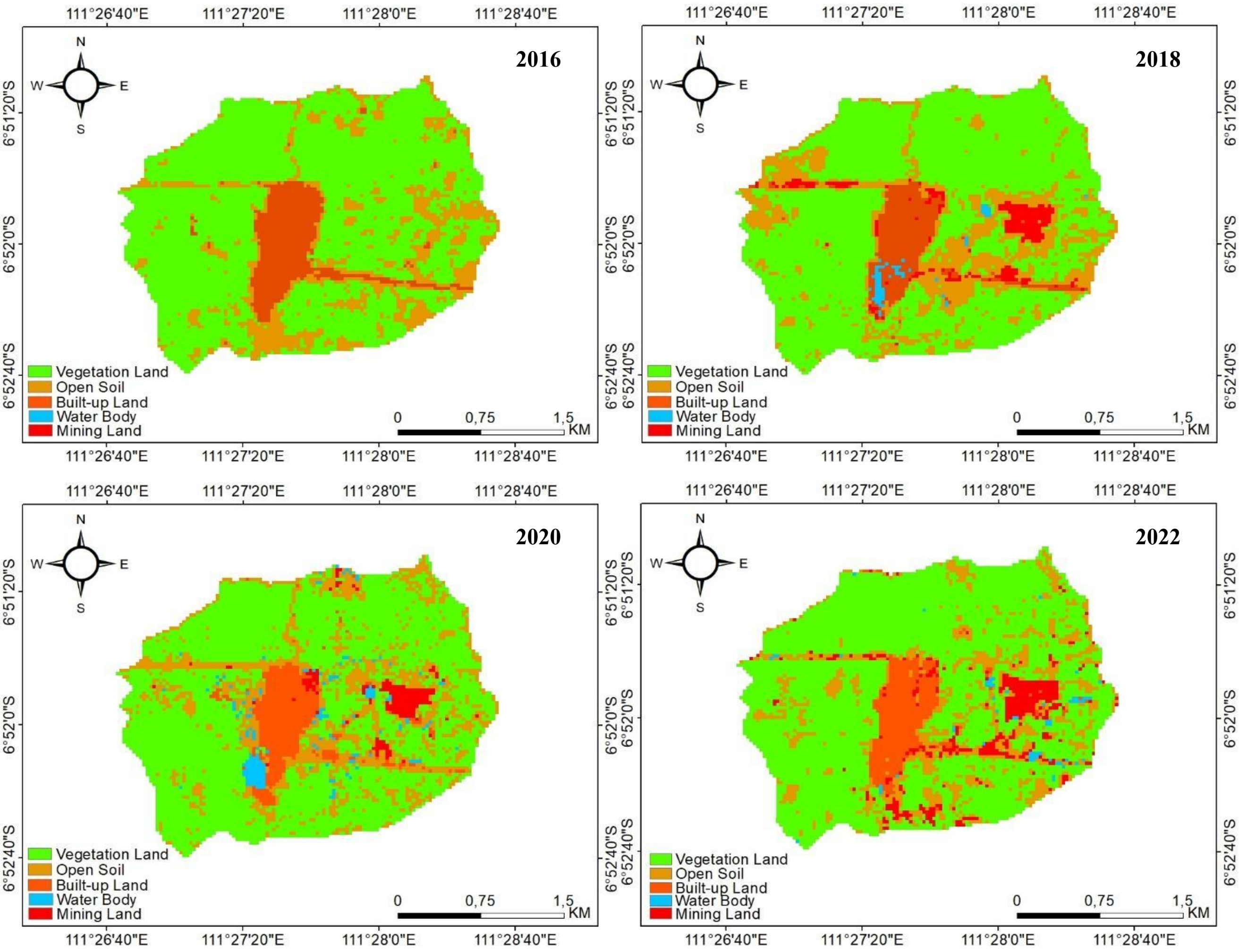

Figure 3. Map of Land Use and Land Cover (LULC) at PT. Semen Gresik Rembang, Indonesia in 2016, 2018, 2020, and 2022

In 2016, the area measured 495.55 ha, which declined to 459.50 ha in 2018 and further to 456.79 ha in 2020. However, in 2022, there was a notable increase to 476.97 ha. Despite this increase, the vegetated land in 2022 is still smaller than the vegetated land in 2016. Within the open soil class, the land area had a growth of 142.96 hectares from 2016 to 2018, followed by a reduction to 142.19 hectares in 2020 and further down to 111.77 hectares in 2022. The conversion of open space to built-up land has led to a significant decline in vegetative land, plantations, and agricultural land mostly because of the fall in groundwater levels (Besser and Hamed 2021).

Occurrence and growth of water bodies

Through the LULC classification that has been carried out, the land use area for water bodies at the study site has been identified (Figure 4). The water body will likely be an ex-mining pond filled with rainwater (Gautama 1994). Water puddles that fill the mine pits are also called voids, which become a storage area for runoff and rainwater in a topography lower than the surrounding area with compacted soil conditions (Sahu et al. 2016). Voids are categorized as dangerous because their depth reaches an average of 4 meters, especially if there are no warning signals. In addition, mine pits are dangerous because they contain residual excavated materials such as acid mine drainage, which is unsuitable for the growth and development of flora and fauna and is at risk of fatalities if contaminated (Yunanto et al. 2021).

Moreover, from 2016 to 2022 (Figure 4), water bodies began to appear in 2018 because the mining process at this location had not yet been carried out in 2016. In 2020, the area of the water body was the largest, with a land coverage of 23.98 ha; this indicates that mining activities have been carried out, but ex-mining pits have not been managed. The area of the water body continued to decrease in the following years by -5.26 ha in 2022. The decrease in area of water bodies suspected to be void has decreased from 2018 to 2022 due to the possibility that the ex-mining pit reclamation has begun by the PT. Semen Gresik Rembang. One of the reclamation management activities that has been carried out by its group companies, PT. Semen Gresik Tuban is the reclamation of limestone mining land into Bukit Daun Park, which is located in Tuban District, East Java, built as a conservation and tourist destination in 2018. In addition, a form of post-mining land reclamation is usually carried out before becoming a tourist attraction through replanting teak (*Tectona grandis*) and trembesi (*Samanea saman*) trees covering an area of 6.8 hectares in 2019 (Siregar et al. 2020).

Vegetation land cover dynamics

Figure 5 shows the NDVI map of PT. Semen Gresik Rembang in 2016, 2018, 2019, and 2020, respectively. The map shows the productivity of improving vegetation areas yearly, with the high vegetation area expanding in 2022 compared to 2016. The map also illustrates the decreasing area of non-vegetation; in 2016, the area of non-vegetation was larger than in 2022. Sparse and moderate vegetation areas dominated the PT. Semen Gresik Rembang area in 2020 prediction (Padmanaban et al. 2017).

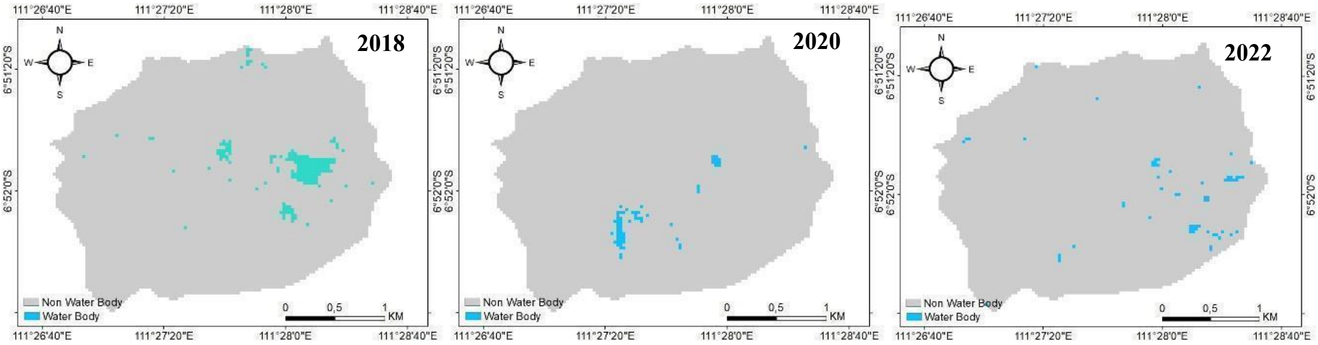

Figure 4. Changes in the location of water body occurrence and growth in 2018, 2020, and 2022 at the PT. Semen Gresik Rembang, Indonesia

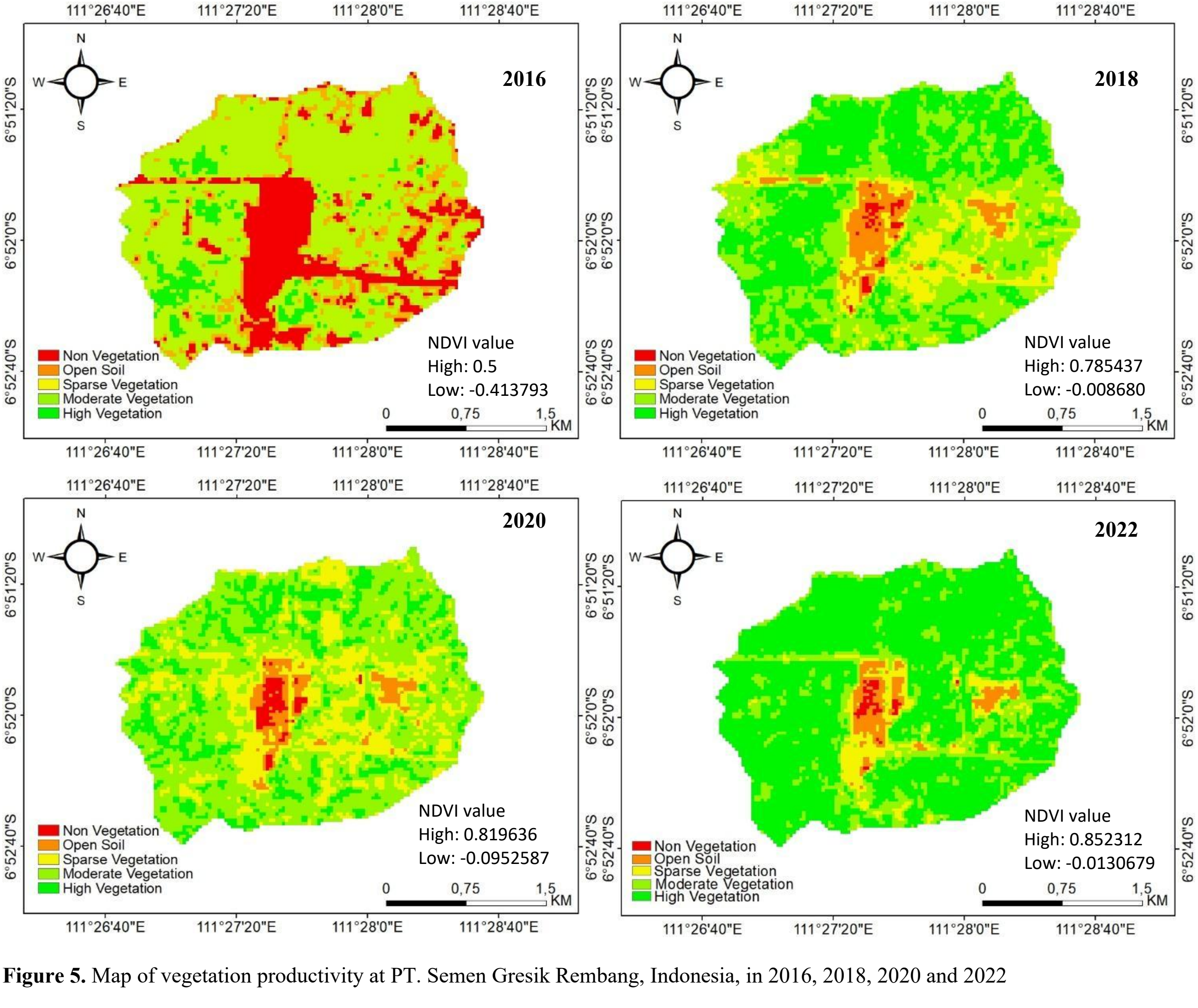

Figure 5. Map of vegetation productivity at PT. Semen Gresik Rembang, Indonesia, in 2016, 2018, 2020 and 2022

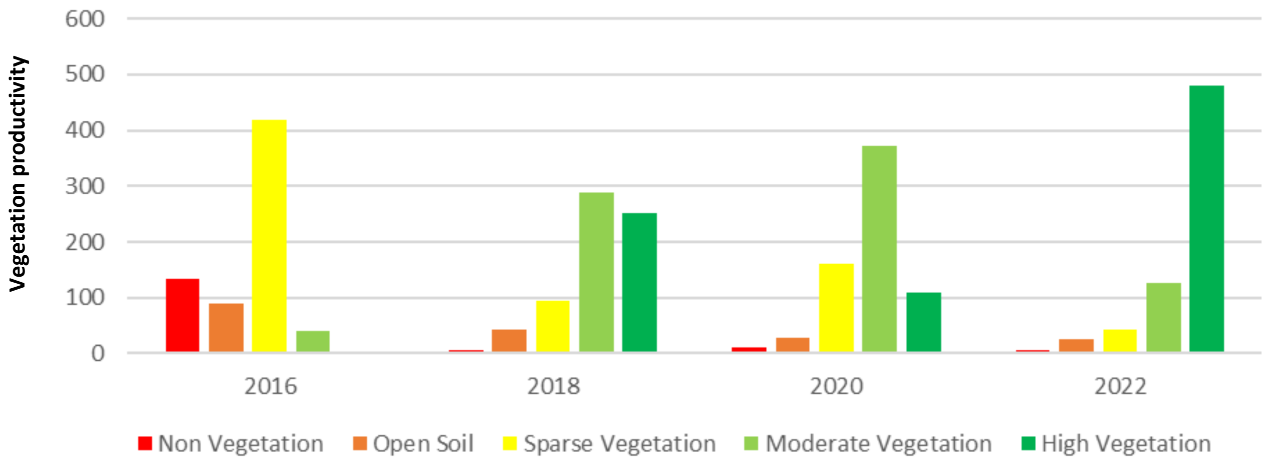

Figure 6. Vegetation productivity at PT. Semen Gresik Rembang, Indonesia in 2016, 2018, 2020, and 2022

Table 4. Vegetation change in the PT. Semen Gresik Rembang, Indonesia coverage area in 2016, 2018, 2020, and 2022

Vegetation productivity class	NDVI value	Change in area coverage (Ha)				Difference (Ha)
		2016	2018	2020	2022	2016-2022
Non vegetation	lowest value-0.1	133.51 (19.63%)	5.61 (0.82%)	10.98 (1.61%)	5.10 (0.75%)	-128.41
Open soil	0.1-0.2	88.44 (13.00%)	41.32 (6.08)%	27.88 (4.10%)	25.09 (3.69%)	-63,35
Sparse vegetation	0.2-0.4	417.94 (61.44%)	94.58 (13.91%)	161.30 (23.71%)	43.49 (6.40%)	-374,45
Moderate vegetation	0.4-0.6	40.38 (5.94%)	288.07 (42.36%)	372.26 (54.72%)	126.76 (18.64%)	86,38
High vegetation	0.6-highest value	-	250.45 (38.83%)	107.85 (15.85%)	479.65 (70.53%)	479.65

Moreover, Table 4 and Figure 6 show a significant change in vegetation productivity at PT. Semen Gresik Rembang, which is associated with an increase and decrease in the area. The non-vegetation area in 2016 was the highest at 133.51 ha and about 19.63% of the total area at 680.26 ha; Figure 6 shows a decrease to -5.61 ha in 2018 and briefly increased to 10.98 ha in 2020 and then fell back to -5.10 ha in 2022. The decrease in the non-vegetation area is good for the ecosystem because the area is covered with a high vegetation area again. The PT. Semen Gresik Rembang vegetation area has increased productivity due to the company's concern for the surrounding vegetation by promoting reforestation activities. PT. Semen Gresik Rembang developed a green belt area to change the limestone mining areas, once barren, to greener environments (Dewi 2016). These greening areas are evidenced by the value of vegetation productivity for the classification of high vegetation areas, which was worth 0 ha in 2016 and can increase rapidly to 479.65 ha or about 70.53% in 2022. The open soil area continues to decline from 2016 at 88.44 ha to about 25.09 ha in 2022. The decline is insignificant because it is dominated by the increase and decrease in sparse, moderate, and high vegetation areas. The sparse vegetation class experienced a decreased area in 2018 to 94.58 ha, increased in 2020 to 161.30 ha, and decreased in 2022 to 43.49 ha. Moderate vegetation from 2016 to 2020 increased from 40.38 ha to 372.26 ha but decreased in 2022 to 126.76 ha. The decrease in moderate vegetation is due to the change of vegetation to high vegetation (Padmanaban et al. 2017).

Discussion

According to Table 3, the LULC data, the total area of vegetative land in 2016 was 495.55 hectares. Table 4 presents the NDVI findings, indicating that no vegetation was observed in the sparse and moderate classes under the high vegetation category. The extent of vegetation classified as sparse has both reduced and increased. However, in 2022, it reached 43.49 hectares, indicating a fall in the sparse vegetation category. The moderate vegetation class experienced significant growth in area between 2018 and 2020, growing from 40.38 hectares to 288.07 hectares and further to 372.26 hectares. Nevertheless, the vegetation class categorised as moderate experienced a reduction to a value of 126.76. The levels of vegetation had both increases and decreases, but in 2022, there was a significant addition of 479.65 hectares. In 2016, according to Table 3, the land class with the highest vegetation was seen, despite the fact that the vegetation was higher compared to the subsequent year. The environmental circumstances in 2022 had improved characteristics, as seen by the heightened productivity of plants, which was bolstered by elevated NDVI values. Ultimately, the current vegetation was characterized by a scarcity of plant life and a moderate amount of vegetation. This is consistent with the study conducted by Johansen and Tømmervik (2014). They found a strong association between NDVI derived from vegetation communities and recorded phytomass, indicating a close relationship.

Therefore, comparing the results between LULC and NDVI may not be accurate, and this is because the two methods have different analytical (da Silva et al. 2020); the different analytical methods comparison are not appropriate. However, in this study, the NDVI results can be used to determine the vegetation level, including low-class, medium-class, and high-class vegetation. Therefore, we can at least know whether the vegetation areas detected using the LULC method have good productivity of land cover by vegetation. Higher NDVI values indicate more vegetation on the land cover than lower NDVI values (Akbar et al. 2020). Based on this, the NDVI value can be used to determine the level of health and productivity of existing vegetation in this research. Even though the vegetation area in 2022 will not be as much as in 2016 (Table 3), at least the reclamation and revegetation efforts of mining land operated by the former mining pit of the PT. Gresik Semen Rembang is showing quite good results. Environmental improvement efforts can be maintained to achieve maximum results in the return to normal conditions; if possible, increasing the reclamation and revegetation of mining land is necessary. Revegetation of tailing dumps improves soil quality through aesthetic improvement, stabilization, pollution control, and soil fertility (Buta et al. 2019). This study also demonstrated how revegetating abandoned mine lands restored their ecological integrity and self-sustainability, leading to significant improvements in soil quality.

Moreover, PT. Semen Gresik Rembang land clearing for mining has changed the open or vegetation land into built-up and mining land. Furthermore, this research begins in 2016 to 2022 because land clearing and built-up development began in 2017 and shows an increase in mining and built-up land areas. The most significant increase occurred between 2020 and 2022 because the mining land area doubled. Research conducted by Shen and Zeng (2022) shows that land clearing for mining sites has also increased rapidly in certain years, changing groundwater levels. A continuous increase in built-up and mining lands in mining areas can cause collisions with unburied mine workings, groundwater intrusion, and surface flooding (Liu and Zhang 2023). However, reclamation has been conducted at this research location, hopefully avoiding possible environmental risks.

The results of this study are similar to previous research conducted by Firozjaei et al. (2021), which indicated that forest cover and green open space decreased from 9,950 hectares in 1989 to 5,900 hectares in 2019 for Sungun mine in Iran; from 42.14 hectares in 1999 to 33.09 hectares in 2019 for Athabasca oil sands in Canada; from 231.46 hectares in 1996 to 263.95 hectares in 2016 for Singrauli coalfield in Indian; and from 180.38 hectares in 1989 to 133.99 hectares in 2017 for Hambach mine, as a result of the expansion and development of mineral activities. The results in Sungun indicate that in the future, by 2039, there is likely to be a decrease in forest cover and green open space by 15% of the total study area, resulting in a decrease in mean NDVI of almost 0.06 and an increase in standardized mean Land Surface Temperature (LST) from 0.52 in 2019 to 0.61 in 2039. The study in Sungun shows that in the future, by 2039, there will most likely be a decrease in forest and green open space cover by 15% of the total study area, resulting in a decrease in mean NDVI of almost 0.06 and an increase in mean standardized Land Surface Temperature (LST) from 0.52 in 2019 to 0.61 in 2039. Research conducted by Firozjaei et al. (2021) showed that for the Athabasca oil sands (Singrauli coalfield, Hambach mine), the average standardized LST and NDVI values will change from 0.5 (0.44 and 0.4) and 0.38 (0.38; 0.35) in 2019 (2016; 2017) to 0.57 (0.5; 0.47) and 0.33 (0.32; 0.28) in 2039 (2036; 2035). This is mainly due to increased past and future mining activity (Firozjaei et al. 2021). Therefore, the potential for mining land degradation is higher if mining activities are carried out continuously without adequate environmental conservation efforts.

In conclusion, the difference in land area of PT. Semen Gresik Rembang in 2016-2022, i.e., the built-up land class, shows an increase in the amount of land of 15.88 hectares. The water body classes 2016-2022 show a land increase of 5.26 hectares, and the mining land classes 2016-2022 show a land increase of 38.07 hectares. The difference in land area in 2016-2022, i.e.: the vegetation land class showed a decrease in land area of -18.58 hectares, while the open soil class experienced a decrease of -8.71 hectares. Vegetated land has changed significantly; where in 2016, an area of 495.55 hectares decreased in 2018 (459.50 hectares) and 2020 (456.79 hectares) and increased quite high in 2022 to 476.97 hectares, but the area of vegetated land in 2022 is still not as large as the vegetated land in 2016. In the open soil class, there was an increase in land area from 2016 to 2018, which was 142.96 hectares, and then decreased in 2020 and 2022 to 142.19 hectares and 111.77 hectares, respectively. The results of the LULC analysis of water bodies show that there is a possibility that water bodies are formed from former mining ponds, and in the prone years 2016 to 2022, it is known that the area of water bodies will decrease because of the PT. Semen Gresik Rembang manages those areas. The addition of vegetated land is accompanied by an increase in NDVI values, where the highest NDVI values in 2016, 2018, 2020, and 2022 are 0.5, 0.79, 0.82, and 0.85, respectively. This indicates that the study area has vegetation with better productivity from year to year. Better vegetation productivity indicates that PT. Semen Gresik Rembang has care and concern for the environment.

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Checklist of microfungi of Biligiri Rangaswamy Temple Wildlife Sanctuary, Karnataka, India

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Abstract. *Dubey R, Chatterjee SS, Pandey AD. 2024. Checklist of microfungi of Biligiri Rangaswamy Temple Wildlife Sanctuary, Karnataka, India. Intl J Trop Drylands 25: 69-82.* Biligiri Rangaswamy Temple Wildlife Sanctuary (BRT WLS) situated at the confluence of Eastern and Western Ghats, India, exhibits a unique blend of climatic and ecological conditions that support a rich and diverse biota. The present study aims to investigate its microfungal diversity and was conducted from 2014 to 2016. Fungi were collected from various substrates including plant litter, living leaves, and rhizospheric soil (rs). Identification of these fungi involved routine microscopic techniques, supplemented by advanced Scanning Electron Microscopy (SEM) for rare and novel fungi. The study resulted in a significant checklist of a total of 290 fungal isolates, categorized into 164 species across 114 genera. Among these, five taxa were newly discovered, including 1 new genus viz., *Biligiriella* S. Sengupta & Rashmi Dubey along with its type species *Biligiriella indica* S. Sengupta & Rashmi Dubey; and 3 other new species viz., *Colemaniella biligiriensis* Rashmi Dubey & S. Sengupta, *Elotespora indica* Rashmi Dubey & S.S. Chatterjee, *Sporidesmium biligiriense* Rashmi Dubey & S. Sengupta.

Keywords: Arbuscular mycorrhizal fungi, foliicolous fungi, fungal diversity, Karnataka, litter fungi, morphology, SEM studies, soil fungi, wild life sanctuary

INTRODUCTION

Karnataka is the seventh largest province of India, covering an area of 191,791 km^2 accounting for 5.83% of the geographical area of India (Government of Karnataka 2023). Karnataka is located in southwestern India along the coastline, bordered by Maharashtra to the north, Goa to the northwest, and Kerala to the south. Karnataka can be divided into three distinct physiographic regions, *viz*., 'Karavali' or 'Canara' (coastal region), the 'Malnad' (hilly region comprising of Western Ghats), and 'Maidan' (plain region comprising of Deccan plateau). Biligiri Rangaswamy (BR) Hills lie in Karnataka at the confluence of Eastern and Western Ghats (Ganeshaiah and Shaanker 1998), having a major portion of the sanctuary lying principally in Western Ghats (Ramesh 1989). This area is part of Biligiri Rangaswamy Temple Wildlife Sanctuary (BRT WLS), formed to preserve the unique ecology of BR hills. BRT WLS derives its name from Biligiri, which means 'white hill', on top of which Lord Ranganatha's temple is situated.

In the BRT Wildlife Sanctuary, the mycobiota is particularly diverse due to the sanctuary's unique geographical position, which blends the climatic and biological influences of both the Eastern and Western Ghats. This strategic location provides a mosaic of habitats that support a wide range of fungal species. Microfungi form a very crucial component of forest ecosystems. They serve as decomposers, saprophytes, nutrient-recyclers, and symbiotic associates (mutualistic, parasitic, and commensalistic), thereby playing a vital role in the long-term stability of ecosystems (Reverchon et al. 2010; Geml et al. 2014). Several works on microfungal biota from different parts of Karnataka are available, such as Raviraja (2005) reported 18 species of fungal endophytes from five medicinal plant species from Kudremukh Range Karnataka; Naik et al. (2008) reported 6,125 fungal endophytes from 15 medicinal plants of Malnad Region; Pande (2008) reported Ascomycetes of peninsular India; Bhat et al. (2009), Bhat (2010) and Pratibha et al. (2012) reported diversity of microfungi from the forests of Western Ghats; Lakshman et al. (2010) reported a higher percentage of root colonization by arbuscular mycorrhizal fungi in *Vigna mungo* than in *Vicia faba*, among the selected leguminous plants of Mercara in Karnataka; and Sreenivasa et al. (2010) reported fungi associated with sorghum grain harvested from Karnataka.

Taxonomic and ecological aspects of aquatic fungal diversity have been explored for Kali River in the Western Ghats Region of Karnataka in a series of publications, such as Sridhar and Sudheep (2011), and Sudheep and Sridhar (2012, 2013a, 2013b). Naveenkumar et al. (2011) compared fungal diversity in the agricultural and non-agricultural soils of Bhadravathi Taluka of Shimoga District; Banakar et al. (2012) studied diversity of soil fungi in dry deciduous forest of Bhadra Wild Life Sanctuary; Rajkumar et al. (2012) examined diversity of arbuscular mycorrhizal fungi associated with some medicinal plants in Western Ghats of Karnataka.

Uzma et al. (2016) isolated 112 endophytic fungi from six wild medicinal plants belonging to Bisle Region, Western Ghats of Karnataka, and studied ecological aspects and extracellular enzyme activities of the isolated fungal endophytes. About 82 species belonging to 32 genera were identified from the soils of Mattavara forest, Chikamagalur, Karnataka by Chandini and Rajeshwari (2017). Recently, Sharma and Mishra (2019) reported a checklist of Fungi in Karnataka containing a total of about 1255 species under about 410 genera and 140 families, which included both microfungi as well as macrofungi. Nevertheless, a comprehensive investigation into the microfungi of the BRT Wildlife Sanctuary (WLS) has not been conducted so far. Therefore, considering the distinctive biogeographical attributes of the BRT Wildlife Sanctuary, the Botanical Survey of India embarked on an extensive study aimed to document the microfungal diversity of this protected area.

MATERIALS AND METHODS

Study area

Biligiri Rangaswamy Temple Wildlife Sanctuary (BRT WLS) is located between 11°47’-12°09’N and 77°00’-77°16’E in the Chamrajnagar District of South-eastern Karnataka, bordering Tamil Nadu Province, India. BR Hills consist of roughly four parallel hill ranges of 600-1800 masl, running north-south, which support heterogeneous mosaic of vegetations, such as moist deciduous forest (25%), dry deciduous forest (36.1%), scrub (28.2%), grassland (3.4%), evergreen forest (6.1%), semi-evergreen forest (0.4%), and shola (0.8%) (Ramesh 1989) There are five forest ranges of the sanctuary - Yelandur, K. Gudi, Punjur, Bylore, Kollegal. Kattari Betta is the highest peak rising to over 1800 masl (Srinivasan and Prashanth 2005). The annual temperature and precipitation vary with elevation (Aravind et al. 2001; Jayanthi and Jalal 2023).

Field data collection

A total of five collection surveys were undertaken between 2014 and 2016, during which all the forest types were explored in all the major seasons. GPS coordinates of collection locations were also recorded. QGIS 3.14 ‘Pi’ version was used for plotting GPS data to prepare a survey map showing collection sites visited during the field surveys (Figure 1). Glimpse of the study areas are presented in Figure 2.

Plant materials infested with fungi were collected during the exploration. The samples include live plants materials, foliicolous plant specimens, litter samples (bark litter, leaf litter, twig litter, branch litter, flower and fruit litter, etc.), dried decaying plant specimens, and rhizospheric soil. In these five field surveys, 322 live plant specimens, 791 dry litter samples (stem litter, twig litter, leaf litter, bark litter, etc.) and 14 rhizosphere soil samples were collected. The foliicolous specimens were collected in the aluminium foil packets to avoid infestation of saprophytes, labelled, and brought to the laboratory for further processing. Stem litter, bark litter, twig litter, leaf litter, fruit and flower litter etc. were collected for the study of litter fungi. The litter samples were collected in brown packets.

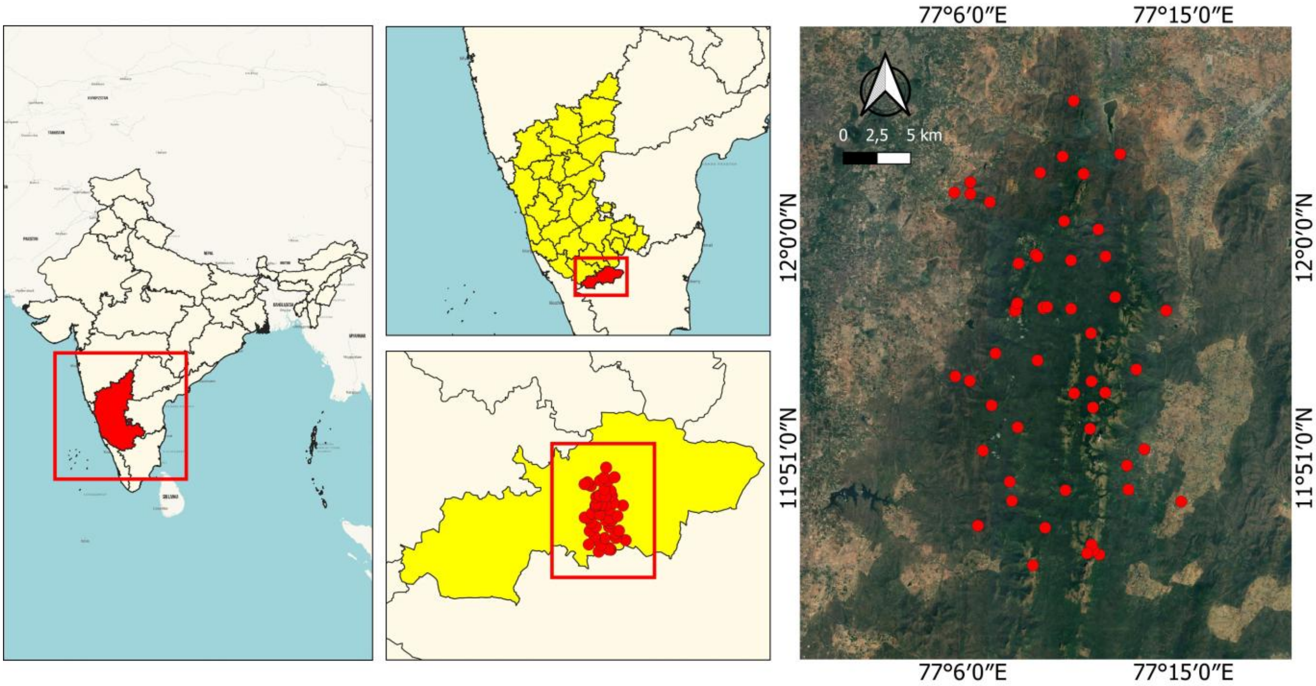

Figure 1. Map of the Biligiri Rangaswamy Temple Wildlife Sanctuary (BRT WLS), Karnataka, India, with collection points plotted on google maps and a map prepared using QGIS. Source: Karnataka Forest Department (for Contour Map)

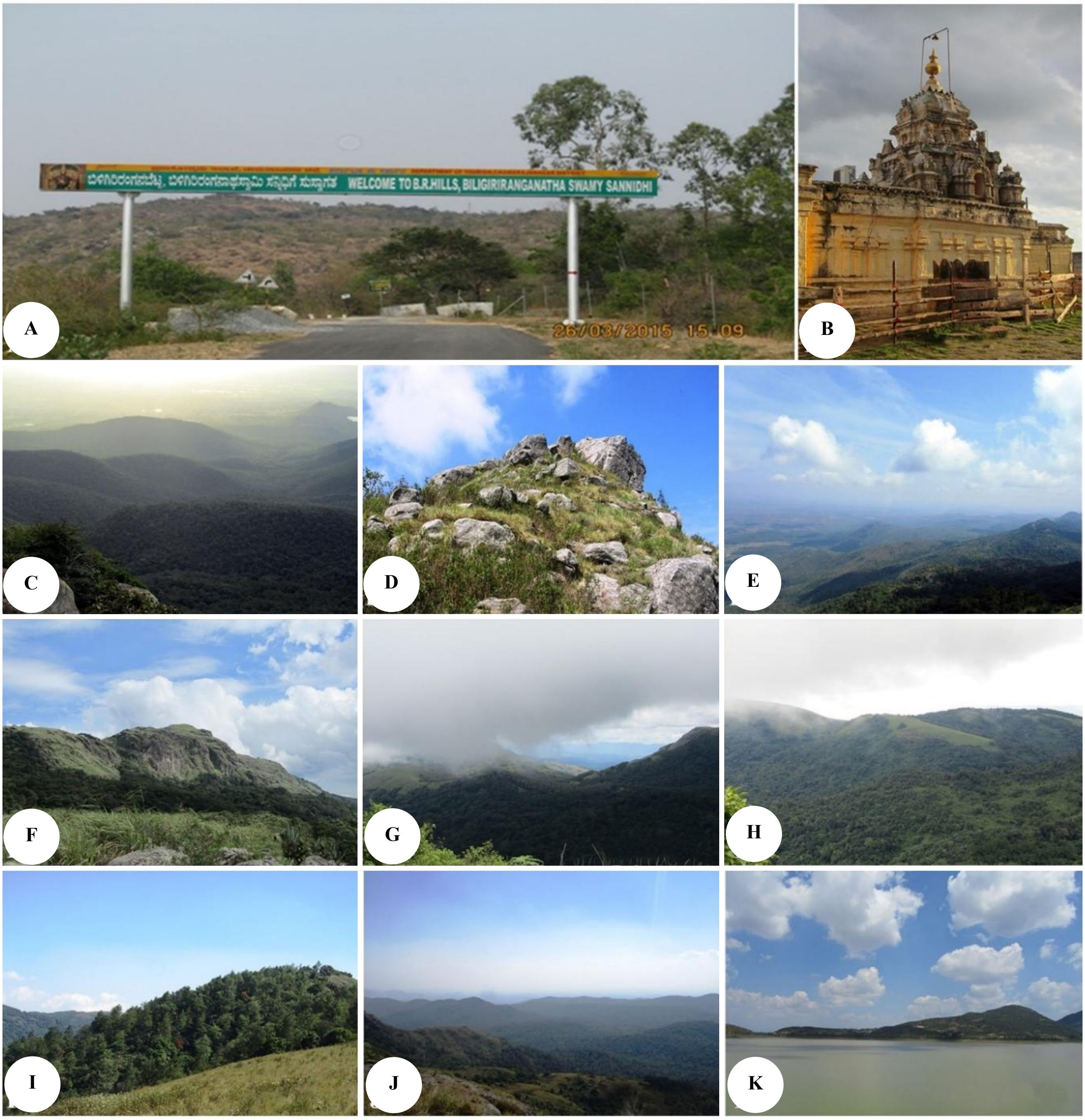

Figure 2. Overview of the Biligiri Rangaswamy Temple Wildlife Sanctuary (BRT WLS), India: A. Entry gate of BRT WLS, B. Biligirirangan Temple, C. BR Hills, D-E. Malkibetta, F. Jodigede, G. Bylore Range, H. Gudi Range, I. Gummanebetta, J. Yelandur Range, K. Gundal Dam

For soil fungi and Vesicular Arbuscular Mycorrhizal (VAM) fungi, rhizosphere soil samples were collected in brown packets. The roots of the plants adjacent to the rhizospheric soil were also collected and preserved in Formalin-Aceto-Alcohol (FAA). Collected samples were properly labelled. For foliicolous and litter fungi, hand sectioning, moist chamber incubation (Hawksworth 1974; Cannon and Sutton 2004), and three-step sterilization process methods were used. For leaf litter fungi, Particle Filtration Method (Bills and Polishook 1994) was used. For Soil fungi, Dilution Plating Method (Waksman 1922, 1927) was used. For Vesicular Arbuscular Mycorrhizal (VAM) fungi, wet sieving and decanting techniques (Gerdemann and Nicolson 1963) were used, and staining procedure was used for arbuscular mycorrhizal root.

Fungal identification

The fungi were identified and described following several monographs, books and reviews from standard books, and journals. Ainsworth et al. (1973) and von Arx (1981) offer identification keys to majority of the fungal groups. Barron (1968) and Barnett and Hunter (1972) were referred for lower fungal groups. Fungal species which form spores in Acervuli or Pcynidia were identified following Sutton (1980) and Raj (1993). Anamorphic Ascomycota were identified from Ellis (1971, 1976), Ellis and Ellis (1985), Seifert et al. (2011). Identification of Ascomycetes was based on Dennis (1978), Hanlin (1998) and Pande (2008). Identification of Bitunicate Ascomycetes was based on Sivanesan (1983). For identification of black mildew fungi, Hosagoudar (1996, 2008, 2012, 2013) were referred. Identification of numerous rust and smut species was done by Cummins and Hirsukta (1983). Gilman (1945), Nagamani et al. (2006), and Guarro et al. (2012) were referred for soil fungi. For the identification of VAM fungi were referred to Schenck and Pérez (1990) and Błaszkowski (2012). The recent taxonomic position of fungal genera and species was recorded from online databases such as Index Fungorum (http://www.indexfungorum.org), Species Fungorum (www.speciesfungorum.org) and Mycobank (http://www.mycobank.org).

RESULTS AND DISCUSSION

Fungal diversity

A total of 164 species were identified from 290 fungal isolates. It includes 122 taxa from 207 litter fungal isolates, 43 taxa from 64 foliicolous fungal isolates, 7 taxa from 11 VAM fungal isolates, and 5 taxa from 8 soil fungal isolates (Figure 3. A). The total taxa do not sum up to 177, since 13 taxa were isolated from more than one type of substrate, viz., litter and foliicolous, hence were not double counted in arriving at the total. The 13 species are *Alternaria* sp., *Alternaria tenuissima*, *Cladosporium* sp., *Cladosporium oxysporum*, *Curvularia brachyspora*, *Dictyoarthrinium sacchari*, *Epicoccum nigrum*, *Neopestalotiopsis asiatica*, *Periconia* sp., *Sordaria fimicola*, *Stachybotrys levisporus*, *Temerariomyces acutulus*, and *Torula herbarum*. Microscopic and SEM images of some morphologically interesting fungi found in the study are given in Figures 4 and 5, respectively. The genera found to be dominant in having most species are *Curvularia* of 8 species, *Alternaria* of 7 species, *Asterina* of 5 species, *Glomus* of 4 species, *Neopestalotiopsis* of 4 species, and *Periconia* of 4 species (Figure 3. B). The species found to be dominant (Figure 3. C) in accounting for most isolates are *S. fimicola* of 20 isolates, *Monodictys putredinis* of 19 isolates, *T. herbarum* of 11 isolates, *S. levisporus* of 6 isolates, *Alternaria alternata* of 5 isolates, *C. oxysporum* of 5 isolates, and *Rhinocladiella cristaspora* of 5 isolates.

The present study also resulted in the discovery of 5 new taxa including 1 new genus viz., *Biligiriella* S. Sengupta & Rashmi Dubey along with its type species *Biligiriella indica* S. Sengupta & Rashmi Dubey (Sengupta and Dubey 2021); and 3 another new species viz., *Colemaniella biligiriensis* Rashmi Dubey & S. Sengupta (Sengupta and Dubey 2016), *Elotespora indica* Rashmi Dubey & S.S. Chatterjee (Chatterjee and Dubey 2019), *Sporidesmium biligiriense* Rashmi Dubey & S. Sengupta (Dubey and Sengupta 2015).

Fungal checklist

A total of 290 fungal isolates were obtained from samples collected from the study area, belonging to 164 species. The following checklist shows location and substrate-wise enumeration of fungi along with collection details, in which SSC refers to collector, Shreya Sengupta Chatterjee; BSI (WRC) is in reference to herbarium of Botanical Survey of India, Western Regional Centre, Pune.

1. *Acanthostigma* sp. (Tubeufiaceae) on **stem litter** from Jodigede, 20/12/2016, SSC, BSI (WRC) 203327.
2. *Acaulospora longula* Spain & N.C. Schenck 1984 (Acaulosporaceae) on **rhizosphere soil** from Bylore, 01/10/2014, SSC, BSI (WRC) 203397.
3. *Acaulospora* sp. (Acaulosporaceae) on **rhizosphere soil** from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 203397; and from Manjigede, 02/10/2014, SSC, BSI (WRC) 203396.
4. *Acrodictys sacchari* M.B. Ellis 1971 (Acrodictyaceae) on **stem litter** from Bylore, 05/09/2015, SSC, BSI (WRC) 202283.
5. *Acrostalagmus luteoalbus* (Link) Zare, W. Gams & Schroers 2004 (Hypocreaceae) on **stem litter** from Arre Pallya, 14/12/2016, SSC, BSI (WRC) 202292.

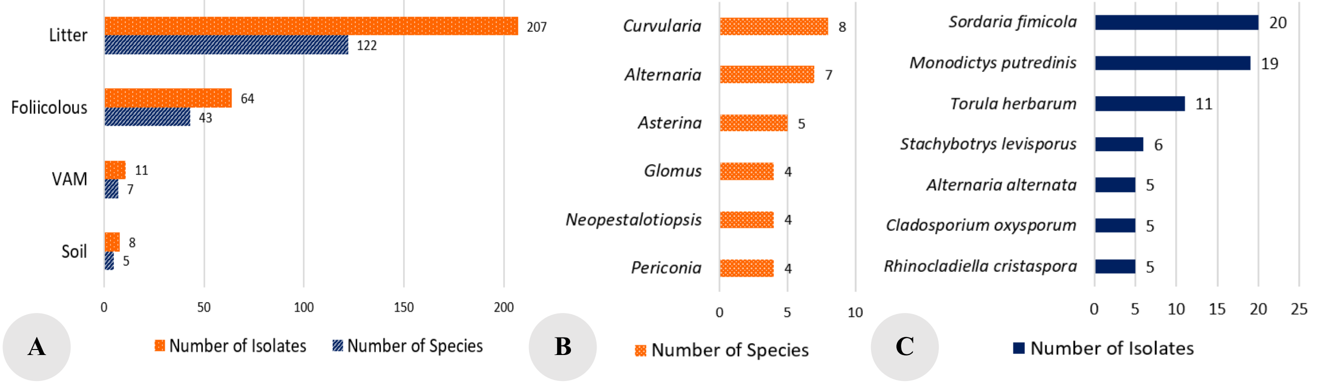

Figure 3. Fungal obtained and identified in the research sites: A. Total number of fungal isolates and species as per the substrates, B. Dominant genera in terms of species, and C. Dominant species in terms of isolates

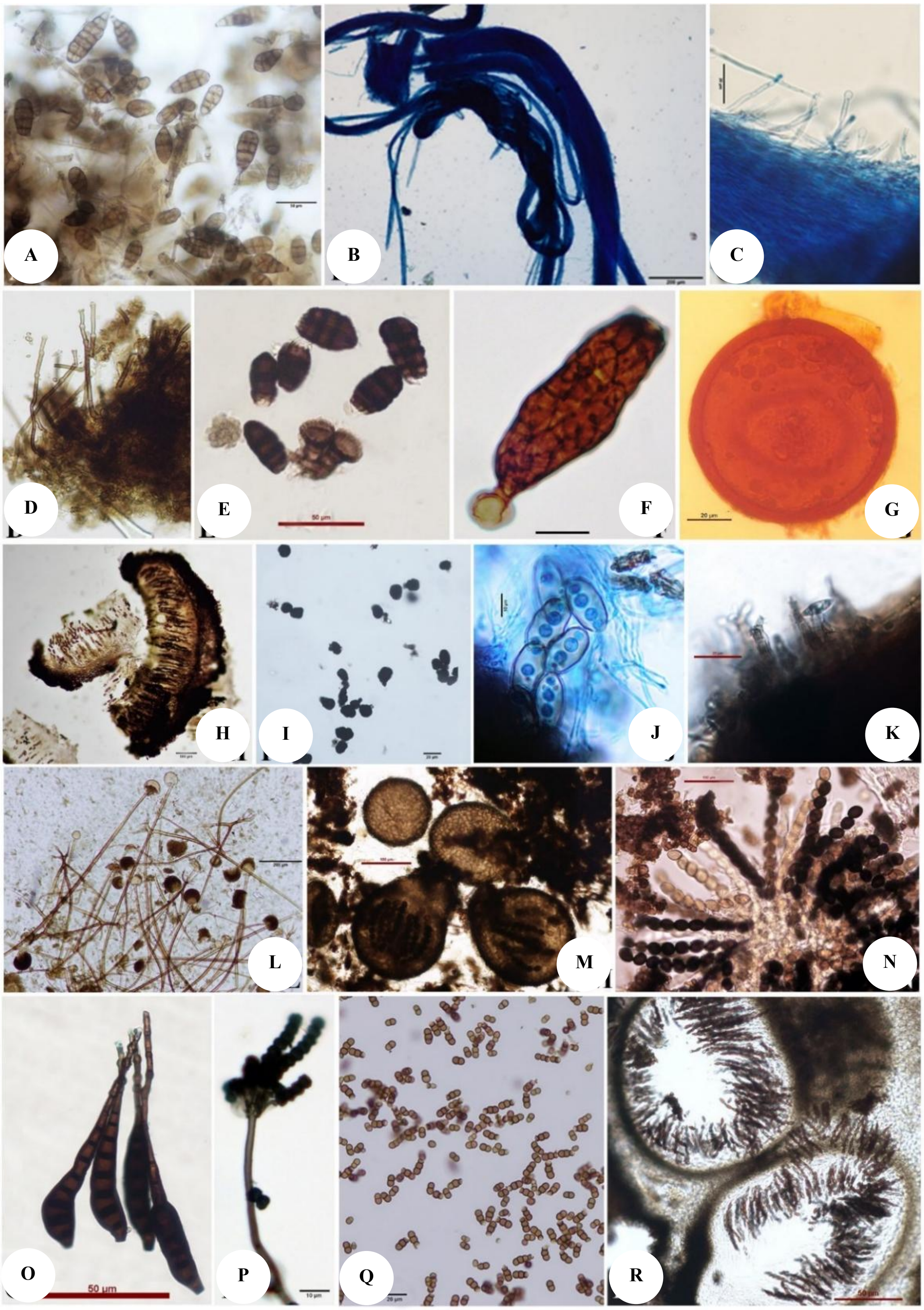

Figure 4. Microfungi of BRT WLS, India: A. *Alternaria alternata*, B-C. *Biligiriella indica*, D. *Cladosporium oxysporum*, E. *Colemaniella biligiriensis*, F. *Elotespora indica*, G. *Glomus macrocarpum*, H. *Hysterium tamarindi*, I. *Monodictys putredinis*, J. *Physalospora alpestris*, K. *Rhinocladiella cristaspora*, L. *Rhizopus stolonifera*, M-N. *Sordaria fimicola*, O. *Sporidesmium biligiriense*, P. *Stachybotrys levisporus*, Q. *Torula herbarum*, R. *Xylaria polymorpha*. (Scale bars: A, D, E, R = 50 µm; B, L = 200 µm; C, G, I, K, O, Q = 20 µm; F, J, P = 10 µm; H, M, N = 100 µm)

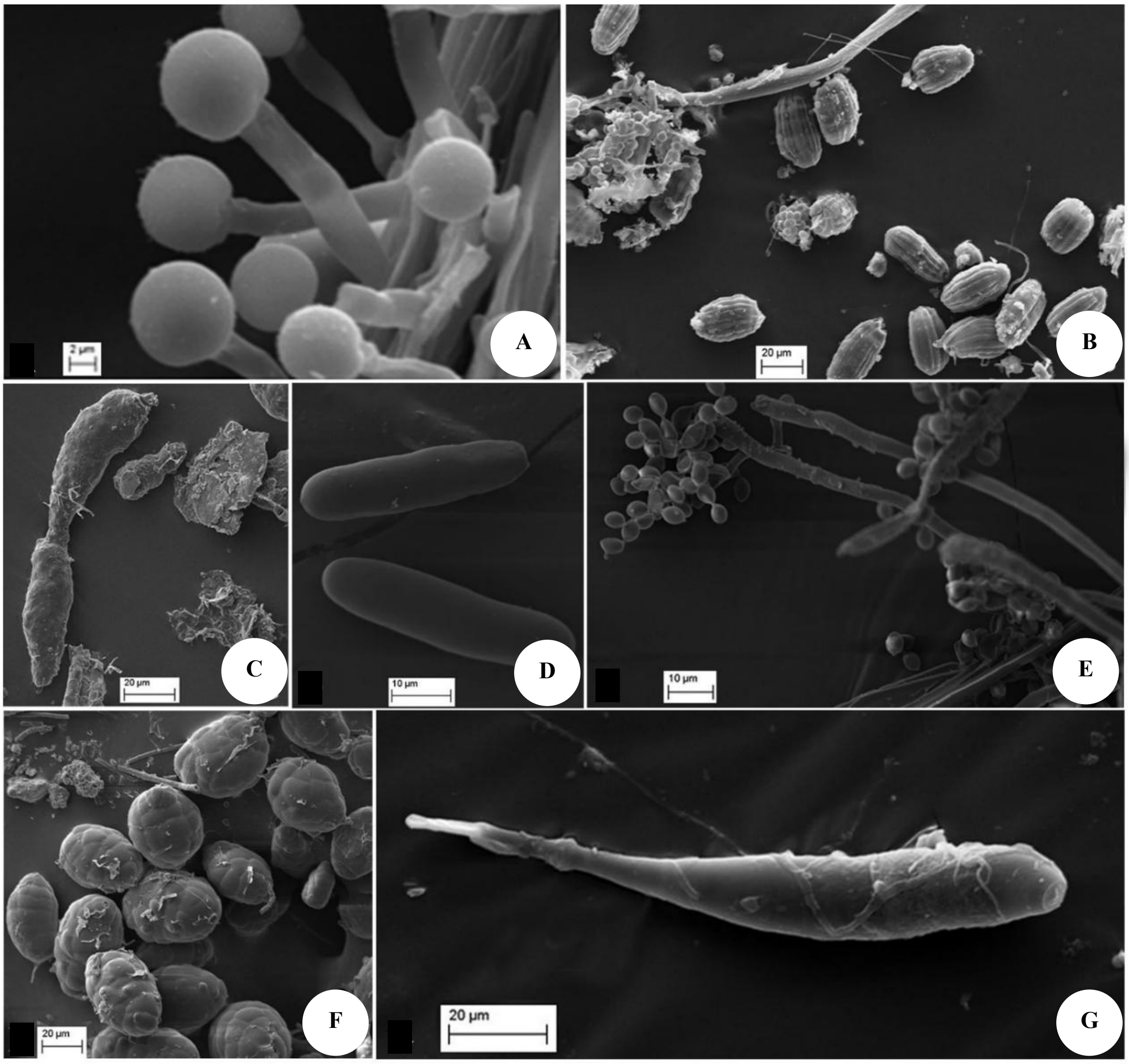

Figure 5. SEM Images of some interesting microfungi of BRT WLS, India: A. *Biligiriella indica*, B. *Colemaniella biligiriensis*, C. *Elotespora indica*, D. *Kirschsteiniothelia atra*, E. *Phaeoblastophora peckii*, F. *Rhexoacrodictys erecta*, G. *Sporidesmium biligiriense*. (Scale bars A = 2 µm; B, C, F, G = 20 µm; D, E = 10 µm)

6. *Alternaria alternata* (Fr.) Keissl. 1912 (Pleosporaceae) on **leaves** of unidentified host from Attikan coffee estate, 03/06/2014, SSC, BSI (WRC) 197564; from Bylore, 01/10/2014, SSC, BSI (WRC) 202121; from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 202295; *Coffea arabica* L. from Manjigede, 02/10/2014, SSC, BSI (WRC) 202139; and *Cordia* sp. from Punajur, 30/05/2014, SSC, BSI (WRC) 197529.
7. *Alternaria botrytis* (Preuss) Woudenb. & Crous 2013 (Pleosporaceae) on **bark litter** from Boreduddi, 02/10/2014, SSC, BSI (WRC) 197585.
8. *Alternaria chlamydospora* Mouch. 1973 (Pleosporaceae) on *Cymbopogon* sp. from Jodigede, 03/06/2014, SSC, BSI (WRC) 197575.
9. *Alternaria dianthicola* Neerg. 1945 (Pleosporaceae) on **leaves** of *Kigelia africana* (Lam.) Benth. from Bedguli, 30/05/2014, SSC, BSI (WRC) 197537.
10. *Alternaria sonchi* Davis 1916 (Pleosporaceae) on **stem litter** from Attikan coffee estate, 03/06/2014, SSC, BSI (WRC) 197570.
11. *Alternaria* sp. (Pleosporaceae) on **leaves** of *Ficus* sp. from Attikan coffee estate, 03/06/2014, SSC, BSI (WRC) 197566; *Cinnamomum* sp. from Attikan coffee estate, 03/06/2014, SSC, BSI (WRC) 197568; unidentified host from Bedguli, 30/05/2014, SSC, BSI (WRC) 197537; unidentified host from Neilekadiru, 29/05/2014, SSC, BSI (WRC) 197518; and **fallen leaves** from Burude, 15/12/2016, SSC, BSI (WRC) 203320.
12. *Alternaria tenuissima* (Kunze) Wiltshire 1933 (Pleosporaceae) on **leaves** of unidentified host from Neilekadiru, 29/05/2014, SSC, BSI (WRC) 197519; and **stem litter** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203350.

13. *Alysidium resinae* (Fr.) M.B. Ellis 1971 (Botryobasidiaceae) on **stem litter** from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203329.
14. *Apiospora arundinis* (Corda) Pintos & P. Alvarado 2021 (Apiosporaceae) on **stem litter** from Gundal dam, 25/03/2015, SSC, BSI (WRC) 203302; from K. Gudi, 08/09/2015, SSC, BSI (WRC) 202264; from K. Gudi, 14/12/2016, SSC, BSI (WRC) 202291; and from Malkibetta, 15/12/2016, SSC, BSI (WRC) 202299.
15. *Aspergillus fumigatus* Fresen. 1863 (Aspergillaceae) on **soil** from Bodipadaga, 08/09/2015, SSC, BSI (WRC) 203386.
16. *Aspergillus nidulans* (Eidam) G. Winter 1884 (Aspergillaceae) on **soil** from Bedguli, 29/03/2015, SSC, BSI (WRC) 203391; from Hoonahmatti, 28/03/2015, SSC, BSI (WRC) 203389; and from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203392.
17. *Aspergillus niger* Tiegh. 1867 (Aspergillaceae) on **soil** from C-matti, 06/09/2015, SSC, BSI (WRC) 203388; and from K. Gudi, 16/12/2016, SSC, BSI (WRC) 203387.
18. *Asterina jambolanae* A.K. Kar & Maity 1970 (Asterinaceae) on **fallen leaves** of *Ficus* sp. from Dodda Sampigge, 02/04/2015, SSC, BSI (WRC) 203333.
19. *Asterina plectranthi* Hosag., Manojk. & H. Biju 2005 (Asterinaceae) on **fallen leaves** from C-matti, 02/04/2015, SSC, BSI (WRC) 203334.
20. *Asterostomella lepianthis* Hosag., M.P. Balakr. & Goos 1996 (Asterinaceae) on **fallen leaves** from Bedguli, 29/03/2015, SSC, BSI (WRC) 203335.
21. *Asterostomella* sp. (Asterinaceae) on **fallen leaves** from Dodda Sampigge, 02/04/2015, SSC, BSI (WRC) 203336.
22. *Asterina averrhoae* Hosag., Kamar. & K.P. Babu 2002 (Asterinaceae) on **fallen leaves** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203314.
23. *Asterina cynanchi* Hosag. & Shiburaj 2002 (Asterinaceae) on **fallen leaves** from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 203313.
24. *Asterina plectranthi* Hosag., Manojk. & H. Biju 2005 (Asterinaceae) on **fallen leaves** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203317.
25. *Bambusaria bambusae* (J.N. Kapoor & H.S. Gill) Jaklitsch, D.Q. Dai, K.D. Hyde & Voglmayr 2015 (Valsariaceae) on **fallen stem** from Attikan coffee estate, 21/12/2016, SSC, BSI (WRC) 203337.
26. *Beltrania mangiferae* Munjal & J.N. Kapoor 1963 (Beltraniaceae) on **fallen leaves** from Bedguli, 30/05/2014, SSC, BSI (WRC) 197586; and from Jodigede, 09/09/2015, SSC, BSI (WRC) 202278.
27. *Beltraniella spiralis* Piroz. & S.D. Patil 1966 (Amphisphaeriaceae) on **stem litter** from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202203.
28. *Bhadradriella hyalina* Nagaraju, Kunwar & Manohar. 2011 (Pezizomycotina) on **leaves** of *Cocos nucifera* L. from Yelandur, 06/09/2015, SSC, BSI (WRC) 202259.
29. *Biligiriella indica* S. Sengupta & Rashmi Dubey 2021 (Pezizomycotina) on **stem litter** from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202199.
30. *Bipolaris papendorfii* (Aa) Alcorn 1983 (Pleosporaceae) on **leaves** of *Casearia* sp. from Hoonahmatti, 31/05/2014, SSC, BSI (WRC) 197541.
31. *Bispora antennata* (Pers.) E.W. Mason 1953 (Pezizomycotina) on **leaves** of *Chromolaena odorata* (L.) King & H.E.Robins from Burude, 28/05/2014, SSC, BSI (WRC) 197508.
32. *Bitunicostilbe clavata* (Ellis & G. Martin) M. Morelet 1971 (Pezizomycotina) on **fallen leaves** from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203348.
33. *Chaetomium globosum* Kunze 1817 (Chaetomiaceae) on **fallen leaves** from Hoonahmatti, 28/03/2015, SSC, BSI (WRC) 203389.
34. *Chaetosphaerulina lignicola* (Sivan., Panwar & S.J. Kaur) J.L. Crane, Shearer & M.E. Barr 1998 (Tubeufiaceae) on **stem litter** from K. Gudi, 02/10/2014, SSC, BSI (WRC) 197600.
35. *Chaetosphaerulina* sp. (Tubeufiaceae) on **stem litter** from Gundal dam, 25/03/2015, SSC, BSI (WRC) 202268.
36. *Chrysosporium* sp. (Onygenaceae) on **fallen twig** from Basunebetta, 21/12/2016, SSC, BSI (WRC) 203303.
37. *Ciliochorella mangiferae* Syd. 1935 (Pestalotiopsidaceae) on **fallen leaves** of *Mangifera indica* L. from Attikan coffee estate, 21/12/2016, SSC, BSI (WRC) 203304; and from K. Gudi, 14/12/2016, SSC, BSI (WRC) 202294.
38. *Cladosporium calotropidis* F. Stevens 1917 (Cladosporiaceae) on **leaves** of unidentified host from K. Gudi, 16/12/2016, SSC, BSI (WRC) 203338.
39. *Cladosporium oxysporum* Berk. & M.A. Curtis 1869 (Cladosporiaceae) on **leaves** of unidentified host from K. Gudi, 03/10/2014, SSC, BSI (WRC) 202157; **fallen bark** of unidentified plant from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197588; **fallen stem** from K. Gudi, 03/10/2014, SSC, BSI (WRC) 202154; from K. Gudi game road, 08/09/2015, SSC, BSI (WRC) 202202; and from Malkibetta, 15/12/2016, SSC, BSI (WRC) 202299.
40. *Cladosporium* sp. (Cladosporiaceae) on **leaves** of *Ficus* sp. from Attikan coffee estate, 03/06/2014, SSC, BSI (WRC) 197566; *Heliocarpus* sp. from Burude, 28/05/2014, SSC, BSI (WRC) 197514; **fallen leaves** from Atree GH, 02/10/2014, SSC, BSI (WRC) 197587; **stem litter** from MPCA, 06/09/2015, SSC, BSI (WRC) 203339; from BR hills, 27/03/2015, SSC, BSI (WRC) 202187; from C-matti, 02/10/2014, SSC, BSI (WRC) 202193; from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 202295; from K. Gudi, 15/12/2016, SSC, BSI (WRC) 203340; and from Manjigede, 02/10/2014, SSC, BSI (WRC) 202146.
41. *Cladotrichum mitratum* Penz. & Sacc. 1902 (Chaetosphaerellaceae) on **dried leaves** of *Bambusa bambos* (L.) Voss from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202261.
42. *Claussenomyces prasinulus* (P. Karst.) Korf & Abawi 1971 (Tympanidaceae) on **stem litter** from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 202289.

43. *Colemaniella biligiriensis* Rashmi Dubey & S. Sengupta 2016 (Pezizomycotina) on **dried leaves** of *Terminalia bellirica* (Gaertn.) Roxb. from Jodigede, 26/03/2015, SSC, BSI (WRC) 202200 [holotype]; and **fallen leaves** from Bodipadaga, 26/03/2015, SSC, BSI (WRC) 203341.
44. *Colletotrichum coffeanum* F. Noack 1901 (Glomerellaceae) on **leaves** of *C. arabica* L. from Manjigede, 02/10/2014, SSC, BSI (WRC) 202139.
45. *Cordana pauciseptata* Preuss 1851 (Cordanaceae) on **fallen stem** from K. Gudi, 16/12/2016, SSC, BSI (WRC) 203342; and from MPCA, 30/03/2015, SSC, BSI (WRC) 203321.
46. *Corynespora masseeanum* (Teng) P.M. Kirk 2014 (Corynesporascaceae) on **fallen stem** from Attikan coffee estate, 10/09/2015, SSC, BSI (WRC) 202204; from Boreduddi, 02/10/2014, SSC, BSI (WRC) 203343; from K. Gudi, 15/12/2016, SSC, BSI (WRC) 202298; and from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203309.
47. *Corynespora* sp. (Corynesporascaceae) on **fallen twig** from C-matti, 02/04/2015, SSC, BSI (WRC) 203344.
48. *Curvularia australiensis* (Bugnic. ex M.B. Ellis) Manamgoda, L. Cai & K.D. Hyde 2012 (Pleosporaceae) on **leaves** of *K. africana* (Lam.) Benth. from Bedguli, 30/05/2014, SSC, BSI (WRC) 197537.
49. *Curvularia brachyspora* Boedijn 1933 (Pleosporaceae) on **leaves** of *Mimosa pudica* L. from K. Gudi, 02/06/2014, SSC, BSI (WRC) 197561; unidentified host from Neilekadiru, 29/05/2014, SSC, BSI (WRC) 197520; **fallen leaves** from Gumbe gallu, 18/12/2016, SSC, BSI (WRC) 203390.
50. *Curvularia eragrostidis* (Henn.) J.A. Mey. 1959 (Pleosporaceae) on **leaves** of *Tarenna asiatica* (L.) Kuntze ex K.Schum. from Bylore, 01/06/2014, SSC, BSI (WRC) 197554.
51. *Curvularia lunata* (Wakker) Boedijn 1933 (Pleosporaceae) on **leaves** of unidentified host from Bylore, 01/10/2014, SSC, BSI (WRC) 202135.
52. *Curvularia pallescens* Boedijn 1933 (Pleosporaceae) on **leaves** of *Myristica fragrans* Houtt. from Hoonahmatti, 31/05/2014, SSC, BSI (WRC) 197538; and unidentified host from Hoonahmatti, 31/05/2014, SSC, BSI (WRC) 197548.
53. *Curvularia* sp. (Pleosporaceae) on **leaves** of *Casearia* sp. from Hoonahmatti, 31/05/2014, SSC, BSI (WRC) 197541.
54. *Curvularia spicifera* (Bainier) Boedijn 1933 (Pleosporaceae) on **leaves** of unidentified host from Neilekadiru, 29/05/2014, SSC, BSI (WRC) 197520.
55. *Curvularia trifolii* (Kauffman) Boedijn 1933 (Pleosporaceae) on **leaves** of *Curculigo* sp. from K. Gudi, 02/06/2014, SSC, BSI (WRC) 197560.
56. *Deightoniella* sp. (Magnaporthaceae) on **branch litter** from Bylore, 14/09/2015, SSC, BSI (WRC) 202260.
57. *Dendryphion vinosum* (Berk. & M.A. Curtis) S. Hughes 1958 (Torulaceae) on **stem litter** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203326.
58. *Deshpandiella jambolana* (T.S. Ramakr., Sriniv. & Sundaram) Kamat & Ullasa 1973 (Phyllachoraceae) on **branch litter** from K. Gudi, 02/10/2014, SSC, BSI (WRC) 202271.
59. *Diatrype* sp. (Diatrypaceae) on **dead stem** of *B. bambos* (L.) Voss from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202261.
60. *Dichotomopilus subfunicola* (X.Wei Wang & L. Cai) X.Wei Wang & Samson 2016 (Chaetomiaceae) on **stem litter** from Burude, 28/05/2014, SSC, BSI (WRC) 202198.
61. *Dictyoarthrinium sacchari* (J.A. Stev.) Damon 1953 (Didymosphaeriaceae) on **leaves** of *Saccharum* sp. from Burude, 28/05/2014, SSC, BSI (WRC) 202196; **stem litter** from Bodipadaga, 26/03/2015, SSC, BSI (WRC) 202197; from Gummanebetta, 03/04/2015, SSC, BSI (WRC) 203322; and from Manjigede, 31/03/2015, SSC, BSI (WRC) 202282.
62. *Diplocladiella scalaroides* G. Arnaud ex M.B. Ellis 1976 (Pezizomycotina) on **leaves** of *Strobilanthes* sp. from C-matti, 06/09/2015, SSC, BSI (WRC) 202254.
63. *Drechslera* sp. (Pleosporaceae) on **leaves** of unidentified host from Hoonahmatti, 31/05/2014, SSC, BSI (WRC) 197547.
64. *Duplicaria empetri* (Pers.) Fuckel 1870 (Rhytismataceae) on **stem litter** from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202279.
65. *Ellisembia bambusicola* (M.B. Ellis) J. Mena & G. Delgado 2000 (Sordariomycetes) on **stem litter** from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 202297; from Malkibetta, 04/10/2014, SSC, BSI (WRC) 202207; and **twig litter** from K. Gudi, 16/12/2016, SSC, BSI (WRC) 203342.
66. *Elotespora indica* Rashmi Dubey & S.S. Chatterjee 2019 (Pezizomycotina) on **twig litter** from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 203311.
67. *Endophragmiella theobromae* M.B. Ellis 1976 (Sordariomycetidae) on **stem litter** from K. Gudi, 26/03/2015, SSC, BSI (WRC) 203345.
68. *Epicoccum nigrum* Link 1816 (Didymellaceae) on **leaves** of *Ficus* sp. from Attikan coffee estate, 03/06/2014, SSC, BSI (WRC) 197566; and **stem litter** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203350.
69. *Epicoccum* sp. (Didymellaceae) on **leaves** of *K. africana* (Lam.) Benth. from Bedguli, 30/05/2014, SSC, BSI (WRC) 197537; and *B. bambos* (L.) Voss, from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202261.
70. *Exosporium gymnemae* P.N. Singh & S.K. Singh 2015 (Pezizomycotina) on **stem litter** from Burude, 28/05/2014, SSC, BSI (WRC) 202198.
71. *Exosporium monanthotaxis* Piroz. 1972 (Pezizomycotina) on **branch litter** from Malkibetta, 01/04/2015, SSC, BSI (WRC) 197589.
72. *Exserohilum turcicum* (Pass.) K.J. Leonard & Suggs 1974 (Pleosporaceae) on **stem litter** from Bedguli, 30/05/2014, SSC, BSI (WRC) 203384.
73. *Funneliformis dimorphicus* (Boyetchko & J.P. Tewari) Oehl, G.A. Silva & Sieverd. 2011 (Glomeraceae) on **rhizosphere soil** from Malkibetta, 15/12/2016, SSC, BSI (WRC) 203399; and from Neerdurgi, 17/12/2016, SSC, BSI (WRC) 203395.

74. *Fusarium* sp. (Nectriaceae) on unidentified host from Bylore, 01/10/2014, SSC, BSI (WRC) 202121.
75. *Fusarium udum* E.J. Butler 1910 (Nectriaceae) on **leaves** of unidentified host from K. Gudi, 30/09/2014, SSC, BSI (WRC) 202114.
76. *Fusicladium britannicum* (M.B. Ellis) U. Braun & K. Schub. 2008 (Venturiaceae) on leaves of *Anogeissus* sp. from Burude, 28/05/2014, SSC, BSI (WRC) 197511.
77. *Glomus macrocarpum* Tul. & C. Tul. 1845 (Glomeraceae) on **rhizosphere soil** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203398.
78. *Glomus macrocarpum* var. *macrocarpum* Tul. & C. Tul. 1845 (Glomeraceae) on **rhizosphere soil** from Bylore, 01/10/2014, SSC, BSI (WRC) 203400.
79. *Glomus microcarpum* Tul. & C. Tul. 1845 (Glomeraceae) on **rhizosphere soil** from Malkibetta, 15/12/2016, SSC, BSI (WRC) 203399.
80. *Glomus* sp. (Glomeraceae) on **rhizosphere soil** from Atree GH, 01/06/2014, SSC, BSI (WRC) 203394; from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 203396; and from Manjigede, 02/10/2014, SSC, BSI (WRC) 203396.
81. *Glonium keralense* A. Pande 2008 (Gloniaceae) on **twig litter** from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203329.
82. *Gonytrichum macrocladum* (Sacc.) S. Hughes 1952 (Chaetosphaeriaceae) on **stem litter** from Gundal dam, 25/03/2015, SSC, BSI (WRC) 202265.
83. *Helhonia rhamnigena* (Fautrey) B. Sutton 1980 (Pezizomycotina) on **fallen leaves** from Burude, 15/12/2016, SSC, BSI (WRC) 203320.
84. *Heteroconium citharexyli* Petr. 1949 (Antennulariellaceae) on **stem litter** from K. Gudi, 16/12/2016, SSC, BSI (WRC) 202296.
85. *Hysterium tamarindi* Tilak & R. Rao 1966 (Hysteriaceae) on **stem litter** from K. Gudi, 26/03/2015, SSC, BSI (WRC) 203345.
86. *Idriella lunata* P.E. Nelson & S. Wilh. 1956 (Microdochiaceae) on **stem litter** from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 202289.
87. *Kamalomyces mahabaleshwarensis* Rashmi Dubey & Moonamb. 2013 (Dothideomycetes) on **dead fallen wood** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197599.
88. *Kirschsteiniothelia atra* (Corda) D. Hawksw. 2014 (Kirschsteiniotheliaceae) on **stem litter** from Malkibetta, 15/12/2016, SSC, BSI (WRC) 203312.
89. *Lasiodiplodia theobromae* (Pat.) Griffon & Maubl. 1909 (Botryosphaeriaceae) on **stem litter** from Boreduddi, 02/10/2014, SSC, BSI (WRC) 203343; from Manjigede, 31/03/2015, SSC, BSI (WRC) 202277; and from Neilekadiru, 27/03/2015, SSC, BSI (WRC) 203346.
90. *Leptopeltis gregaria* (Petr.) L. Holm & K. Holm 1977 (Leptopeltidaceae) on **stem litter** from Burude, 28/05/2014, SSC, BSI (WRC) 202267.
91. *Massarina albocarnis* (Ellis & Everh.) M.E. Barr 1992 (Massarinaceae) on **stem litter** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203325.
92. *Melanographium citri* (Gonz. Frag. & Cif.) M.B. Ellis 1963 (Pezizomycotina) on **stem litter** from Burude, 15/12/2016, SSC, BSI (WRC) 203310; and from Madigudi, 05/09/2015, SSC, BSI (WRC) 202287.
93. *Meliola buteae* Hafiz Khan, Azmatullah & Kafi 1955 (Meliolaceae) on **fallen leaves** from Malkibetta, 15/12/2016, SSC, BSI (WRC) 203347.
94. *Meliola mitragynae* Syd. & P. Syd. 1913 (Meliolaceae) on **fallen leaves** from Bedguli, 01/04/2015, SSC, BSI (WRC) 203348.
95. *Monodictys putredinis* (Wallr.) S. Hughes 1958 (Pezizomycotina) on **stem litter** from Boreduddi, 02/10/2014, SSC, BSI (WRC) 197581; from Gundal dam, 25/03/2015, SSC, BSI (WRC) 202274; from Basunebetta, 21/12/2016, SSC, BSI (WRC) 203305; from Burude, 20/12/2016, SSC, BSI (WRC) 203354; from Dupabare, 20/12/2016, SSC, BSI (WRC) 203306; from Gundal dam, 25/03/2015, SSC, BSI (WRC) 202274; from Gundal dam, 22/12/2016, SSC, BSI (WRC) 203357; from Manjigede, 31/03/2015, SSC, BSI (WRC) 202275; from Gummanebetta, 26/03/2015, SSC, BSI (WRC) 197700; from BR hills, 16/12/2016, SSC, BSI (WRC) 203355; from K. Gudi, 15/12/2016, SSC, BSI (WRC) 203312; from K. Gudi, 15/12/2016, SSC, BSI (WRC) 203318; **twig litter** from Arre pallya, 14/12/2016, SSC, BSI (WRC) 202293; from Burude, 17/12/2016, SSC, BSI (WRC) 203353; from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203329; from Hoonahmatti, 28/03/2015, SSC, BSI (WRC) 203356; **bark litter** from Boreduddi, 02/10/2014, SSC, BSI (WRC) 197583; from Madigudi, 30/09/2014, SSC, BSI (WRC) 197579; **branch litter** from Kumaramathi, 06/09/2015, SSC, BSI (WRC) 202253.
96. *Moorella speciosa* P.Rag. Rao & D. Rao 1964 (Pezizomycotina) on **twig litter** from Gundal dam, 25/03/2015, SSC, BSI (WRC) 202268; **stem litter** from Manjigede, 02/10/2014, SSC, BSI (WRC) 202190; and from K. Gudi, 02/10/2014, SSC, BSI (WRC) 197600.
97. *Mucor mucedo* Fresen. 1850 (Mucoraceae) on **soil** from C-matti, 06/09/2015, SSC, BSI (WRC) 203388.
98. *Mycosphaerella deightonii* M. Morelet 1973 (Mycosphaerellaceae) on **leaves** of *C. odorata* (L.) King & H.E.Robins from Burude, 28/05/2014, SSC, BSI (WRC) 197504.
99. *Neoarthrinium urticae* (M.B. Ellis) Ning Jiang 2022 (Apiosporaceae) on **branch litter** from Malkibetta, 04/10/2014, SSC, BSI (WRC) 202192.
100. *Neopestalotiopsis asiatica* (Maharachch. & K.D. Hyde) Maharachch., K.D. Hyde & Crous 2014 (Pestalotiopsidaceae) on **leaves** of unidentified host from K. Gudi, 30/09/2014, SSC, BSI (WRC) 202109; and **fallen leaves** from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202257.
101. *Neopestalotiopsis chrysea* (Maharachch. & K.D. Hyde) Maharachch., K.D. Hyde & Crous 2014 (Pestalotiopsidaceae) on **fallen leaves** from Gundal dam, 25/03/2015, SSC, BSI (WRC) 202266; and from K. Gudi, 16/12/2016, SSC, BSI (WRC) 203360.

102. *Neopestalotiopsis clavispora* (G.F. Atk.) Maharachch., K.D. Hyde & Crous 2014 (Pestalotiopsidaceae) on **fallen leaves** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197584.
103. *Neopestalotiopsis* sp. (Pestalotiopsidaceae) on **fallen leaves** from Neerdurgi, 17/12/2016, SSC, BSI (WRC) 203361.
104. *Niesslia* sp. (Niessliaceae) on **stem litter** from Attikan coffee estate, 11/09/2015, SSC, BSI (WRC) 202288.
105. *Nigrospora oryzae* (Berk. & Broome) Petch 1924 (Sordariomycetes) on **stem litter** from Malkibetta, 15/12/2016, SSC, BSI (WRC) 202299.
106. *Paradictyoarthrinium diffractum* Matsush. 1996 (Paradictyoarthriniaceae) on **stem litter** from Arre pallya, 14/12/2016, SSC, BSI (WRC) 203358; from Yelandur gate, 24/12/2016, SSC, BSI (WRC) 203359; and **branch litter** from Yelandur, 06/09/2015, SSC, BSI (WRC) 202255.
107. *Parapericonia* sp. (Ascomycota) on **stem litter** from Bylore, 05/09/2015, SSC, BSI (WRC) 202286.
108. *Periconia cambrensis* E.W. Mason & M.B. Ellis 1953 (Pleosporales) on **twig litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197595.
109. *Periconia digitata* (Cooke) Sacc. 1886 (Pleosporales) on **bark litter** from Boreduddi, 02/10/2014, SSC, BSI (WRC) 197585.
110. *Periconia kambakkamensis* Subram. 1955 (Pleosporales) on **stem litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197593.
111. *Periconia* sp. (Pleosporales) on **leaves** of *B. bambos* (L.) Voss from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202261; and **stem litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197598.
112. *Phaeoblastophora peckii* (Sacc. & P. Syd.) Partr. & Morgan-Jones 2002 (Botryobasidiaceae) on **twig litter** from Kumaramathi, 17/12/2016, SSC, BSI (WRC) 203316.
113. *Phoma epicoccina* Punith., M.C. Tulloch & C.M. Leach 1972 (Didymellaceae) on **stem litter** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203350.
114. *Phoma herbarum* Westend. 1852 (Didymellaceae) on **fallen submerged leaves** from K. Gudi, 30/09/2014, SSC, BSI (WRC) 203351.
115. *Phoma* sp. (Didymellaceae) on **fallen submerged leaves** from Manjigede, 05/09/2015, SSC, BSI (WRC) 203362.
116. *Physalospora alpestris* Niessl 1876 (Hyponectriaceae) on **stem litter** from K. Gudi, 14/12/2016, SSC, BSI (WRC) 203324.
117. *Pithomyces ellisii* V.G. Rao & Chary 1972 (Astrosphaeriellaceae) on **twig litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 202191.
118. *Pithomyces sumiderensis* Hol.-Jech. 1986 (Astrosphaeriellaceae) on **stem litter** from K. Gudi, 02/10/2014, SSC, BSI (WRC) 197600.
119. *Podosporiella faureae* (Chupp & Doidge) M.B. Ellis 1976 (Pezizomycotina) on **branch litter** from Manjigede, 05/09/2015, SSC, BSI (WRC) 202290.
120. *Pseudocercospora glomerata* (Harkn.) U. Braun & Crous 2003 (Mycosphaerellaceae) on **fallen leaves** from Dodda alla, 17/12/2016, SSC, BSI (WRC) 203374.
121. *Pseudopithomyces maydicus* (Sacc.) Jun F. Li, Ariyaw. & K.D. Hyde 2015 (Didymosphaeriaceae) on **leaves** of unidentified host from Neilekadiru, 29/05/2014, SSC, BSI (WRC) 197524.
122. *Ramularia pusilla* Unger 1833 (Mycosphaerellaceae) on **fallen leaves** from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203307.
123. *Rhexoacrodictys erecta* (Ellis & Everh.) W.A. Baker & Morgan-Jones 2002 (Pleurotheciaceae) on **stem litter** from Gumbe gallu, 18/12/2016, SSC, BSI (WRC) 203323; and from Malkibetta road, 15/12/2016, SSC, BSI (WRC) 203319.
124. *Rhinocladiella cristaspora* Matsush. 1971 (Herpotrichiellaceae) on **unidentified host** from Burude, 28/05/2014, SSC, BSI (WRC) 197505; from Bylore, 01/10/2014, SSC, BSI (WRC) 202129; from K. Gudi, 30/09/2014, SSC, BSI (WRC) 202101; from K. Gudi, 03/10/2014, SSC, BSI (WRC) 202159; and from Punajur, 02/10/2014, SSC, BSI (WRC) 202149.
125. *Rhinocladiella selenoides* (de Hoog) Onofri & Castagn. 1983 (Herpotrichiellaceae) on **unidentified host** from K. Gudi, 15/12/2016, SSC, BSI (WRC) 203331.
126. *Rhizopus stolonifer* (Ehrenb.) Vuill. 1902 (Rhizopodaceae) on **soil** from Hoonahmatti, 31/05/2014, SSC, BSI (WRC) 197541.
127. *Rhodoveronaea varioseptata* Arzanlou, W. Gams & Crous 2007 (Sordariomycetidae) on **dead fallen stem** of *B. bambos* (L.) Voss from Hoonahmatti, 09/09/2015, SSC, BSI (WRC) 202261.
128. *Sadasivania* sp. (Pezizomycotina) on **dried submerged leaves of palm** from Gumbe gallu, 18/12/2016, SSC, BSI (WRC) 203364.
129. *Sarcinella indica* Kamal & Narayan 1987 (Englerulaceae) on **fallen submerged leaves** from K. Gudi, 30/09/2014, SSC, BSI (WRC) 203351.
130. *Sarcopodium circinatum* Ehrenb. 1818 (Pezizomycotina) on **stem litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 202189.
131. *Scytalidium lignicola* Pesante 1957 (Helotiales) on **leaf litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197590.
132. *Seimatosporium* sp. (Sporocadaceae) on **leaves** of *Cinnamomum* sp., from Attikan coffee estate, 03/06/2014, SSC, BSI (WRC) 197568; and unidentified host from K. Gudi, 30/09/2014, SSC, BSI (WRC) 202104.
133. *Solicorynespora foveolata* (Pat.) Shirouzu & Y. Harada 2008 (Pezizomycotina) on **branch litter** from C-matti, 02/04/2015, SSC, BSI(WRC) 203344.
134. *Sordaria fimicola* (Roberge ex Desm.) Ces. & De Not. 1863 (Sordariaceae) on **leaves** of *C. nucifera* L. from Burude, 13/09/2015, SSC, BSI (WRC) 202273; *M. indica* L. from Neilekadiru, 29/05/2014, SSC, BSI (WRC) 197522; **stem litter** from Dupabare, 15/12/2016, SSC, BSI (WRC) 203368; from Bodipadaga, 26/03/2015, SSC, BSI (WRC) 202269; from Dodda alla, 17/12/2016, SSC, BSI (WRC)

203367; from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197594; from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197597; from Gundal dam, 25/03/2015, SSC, BSI (WRC) 202276; from Hoonahmatti coffee estate, 09/09/2015, SSC, BSI (WRC) 202280; from Hoonahmatti, 28/03/2015, SSC, BSI (WRC) 203370; from Jodigede, 08/09/2015, SSC, BSI (WRC) 202188; from Jodigede, 18/12/2016, SSC, BSI (WRC) 203366; from K. Gudi, 14/12/2016, SSC, BSI (WRC) 202263; from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203301; from Malkibetta road, 15/12/2016, SSC, BSI (WRC) 203340; from Neerdurgi, 17/12/2016, SSC, BSI (WRC) 203369; **twig litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197592; from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197598; from Manjigede, 31/03/2015, SSC, BSI (WRC) 202282; and **branch litter** from Hoonahmatti, 18/12/2016, SSC, BSI (WRC) 203365.

135. *Spegazzinia sundara* Subram. 1956 (Apiosporaceae) on **stem litter** from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197591; and from Malkibetta, 15/12/2016, SSC, BSI (WRC) 202300.
136. *Spiropes intricatus* (Sacc.) M.B. Ellis 1968 (Pezizomycotina) on **stem litter** from Bylore, 05/09/2015, SSC, BSI (WRC) 197577.
137. *Sporidesmium biligiriense* Rashmi Dubey & S. Sengupta 2015 (Pleosporomycetidae) on **stem litter** from Manjigede, 02/10/2014, SSC, BSI (WRC) 197580.
138. *Sporidesmium cookei* (S. Hughes) M.B. Ellis 1958 (Pleosporomycetidae) on **stem litter** from Malkibetta, 15/12/2016, SSC, BSI (WRC) 203330.
139. *Sporidesmium vagum* Nees & T. Nees 1818 (Pleosporomycetidae) on **stem litter** from Gumbe gallu, 18/12/2016, SSC, BSI (WRC) 203323.
140. *Stachybotrys levisporus* (Subram.) Yong Wang bis, K.D. Hyde, McKenzie, Y.L. Jiang & D.W. Li 2015 (Stachybotryaceae) on **leaves** of *Strobilanthes* sp. from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197596; *Musa* x *paradisiaca* L. from Hoonahmatti, 06/09/2015, SSC, BSI (WRC) 202252; **twig litter** from Bedguli, 29/03/2015, SSC, BSI (WRC) 203349; **stem litter** from Burude, 28/05/2014, SSC, BSI (WRC) 202198; from Manjigede, 31/03/2015, SSC, BSI (WRC) 202282; and **bark litter** from Dodda Sampigge, 02/04/2015, SSC, BSI (WRC) 202275.
141. *Stachybotrys proliferatus* K.G. Karand., S.M. Kulk. & Patw. 1992 (Stachybotryaceae) on **leaves** of *Strobilanthes* sp., from Dodda Sampigge, 03/10/2014, SSC, BSI (WRC) 197596.
142. *Taeniolina scripta* (P. Karst.) P.M. Kirk 1981 (Pezizomycotina) on **stem litter** from Bedguli, 01/04/2015, SSC, BSI (WRC) 203371; and from Jodigede, 10/09/2015, SSC, BSI (WRC) 202262.
143. *Temerariomyces acutulus* B. Sutton 1993 (Pezizomycotina) on **leaves** of *Areca catechu* L. from Dodda Sampigge, 02/04/2015, SSC, BSI (WRC) 202270; and **fallen submerged leaves** from Malkibetta, 15/12/2016, SSC, BSI (WRC) 203372.
144. *Tetraploa aristata* Berk. & Broome 1850 (Tetraplosphaeriaceae) on **branch litter** from Bylore, 05/09/2015, SSC, BSI (WRC) 202258.
145. *Tharoopama livistonae* Rashmi Dubey & Moonamb. 2013 (Pezizomycotina) on **leaves** of *C. nucifera* L., from Burude, 13/09/2015, SSC, BSI (WRC) 202273.
146. *Thyronectria sinopica* (Fr.) Jaklitsch & Voglmayr 2014 (Sordariomycetes) on **stem litter** from Hoonahmatti coffee estate, 09/09/2015, SSC, BSI (WRC) 202281.
147. *Torula herbarum* (Pers.) Link 1809 (Torulaceae) on **leaves** of *Saccharum* sp., from Burude, 28/05/2014, SSC, BSI (WRC) 202196; *C. nucifera* L., from Burude, 25/03/2015, SSC, BSI (WRC) 202195; **branch litter** from Boreduddi, 02/10/2014, SSC, BSI (WRC) 202272; from Burude, 28/05/2014, SSC, BSI (WRC) 202256; from Manjigede, 31/03/2015, SSC, BSI (WRC) 202277; **stem litter** from Burude, 28/05/2014, SSC, BSI (WRC) 202198; from Gundal dam, 25/03/2015, SSC, BSI (WRC) 197699; from K. Gudi, 30/09/2014, SSC, BSI (WRC) 197582; from K. Gudi, 26/03/2015, SSC, BSI (WRC) 197700; from Manjigede, 31/03/2015, SSC, BSI (WRC) 202282; from Neerdurgi, 17/12/2016, SSC, BSI (WRC) 203308.
148. *Trematosphaeria crassiseptata* Kaz. Tanaka, Y. Harada & M.E. Barr 2005 (Trematosphaeriaceae) on **stem litter** from Dodda Sampigge, 23/12/2016, SSC, BSI (WRC) 202285; from Dupabare foothills, 20/12/2016, SSC, BSI (WRC) 202297; and from Malkibetta, 04/10/2014, SSC, BSI (WRC) 202207.
149. *Trematosphaeria pertusa* Fuckel 1870 (Trematosphaeriaceae) on **stem litter** from Malkibetta road, 15/12/2016, SSC, BSI (WRC) 203352.
150. *Triadelphia heterospora* Shearer & J.L. Crane 1971 (Triadelphiaceae) on **stem litter** from Bodipadaga, 08/09/2015, SSC, BSI (WRC) 202284.
151. *Trichocladium griseum* (Traaen) X. Wei Wang & Houbraken 2018 (Chaetomiaceae) on **fallen leaves** from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203392.
152. *Trichoderma viride* Pers. 1794 (Hypocreaceae) on **fallen leaves** from C-matti, 06/09/2015, SSC, BSI (WRC) 203393; and from Kataribetta, 21/12/2016, SSC, BSI (WRC) 203392.
153. *Trichothecium excentricum* Matsush. 1981 (Hypocreales) on **leaves** of unidentified host from K. Gudi, 03/10/2014, SSC, BSI (WRC) 202152.
154. *Trichothecium roseum* (Pers.) Link 1809 (Hypocreales) on **leaves** of unidentified host from Burude, 15/12/2016, SSC, BSI (WRC) 203340; from Bylore, 01/10/2014, SSC, BSI (WRC) 202125; and from Manjigede, 02/10/2014, SSC, BSI (WRC) 202141.
155. *Trimmatostroma saksenae* V.G. Rao & Varghese 1981 (Mollisiaceae) on **stem litter** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203315.
156. *Trimmatostroma scutellare* (Berk. & Broome) M.B. Ellis 1976 (Mollisiaceae) on **stem litter** from Jodigede, 01/04/2015, SSC, BSI (WRC) 202194; and from K. Gudi, 14/12/2016, SSC, BSI (WRC) 203377.

157. *Tripospermum myrti* (Lind) S. Hughes 1951 (Capnodiaceae) on **stem litter** from Dodda Sampigge, 02/04/2015, SSC, BSI (WRC) 203333; and from Hoonahmatti, 28/03/2015, SSC, BSI (WRC) 203373.
158. *Urohendersonia indica* Syd. & P. Syd. 1916 (Pezizomycotina) on **fallen leaves** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203328.
159. *Uromyces* sp. (Pucciniaceae) on **fallen leaves** from K. Gudi game road, 06/09/2015, SSC, BSI (WRC) 203363.
160. *Virgariella globigera* (Sacc. & Ellis) S. Hughes 1953 (Pezizomycotina) on **stem litter** from K. Gudi, 14/12/2016, SSC, BSI (WRC) 203376.
161. *Volutina concentrica* Penz. & Sacc. 1902 (Nectriaceae) on **stem litter** from Hoonahmatti coffee estate, 09/09/2015, SSC, BSI (WRC) 202280.
162. *Xylaria polymorpha* (Pers.) Grev. 1824 (Xylariaceae) on **stem litter** from Bylore, 15/12/2016, SSC, BSI (WRC) 203378.
163. *Zygosporium masonii* S. Hughes 1951 (Zygosporiaceae) on **stem litter** from Bedguli, 18/12/2016, SSC, BSI (WRC) 203379.
164. *Zygosporium oscheoides* Mont. 1842 (Zygosporiaceae) on **stem litter** from Jodigede, 30/09/2014, SSC, BSI (WRC) 202161.

Discussion

The present study on the microfungi of BRT WLS is a landmark contribution to mycological research and forest ecology. By employing meticulous methodologies, including advanced microscopy, the research has significantly enhanced the understanding of fungal diversity and taxonomy in this unique biogeographical region of India.

The present study resulted in enumeration of 164 species from 290 fungal isolates. The isolated fungi belonged to 4 broad classes of substrates viz., Litter, Foliicolous, Arbuscular Mycorrhizal and Soil Fungi, among which Litter fungi dominated with 122 species identified from 207 isolates. *Curvularia* was most dominant species, having been represented by 8 species, while *S. fimicola* was most dominant species, having been identified from 20 isolates.

It also led to the publication of 5 new taxa which include 1 new genus with its type species and other 3 new species. Also, 75 genera and 129 species reported in the present study were not reported in the Checklist of Fungi of Karnataka by Sharma and Mishra (2019). The 129 species of microfungi are as follows: *Acanthostigma* sp., *A. longula, Acaulospora* sp., *A. sacchari, A. luteoalbus, A. botrytis, A. chlamydospora, A. dianthicola, A. sonchi, A. resinae, A. arundinis, A. jambolanae, A. plectranthi, A. lepianthis, Asterostomella* sp., *B. bambusae, B. mangiferae, B. spiralis, B. hyalina, B. indica, B. papendorfii, B. antennata, B. clavata, C. globosum, C. lignicola, Chrysosporium* sp., *C. mangiferae, C. oxysporum, C. mitratum, C. prasinulus, C. biligiriensis, C. pauciseptata, C. masseeanum, C. australiensis, C. pallescens, Deightoniella* sp., *D. vinosum, D. jambolana, D. subfunicola, D. sacchari, D. scalaroides, Drechslera* sp., *D. empetri, E. bambusicola, E. indica, E. theobromae, E. gymnemae, E. monanthotaxis, E. turcicum, F. dimorphicus, Fusarium* sp., *F. udum, F. britannicum, G. macrocarpum, G. macrocarpum* var. *macrocarpum, G. microcarpum, G. keralense, G. macrocladum, H. rhamnigena, H. citharexyli, H. tamarindi, I. lunata, K. mahabaleshwarensis, K. atra, L. theobromae, L. gregaria, M. albocarnis, M. citri, M. putredinis, M. speciosa, M. mucedo, M. deightonii, N. urticae, N. asiatica, N. chrysea, N. clavispora, Neopestalotiopsis* sp., *Niesslia* sp., *N. oryzae, P. diffractum, Parapericonia* sp., *P. cambrensis, P. digitata, P. kambakkamensis, P. peckii, P. epicoccina, P. herbarum, P. alpestris, P. ellisii, P. sumiderensis, P. faureae, P. glomerata, P. maydicus, R. pusilla, R. erecta, R. cristaspora, R. selenoides, R. varioseptata, Sadasivania* sp., *S. indica, S. circinatum, S. lignicola, Seimatosporium* sp., *S. foveolata, S. fimicola, S. sundara, S. intricatus, S. biligiriense, S. cookei, S. vagum, S. levisporus, S. proliferatus, T. scripta, T. acutulus, T. aristata, T. livistonae, T. sinopica, T. herbarum, T. crassiseptata, T. pertusa, T. heterospora, T. griseum, T. excentricum, T. saksenae, T. scutellare, U. indica, V. globigera, V. concentrica, Z. masonii, Z. oscheoides*.

The 75 genera are: *Acanthostigma, Acaulospora, Acrodictys, Acrostalagmus, Alysidium, Asterostomella, Bambusaria, Beltraniella, Bhadradriella, Biligiriella, Bispora, Bitunicostilbe, Chrysosporium, Ciliochorella, Cladotrichum, Claussenomyces, Colemaniella, Cordana, Deightoniella, Dendryphion, Deshpandiella, Dichotomopilus, Dictyoarthrinium, Diplocladiella, Drechslera, Duplicaria, Ellisembia, Elotespora, Endophragmiella, Exserohilum, Funneliformis, Fusicladium, Glonium, Gonytrichum, Helhonia, Heteroconium, Hysterium, Idriella, Kamalomyces, Kirschsteiniothelia, Lasiodiplodia, Leptopeltis, Massarina, Melanographium, Monodictys, Moorella, Neopestalotiopsis, Niesslia, Paradictyoarthrinium, Parapericonia, Phaeoblastophora, Podosporiella, Pseudopithomyces, Ramularia, Rhexoacrodictys, Rhinocladiella, Rhodoveronaea, Sadasivania, Sarcopodium, Scytalidium, Seimatosporium, Solicorynespora, Sordaria, Spegazzinia, Sporidesmium, Taeniolina, Temerariomyces, Tetraploa, Tharoopama, Thyronectria, Torula, Triadelphia, Trichocladium, Virgariella, Volutina*. Thus, the present study makes a significant contribution to the mycobiota of Karnataka. The findings underscore the critical ecological roles of microfungi and highlight the importance of conserving such rich and diverse ecosystems.

The BRT WLS, located in the southern Western Ghats of India is recognized for its rich biodiversity and unique ecological features. The thorough documentation of microfungi in this sanctuary not only highlights the ecological complexity of the area but also underscores its importance as a habitat for a diverse range of fungal species. This study has significantly expanded our understanding of the microfungal diversity within the BRT WLS by documenting a total of 75 genera and 129 species of microfungi. By identifying 75 genera and 129 species, the study provides a detailed inventory of the microfungal community in the BRT WLS. The genus *Curvularia*, with 8 recorded species, was the most dominant genus, followed by *Alternaria* 7 species, and *Asterina* 5 species. The *S. fimicola* was the most prevalent species, with 20 isolates, followed by *M. putredinis* with 19 isolates and *T. herbarum* with 11 isolates.

This represents a substantial contribution to the mycological knowledge of the region, showcasing the variety of microfungi that inhabit this specific ecological niche. The detailed inventory provided by this study serves as a foundational reference for future research. It opens up various avenues for further scientific inquiry, such as the exploration of the ecological roles of these fungi, their interactions with other organisms, and their responses to environmental changes. Additionally, it provides a baseline for monitoring changes in fungal diversity over time, which can be critical for assessing the impacts of climate change, habitat disturbance, and conservation efforts. This research adds valuable data to the global mycological database, contributing to a more complete understanding of fungal diversity in tropical and subtropical regions. By documenting species in a relatively understudied area, the study enriches our global knowledge of fungal biodiversity and distribution patterns. Overall, the study underscores the BRT WLS's significance as a critical area for both fungal biodiversity and conservation. It not only lays a robust foundation for future scientific research but also emphasizes the need for continued conservation efforts to protect and sustain the rich microfungal communities that contribute to the ecological health of this sanctuary.

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Survey of the butterflies (Lepidoptera: Rhopalocera) species of the northern coast of East Java, Indonesia

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Abstract. *Arof AS, Barbosa FF. 2024. Survey of the butterflies (Lepidoptera: Rhopalocera) species of the northern coast of East Java, Indonesia. Intl J Trop Drylands 8: 83-94.* The cosmopolitan order Lepidoptera Linnaeus, 1758, is one of the major orders of hexapods and a megadiverse clade of holometabolous insects. Within this order is included, the mostly diurnal butterflies (Lepidoptera: Rhopalocera: Papilionoidea *sensu* Kawahara and Breinholt 2014). The worldwide butterfly species richness is estimated to be ~18,768 species, distributed in ~1,815 genera and seven families. This group presents well-known ecologically important species that may serve as bioindicators. They are relatively well-studied, particularly in temperate biomes, although considerable gaps in information persist in tropical areas. The study area is classified as a tropical and subtropical moist broadleaf forest biome, specifically in the Eastern Java-Bali rain forests ecoregion in the Indo-Malayan realm, and is classified as a critical or endangered biome. More specifically, this area is located on the Java island, East Java province (Oriental Java), northern coast. Also, it is part of Sundaland, which is considered one of the major biodiversity hotspots. From October 2016 to August 2024, twice at a weekly, the authors employed the exploring method along with a visual encounter survey, observing, capturing, and documenting the species encountered to access the species composition. This study covers 126 species belonging to 85 genera, 41 tribes, and 17 subfamilies of five families, and this distribution in the frequency of species among families broadly reflects the global distribution of species of butterflies. This is the first field investigation to study the butterfly richness specifically on the northern coast of East Java. The present study contributes to the knowledge of the butterfly fauna in the Indonesian archipelago. Additionally, this study contributes to future studies of the conservation of biodiversity in this key endangered region. Moreover, this study can be the first step towards future studies focusing on community ecology, population dynamics, and the use of butterflies as bioindicators in the northern coast of East Java.

Keywords: Biodiversity hotspot, butterfly species composition, butterfly species richness, endangered biome, Southeast Asia

INTRODUCTION

Insects, including butterflies, are animals that play a crucial role in ecosystems and human life. They are essential pollinators for many plants, including important food crops, contributing significantly to global agriculture development and biodiversity (Gullan and Cranston 2004; Grimaldi and Engel 2005). Moths and butterflies are classified in the cosmopolitan order Lepidoptera Linnaeus, 1758 (from the Greek *lepídos*, meaning “scale” and *pterón* meaning “wing”). It is one of the major orders of hexapods and a megadiverse clade of holometabolous insects, alongside Coleoptera, Diptera, and Hymenoptera (Misof et al. 2014). The worldwide lepidopteran species richness is estimated to be ~157,424 species, distributed in ~15,578 genera, 126 families, 43 superfamilies, and four suborders (van Nieukerken et al. 2011). They undergo complete metamorphosis through four distinct stages: egg, caterpillar (larva), pupa, and imago (Gullan and Cranston 2004; Grimaldi and Engel 2005).

Within this order is included, the mostly diurnal butterflies (Lepidoptera: Rhopalocera: Papilionoidea *sensu* Kawahara and Breinholt 2014). In the present study the re-definition of the group by the phylogenomic study of Kawahara and Breinholt (2014) was applied, which strongly supported the monophyly of all butterfly families, including the Hesperiidae and Hedylidae families (see also van Nieukerken et al. 2011). The worldwide butterfly species richness is estimated to be ~18,768 species, distributed in ~1,815 genera and seven families: one Neotropical family, Hedylidae; and six worldwide distributed families, Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae, Pieridae, and Riodinidae (van Nieukerken et al. 2011; Lamas 2014). In the Oriental and Australian tropics, it is estimated to presents ~4,500 species of butterflies (Lamas 2014), and specifically, in the Indonesian archipelago, there are ~2,000 species registered (Murwitaningsih et al. 2019).

This group exhibits seasonal and population polymorphism, mimetic rings, and can play important roles in ecosystems around the world, serving both as pollinators and as a food source within the ecological network chains (Gullan and Cranston 2004; Grimaldi and Engel 2005; Rader et al. 2016). Also, they are highly dependent on interactions with host plants to complete their life cycles, which often makes them highly seasonal- and habitat-specific (Robinson et al. 2023). Furthermore, butterflies are recognized as bioindicator species (Ismail et al. 2020) to evaluate the health of ecosystems and the effects of climate change. This is due to the fact that they are very sensitive and well-responsive to changes in their environment, including habitat loss, an array of abiotic factors, and anthropogenic pressures. Therefore, variations in butterfly population dynamics can reflect disturbances in habitat conditions (Ismail et al. 2020).

Additionally, butterflies are attractive insects with a visual aesthetic appeal, which makes this group popular among the general public (Gullan and Cranston 2004). Consequently, they are a relatively well-studied group globally, particularly in temperate biomes. However, considerable gaps in information and species diversity and distribution persist in tropical biomes (Lewis and Senior 2011; Ismail et al. 2020), including the Indonesian archipelago, which is well-known as a megadiverse region. Several known factors, like biogeographic, climatic, ecological, and geological ones, contributed to the development of a megadiverse fauna and flora in the region, with a high degree of endemic species and complex ecological interactions (Lohman et al. 2011; Koneri et al. 2017; von Rintelen et al. 2017; Murwitaningsih et al. 2019; Kurniawan et al. 2020; Umami et al. 2024).

Climate and vegetation coverage on Java Island, in the Indonesian archipelago, can be described as progressively changing from west to east. In this view, it can be clearly observed that an environmental transition happens from the rainforest regions of western Java to the savanna regions in eastern Java (Umami et al. 2024). The present study is a preliminary survey that aims to present the first species records in the area, with a list of the butterfly species assemblage (*sensu* Stroud et al. 2015), measuring specifically the species richness, of a tropical area belonging to the Eastern Java-Bali Rain Forests Ecoregion in East Java (Indonesia). This region is part of Sundaland (Dixit et al. 2023), which is considered one of the 36 currently recognized biodiversity hotspots, which are regions characterized by a significant presence of endemic species that are severely endangered due to habitat loss (Myers et al. 2000).

MATERIALS AND METHODS

Study area

The study area is classified as a tropical and subtropical moist broadleaf forest biome, specifically in the Eastern Java-Bali rain forests ecoregion (Eco ID: 230; Scientific code: IM0113; ~5,387,175 km) in the Indo-Malayan realm, and is classified as a critical or endangered biome (World Wildlife Fund 2014). Also, it is part of Sundaland, which is considered one of the major global biodiversity hotspots (Myers et al. 2000; https://www.cepf.net/our-work/biodiversity-hotspots). More specifically, this area is located on the Java Islands, East Java province (Oriental Java), northern coast: Regencies of Bangkalan (07° 03’ S, 112° 56’ E), Gresik (07° 09’ 14” S, 112° 39’ 22” E), Lamongan (07° 07’ S, 112° 25’ E), Sidoarjo (07° 27’ S, 112° 42’ E), and Surabaya City (07° 14’ 45” S, 112° 44’ 16” E). The study area with location sites is presented in a map (Figure 1) generated using the online tool SimpleMappr (Shorthouse 2010). Furthermore, the present study is a preliminary survey that aims to present the first record of the butterfly species assemblage for this study area, since no known species list was previously recorded.

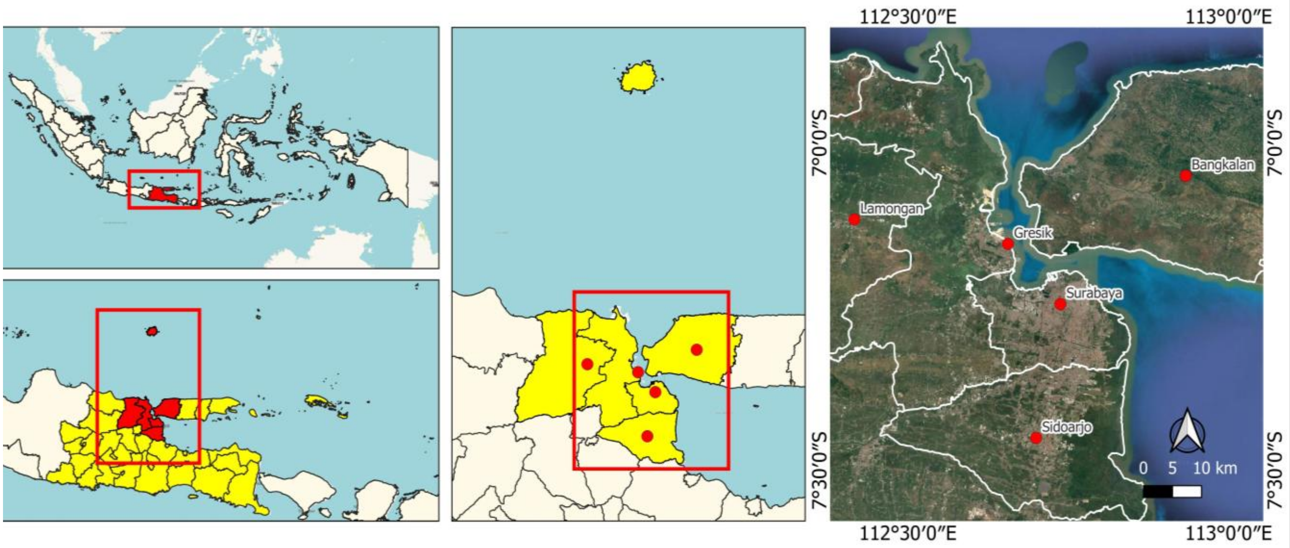

Figure 1. Study area and location sites. Indonesia; Java Island; East Java province (Oriental Java); Northern coast, specifically: Districts of Bangkalan (07° 03’ S, 112° 56’ E), Gresik (07° 09’ 14” S, 112° 39’ 22” E), Lamongan (07° 07’ S, 112° 25’ E), Sidoarjo (07° 27’ S, 112° 42’ E), and Surabaya city (07° 14’ 45” S, 112° 44’ 16” E).

Sampling and photography

From October 2016 to August 2024, twice at a week, the authors employed the exploring method along with a visual encounter survey, observing, capturing, and documenting the species encountered to access the species composition. Surveys, field observations, and collections were in the early morning or into the evening (about ~6 hours for each independent survey). The butterflies were visually registered, not all butterfly specimens were captured, but almost all of them were documented with cellphone cameras for further identification and data analysis. Some specimens were reared in the laboratory with host plants found in the field. In some cases, specimens were frozen (about ~2 days) for further investigation, and finally, some dead specimens were stored (about ~2 days) in a relaxing tube. Then the specimens were pinned and dried for further identification.

The identification of species and their distribution across various families, subfamilies, tribes, and genera was primarily based on identification keys that use traits like the pattern of color and shape of their wings by consulting the available literature for Asian and Australasian butterfly species (D'Abrera 1982, 1985, 1986; Schulze 2013; Braby et al. 2018). Taxonomic names, author, and year were revised via the "Global Butterfly Names: The Lepidoptera Taxome Project" catalog (Lamas 2014), the Google Play app Kupunesia 1.0 for butterflies of Indonesia: https://play.google.com/store/apps/details?id=org.kupunesia (Peggie et al. 2022), and the "Lepidoptera and some other life forms" catalog: https://ftp.funet.fi/pub/sci/bio/life/intro.html. Additionally, a recent study (Umami et al. 2024) was used as a guide concerning butterfly diversity in other East Java locations, in this case, the mountainous site of Kedung Klurak Tourism Area, Mojokerto District, East Java, Indonesia. All photographs are of copyright of Agus Shoumul Arof (@kal_el_arofy) and available at the link: https://figshare.com/s/d10074221b653ce58f6f.

RESULTS AND DISCUSSION

This study registered 126 butterfly species belonging to 85 genera, 41 tribes, 17 subfamilies, five families (Figures 2-8). The Nymphalidae family was the most diverse concerning species richness (51 species; 29 genera; 13 tribes; eight subfamilies), followed by the Lycaenidae family (32 species; 28 genera; 10 tribes; three subfamilies), the Pieridae family (17 species; ten genera; seven tribes; two subfamilies), the Hesperiidae family (16 species; 14 genera; eight tribes; three subfamilies), and finally, the Papilionidae family (ten species; four genera; three tribes; one subfamily) (Table 1). This distribution pattern in species frequency among families broadly reflects the global distribution of species of butterflies, in which Nymphalidae (~6,152 species) and Lycaenidae (~5,201 species) presents globally the biggest number of species, followed by Hesperiidae (~4,133 species), Pieridae (~1,164 species), and Papilionidae (~570 species). The family Riodinidae (~1,532 species) was not sampled in the present survey (van Nieukerken et al. 2011; Lamas 2014).

One species, *Deudorix epijarbas* (Moore, 1857) (Lycaenidae: Theclinae: Deudorigini), the "cornelian" or "hairy line blue", was found as a larva in Rambutan fruits and leaves, *Nephelium lappaceum* L. (Sapindaceae) from an unknown East Java location. This larva was reared until imago, and the identification was confirmed. Since there is no confirmation about the origin of these fruits, the location of this species was scored as "EJ – East Java, with no more specific location defined".

Two species of *Delias* Hübner, [1819] (Pieridae: Pierinae: Pierini) were recorded in the present survey, commonly known as "*jezebels*", which is the most speciose butterfly genus in the world, with ~251 species (Liang et al. 2024). These are *Delias hyparete* (Linnaeus, 1758), the "painted jezebel", and *Delias periboea* (Godart, 1819). This genus is distributed throughout Asia, Australia, and Melanesia with a high degree of endemism, in which numerous species occur on only a few islands or mountains. This high diversity can be explained biogeographically via dispersal events between islands, followed by divergence, the founder effect, and the orogeny of the Central Highlands of New Guinea (Liang et al. 2024). Interestingly, neither of the two species recorded has a high level of endemism; *D. hyparete* is widely distributed in southern Asia, including the Indian subcontinent, southern China, and the Indonesian archipelago; and *D. periboea* is widely distributed in the Indonesian archipelago. The same is true for *Delias belisama* (Cramer, [1779]), registered by Umami et al. (2024), also in East Java, but other locations (see information about the distributions of these species in the "Lepidoptera and some other life forms" catalog https://ftp.funet.fi/pub/sci/bio/life/intro.html).

The species composition recorded in our survey was further compared with the recent study of Umami et al. (2024) concerning butterfly diversity in other East Java locations, in this case, the mountainous site of Kedung Klurak Tourism Area, Mojokerto District, East Java. These authors registered a total of 37 species (see Table 1 from Umami et al. 2024) and the same families that were sampled in our study (Table 1 of the present study). All three Hesperiidae species registered by Umami et al. (2024); *Pelopidas mathias* (Fabricius, 1798), *Potanthus ganda* (Fruhstorfer, 1911), and *Pseudocoladenia dan* (Fabricius, 1787), were not registered in the present study. In the Lycaenidae family, only *Zizula hylax* (Fabricius, 1775) was registered by both Umami et al. (2024) and in the present study. The other four Lycaenidae registered by these authors, *Heliophorus epicles* (Godart, 1823), *Nacaduba kurava* (Moore, 1858), *Taraka hamada* (Druce, 1875), and *Udara dilectus* (Moore, 1879), were not registered in the present study.

Table 1. Species diversity distribution among butterflies (Lepidoptera: Rhopalocera: Papilionoidea) families, subfamilies, tribes, and genera reported for the northern coast of East Java (Indonesia) in the present study among locations: BA: Bangkalan District; GR: Gressik District; LA: Lamongan District; SI: Sidoarjo District; SU: Surabaya City; and EJ: East Java, with no more specific location defined

Family	Subfamily	Tribe	Genus	Species	BA	GR	LA	SI	SU	EJ
Hesperiidae	Coeliadinae	Coeliadini	*Badamia* Moore, [1881]	*Badamia exclamationis* (Fabricius, 1775)		●	●			
			Bibasis Moore, [1881]	*Bibasis sena* (Moore, [1866])		●	●			
			Burara Swinhoe, 1893	*Burara oedipodea* (Swainson, 1820)		●	●			
	Hesperiinae	Ancistroidini	*Udaspes* Moore, [1881]	*Udaspes folus* (Cramer, [1775])		●	●			
		Baorini	*Borbo* Evans, 1949	*Borbo cinnara* (Wallace, 1866)				●		
		Erionotini	*Erionota* Mabille, 1878	*Erionota thrax* (Linnaeus, 1767)	●	●	●	●	●	
			Matapa Moore, [1881]	*Matapa aria* (Moore, [1866])		●			●	
			Suastus Moore, [1881]	*Suastus gremius* (Fabricius, 1798)	●	●	●	●	●	
		Gegenini	*Pelopidas* Walker, 1870	*Pelopidas cf. conjuncta* (Herrich-Schäffer, 1869)		●				
		Taractrocerini	*Potanthus* Scudder, 1872	*Potanthus cf. fettingi* (Möschler, 1878)					●	
			Taractrocera Butler, [1870]	*Taractrocera archias* (Felder, 1860)		●				
				Taractrocera nigrolimbata (Snellen, 1876)				●	●	
			Telicota Moore, [1881]	*Telicota colon* (Fabricius, 1775)		●				
				Telicota sp.		●				
	Pyrginae	Pyrgini	*Caprona* Wallengren, 1857	*Caprona agama* (Moore, [1858])		●				
		Tagiadini	*Tagiades* Hübner, [1819]	*Tagiades japetus* (Stoll, [1781])	●	●	●			
Lycaenidae	Miletinae	Miletini	*Miletus* Hübner, [1819]	*Miletus symethus* (Cramer, [1777])		●				
		Spalgini	*Spalgis* Moore, 1879	*Spalgis epius* (Westwood, 1852)		●				
	Polyommatinae	Lycaenesthini	*Anthene* Doubleday, 1847	*Anthene emolus* (Godart, [1824])		●				
				Anthene lycaenina (Felder, 1868)		●				
		Polyommatini	*Catochrysops* Boisduval, 1832	*Catochrysops panormus* (Felder, 1860)		●				
				Catochrysops strabo (Fabricius, 1793)		●				
			Catopyrops Toxopeus, 1929	*Catopyrops rita* (Grose-Smith, 1895)		●				
			Castalius Hübner, [1819]	*Castalius rosimon* (Fabricius, 1775)		●	●		●	
			Chilades Moore, [1881]	*Chilades pandava* (Horsfield, [1829])		●			●	
			Discolampa Toxopeus, 1929	*Discolampa ethion* (Westwood, 1851)		●				
			Euchrysops Butler, 1900	*Euchrysops cnejus* (Fabricius, 1798)		●				
			Everes Hübner, [1819]	*Everes lacturnus* (Godart, [1824])		●				
			Freyeria Courvoisier, 1920	*Freyeria putli* (Kollar [1844])		●			●	
			Jamides Hübner, [1819]	*Jamides alecto* (Felder, 1860)		●				
				Jamides celeno (Cramer, [1775])		●	●			
			Lampides Hübner, [1819]	*Lampides boeticus* (Linnaeus, 1767)		●	●		●	
			Leptotes Scudder, 1876	*Leptotes plinius* (Fabricius, 1793)		●	●			
			Megisba Moore, [1881]	*Megisba malaya* (Horsfield, [1828])		●				
			Nacaduba Moore, [1881]	*Nacaduba berenice* (Herrich-Schäffer, 1869)		●				
				Nacaduba biocellata (C. & R. Felder, [1865])		●	●			
			Prosotas Druce, 1891	*Prosotas dubiosa* (Semper, [1879])		●			●	
			Zizeeria Chapman, 1910	*Zizeeria karsandra* (Moore, 1865)		●			●	
			Zizina Chapman, 1910	*Zizina otis* (Fabricius, 1787)		●	●	●	●	
			Zizula Chapman, 1910	*Zizula hylax* (Fabricius, 1775)		●	●	●	●	

	Theclinae	Amblypodiina	*Amblypodia* Horsfield, [1829]	*Amblypodia narada* (Horsfield, [1829])		●				
		Arhopalini	*Arhopala* Boisduval, 1832	*Arhopala centaurus* (Fabricius, 1775)		●	●		●	
			Flos Doherty, 1889	*Flos apidanus* (Cramer, [1777])		●				
		Deudorigini	*Deudorix* Hewitson, [1863]	*Deudorix epijarbas* (Moore, 1857)						●
		Hypolycaenini	*Hypolycaena* C. & R. Felder, 1862	*Hypolycaena erylus* (Godart, [1824])		●	●		●	
		Iolaini	*Tajuria* Moore, [1881]	*Tajuria cippus* (Fabricius, 1798)		●				
		Theclini	*Loxura* Horsfield, [1829]	*Loxura atymnus* (Stoll, [1780])		●			●	
			Rapala Moore, [1881]	*Rapala manea* (Hewitson, 1863)		●			●	
Nymphalidae	Biblidinae	Biblidini	*Ariadne* Horsfield, [1829]	*Ariadne ariadne* (Linnaeus, 1763)		●			●	
				Ariadne specularia (Fruhstorfer, 1899)		●				
	Charaxinae	Charaxini	*Polyura* Billberg, 1820	*Polyura alphius* (Staudinger, 1886)		●		●	●	
				Polyura schreiber (Godart, [1824])		●				
	Danainae	Danaini	*Danaus* Kluk, 1780	*Danaus affinis* (Fabricius, 1775)					●	
				Danaus chrysippus (Linnaeus, 1758)	●	●	●	●	●	
				Danaus genutia (Cramer, [1779])		●				
			Euploea Fabricius, 1807	*Euploea climena* (Stoll, [1782])		●				
				Euploea corinna (Macleay, [1780])		●	●	●	●	
				Euploea eleusina (Cramer, [1780])	●	●				
				Euploea mulciber (Cramer, [1777])		●	●	●	●	
				Euploea sylvester (Fabricius, 1793)		●				
			Ideopsis Horsfield, 1857	*Ideopsis juventa* (Cramer, [1777])		●	●			
			Tirumala Moore, [1880]	*Tirumala hamata* (MacLeay, [1826])		●				
				Tirumala limniace (Cramer, [1775])		●				
	Heliconiinae	Acraeini	*Acraea* Fabricius, 1807	*Acraea terpsicore* (Linnaeus, 1758)	●	●	●	●	●	
			Cethosia Fabricius, 1807	*Cethosia penthesilea* (Cramer, [1777])	●	●				
		Vagrantini	*Cupha* Billberg, 1820	*Cupha erymanthis* (Drury, [1773])		●	●		●	
			Phalanta Horsfield, [1829]	*Phalanta phalantha* (Drury, [1773])		●	●	●	●	
			Vindula Hemming, 1934	*Vindula erota* (Fabricius, 1793)		●				
				Vindula dejone (Erichson, 1834)		●				
	Limenitidinae	Adoliadini	*Euthalia* Hübner, [1819]	*Euthalia aconthea* (Cramer, [1777])		●	●	●	●	
				Euthalia adonia (Cramer, [1780])		●			●	
		Limenitidini	*Athyma* Westwood, [1850]	*Athyma nefte* (Cramer, [1780])		●				
				Athyma perius (Linnaeus, 1758)		●				
			Moduza Moore, [1881]	*Moduza procris* (Cramer, [1777])		●	●	●	●	
			Pantoporia Hübner, [1819]	*Pantoporia hordonia* (Stoll, [1790])		●				
		Neptini	*Neptis* Fabricius, 1807	*Neptis hylas* (Linnaeus, 1758)	●	●	●	●	●	
			Phaedyma Felder, 1861	*Phaedyma columella* (Cramer, [1780])	●	●	●	●	●	
	Morphinae	Amathusiini	*Amathusia* Fabricius, 1807	*Amathusia phidippus* (Linnaeus, 1763)		●				
			Discophora Boisduval, [1836]	*Discophora sondaica* Boisduval, 1836		●				
	Nymphalinae	Junoniini	*Junonia* Hübner, [1819]	*Junonia almana* (Linnaeus, 1758)	●	●	●	●	●	
				Junonia atlites (Linnaeus, 1763)		●	●	●	●	
				Junonia erigone (Cramer, [1775])		●			●	
				Junonia hedonia (Linnaeus, 1764)		●	●	●	●	
				Junonia iphita (Cramer, [1779])		●	●		●	
				Junonia orithya (Linnaeus, 1758)	●	●	●	●	●	

				Junonia villida (Fabricius, 1787)		●			
			Yoma Doherty, 1886	*Yoma sabina* (Cramer, [1780])		●			
		Kallimini	*Doleschallia* C. & R. Felder, 1860	*Doleschallia polibete* (Cramer, [1779])		●	●	●	●
			Hypolimnas Hübner, [1819]	*Hypolimnas bolina* (Linnaeus, 1758)	●	●	●	●	●
				Hypolimnas misippus (Linnaeus, 1764)		●		●	●
	Satyrinae	Elymniini	*Elymnias* Hübner, 1818	*Elymnias hypermnestra* (Linnaeus, 1763)		●	●	●	●
			Lethe Hübner, [1819]	*Lethe europa* (Fabricius, 1787)		●			
			Melanitis Fabricius, 1807	*Melanitis leda* (Linnaeus, 1758)	●	●	●	●	●
			Mycalesis Hübner, 1818	*Mycalesis horsfieldii* (Moore, [1892])		●			
				Mycalesis mineus (Linnaeus, 1758)		●	●		●
				Mycalesis perseus (Fabricius, 1775)		●	●		●
			Orsotriaena Wallengren, 1858	*Orsotriaena medus* (Fabricius, 1775)	●	●			
		Ypthimini	*Ypthima* Hübner, 1818	*Ypthima cf. aphnius* (Godart, [1824])		●			
				Ypthima philomela (Linnaeus, 1763)		●			
Papilionidae	Papilioninae	Leptocircini	*Graphium* Scopoli, 1777	*Graphium agamemnon* (Linnaeus, 1758)	●	●	●	●	●
				Graphium antiphates (Cramer, [1775])	●	●	●		
				Graphium doson (C. & R. Felder, 1864)		●	●	●	●
				Graphium sarpedon (Linnaeus, 1758)		●			
		Papilionini	*Papilio* Linnaeus, 1758	*Papilio demoleus* Linnaeus, 1758	●	●	●	●	●
				Papilio memnon Linnaeus, 1758		●	●	●	●
				Papilio peranthus Fabricius, 1787		●			
				Papilio polytes Linnaeus, 1758		●	●	●	●
		Troidini	*Pachliopta* Reakirt, [1865]	*Pachliopta adamas* (Zinken, 1831)		●			
			Troides Hübner, [1819]	*Troides helena* (Linnaeus, 1758)		●			
Pieridae	Coliadinae	Coliadini	*Catopsilia* Hübner, [1819]	*Catopsilia pomona* (Fabricius, 1775)	●	●	●	●	●
				Catopsilia pyranthe (Linnaeus, 1758)		●			●
				Catopsilia scylla (Linnaeus, 1763)				●	●
		Euremini	*Eurema* Hübner, [1819]	*Eurema alitha* (C. & R. Felder, 1862)		●			
				Eurema blanda (Boisduval, 1836)	●				
				Eurema hecabe (Linnaeus, 1758)		●	●		●
	Pierinae	Anthocharini	*Hebomoia* Hübner, [1819]	*Hebomoia glaucippe* (Linnaeus, 1758)		●	●		●
		Leptosiaini	*Leptosia* Hübner, 1818	*Leptosia nina* (Fabricius, 1793)	●	●	●	●	●
		Nepheroniini	*Pareronia* Bingham, 1907	*Pareronia valeria* (Cramer, [1776])		●	●		●
		Pierini	*Appias* Hübner, [1819]	*Appias lyncida* (Cramer, [1777])		●	●	●	●
				Appias olferna Swinhoe, 1890	●	●	●	●	●
			Belenois Hübner, [1819]	*Belenois java* (Linnaeus, 1768)	●	●	●	●	●
			Cepora Billberg, 1820	*Cepora nerissa* (Fabricius, 1775)		●	●	●	●
				Cepora temena (Hewitson, 1861)		●			
			Delias Hübner, [1819]	*Delias hyparete* (Linnaeus, 1758)		●	●	●	●
				Delias periboea (Godart, 1819)		●	●	●	●
		Teracolini	*Ixias* Hübner, [1819]	*Ixias venilia* (Godart, 1819)		●	●	●	●

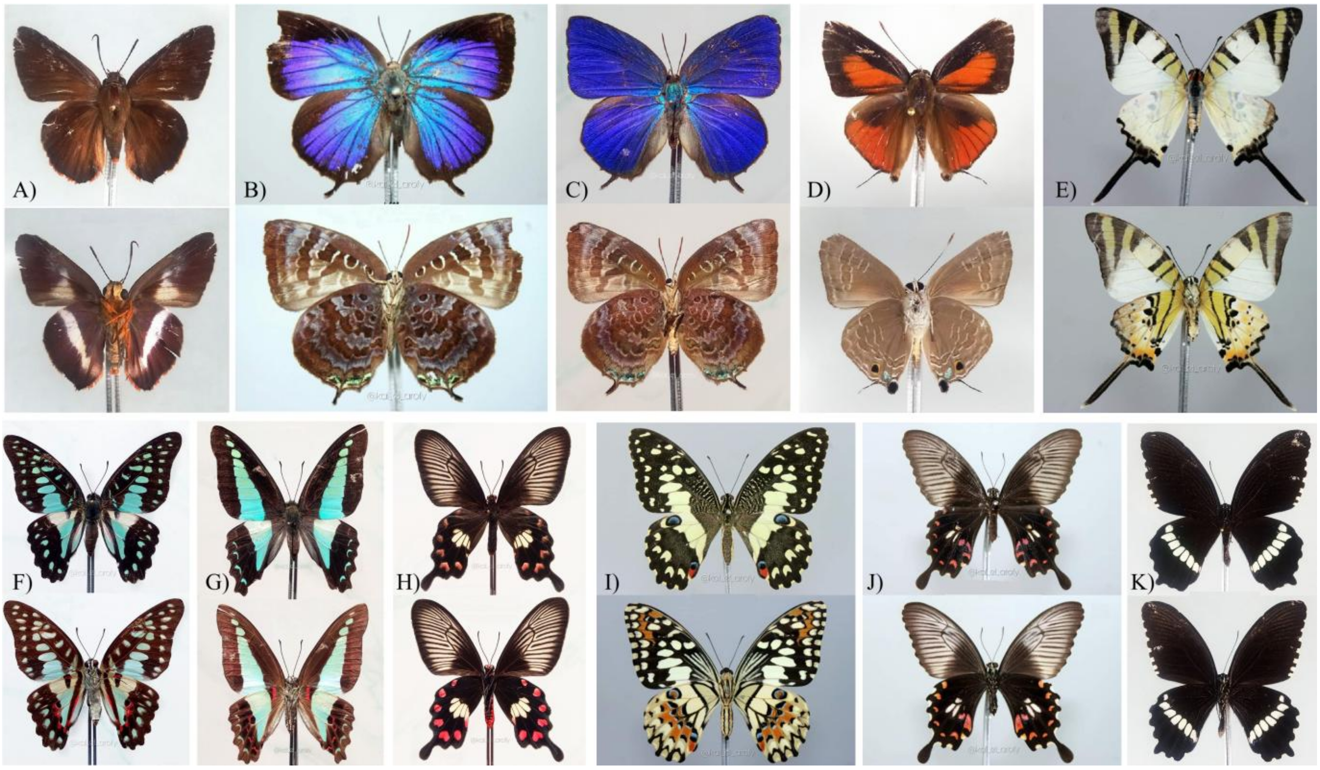

Figure 2. From left to right, top to bottom. Dorsal (image above) and ventral (image below) view. Hesperiidae: A. *Bibasis sena* (Moore, [1866]). Lycaenidae: B. *Arhopala centaurus* (Fabricius, 1775) ♀; C. *Arhopala centaurus* (Fabricius, 1775) ♂; D. *Deudorix epijarbas* (Moore, 1857). Papilionidae: E. *Graphium antiphates* (Cramer, [1775]); F. *Graphium doson* (C. & R. Felder, 1864); G. *Graphium sarpedon* (Linnaeus, 1758); H. *Pachliopta adamas* (Zinken, 1831); I. *Papilio demoleus* Linnaeus, 1758; J. *Papilio polytes* Linnaeus, 1758 ♀; K. *Papilio polytes* Linnaeus, 1758 ♂

Figure 3. From left to right, top to bottom. Dorsal (image above) and ventral (image below) view. Nymphalidae: A. *Acraea terpsicore* (Linnaeus, 1758); B. *Amathusia phidippus* (Linnaeus, 1763); C. *Ariadne ariadne* (Linnaeus, 1763); D. *Athyma perius* (Linnaeus, 1758); E. *Cethosia penthesilea* (Cramer, [1777]); F. *Danaus affinis* (Fabricius, 1775) ♂; G. *Danaus chrysippus* (Linnaeus, 1758) ♂; H. *Elymnias hypermnestra* (Linnaeus, 1763) ♀; I. *Elymnias hypermnestra* (Linnaeus, 1763) ♂; J. *Neptis hylas* (Linnaeus, 1758); K. *Phaedyma columella* (Cramer, [1780]); L. *Polyura alphius* (Staudinger, 1886)

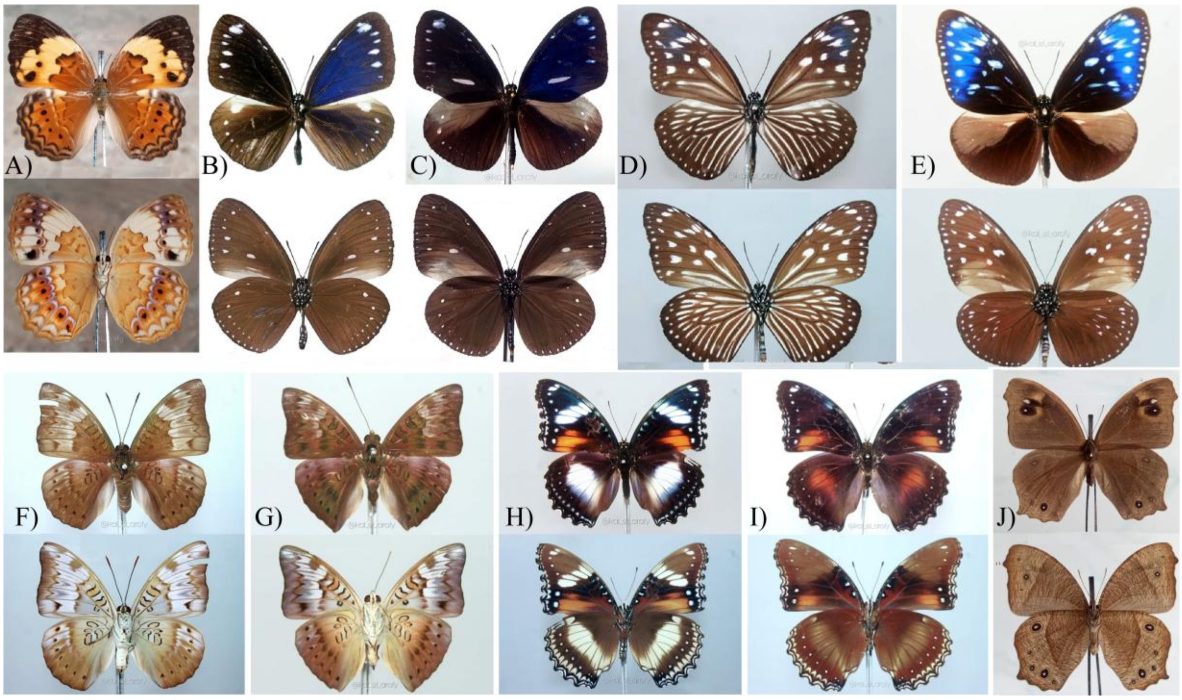

Figure 4. From left to right, top to bottom. Dorsal (image above) and ventral (image below) view. Nymphalidae: A. *Cupha erymanthis* (Drury, [1773]); B. *Euploea eleusina* (Cramer, [1780]) ♀; C. *Euploea eleusina* (Cramer, [1780]) ♂; D. *Euploea mulciber* (Cramer, [1777]) ♀; E. *Euploea mulciber* (Cramer, [1777]) ♂; F. *Euthalia aconthea* (Cramer, [1777]) ♀; G. *Euthalia aconthea* (Cramer, [1777]) ♂; H. *Hypolimnas bolina* (Linnaeus, 1758) ♀; I. *Hypolimnas bolina* (Linnaeus, 1758) ♀; J. *Melanitis leda* (Linnaeus, 1758)

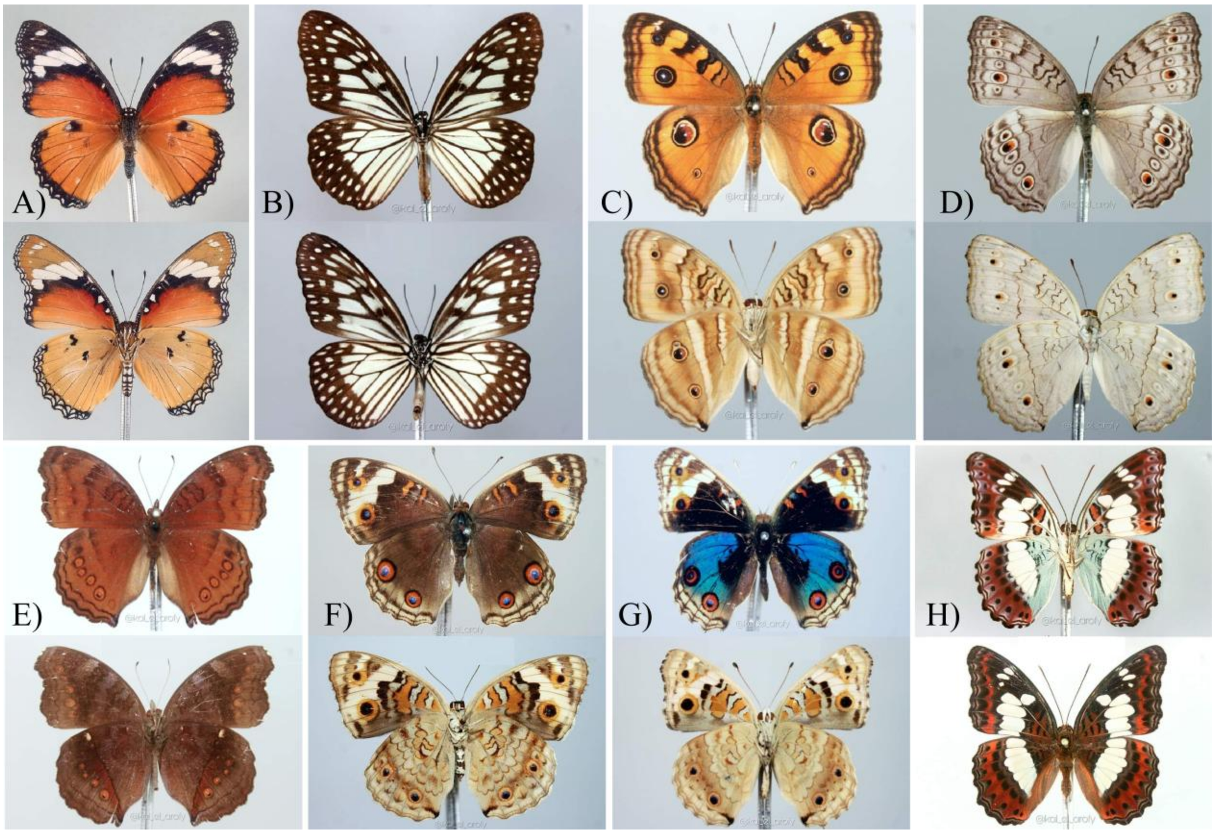

Figure 5. From left to right, top to bottom. Dorsal (image above) and ventral (image below) view. Nymphalidae: A. *Hypolimnas misippus* (Linnaeus, 1764) ♀; B. *Ideopsis juventa* (Cramer, [1777]); C. *Junonia almana* (Linnaeus, 1758); D. *Junonia atlites* (Linnaeus, 1763); E. *Junonia hedonia* (Linnaeus, 1764); F. *Junonia orithya* (Linnaeus, 1758) ♀; G. *Junonia orithya* (Linnaeus, 1758) ♂; H. *Moduza procris* (Cramer, [1777])

Figure 6. From left to right, top to bottom. Dorsal (image above) and ventral (image below) view. Pieridae: A. *Appias lyncida* (Cramer, [1777]) ♀; B. *Appias lyncida* (Cramer, [1777]) ♂; C. *Appias olferna* Swinhoe, 1890 ♀; D. *Appias olferna* Swinhoe, 1890 ♂; E. *Belenois java* (Linnaeus, 1768)♂; F. *Catopsilia pyranthe* (Linnaeus, 1758); G. *Catopsilia pomona* (Fabricius, 1775) ♀; H. *Catopsilia pomona* (Fabricius, 1775) ♂; I. *Catopsilia scylla* (Linnaeus, 1763) ♀; J. *Catopsilia scylla* (Linnaeus, 1763) ♂

Figure 7. From left to right, top to bottom. Dorsal (image above) and ventral (image below) view. Pieridae: A. *Cepora temena* (Hewitson, 1861) ♀; B. *Cepora temena* (Hewitson, 1861) ♂; C. *Delias hyparete* (Linnaeus, 1758); D. *Delias periboea* (Godart, 1819) ♀; E. *Delias periboea* (Godart, 1819) ♂; F. *Eurema hecabe* (Linnaeus, 1758); G. *Hebomoia glaucippe* (Linnaeus, 1758); H. *Ixias venilia* (Godart, 1819) ♂; I. *Pareronia valeria* (Cramer, [1776]) ♀; J. *Pareronia valeria* (Cramer, [1776]) ♂

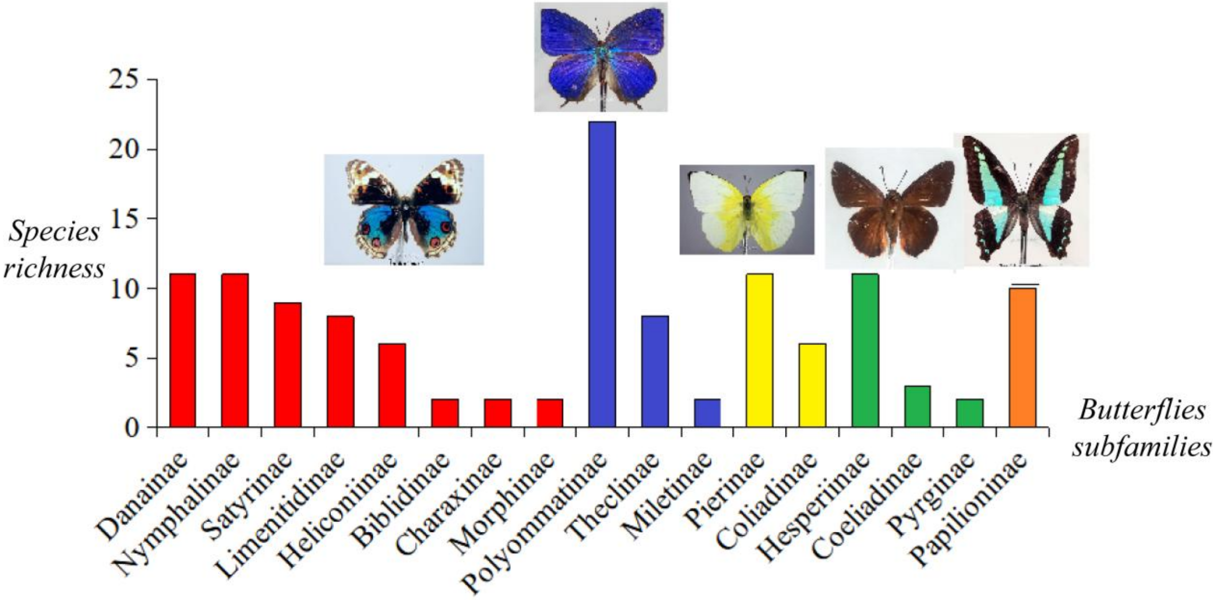

Figure 8. Species diversity (Species richness) distribution among butterflies (Lepidoptera: Rhopalocera: Papilionoidea) families and subfamilies. Red – Nymphalidae, Blue – Lycaenidae, Yellow – Pieridae, Green – Hesperiidae, Orange – Papilionidae, and respective subfamilies were reported for the northern coast of East Java (Indonesia) in the present study

In the case of the Nymphalidae family, ten species were registered by both Umami et al. (2024) and in the present study, *Doleschallia polibete* (Cramer, 1782), *Euploea mulciber* (Cramer, [1777]), *Junonia atlites* (Linnaeus, 1763), *Junonia erigone* (Cramer, [1775]), *Junonia hedonia* (Linnaeus, 1764), *Junonia iphita* (Cramer, 1782), *Neptis hylas* (Linnaeus, 1758), *Orsotriaena medus* (Fabricius, 1775), *Tirumala hamata* (MacLeay, [1826]), and *Mycalesis horsfieldii* (Moore, [1892]). On the other hand, also in the Nymphalidae family, seven species were registered by Umami et al. (2024), but not in the present study, *Chersonesia rahria* (Westwood, 1857), *Lethe confusa* (Aurivillius, 1897), *Neptis vikasi* (Horsfield, 1829), *Parantica aspasia* (Fabricius, 1787), *Tanaecia trigerta* (Moore, 1857), *Ypthima iarba* (Nicéville, 1895), and *Ypthima pandocus* (Moore, 1857).

In the Papilionidae family, all six species registered by these authors, *Graphium agamemnon* (Linnaeus, 1758), *Graphium sarpedon* (Linnaeus, 1758), *Pachliopta adamas* (Zincken, 1831), *Papilio memnon* Linnaeus, 1758, *Papilio polytes* Linnaeus, 1758, and *Troides helena* (Linnaeus, 1758) were also registered in the present study. Finally, in the Pieridae family, five species, *Appias lyncida* (Cramer, 1779), *Eurema blanda* (Boisduval, 1836), *Eurema hecabe* (Linnaeus, 1758), *Hebomoia glaucippe* (Linnaeus, 1758), and *Leptosia nina* (Fabricius, 1793), were registered by both Umami et al. (2024) and in the present study. Only one Pieridae species registered by these authors, *Delias belisama* (Cramer, 1779), was not registered in the present study. Since there is no clear pattern in the species composition among the sampled families when the present survey is compared with the study of Umami et al. (2024), further studies need to be done to explore the real differences in assemblages of butterflies in these several sampled regions of East Java. Perhaps a hypothesis can be generated involving differences in ecological niches (Pocheville 2014) of butterfly species associated with the elevation, reflecting on differences on the species composition, since our study sampled butterflies on the northern coast of East Java and Umami et al. (2024) sampled butterflies in a more mountainous region, but this is speculative since at the moment we lack more precise information about the exact elevation of the sites. Furthermore, both studies diverge in the sampling methods, so further sampling and standardization are necessary for future comparisons.

Despite the speculative nature of this hypothesis regarding the composition of species at different altitudes, previous studies (Rödder et al. 2021) are in accordance. They concluded that more mobile and generalist butterfly species, which have a wide ecological range, are more likely to migrate uphill compared to specialist and sedentary species. These authors identified climatic conditions and topographic factors, such as insolation and solar irradiation, as the main drivers of this altitudinal movement.

Another study in Indonesia (Koneri et al. 2017), specifically in the Tangkoko Nature Reserve (TNR) in North Sulawesi, reached the conclusion that the butterfly community in primary forests shares more similarities with those found on farms, while the butterflies in shrub areas are more closely related to those in secondary forests. Unfortunately, a direct comparison cannot be made since no precise information about soil use and habitat type in the present survey was recorded. Furthermore, the biological diversity of Nymphalidae observed in the Neotropics is primarily a result of low extinction rates rather than high speciation rates or biotic exchanges with other regions that are infrequent. In contrast, Southeast Asia, including the Indonesian archipelago, is marked by a low speciation rate as well, but the primary source of biological diversity can be attributed to several dispersal events throughout geological time (Chazot et al. 2021).

In addition to the ideas mentioned earlier, other factors may be important and were previously indicated as diversity-driven in butterfly communities as well. In this sense, mutualistic interactions can promote convergent evolution across various ecological axes, often surpassing the influences of phylogenetic history and ecological competition in determining community structure (Doré et al. 2022). This indicates that ecological communities are adapted to a much greater extent than previously assumed. In this sense, it is highlighted that there is a strong connection between phenotypes and ecological interactions, supporting the notion that memetic rings can facilitate ecological speciation (Doré et al. 2022). Finally, these findings can be interpreted as a compelling empirical support for the Müllerian mimicry model at a macroecological scale, especially among the subfamilies Danainae and Ithomiinae of Nymphalidae (Doré et al. 2022).

In the near future, climate change is expected to strongly impact butterfly diversity around the world, including the northern coast of East Java. This will potentially lead to rising sea levels, average temperatures, atmospheric levels of carbon dioxide, and altered rainfall patterns resulting from global and regional climate shifts (Abbass et al. 2022; https://science.nasa.gov/climate-change/). These changes could impact the food resources and host plants available to butterflies and impact their life cycles. Additionally, anthropogenic activities on the northern coast of East Java may further exacerbate the effects of environmental changes that can alter the ecosystem dynamics, posing further threats to butterfly populations (Kurniawan et al. 2020). More specifically, in the studied region, it was noted through personal observation that the butterfly population in the vicinity of Ketanen village in Gresik District has apparently experienced a decline. A limestone hill, between Ketanen and Pantenan villages, previously a notable habitat for butterfly species, has been flattened and transformed into a tourist attraction featuring a swimming pool.

This is the first field investigation to study the butterfly richness specifically on the northern coast of East Java. This study contributes to the knowledge of the butterfly fauna in the Indonesian archipelago, as well as the general diversity of species in Southeast Asia. Additionally, this study contributes to future studies of the conservation of biodiversity in this key endangered region, which is located on the most human-populated island in the world, in the fourth-most-populated country in the world. Moreover, this study can be the first step towards future studies focusing on community ecology, population dynamics and the use of butterflies as bioindicators in the northern coast of East Java.

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Unveiling the interplay between tree stand attributes, species diversity, and biomass carbon in Chunati Wildlife Sanctuary, Southeastern Bangladesh

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Manuscript received: 1 October 2024. Revision accepted: 3 December 2024.

Abstract. *Rakib MH, Hossain SMS, Sadnan MWM, Chowdhury MIH. 2024. Unveiling the interplay between tree stand attributes, species diversity, and biomass carbon in Chunati Wildlife Sanctuary, Southeastern Bangladesh. Intl J Trop Drylands 8: 95-105.* Biodiversity plays a pivotal role in maintaining ecosystem health and resilience, especially in tropical forest landscapes. This study investigates the intricate relationships between stand structure, biodiversity indices, and biomass carbon within forest ecosystems, specifically focusing on the Chunati Wildlife Sanctuary (CWS), a tropical forestland in Southeastern Bangladesh. The key structural attributes, i.e. tree height, diameter at breast height (DBH), basal area, and stand density, as well as biodiversity indices, were analyzed to understand their correlations with biomass carbon. The study exhibits the measured soil carbon levels ranging from 35.26 to 93.26 Mg C ha^{-1} and tree biomass carbon from approximately 131.13 to 387.23 Mg C ha^{-1}. The findings revealed a strong positive correlation between tree height and biomass carbon ($R^2 = 0.6517$), indicating that taller trees generally store more carbon due to enhanced photosynthesis. Notably, DBH exhibited a robust correlation ($R^2 = 0.8683$), highlighting the significance of larger trees as carbon sinks. The basal area emerged as the strongest predictor of biomass carbon, with an impressive correlation ($R^2 = 0.9119$). The Shannon-Wiener and Margalef's richness indices had moderate to strong correlations with biomass carbon ($R^2 = 0.4473$ and $R^2 = 0.5663$) respectively. These results underscore the importance of maintaining diverse and structurally complex forests for effective carbon sequestration. The future study should incorporate additional ecological variables to refine models for predicting forest carbon dynamics with the vast change in tropical landscapes and inform better conservation strategies, leading to tropical biodiversity conservation and climate change mitigation efforts on tropical landscapes.

Keywords: Carbon stock, fossil carbon, phytosociology, tree biomass, tropical-forest

INTRODUCTION

Protected areas are essential for conserving biodiversity and delivering ecosystem services (Mamun et al. 2022). In Bangladesh, protected area coverage increased slightly from 1.67% in 2008 to 1.80% of the total forest land area in 2015, one of the lowest globally (Islam et al. 2022). The government has designated 49 protected areas, 17 of which are under the co-management system (Uddin et al. 2020a). Among these, Chunati Wildlife Sanctuary (CWS), covering approximately 7,764 hectares in southeastern Bangladesh, plays a vital role in conserving biodiversity while supporting the livelihoods of approximately 50,000 people across 9,400 households (Hossain et al. 2020). It encompasses various forest types, including tropical evergreen, semi-evergreen, and deciduous forests, contributing to its rich biodiversity (Festus et al. 2024). However, deforestation, illegal logging, and land conversion jeopardize this biodiversity.

The success of conservation efforts in protected areas is intricately tied to the well-being of forest-dependent communities (Hossain et al. 2020). Empowering local communities living around protected areas has been identified as a key strategy for biodiversity conservation (Rahman et al. 2018). In CWS, 70% of the population is considered poor, 19% extremely poor, 10% middle class, and just 1% rich (Rahman et al. 2016). The primary occupations include day labor and non-wage agricultural work, with an unemployment rate at 17% (Rahman et al. 2017; Rahman and Obaydullah 2020). This heavy reliance on forest resources (Akwaji and Onah 2023), coupled with high unemployment, threatens CWS's ecological integrity (Rahman and Obaydullah 2020). To mitigate forest degradation, the Bangladesh Forest Department (BFD), in collaboration with USAID, launched the Nishorgo support project in 2004, followed by the integrated protected area co-management (IPAC) initiative (Kufata et al. 2024), which promoted community co-management and alternative income activities (Chowdhury 2014). However, limited livelihood support from these projects has reduced their effectiveness in decreasing forest dependency (Roy et al. 2015).

Forests are critical for maintaining ecological balance, regulating climate, providing habitats for species, and serving as carbon sinks (Ali et al. 2022). Consequently, understanding forest ecosystems' biodiversity and carbon stock is vital for effective conservation and sustainable management (Ali et al. 2022; Islam et al. 2018, 2020). To assess species diversity, researchers use indices such as the Shannon-Wiener index, and Margaleaf richness index, which provide insights into species richness, evenness, and distribution (Kessler et al. 2009; Hasan et al. 2023; Scherer et al. 2023). These metrics inform conservation planning and biodiversity management. Assessing carbon stocks, including tree biomass carbon and soil organic carbon (SOC), is equally crucial for understanding a forest's role in carbon sequestration (Alongi 2011; Shaheed and Chowdhury 2014; Ali et al. 2022).

This study aims to evaluate the biodiversity and carbon stock in the Chunati Wildlife Sanctuary, offering a comprehensive understanding of its ecological status. The primary objectives are to analyze species diversity using the Shannon-Wiener index, Simpson's index, and Pielou's evenness index, and to quantify carbon stock by measuring both tree biomass carbon and SOC. The leading question of the study: (i) How do structural attributes such as tree height, diameter at breast height (DBH), and basal area predict biomass carbon stock in the Chunati Wildlife Sanctuary; (ii) To what extent do biodiversity indices, such as the Shannon-Wiener and Margalef's richness indices, influence the carbon sequestration capacity of tropical forest ecosystems, and how can these relationships guide conservation efforts for enhancing carbon storage?

By examining the interplay between biodiversity indices, tree stand structure, and carbon stock, this research seeks to contribute to the existing knowledge base on tropical forest biodiversity and carbon sequestration in Bangladesh. Additionally, it provides baseline data for monitoring changes in CWS's ecological parameters over time, which is essential for assessing conservation measures' effectiveness and informing forest management decisions. The findings will support policy-making at both national and international levels, particularly regarding biodiversity conservation and climate change mitigation. Insights from this study will aid in the protection and sustainable management of CWS, benefiting both local conservation initiatives and global efforts to combat climate change. By providing data on species diversity and carbon sequestration potential, this research will inform strategies to preserve biodiversity and enhance carbon storage in tropical forests.

MATERIALS AND METHODS

Study site

The Chunati Wildlife Sanctuary (CWS) is situated at 21°40' North and 92°07' East, in the southeastern part of Bangladesh (Figure 1). It encompasses the Banshkhali and Lohagara Upazila of Chittagong District and the Chakoria Upazila of Cox's Bazar District. The Chunati Wildlife Sanctuary experiences a tropical moist climate with annual rainfall ranging from 3,000 to 3,500 mm. The air temperature fluctuates between 16 and 34°C, while relative humidity remains high, typically between 70 and 90%. The soil in the sanctuary is predominantly sandy loam, supporting a rich biodiversity and influencing the carbon sequestration potential of the forest. The sanctuary covers seven Union Parishads: Chunati, Adhunagar, Herbang, Puichari, Banskhali, Borohatia, and Toitong. CWS was established in 1986 and spans 7,764 hectares of Reserve Forest. The Wildlife and Nature Conservation Division of Chittagong oversees the administration of the sanctuary. It is divided into two Forest Ranges and seven forest beats (smallest forest management unit): The Chunati range, which covers a total area of 3,332 ha and includes Chunati, Aziznagar, and Harbang beats; and the Jaldi range, which encompasses a total area of 4,432 ha and comprises Jaldi, Chambal, Napora, and Puichari (Islam et al. 2018; Mamun et al. 2022; Rahman et al. 2022).

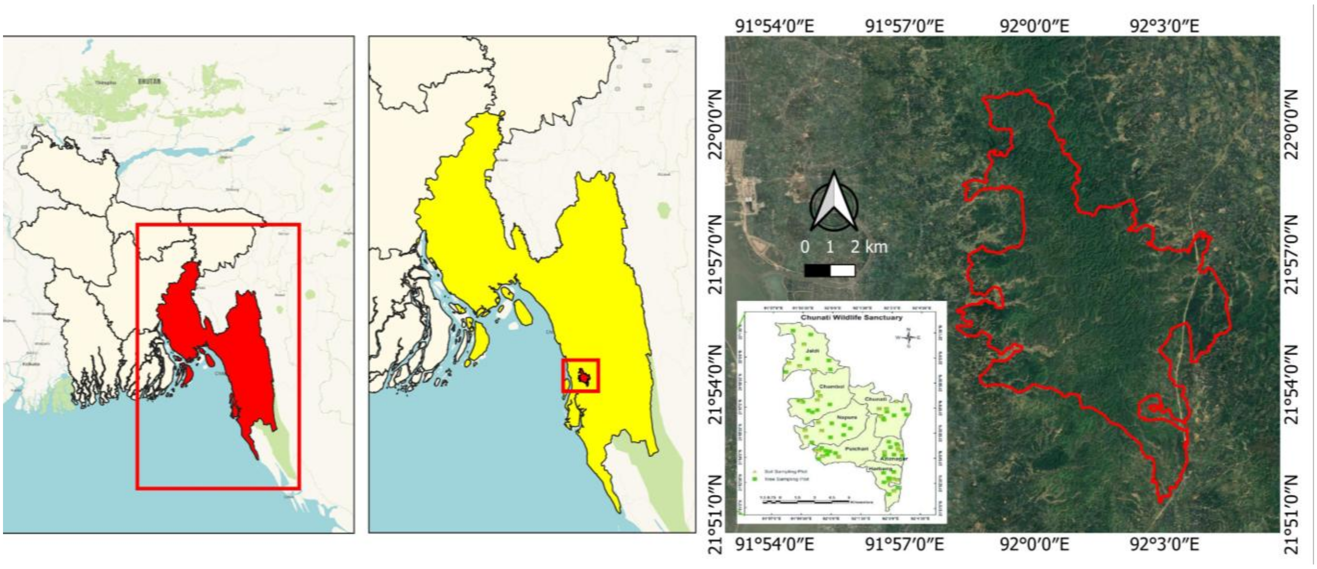

Figure 1. Map of the study area with sampling (vegetation and soil) points throughout the seven Forest Beats of the Chunati Wildlife Sanctuary. The maps are created using Arcmap10.8

Table 1. Equations used in the calculation for phytosociological parameters and biodiversity indices of tree species in this study

Equation	References
Basal area (m^2 ha^{-1}) = $\frac{\Sigma\frac{\pi\times D^2}{4}}{\Sigma \text{Area of all quadrats}} \times 10000$	(Shukla and Chandel 2016); Chowdhury et al. (2019)
Relative density, R_d (%) = $\frac{S}{n} \times 100$	Dallmeier et al. (1992); Das (2024)
Relative frequency, R_f (%) = $\frac{F_i}{\Sigma F_i}$	Dallmeier et al. (1992); Das (2024)
Relative dominance, RD_o (%) = $\frac{\text{Basal area of one species}}{\text{Total Basal area}} \times 100$	Hossain et al. (2013); Chowdhury et al. (2019)
Important Value Index (IVI) = $R_d + R_f + RD_o$	Hossain et al. (2013)
Shannon-Wiener index, $H' = -\Sigma P_i \ln P_i$	Michael (1984); Hop et al. (2023)
Margalef richness index = $\frac{S-1}{\ln N}$	Kohli et al. (1996)

Note: D: The diameter at breast height, F_i: The frequency of a species, P_i: The abundance of the species in each plot, S: the total number of species, N: The total number of individuals of all the species

Table 2. Equations used in the estimation of biomass, and soil organic carbon in this study

Equation	References
AGB (kg) = $(0.0673\times(\rho\ (DBH)^2\ H)^{0.976})$	Chave et al. (2014)
Biomass C (Mg ha^{-1}) = Biomass (dry mass, Mg ha^{-1}) × 0.5 Mg C	Sandra Brown (1997); Baul et al. (2021a)
Loss of ignition, LOI % = $\frac{W_1}{W_2} \times 100$	Ball (1964)
Soil organic carbon, SOC % = 0.47 × (% LOI – 1.87)	Ball (1964); Baul et al. (2021b)
SOC stock (Mg ha^{-1}) = SOC % × BD × SD	Pearson et al. (2005)

Note: AGB (kg): Above-ground biomass, ρ wood density (g cm^{-3}), D: Tree DBH (cm), H: Tree height (m), W_1: the loss in mass (g), W_2: Oven-dried soil (g), BD: Bulk density of soil (g cm^{-3}), and SD means the soil depth (cm). Living root biomass was estimated as 15% of AGB (Macdicken K. 2015). To estimate AGB, wood density (g cm^{-3}), a required variable, was collected from the Bangladesh Forest Research Institute (Sattar et al. 1999). For those not found in BFRI publications, we used the global wood density database (Chave et al. 2009)

Data collection

Vegetation survey

Vegetation survey was conducted to assess the biodiversity indices, and biomass carbon estimation of CWS between October to December 2023. A total of 70 plots (10 from each beat) with size of 20 × 20 m were randomly located (Figure 1). In each plot, DBH (diameter at breast height; 1.3 m above the ground), the total height of all trees having dbh ≥5 cm were recorded using Range finder and Suunto clinometer. All the surveyed species were identified and recorded in local and scientific name. In the case of unknown species plant samples were collected to be identified by professional taxonomists from the Bangladesh Forest Research Institute (BFRI).

Sampling of soil

A pit of 30 cm depth, under the litter layer approximate center of the same vegetation plot, was dug using a soil auger, and soil samples were collected from three vertical layers at 0-10, 11-20, and 21-30 cm depth. Hence 12 (3 depths × 4 points) samples from each beat which makes the result of a total of 84 (12 × 7 beats) samples are collected from the CWS (Figure 1). Collected soil samples were performed under lab analysis for SOC estimation.

Data analysis

Many indices are available worldwide that measure phytosociological parameters, biodiversity indices, biomass estimation, and soil organic carbon. In this study, different phytosociological and biodiversity indices were calculated for all the beats of CWS using the equations presented in Table 1. The estimation of biomass and soil organic carbon, the equations presented in Table 2 were used.

RESULTS AND DISCUSSION

Phytosociological status

The tree species survey in the CWS recorded 100 species belonging to 41 families. Among all the families Fabaceae (9 species) contained the highest number of tree species followed by Moraceae (8 species), Myrtaceae (8 species), and Eupharbiaceae (7 species). The highest basal area was occupied by *Ficus bengalensis* (11.10 m^2 ha^{-1}) in the contrary *Garcinia lanceifolia* (0.05 m^2 ha^{-1}) scored the lowest (Table 3). The highest relative density was *Acacia auriculiformis* (20.61%) followed by *Dipterocarpus turbinatus* (9.10%) and *Swietenia macrophylla* (5.11%). Among all the recorded tree species *Lagerstroemia speciosa* (2.44%) and 22 others showed identical maximum relative frequency followed by *Sterospermum personatum* (2.24%) and *A. auriculiformis* (2.21%). The species with the highest relative dominance was *F. bengalensis* (8.06%) whereas *G. lanceifolia* (0.04%) scored the lowest. The most important species of CWS in terms of IVI was *A. auriculiformis* (23.25) followed by *D. turbinatus* (14.37) and *S. robusta* (10.58), while, *G. lanceifolia* (0.17) had the lowest IVI. It is a clear indication that exotic species alongside some native species mostly dominate the CWS. These exotic species are playing a role in the overall ecosystem degradation of the CWS.

Estimation of biomass and soil organic carbon

The comparative analysis of tree biomass carbon and soil organic carbon (SOC) across the seven forest beats of Chunati Wildlife Sanctuary indicates significant variability in both tree biomass carbon and SOC. Tree biomass carbon ranges from approximately 131.13 to 387.23 Mg C ha^{-1}, with the highest values observed in beats dominated by larger trees and higher basal areas. In contrast, SOC ranges from 35.26 to 93.26 Mg C ha^{-1} across different soil layers (0-10, 11-20, and 21-30 cm), with higher values in areas with denser tree cover and organic matter input (Figure 2.B).

The substantial range in tree biomass carbon suggests that forest structure, species composition, and management practices significantly influence carbon storage capacity. The mean biomass carbon (224.43 Mg C ha^{-1}) in the study area (Figure 2.A) is considerably higher than that of other regions in Bangladesh, such as the homestead forests in Rangpur (54 Mg C ha^{-1}) and Sundarbans (99 Mg C ha^{-1}), indicating the sanctuary's critical role in carbon sequestration (Baul et al. 2021b; Jaman et al. 2016). The SOC values are comparable to those found in similar tropical ecosystems, with the mean SOC (53.59 Mg C ha^{-1}) closely matching that of the Chittagong Hill Tracts (52.83 Mg C ha^{-1}) but exceeding that of the Sal Forest (48.3 Mg C ha^{-1}) and Sundarbans (38.8 Mg C ha^{-1}) (Baul et al. 2021b; Mukul et al. 2014).

Table 3. Phytosociological attributes of vegetation in Chunati Wildlife Sanctuary, Bangladesh

Scientific name	Family	BA (m^2 ha^{-1})	R_d (%)	R_f (%)	RD_o (%)	IVI
Mangifera indica L.	Anacardiaceae	1.57	4.47	2.20	1.16	7.83
Lannea coromandelica Merr.	Anacardiaceae	0.12	0.05	0.03	0.09	0.17
Anacardium occidentale L.	Anacardiaceae	1.44	0.16	0.08	1.07	1.31
Mangifera sylvatica Roxb.	Anacardiaceae	4.70	0.27	0.13	3.47	3.87
Alstonia scholaris L.	Apocynaceae	0.78	0.27	2.44	0.57	3.28
Arenga pinnata Merr.	Arecaceae	0.18	0.05	2.44	0.14	2.63
Stereospermum personatum Hassk.	Bignoniaceae	1.07	0.59	2.24	0.79	3.62
Stereospermum suaveolens Roxb.	Bignoniaceae	0.22	0.05	0.20	0.16	0.42
Eruca vesicaria L.	Brassicaceae	0.15	0.11	2.44	0.11	2.66
Bursera serrata Wall.	Burseraceae	1.04	1.13	2.44	0.77	4.34
Bauhinia acuminata L.	Caesalpiniaceae	0.48	0.16	0.73	0.36	1.25
Senna siamea Lam.	Caesalpiniaceae	1.39	0.16	0.73	1.03	1.92
Tamarindus indica L.	Caesalpiniaceae	5.17	0.22	0.98	3.82	5.01
Bhesa robusta Roxb.	Celastraceae	1.32	0.22	2.44	0.97	3.63
Garcinia lanceifolia Roxb.	Clusiaceae	0.05	0.05	0.07	0.04	0.17
Garcinia cowa Roxb.	Clusiaceae	0.20	1.18	1.63	0.15	2.96
Garcinia speciosa Wall.	Clusiaceae	0.19	0.22	0.30	0.14	0.65
Mesua ferrea L.	Clusiaceae	0.76	0.32	0.44	0.56	1.33
Terminalia arjuna DC.	Combretaceae	1.53	1.56	0.98	1.13	3.67
Terminalia bellirica Gaertn.	Combretaceae	1.07	0.91	0.58	0.79	2.28
Terminalia chebula Retz.	Combretaceae	0.29	1.29	0.81	0.21	2.32
Terminalia paniculata Roth.	Combretaceae	1.28	0.11	0.07	0.94	1.12
Dillenia indica L.	Dilleniaceae	0.83	0.11	0.81	0.61	1.53
Dillenia pentagyna Roxb.	Dilleniaceae	0.15	0.22	1.63	0.11	1.95
Dipterocarpus costatus Gaertn.	Dipterocarpaceae	2.94	2.42	0.33	2.17	4.93
Shorea robusta Gaertn.	Dipterocarpaceae	8.24	4.04	0.55	6.09	10.68
Dipterocarpus turbinatus Gaertn.	Dipterocarpaceae	5.56	9.10	1.24	4.11	14.44
Hopea odorata Roxb.	Dipterocarpaceae	1.47	2.31	0.32	1.09	3.72
Diospyros malabarica Kostel.	Ebenaceae	0.69	0.05	2.44	0.51	3.01
Elaeocarpus serratus L.	Elaeocarpaceae	2.43	0.48	2.44	1.80	4.72
Phyllanthus emblica L.	Euphorbiaceae	1.38	0.86	0.67	1.02	2.55
Aporosa wallichii Hook.	Euphorbiaceae	0.35	0.22	0.17	0.26	0.64
Antidesma velutinum Tul.	Euphorbiaceae	0.14	0.11	0.08	0.10	0.30
Antidesma ghaesembilla Gaertn.	Euphorbiaceae	0.17	0.16	0.13	0.13	0.41
Baccaurea ramiflora Lour.	Euphorbiaceae	0.10	0.22	0.17	0.07	0.45
Trewia nudiflora L.	Euphorbiaceae	0.86	1.51	1.18	0.63	3.32

Vernicia fordii Hemsl.	Euphorbiaceae	0.35	0.05	0.04	0.26	0.35
Acacia auriculiformis A.	Fabaceae	0.59	20.61	2.21	0.43	23.26
Pongamia pinnata L.	Fabaceae	0.21	0.05	0.01	0.15	0.21
Castanopsis indica Roxb.	Fabaceae	0.49	1.18	0.13	0.36	1.67
Ormosia robusta Baker	Fabaceae	0.15	0.11	0.01	0.11	0.23
Acacia hybrida G.Lodd.	Fabaceae	0.53	0.16	0.02	0.39	0.57
Quercus dentata Thunb.	Fabaceae	0.30	0.05	0.01	0.22	0.28
Xylia xylocarpa Roxb.	Fabaceae	3.63	0.05	0.01	2.68	2.74
Erythrina variegata L.	Fabaceae	1.13	0.32	0.03	0.84	1.19
Butea monosperma Lam.	Fabaceae	0.72	0.16	0.02	0.53	0.71
Gmelina arborea Roxb.	Lamiaceae	1.13	3.28	1.75	0.84	5.87
Tectona grandis L.	Lamiaceae	2.01	1.29	0.69	1.49	3.47
Cinnamomum tamala Buch.	Lauraceae	0.72	0.11	2.44	0.53	3.08
Barringtonia acutangula L.	Lecythidaceae	0.69	0.11	2.44	0.51	3.06
Lagerstroemia speciosa (L.) Pers.	Lythraceae	0.95	1.83	2.44	0.70	4.97
Magnolia champaca (L.) Baill. ex Pierre	Magnoliaceae	2.23	0.54	2.44	1.65	4.63
Sterculia foetida L.	Malvaceae	0.89	0.05	0.17	0.66	0.89
Brownlowia elata R. Br.	Malvaceae	1.26	0.05	0.17	0.93	1.16
Bombax ceiba L.	Malvaceae	0.45	0.59	1.92	0.33	2.84
Abroma augustum (L.) L. f.	Malvaceae	0.75	0.05	0.17	0.55	0.78
Chukrasia tabularis A. Juss.	Meliaceae	0.70	1.83	0.60	0.52	2.95
Swietenia macrophylla King	Meliaceae	4.15	5.11	1.68	3.07	9.86
Azadirachta indica A. Juss.	Meliaceae	2.59	0.43	0.14	1.91	2.48
Aphanamixis polystachya (Wall.) R. Parker	Meliaceae	0.52	0.05	0.02	0.39	0.46
Albizia lebbeck (L.) Benth.	Mimosaceae	1.99	0.48	0.32	1.47	2.27
Acacia mangium Willd.	Mimosaceae	0.71	0.48	0.32	0.52	1.33
Samanea saman (Jacq.) Merr.	Mimosaceae	4.62	1.56	1.04	3.41	6.01
Albizia richardiana (Voigt) King & Prain	Mimosaceae	4.47	0.16	0.11	3.30	3.57
Albizia procera (Roxb.) Benth.	Mimosaceae	2.41	0.97	0.65	1.78	3.39
Ficus religiosa L.	Moraceae	1.38	0.38	0.12	1.02	1.52
Ficus benghalensis L.	Moraceae	11.10	0.32	0.11	8.21	8.64
Artocarpus chama Buch.-Ham.	Moraceae	0.78	1.88	0.62	0.57	3.08
Artocarpus lacucha Buch.-Ham.	Moraceae	1.35	0.43	0.14	1.00	1.57
Ficus racemosa L.	Moraceae	0.36	2.15	0.71	0.26	3.12
Artocarpus heterophyllus Lam.	Moraceae	0.58	1.72	0.57	0.43	2.72
Ficus auriculata Lour.	Moraceae	0.24	0.05	0.02	0.18	0.25
Streblus asper Lour.	Moraceae	1.11	0.48	0.16	0.82	1.47
Muntingia calabura L.	Muntingiaceae	0.26	0.48	2.44	0.20	3.12
Syzygium grande (Wight) Walp.	Myrtaceae	1.74	4.31	1.04	1.29	6.64
Eucalyptus globulus Labill.	Myrtaceae	0.45	2.10	0.51	0.34	2.94
Syzygium cumini (L.) Skeels	Myrtaceae	3.60	1.13	0.27	2.66	4.06
Melaleuca alternifolia (Maiden & Betche) Cheel	Myrtaceae	0.79	0.05	0.01	0.58	0.65
Psidium guajava L.	Myrtaceae	0.26	0.70	0.17	0.19	1.06
Syzygium praecox (Roxb.) Rathakr. & Chithra	Myrtaceae	0.11	0.22	0.05	0.08	0.35
Syzygium fruticosum (Roxb.) A. M. Cowan & Cowan	Myrtaceae	0.79	1.40	0.34	0.59	2.32
Eucalyptus hybrida (no specific authority, hybrid designation)	Myrtaceae	0.69	0.16	0.04	0.51	0.71
Nyctanthes arbor-tristis L.	Oleaceae	0.20	0.05	2.44	0.15	2.64
Averrhoa carambola L.	Oxalidaceae	0.52	0.32	2.44	0.38	3.14
Glochidion lanceolarium (Roxb.) Voigt	Phyllanthaceae	0.67	1.29	2.44	0.50	4.23
Ziziphus mauritiana Lam.	Rhamnaceae	0.21	0.16	2.44	0.16	2.76
Prunus amygdalus Batsch	Rosaceae	1.03	0.16	2.44	0.76	3.36
Adina cordifolia (Roxb.) Hook. f. ex Brandis	Rubiaceae	1.32	0.11	0.41	0.97	1.49
Neolamarckia cadamba (Roxb.) Bosser	Rubiaceae	5.75	0.54	2.03	4.25	6.82
Zanthoxylum rhetsa (Roxb.) DC.	Rutaceae	1.31	0.05	0.81	0.97	1.83
Aegle marmelos (L.) Corrêa	Rutaceae	0.95	0.05	0.81	0.70	1.57
Citrus limetta Risso	Rutaceae	0.05	0.05	0.81	0.04	0.91
Litchi chinensis Sonn.	Sapindaceae	0.14	0.65	2.44	0.10	3.19
Madhuca longifolia (J. König) J. F. Macbr.	Sapotaceae	0.38	0.05	2.44	0.28	2.78
Spondias mombin L.	Spondiadaceae	3.05	0.05	2.44	2.25	4.75
Sterculia villosa Roxb.	Sterculiaceae	0.27	0.11	2.44	0.20	2.75
Tamarix dioica Roxb. ex Roth	Tamaricaceae	0.46	0.48	2.44	0.34	3.26
Aquilaria malaccensis Lam.	Thymelaeaceae	0.66	0.48	2.44	0.49	3.41
Vitex peduncularis Wall. ex Schauer	Verbenaceae	0.30	0.05	0.49	0.22	0.76
Vitex pinnata L.	Verbenaceae	0.83	0.22	1.95	0.61	2.78
Total		135.3	100	100	100	300

Note: basal area (BA m^2 ha^{-1}), relative density (Rd %), relative frequency (Rf %), relative dominance (Rdo %), and important value index (IVI) found from the recorded tree species

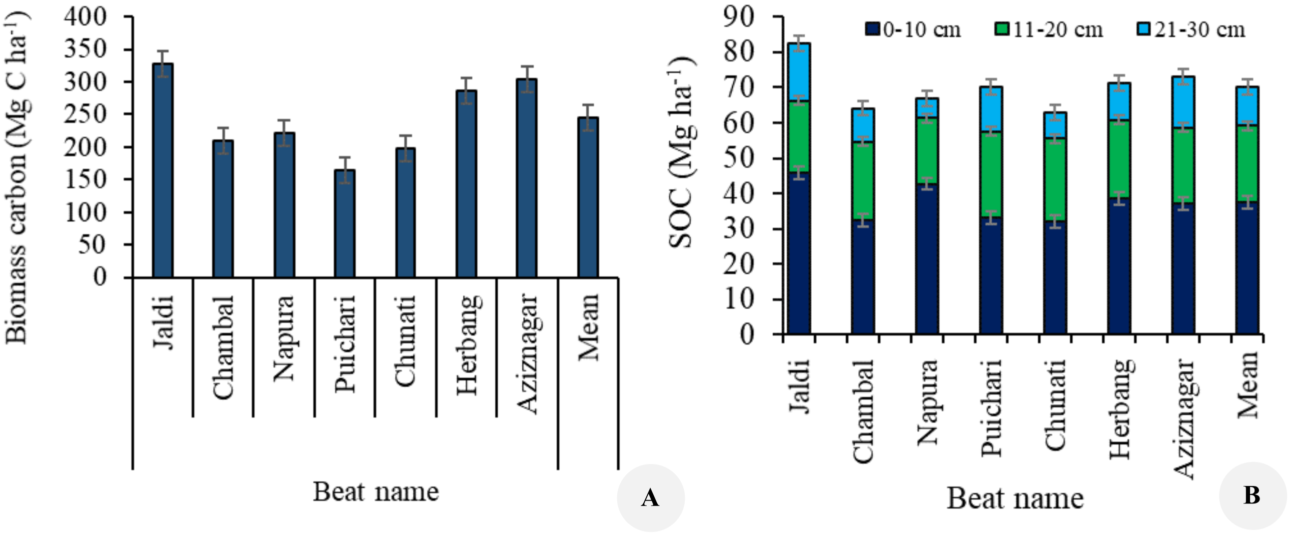

Figure 2. A beat-wise comparison among the seven beats in Chunati Wildlife Sanctuary in term of: A. tree biomass carbon stock; B. average soil organic carbon across 3 vertical layers (0-10, 11-20, 21-30 cm). The error bar represents the standard error of the mean

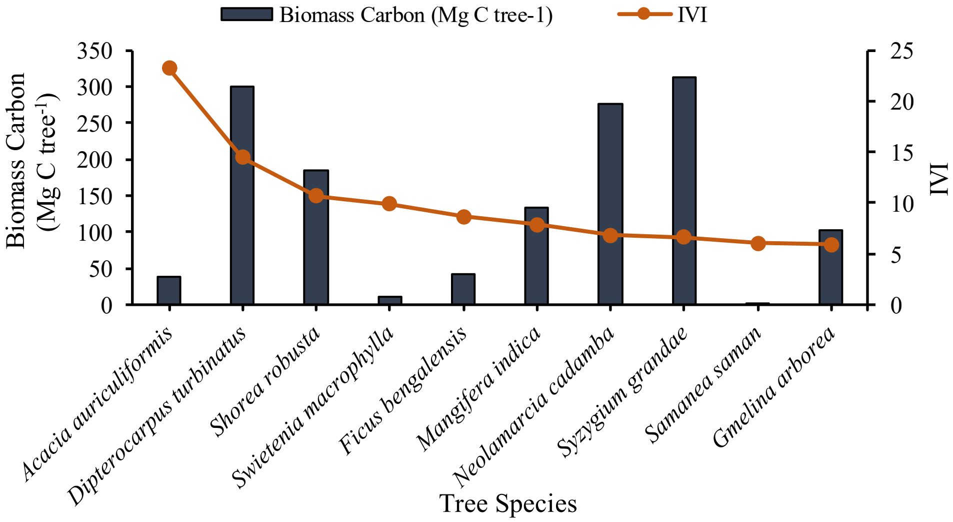

Figure 3. The tree biomass carbon of ten tree species with the most Important Value Index (IVI) in the Chunati Wildlife Sanctuary

This figure underscores the importance of both tree biomass and soil carbon in assessing the overall carbon storage potential of tropical forests. The variation across different beats highlights the need for site-specific forest management strategies to maximize carbon sequestration while maintaining biodiversity (Rahman et al. 2018). The findings align with existing literature, which emphasizes the crucial role of forest structure in carbon dynamics and highlights the potential of tropical forest ecosystems for significant carbon sequestration (Chave et al. 2014).

Figure 3 illustrates the biomass carbon contributions of the ten most dominant tree species in Chunati Wildlife Sanctuary based on their Importance Value Index (IVI). Species like *Dipterocarpus turbinatus*, *Shorea robusta*, and *Neolamarckia cadamba* demonstrate the highest biomass carbon storage, indicating their significant role in carbon sequestration within the sanctuary. In contrast, fast-growing exotic species such as *Acacia auriculiformis* and *Swietenia macrophylla*, despite being dominant by IVI, show relatively lower biomass carbon, suggesting that while these species thrive in number, they contribute less to carbon storage compared to native slow-growing species. This disparity highlights the ecological importance of preserving native species for maximizing carbon sequestration in tropical forests.

Interplay between tree stands structure and biomass carbon

The relationship between tree biomass carbon and various stand structure parameters is crucial for understanding forest carbon dynamics and for developing effective strategies for carbon sequestration in forest ecosystems. Figure 4 illustrates these relationships by examining tree height, tree diameter at breast height (DBH), basal area, and stand density, all of which are key structural attributes of forest stands (Pozo and Säumel

2018). By analyzing these parameters, we can gain insights into how forest structure influences carbon storage and, by extension, the role of forests in mitigating climate change.

Tree height and biomass carbon

Tree height is a fundamental parameter in forestry as it often correlates with the overall growth and productivity of a tree. Figure 4.A shows the relationship between tree height and biomass carbon is shown to be positively correlated. The regression equation $y = 32.99x - 201.07$ reveals that biomass carbon increases with tree height. The coefficient of determination $R^2 = 0.6517$ indicates that approximately 65% of the variation in biomass carbon can be explained by tree height (Ali et al. 2022; Chowdhury and Das 2024a; Chowdhury and Rakib 2024b). This strong correlation suggests that taller trees generally accumulate more biomass carbon, likely due to their greater leaf area and increased photosynthetic capacity, which leads to higher growth rates and carbon assimilation. However, the fact that 35% of the variation remains unexplained suggests that other factors (Scherer et al. 2023), such as species-specific growth patterns (Hossain et al. 2020), soil fertility (Mamun et al. 2022), and climatic conditions, also play significant roles in determining biomass carbon. This finding aligns with previous studies that have emphasized the importance of tree height in carbon storage but also highlight the need to consider additional factors that might influence carbon sequestration at different stages of tree growth (Zukswert et al. 2023).

Tree DBH and biomass carbon

Tree DBH is another critical indicator of forest stand structure and is often used in allometric equations to estimate tree biomass and carbon storage. Figure 4.B shows a robust positive correlation between tree DBH and biomass carbon, with a regression equation of $y = 20.376x - 268.74$ and a high $R^2 = 0.8683$. This suggests that 87% of the variation in biomass carbon is explained by tree DBH, making DBH one of the most reliable predictors of biomass carbon in forest ecosystems. Larger DBH typically indicates older and more mature trees (Rahman et al. 2018; Mehta et al. 2021), which have had more time to accumulate biomass (Sheikh et al. 2011). This strong relationship underscores the importance of preserving large-diameter trees in forests, as they serve as significant carbon sinks. The remaining 13% of unexplained variation could be attributed to factors such as tree species composition, age, and environmental conditions, which can influence how biomass is distributed within a tree and across different trees in a stand (Mamun et al. 2022; Ali et al. 2022). This finding suggests that forest management practices should prioritize the protection and maintenance of large-diameter trees to enhance carbon sequestration efforts (Hossain et al. 2020).

Basal area and biomass carbon

Basal area (BA) is a measure of the cross-sectional area of a tree trunk and is often used as an indicator of forest density and productivity. Figure 4.C demonstrates a very strong positive correlation between basal area and biomass carbon with the regression equation $y = 1.7256x - 44.008$ and an impressive $R^2 = 0.9119$. This suggests that about 91% of the variability in biomass carbon is explained by basal area, making it the strongest predictor among the variables analyzed. Basal area is directly related to the total wood volume in a forest stand, and thus, higher basal areas typically correspond to greater biomass and carbon storage (Rahman et al. 2018; Mamun et al. 2022). The strong relationship between basal area and biomass carbon highlights the importance of managing forest stands to maintain or increase basal area, particularly in the context of forest conservation and carbon sequestration efforts. The small amount of unexplained variation (9%) might be due to differences in tree form, species diversity, and stand age, which can influence the distribution of biomass within a stand (Simon et al. 2018; Hossain et al. 2020; Miah et al. 2023).

Stand density and biomass carbon

Stand density, measured as the number of trees per hectare, is another important structural attribute of forests that can influence biomass carbon. Figure 4.D shows the relationship between stand density and biomass carbon with the regression equation $y = 0.7044x - 399.7$ and $R^2 = 0.6175$. This indicates that 62% of the variation in biomass carbon is related to stand density. While this relationship is still significant, it is weaker than those observed for tree height, DBH, and basal area. Stand density can influence competition among trees for resources such as light, water, and nutrients, which in turn affects growth rates and biomass accumulation. Higher stand densities might not always lead to higher biomass carbon if competition for resources, such as light, water, and nutrients, becomes too intense among trees, leading to stunted growth, lower biomass accumulation and increased mortality (Scherer et al. 2023). Conversely, lower densities might reduce competition but also limit the total biomass that can be supported in a given area (Hossain et al. 2020). The 38% of unexplained variation suggests that stand density alone is not a sufficient predictor of biomass carbon, and that factors like species composition, stand age, and management practices must also be considered.

The interplay between tree diversity and biomass carbon

Figure 5 presents the relationship between tree biomass carbon and two diversity indices: the Shannon-Wiener diversity index and the Margalef richness index. These indices are widely used to assess biodiversity within ecological communities, and their relationship with biomass carbon offers insights into how biodiversity might influence carbon storage in forest ecosystems.

Diversity index and biomass carbon

Figure 5.A illustrates the relationship between the Shannon-Wiener diversity index and biomass carbon. The regression equation $y=109.72x - 45.844$ and the coefficient of determination $R^2 = 0.44$ indicate a positive correlation, with approximately 45% of the variation in biomass carbon explained by the Shannon-Wiener diversity index. This

suggests that higher biodiversity, as measured by the Shannon-Wiener index, is associated with greater biomass carbon storage. The Shannon-Wiener index accounts for both species richness and evenness, meaning that more diverse and evenly distributed species communities tend to support higher levels of biomass (Rahman et al. 2018). However, with 55% of the variation left unexplained, it is clear that while biodiversity is an important factor, other variables such as environmental conditions, species-specific traits, and forest management practices also significantly influence biomass carbon.

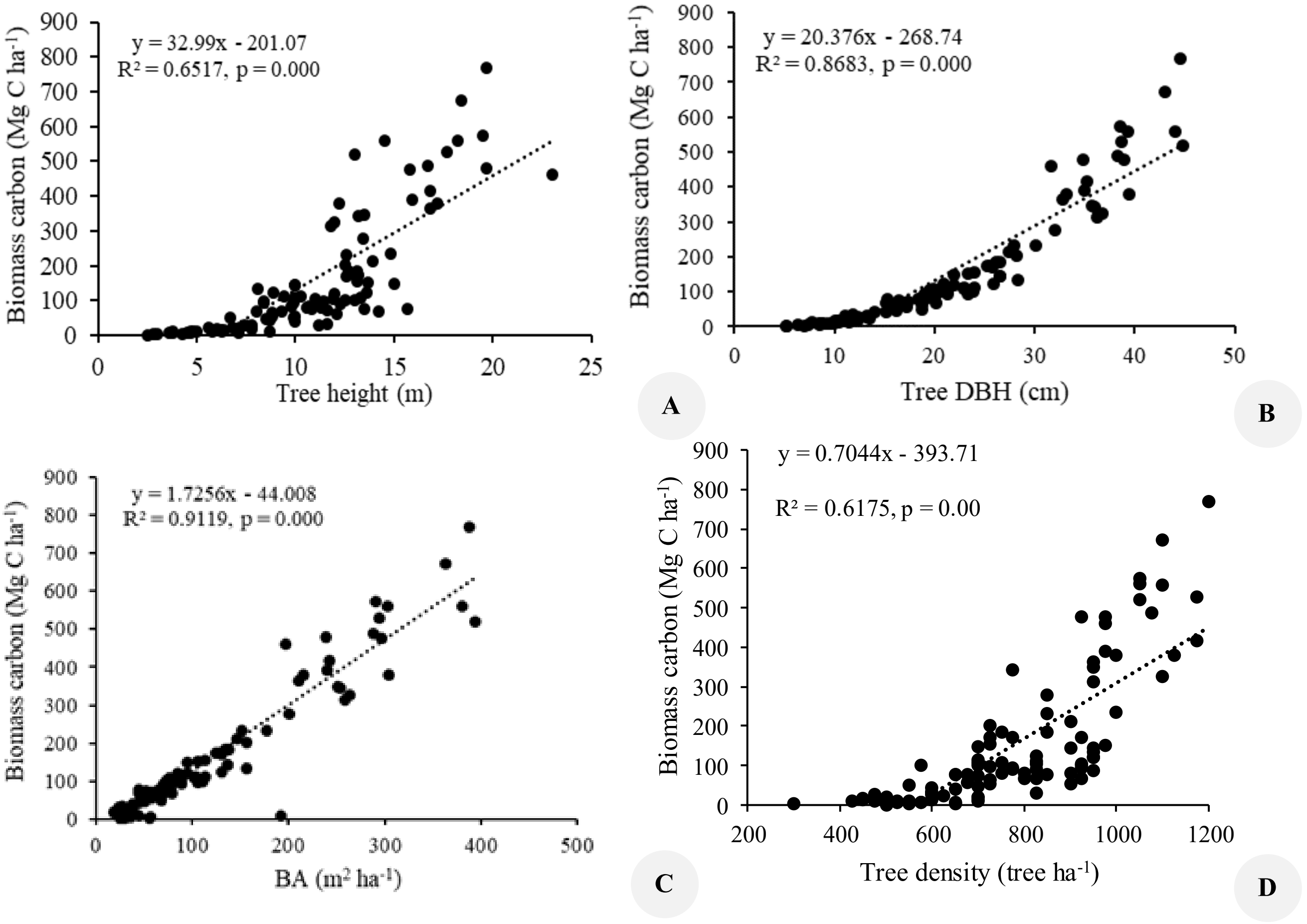

Figure 4. Relationship between tree biomass carbon and stand structure in term of: A. Tree height; B. Tree DBH; C. Basal area; and D. Stand density

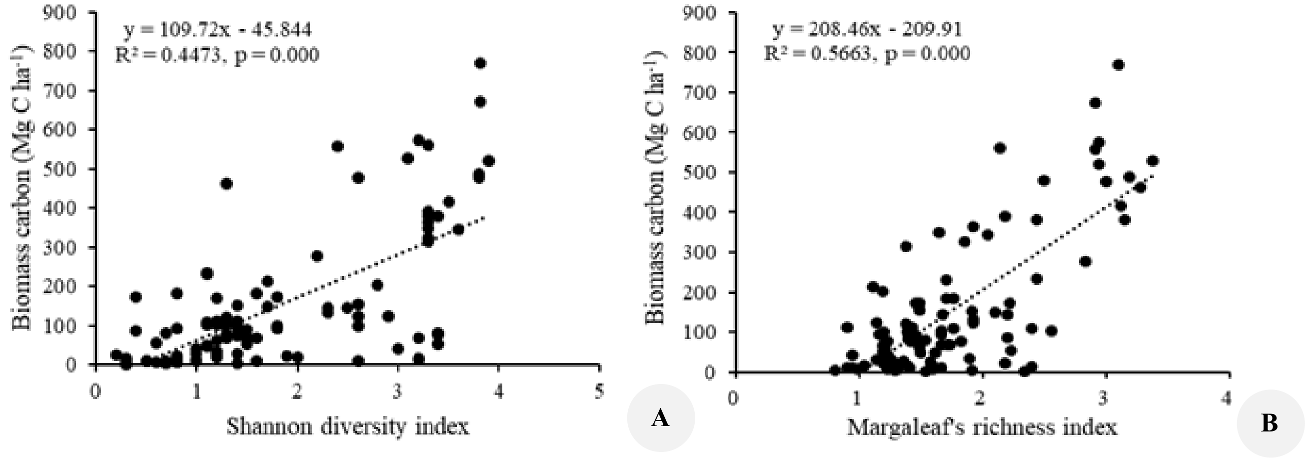

Figure 5. Relationship between tree biomass carbon and A. Shannon-Weiner diversity index; B. Margaleaf's richness index

Richness index and biomass carbon

Figure 5.B examines the relationship between the Margalef richness index and biomass carbon, showing a regression equation of y= 208.46x - 209.91 with an R^2 = 0.56. This indicates a stronger correlation compared to the Shannon-Wiener index, with about 57% of the variation in biomass carbon explained by species richness alone. The Margalef index specifically measures species richness, reflecting the number of different species within a community. The stronger relationship here suggests that species richness is a critical component of biomass carbon storage, potentially because a greater variety of species can lead to more efficient resource utilization, higher productivity, and, consequently, more biomass accumulation. However, similar to the Shannon-Wiener index, the remaining 43% of unexplained variation highlights the complexity of the factors that govern biomass carbon storage in forests (Hossain et al. 2020).

The results of this study emphasize the critical role of tree DBH (diameter at breast height) and basal area as primary predictors of biomass carbon in forest stands. These structural parameters, alongside tree height and stand density, offer significant insights into how forest composition influences carbon storage. The strong correlations observed for DBH and basal area indicate that maintaining or enhancing these attributes through sustainable forest management practices could be pivotal in maximizing carbon sequestration in forests. Nonetheless, the unexplained variation in each relationship highlights the inherent complexity of forest ecosystems and underscores the need for a comprehensive approach that considers multiple factors—including species diversity, environmental conditions, and stand dynamics—in efforts to boost forest carbon storage and mitigate climate change.

We also found that biodiversity, whether assessed through species richness or a combination of richness and evenness, plays a substantial role in determining biomass carbon levels in forest ecosystems (Rahman et al. 2018). The stronger correlation observed with the Margalef richness index suggests that species richness may have a more direct impact on biomass carbon than overall diversity captured by the Shannon-Wiener index. These findings reinforce the importance of conserving biodiversity, not only for its intrinsic value but also for its crucial role in enhancing ecosystem services like carbon sequestration (Kongsager et al. 2013). However, the considerable unexplained variation in both models indicates that biodiversity is just one component of a larger, intricate system. Future research should integrate additional ecological and environmental factors that contribute to biomass carbon storage, aiming to develop more comprehensive models capable of better-predicting carbon dynamics in diverse forest ecosystems.

This study underscores the intricate interactions between native and exotic species within the CWS, with a few dominant species significantly influencing the forest's ecological balance. These findings highlight the urgent need for targeted conservation strategies to safeguard native biodiversity and maintain the ecological integrity of the reserve (Ali et al. 2022). Future research should prioritize long-term monitoring of these species and assess the effectiveness of management practices in enhancing biodiversity and ecosystem resilience (Mitra et al.2023). Similarly, while structural attributes such as DBH and basal area are reliable indicators of biomass carbon, the complexity of forest ecosystems necessitates a holistic approach that incorporates various factors, including biodiversity (Scherer et al. 2023), environmental conditions Teets et al. (2023), and stand dynamics, to optimize carbon storage and address climate change (Hossain et al. 2020). Future studies should aim to incorporate additional ecological and environmental variables to refine models predicting carbon dynamics across diverse forest ecosystems.

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Trees outside forest for Chure dry land conservation in Makawanpur District, Nepal

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Abstract. *Bolakhe S, Ghimire P, Paudel P, Lamichhane U. 2024. Trees outside forest for Chure dry land conservation in Makawanpur District, Nepal. Intl J Trop Drylands 8: 106-113.* Trees outside forest (TOF) are considered as a potential strategy to meet the needs for timber, fuel wood, fodder and fruits of growing population and crop diversification to address land management problems and ecological concerns. In this backdrop, this study attempts to explore the contribution of TOF to Chure dry land conservation in Hetauda Sub-metropolitan City, Nepal. Field observation, household surveys (n=123), and in-depth discussions with local key informants were conducted to extract information about TOFs. The study documented 27 species of trees outside forest. About 19 species were present per household distributed on different locations like home gardens, terrace raisers, borderlands etc. More than 80% of these trees found on farmlands were planted, and only a few were naturally retained. Fruit trees (jackfruit and mango) dominated, followed by fodder (*Litsea* and *Ficus*) and other multipurpose species. Among the naturally regenerated trees, multipurpose species were abundant (>45%) and myriad fruit species (>60%) were seen among those planted. TOFs contributed to more than 40% of annual demands for fuel wood, fodder and bedding materials, whereas timber and poles are extracted in comparatively less amount. Almost all of the respondents agreed upon the positive impacts of TOFs on crop production, greenery enhancement and adaptation against drought. More than 90% of the respondents were positive about enhancing TOF for land productivity optimization and reducing pressure on forest to conserve fragile ecosystem of Chure dry land.

Keywords: Chure, dry land, ecosystem service, multipurpose tree, plantation

Abbreviations: ToF: Tree outside Forest

INTRODUCTION

Trees outside forest (TOF) are all trees that exist beyond the forest and other wooded land defined under the Forest Resources Assessment (FRA) by Food and Agricultural Organizations (FAO 2002). TOF may occur on agricultural land (such as meadows and pasture), built-up land (such as settlements and infrastructure), and barren land (such as sand dunes and rocky outcroppings) (FAO 2002). TOF offers a range of ecological, economic, social and religious functions (Pain-Orcet and Bellefontaine 2004; Tamang et al. 2019). These functions include carbon sequestration and other environmental services, resembling a win-win land-use strategy for climate change mitigation and adaptation, and ecosystem-based disaster risk reduction (Tamang et al. 2019; Peros et al. 2022; Liu et al. 2023).

The Chure region, also known as the Siwalik Hills, stretches over Nepal's southern belt and serves as an ecological transition zone between the lowland Terai and the Mid-hills (Singh 2017; FRTC 2022). It is one of the geographically young and fragile landscapes in Nepal and highly susceptible to environmental degradation due to its fragile geology, steep slopes, and high precipitation variability (Bishwokarma et al. 2016; Singh 2017). Over the years, unsustainable practices like overgrazing, illicit logging, deforestation, and unregulated sand mining have all contributed to the region's vulnerability, resulting in significant soil erosion, landslides, biodiversity loss, and depleted water resources (Singh 2017; FRTC 2022). high dependence of more than 80% of communities on forest and agriculture for livelihood further exacerbates the condition of the fragile ecosystem in this region (Bishwokarma et al. 2016; Singh 2017). These issues have had a cascade effect on local livelihoods, agriculture, and ecosystem services, making the Chure region an important conservation target.

Trees in agricultural landscapes have massive, yet unexploited, potential benefits to people and environment. On the one hand, it plays an important role in sustaining and restoring the physical environment, particularly by enriching soil fertility, reducing erosion, improving air and water quality, enhancing biodiversity and sequestering carbon (Pain-Orcet and Bellefontaine 2004; Prevedello et al. 2018; Tamang et al. 2019). On the other hand, it serves as source of livelihood for rural household economy by producing food, fuel and fodder (Pain-Orcet and Bellefontaine 2004; Ghimire et al. 2020; Lamichhane and Ghimire 2023). In the dry and fragile landscape, systematic management and fostering of non-forest trees could considerably contribute to increasing tree carbon stocks and landscape diversity (Prevedello et al. 2018; Peros et al. 2022). TOFs are crucial for conserving land in dry areas, where natural forests are scarce or absent (Liu and Slik 2014; Fremout et al. 2020; Peros et al. 2022). They stabilize soils, improve water retention, and enhance ecosystem resilience. TOFs anchor the soil, reducing wind and water erosion, and maintaining land fertility (Fremout et al. 2020). They improve the microclimate by providing shade, lowering temperatures, and reducing soil moisture evaporation, leading to higher agricultural productivity (Liu and Slik 2014; Yadav et al. 2017; Fremout et al. 2020). Trees facilitate water infiltration, allowing groundwater recharge, and sustaining ecosystem functions and livelihoods (Liu and Slik 2014; Fremout et al. 2020; Pati et al. 2022). TOFs also promote biodiversity in dryland ecosystems, providing microhabitats for various species and serving as windbreaks to protect crops and soils from strong, dry winds.

In recent times, policymakers have also recognized the significance of trees outside forests in achieving sustainable development and food security (Schnell et al. 2015; Lohbeck et al. 2016). The recognition of TOF is important to acknowledge their role in human livelihoods, environment and biodiversity (FAO 2002; Pain-Orcet and Bellefontaine 2004; Yadav et al. 2017; Prevedello et al. 2018; Peros et al. 2022). To enhancing the contribution of tree outside the forest to sustainable livelihoods, several reports and case studies were conducted (e.g. FAO 2002; Rawat et al. 2003). Recently, the increasing interest in global issues like climate change mitigation, carbon sequestration, and poverty alleviation makes TOF even more important. However, more research is needed to understand their state and influence on biodiversity conservation over time, as trees grown in non-forest areas are essential components of planning and development policies (FAO 2002).

In Nepal, trees outside forest area contribute significantly to sustainable development and people's livelihood. However, the primary focus has always been on trees in the forests, which are viewed as a resource and a repository of biological diversity (FAO 2002; Giri 2017; Ghimire and Bolakhe 2020). Despite their potential, the management and promotion of TOFs in Nepal remain underexplored. Furthermore, TOF have not been included in the national forest inventory, despite the fact that they serve a variety of functions for human well-being and environmental conservation (Oli 2017; Ghimire et al. 2020). TOF provides various environmental, economic, and socio-cultural services and functions, but people are not fully aware and benefit from these services because TOF is neither well documented nor given enough attention in Nepal. Recent policies and initiatives from the government aims at reducing pressure on forest and thereby developing ecosystem beyond forest areas. Given the critical importance of conserving the Chure region, this study highlight the pivotal role of TOFs in addressing both environmental and socio-economic challenges. It explores the role of TOFs in stabilizing the Chure region's ecological integrity while ensuring socio-economic benefits for communities.

MATERIALS AND METHODS

Study area

This study was conducted in Ward no. 16 of Hetauda Sub-Metropolitan City, Makwanpur District, Bagmati Province, Nepal (Figure 1). It covers 18.95 km^2 area and consists of 1228 households. The study area lies in the Chure region of Makwanpur District and is geographically situated at 27°25' N and 85°02' E at 300-390 masl. Covering about 12.78% of the total land mass of the country, Chure region is a critical ecological region in Nepal, providing a buffer zone for the fragile ecosystems of the southern Terai and northern mid-hills (FRTC 2022). This is an environmentally sensitive region characterized by fragile geology, deforestation, and soil erosion. Human-induced activities like overgrazing, unsustainable farming, and illegal logging have intensified the vulnerability of the Chure. This biologically rich but geologically fragile region is the home to many species and provides many ecosystem services to millions of people (Hetauda Sub-Metropolitan City Office 2018; FRTC 2022). The study area harbors globally importance biodiversity with diverse community and provides ecosystem services that support the socio-economic well-being of people and development in Chure region of Nepal. The extent and scale of the landscape also allow for assessing TOF for climate change adaptation strategies (Bishwokarma et al. 2016).

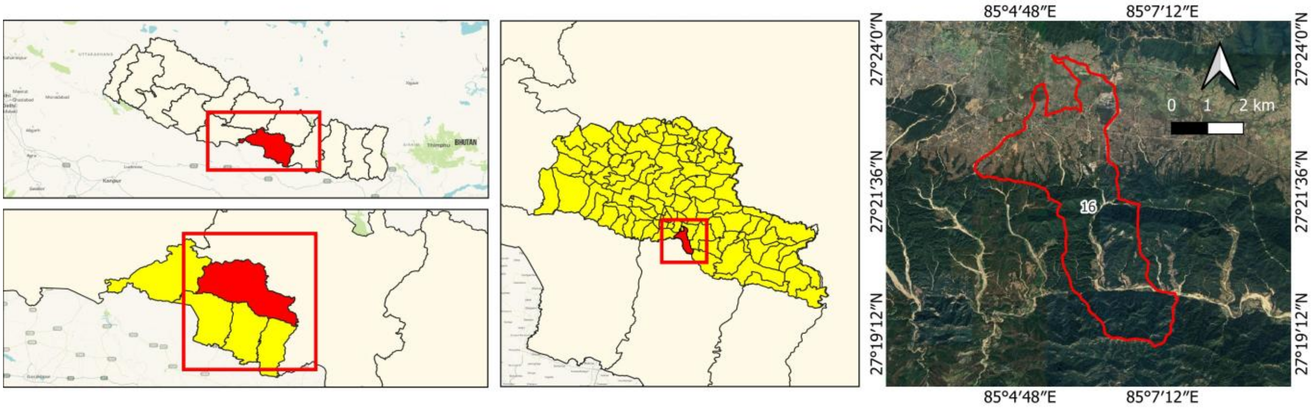

Figure 1. Map of the study area in Ward no. 16 of Hetauda Sub-Metropolitan City, Makwanpur District, Bagmati Province, Nepal

Sampling design and data collection

Simple random sampling with 10% sampling intensity was taken for the collection of data. Both qualitative and quantitative data for this study were collected. A total of 41 circular plots of size 1,000 m^2 having radius of 17.84 m were laid out randomly to collect tree species abundance. Socio-economic and ecological importance of TOF was assessed by applying various practical approaches in order to bring the realistic and acceptable role of TOF for extension to local level. Semi-structured questionnaire survey (n=123), and focus group discussion (n=3) with key informants and ward executive committee members were used to collect the socio-economic and ecological importance of TOFs. The secondary data required were extracted from the Hetauda Sub-metropolitan City Office profile (Hetauda Sub-Metropolitan City Office 2018).

Data analysis

The total 123 households sampled for this study had 90% CI and 10% margin of error. The information gathered from both primary and secondary sources was analyzed using Statistical Package for Social Science (SPSS) and presented in tables, figures and bar charts, etc.

RESULTS AND DISCUSSION

Number of species and abundance

In total, 27 species of trees outside forest were recorded in this study (Figure 2). Among these, *Artocarpus heterophyllus, Melia azedarach, Litsea polyanthus, Dalbergia sissoo, Shorea robusta* and *Tectona grandis* were the species with higher frequency. Ghimire and Bolakhe (2020) and Lamichhane and Ghimire (2023) reported 71 and 63 species in the farmlands of Makawanpurgadhi rural municipality and Bhimphedi rural municipality respectively, in Makawanpur District, Nepal. The variation in the number of species can be attributed to the change in the physiographic zones, and within a given physiographic zone, it varies with location. Similary, Paudel et al. (2019) reported 32 tree species in the agroforestry land of Likhu rural municipality in Dolakha District, Nepal. A total of 1252 trees belonging to 85 species, 73 genera and 38 families were recorded in outside forest area in central India (Pati et al. 2022). The presence of wide diversity of tree species shows that area outside of forest or farmlands are good repository of high floral diversity (Marchetti et al. 2018; Tamang et al. 2019; Bhandari et al. 2021).

Regeneration mode and tree location

The presence of trees outside forest in the study area was originated from planting and naturally regenerating (Figure 3). More than 80% of these trees found on farmlands were planted, and only a few were growing naturally. Planting was the most preferred method to grow fodder and fruit species in borderland, farmland, and home garden whereas natural regeneration occurred in trace raiser and dikes. Natural regeneration was done mostly for slope stabilization and soil conservation purposes. Ghimire et al. (2020) also found that trees in farmlands, fallow lands and borderlands in Sindhupalchok District, Nepal mostly raised in terrace raiser. On the other hand, a study by Paudel et al. (2019) found that tree species planted were commonly on farmlands and home gardens.

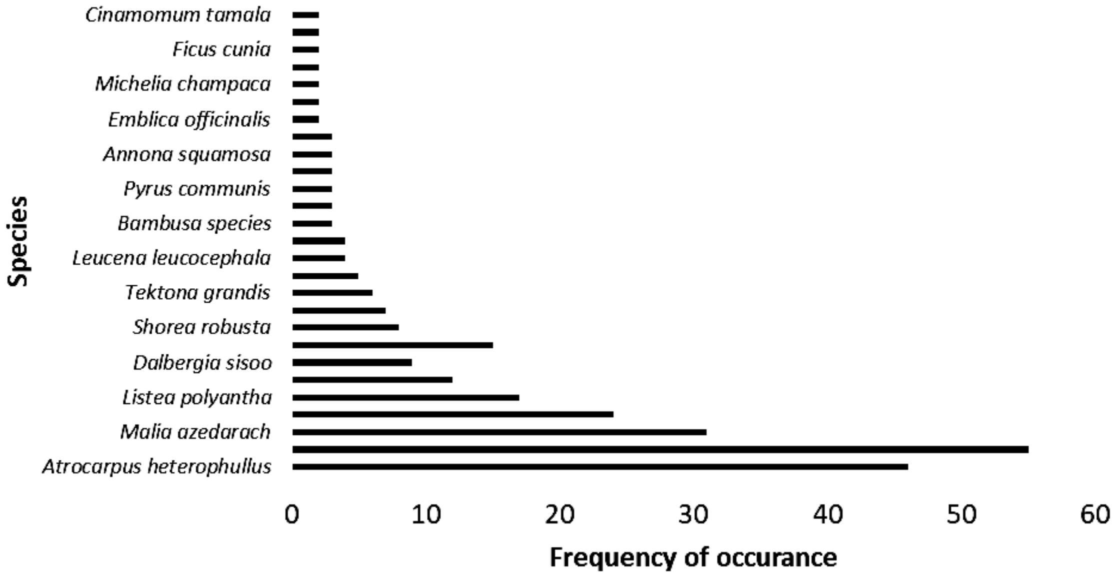

Figure 2. Tree species and its abundance across the sampled plots in Makwanpur District, Bagmati Province, Nepal

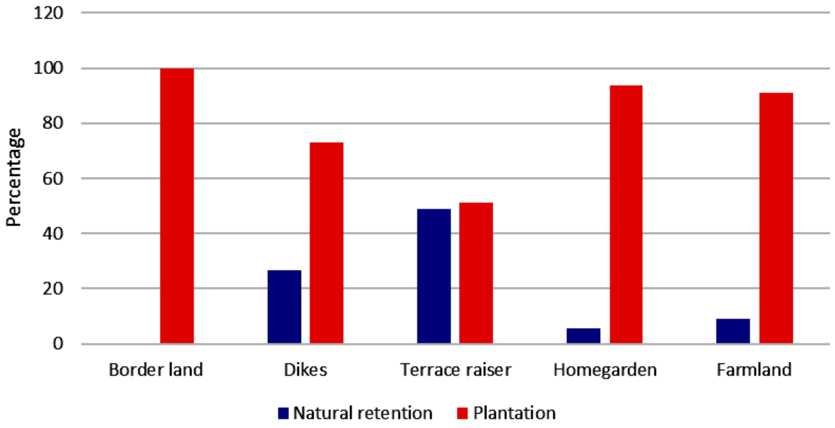

Figure 3. The proportion of trees outside forest based on the location and mode of regeneration

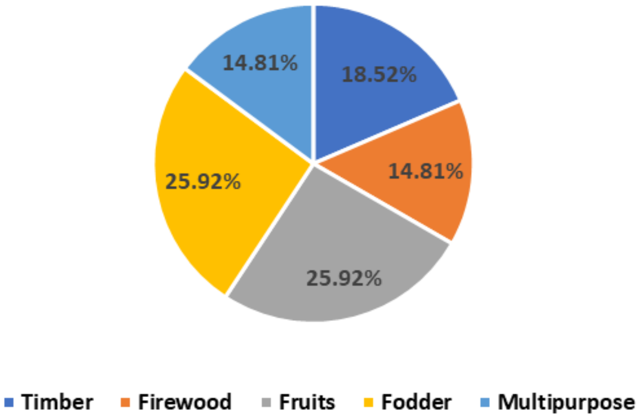

Figure 4. The proportion of trees outside forest based on the uses by community

Uses of tree species

Fodder, fruits and timber tress were the dominant tree species in the study area. Fodder species like *Litsea monopetala*, *Ficus* spp. dominated the composition with 25.92%, followed by *Shorea robusta* and *Tectona grandis* (18.52%) and other multipurpose trees like *Melia* (14.81%) (Figure 4). Species like *Ficus bengalensis*, *Ficus religiosa*, *Nyctanthes arbor-tristis* and *Elaeocarpus sphaericus* were also available in noticeable amount. This shows that people especially like to grow fodder trees on their farmland in order to fulfill their livestock needs and diet. Amatya et al. (2018) highlighted that trees in farmland are mainly multipurpose and choices are governed by primary household needs, such as timber, firewood and fodder.

The use value of TOFs goes beyond their ecological role, providing significant socio-economic and environmental benefits. TOFs, which can be found in agricultural landscapes, urban areas, along roadsides, and around homesteads, directly benefits the livelihoods of both rural and urban communities (Pati et al. 2022; Peros et al. 2022). These trees provide products such as fodder, fuelwood, fruits, timber, and medicinal plants, which support local economies and household needs. Furthermore, TOFs improve ecosystem services by enhancing soil fertility, sequestering carbon, regulating water cycles, and offering shade and shelter. TOFs improves urban aesthetics, reduce air pollution, lower temperatures, and promote mental well-being by enhancing green spaces (Ghosh et al. 2019; Pati et al. 2022; Peros et al. 2022). Their versatility and accessibility make TOFs critical in enhancing the resilience of both rural and urban populations to climate change and economic challenges.

Number of trees and landholding

Figure 5 presents the relation between land holding (ha) and number of trees per household. It was found that with increase in area, number of trees are increasing but there is no strong relationship between them. This signifies that tree in private land is either depends in family living standard or types of land they hold. Figure 6 shows the relationship between a number of livestock and the number of trees. This also shows no significant relationship between them, but there is a slight increase in trend, i.e., when the number of live stocks increases, trees also increase.

Goods and services provided by TOF

In addition to its function in farmland, TOF are considered important in term of delivering ecosystem goods services. Different provisioning and regulating services from TOF were recorded in the study area, including major provisioning services of timber products, poles, firewood, fodder, and bedding materials. About 40% of annual demand for bedding materials, fodder and fuel wood was fulfilled by TOF whereas timber and poles were extracted comparatively in less amount (Figure 7). The contribution to timber annual supply from TOF was also significant. This shows that TOF is reducing pressure on forests and can be promoted as alternative forest product supply measures.

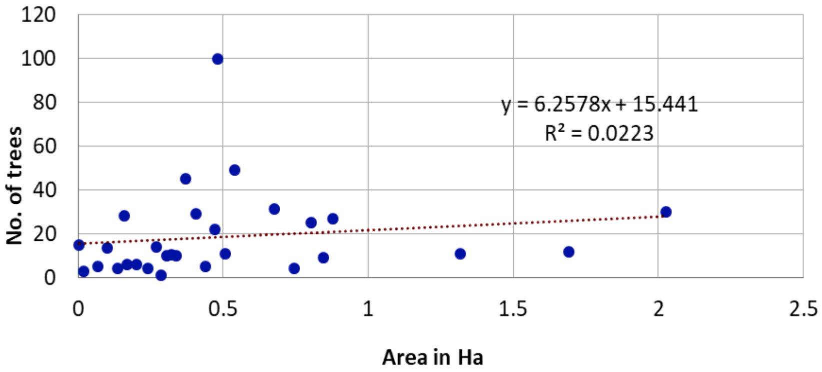

Figure 5. The relationship between the number of trees outside forest and extent of landholding

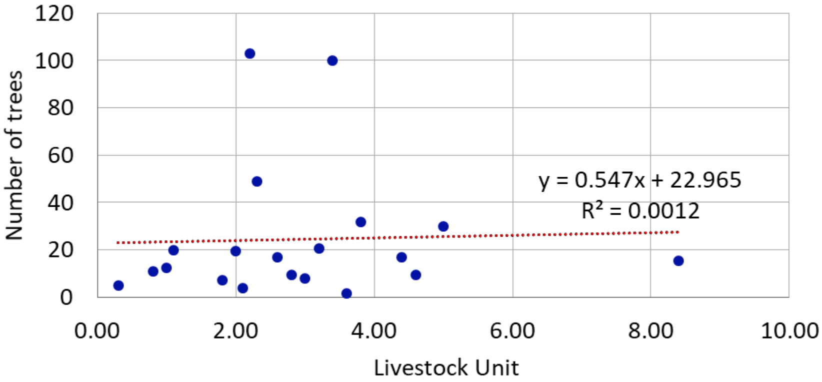

Figure 6. The relationship between the number of trees outside forest and the number of livestock units

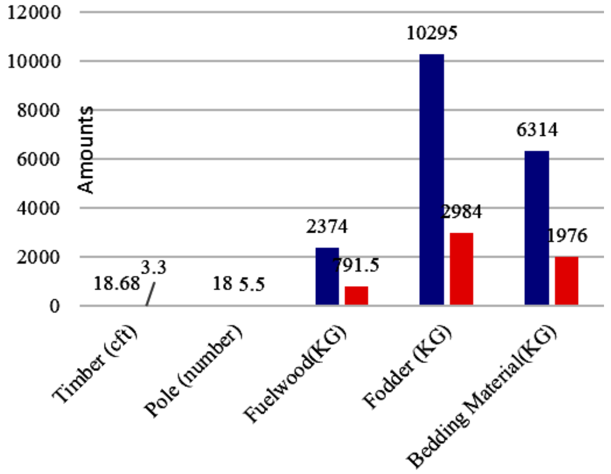

Figure 1. Provisioning goods and services from trees outside forest and its contribution to livelihoods

Similarly, seven regulating services were recorded in study area (Figure 8). People believe that TOF primarily helps with soil conservation, erosion control, slope stabilization, and flood control which directly helps to stabilize Chure Hill. While, other services like water quality improvement, habit improvement and carbon storage also signified the importance of TOF.

TOFs can produce wide range of products and services (Tamang et al. 2019; Peros et al. 2022). Trees in and around farmlands produces products like timber, firewood, fruits, fodder medicines etc. (Ghimire et al. 2020, 2024) which can directly be traded. Whereas, services like reducing soil erosion, stabilizing slope, maintaining soil fertility, minimizing drought, improving water table and working as windbreaks are more valuable to maintain biodiversity (Lasco et al. 2014; Varma et al. 2023; Ghimire et al. 2024) and to mitigate the impacts of climate changes for mountainous communities. There has been increasing accumulation of evidence that supports the ecosystem services and environmental benefits claims of TOF including agroforestry systems in both the tropical and temperate regions (Guo et al. 2014; Lohbeck et al. 2016; Ghosh and Sinha 2019). Ghimire et al. (2020) highlighted the significant value of TOFs for the maintenance of both provisioning and regulatory services in Sindhupalchok District, Nepal. Furthermore, a study by Baral et al. (2013) in Kanchanpur District of Nepal supports the significant importance of TOF for provision of ecosystem services and biodiversity conservation. In recent decade, TOF are becoming critical for ecosystem services and economic benefits, such as potential contribution to agriculture, food supply and income through the provision of goods and services, conservation of biodiversity and carbon sequestration (Chakravarty et al. 2019).

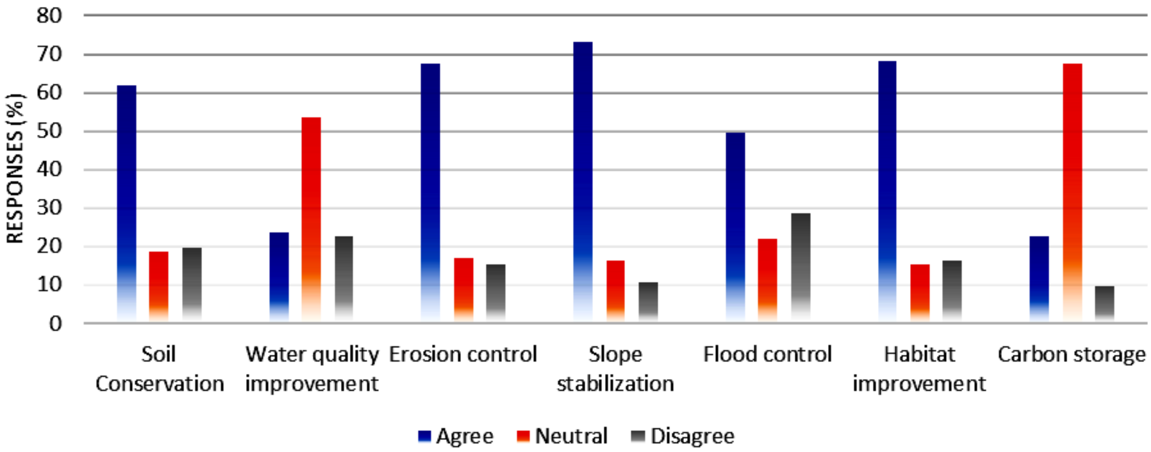

Figure 8. Regulating services from trees outside forest perceived by the respondents

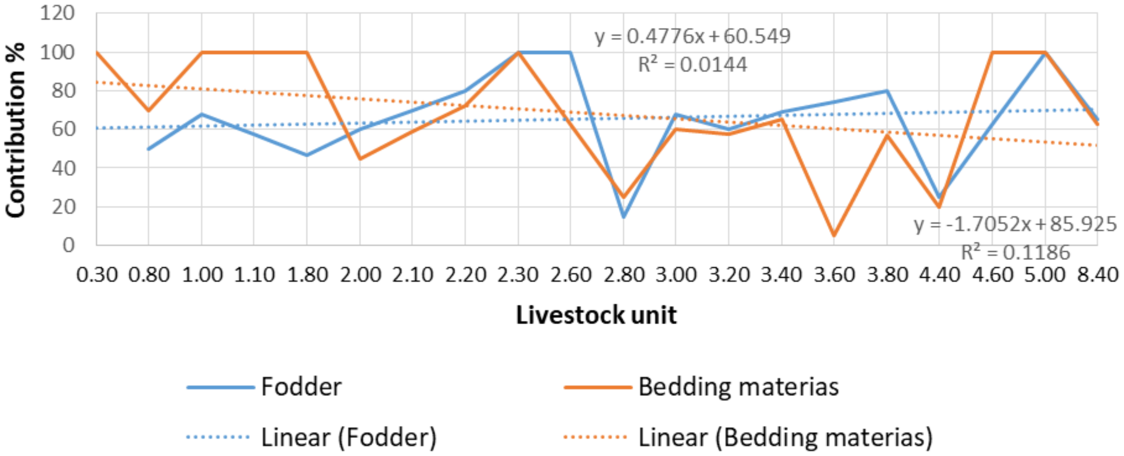

Figure 9. The contribution of trees outside forest for fodder and bedding materials and its relationship with livestock unit

Contribution of TOF to livestock production

Figure 9 shows the relation between livestock units and the contribution percentage of TOF. It shows that with increase in livestock unit, TOF contribution to fodder supply is also increasing. This is mainly due to fodder trees like *Leucaena leucocephala*, *Litsea monopetala* and *Ficus lacor*, resulting in the decreasing of the contribution to bedding materials. It is also clear that TOF is contributing to reducing pressure on forests. Amatya et al. (2018) highlighted that forestry sector contributes to 40% of the livestock fodder consumption in Nepal. Tree-growing practices in and around homesteads and farmland have long been associated with rural Nepal, and are thus regarded as integral components of rural livelihoods (Giri 2017; Oli 2017). TOFs have been found to be economically and environmentally sustainable both at small and large scales. Farm trees and home gardens are major sources of fodder for livestock in rural landscape (Rossi et al. 2016; Jose et al. 2019; Lamichhane and Ghimire 2023).

Promotion of tree outside forest

The existence of trees in farmland is a part of traditional as well as contemporary farming systems in rural areas of both developed and developing countries. It is well known that TOF offers a range of ecological, economic, social and religious functions to conserve biodiversity and to uplift the local people livelihood. During the study, more than 90% of the respondents were positive about enhancing TOF for land productivity optimization and reducing pressure on forests to conserve the fragile ecosystem of Chure region (Figure 10). Hence, the importance of TOF to conserve biodiversity by reducing the pressure on forest resources could be recognized both at national and international level.

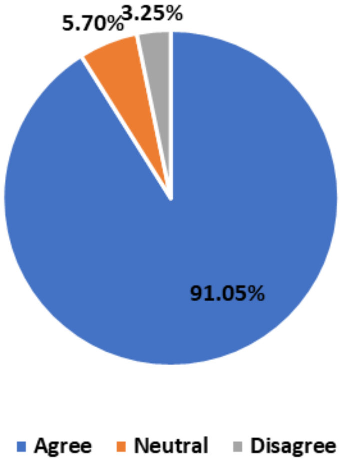

Figure 10. Respondents' perception on the promotion of trees outside forest for Chure conservation

People believe that to conserve Chure region, activities should be separated into two part: activities inside forest and outside forest. In-situ activities, like tree planting, reducing grazing and logging along with proper infrastructure development activities, promotion of TOF, education and alternative job opportunities can significantly reduce the pressures on Chure forest (Bishwokarma et al. 2016; Singh 2017). People believe that promoting TOF helps to conserve Chure by reducing the pressures for fodder, fuel wood and timber (Bishwokarma et al. 2016; Singh 2017; Bhandari et al. 2022). Proper research to recommend species based on major agriculture crops is urgent.

In conclusion, the importance of trees outside forest for dryland conservation is undeniable, as they play a critical role in sustaining ecosystems and supporting human livelihoods in fragile environments. This study focuses on the multifunctional benefits of trees outside forest in drylands, where their presence is critical for reducing land degradation, improving soil fertility, and enhancing water retention. TOFs act as natural windbreaks, reducing soil erosion and protecting agricultural crops from harsh climatic conditions. They also provide essential products such as fuelwood, fodder, and food, which are crucial for the survival of rural. Moreover, TOFs helps to conserve biodiversity by offering habitat and food sources for wildlife. Their ability to sequester carbon and regulate microclimates aids in mitigating climate change. Therefore, TOFs could be a viable option for conserving Chure dry land by balancing biodiversity conservation and production. The local community also recommended using TOFs as a significant approach to conserve Chure region. Integrating TOF into Chure dryland management strategies is critical for promoting environmental sustainability, enhancing agricultural productivity, and strengthening the resilience of communities living in the Chure area. This study highlights the importance of policies and practices that promote the sustainable management and expansion of TOF in Chure conservation efforts.

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Short Communication: Diversity of fauna and local wisdom of Somopuro Cave, Pacitan District, East Java, Indonesia

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Abstract. *Sholiqin M, Mahendra AS, Waskito DN, Fathoni MFM, Maheswara VD, Indrawan M, Junaedi E, Setyawan AD. 2024. Short Communication: Diversity of fauna and local wisdom of Somopuro Cave, Pacitan District, East Java, Indonesia. Intl J Trop Drylands 8: 114-125.* Karst is an area that has a remarkable landscape and hydrological pattern that is formed from a combination of rock properties that have a high level of solubility and well-developed secondary porosity. This research aims to determine the diversity of fauna and local wisdom in the Somopuro Cave karst area, Pacitan, East Java, Indonesia. The sampling was conducted in December 2023. The method used was direct observation and interviews regarding animals and the local wisdom of the local people. The fauna sampling technique and local wisdom are combining hand collection with trap method, direct count and in-depth interviews with Somopuro Cave sources. Data analysis used the formulas for the Shannon Wiener diversity, Evenness Index, Dominance Index, Species Richness Index, and local wisdom analysis through interviews with residents. The animal species obtained includes Actinopterygii (*Barbodes binotatus, Poecilia reticulata, Barbonymus gonionotus,* and *Channa striat*a), mammals (*Eonycteris spelaea*), crustacea (*Cardisoma carnifex* and *Penaeus merguiensis*), arthropods (*Limnogonus fossarum, Phrynus exsul,* and *Diestrammena heinrichi*), Amphibians (*Fejervarya cancrivora*), and Mollusca (*Faunus ater*). The calculation results obtained a Diversity Index value of 1.26 in the medium diversity category, Evenness Index (0.45) in the medium evenness category, Dominance Index (0.44) in the low dominance category, and Species Richness Index (2.46) in the low species richness category. The value of fauna species diversity is still low in the community, and low dominance indicates balanced competition between fauna populations. The local wisdom found in Somopuro Cave is *Tapa Mangsa* which means meditating in a special month and makes the cave considered sacred and mystical. This action aims to gain peace, maintain the surrounding environment, and preserve the ecosystem so that it is not exploited or damaged by humans. The development of the modern era has made the community's analogy towards this belief decline so that currently, there is a lot of use of fauna resources in the cave by the community.

Keywords: Culture, environment, karst, species

INTRODUCTION

Karst is formed from a combination of a special hydrological system against limestone that undergoes a karstification process to form natural features in the form of valleys, hills, caves, and dolines (Wang et al. 2019). Biogeochemical processes in karst ecosystems are both temporally and spatially heterogeneous (Li et al. 2021). The upper part of the karst area allows for a long delay in the flow of rainwater into underground rivers (Goldscheider 2019). The karst ecosystem also acts as a carbon catchment area, capturing twice as much carbon as forests (Widyaningsih 2017). Karst ecosystems regulate the terrestrial carbon cycle and potentially mitigate climate change. However, rocky desertification has emerged as one of the most serious environmental problems in karstic areas because of long-term overexploitation (Tang et al. 2022).

As an ecosystem, karst has various important values that must be preserved, including the biodiversity in karst environments (Haryono et al. 2022). Karst ecosystems are diverse; several terrestrial fauna also live and adapt to karst environments. Examples of terrestrial fauna that can adapt to karst include the Araneae, Coleoptera, and Hymenoptera families (Hongbo et al. 2018). Biodiversity plays an important role in conservation efforts, which karst also contributes to, and karst is the basis for the continuity of biodiversity (Veress 2022). The function of karst can cause the diversity of fauna that live in karst ecosystems as a safe habitat for rare fauna species, as well as limestone, which regulates the water flows, maintaining the endokarst groundwater basin where the womb and life chain of living things are (Konradus 2021). However, the threat of natural greening, urbanization, and unsustainable waste management are significant and affect biodiversity in karst environments (Breg et al. 2018).

Caves are one of the characteristics of subsurface karst, developing when acidic water begins to break down the bedrock near cracks (Zhu et al. 2019). Because caves are characterized by darkness, low to moderate temperatures, high humidity, and limited nutrients, they can be discriminated from land surface substrates. In the absence of sunlight, microorganisms in cave habitats cannot photosynthesize and are forced to rely on alternative primary production strategies to compensate for the lack of an exogenous carbon source (Zang and Chai 2019). Microorganisms are important in nutrient regulation and strengthening karst conservation and restoration (Xiao et al. 2022). Karst ecosystem recovery likely relies on the persistence of soil functions at the microbial scale where soil remains between the exposed rocks (Xue et al. 2020). Populations found in karst areas have received more attention due to the origin and diversification of high biodiversity, which has caused great ecological and evolutionary value and priority of karst areas (Yang et al. 2021).

Extensive research has been conducted on fauna diversity, including in karst ecosystems. Species that can live in karst caves have special characteristics that help them adapt to the existing environment. This is why only adaptable species can survive (Suhendar et al. 2018); fauna with karst cave habitats must have distinctive physical characteristics (Poerwanto et al. 2020). Studies of the causes and impacts of biodiversity differences between communities require appropriate species richness and diversity measurements. These measurements include the number of individuals of a species in a community and are a function of the relative frequencies of different species (Omayio and Mzungu 2019). Research conducted by Salas et al. (2005) showed that the Sangkulirang peninsula in East Kalimantan province is home to high levels of diversity for snails, insects, birds, and bats. Additionally, several new animal species were discovered, including what may be the world's largest cave cockroach (*Blattella asahinai*) and a very small blind crab (*Gandalfus yunohana*). Another karst region in southwest China, one of the largest continuous karsts in the world, is known for its unique landscape and rich biodiversity. However, karst ecosystems are very vulnerable to damage due to human activities (Wang et al. 2019). It's in this delicate balance that human activities, guided by local wisdom, play an important and respectful role in the survival of fauna. Prabowo (2011) explains that local wisdom is a culture or habit of local people that is useful for maintaining the environment, which is implemented in the form of local customs. Good local wisdom will bring life to the environment, and harmful human activities can threaten the life of existing fauna, such as in the Mojokerto area, which has preserved conservation with local wisdom that can protect water sources, flora, and fauna (mahogany, sengon, pine, teak, and fauna such as monkeys, wild dogs, and wild boar (wild boar) can easily be found (Lestari et al. 2021).

Karst ecosystems, with their unique features, are known for their diverse fauna. This manuscript will specifically explore the diversity of fauna species in the Somopuro Karst cave and the local wisdom of the surrounding community in their efforts to preserve this diversity. Our primary goal is to uncover the extent of fauna diversity in Somopuro Cave and to highlight the local practices that are instrumental in protecting and nurturing the ecosystem. We believe that this research has the potential to not only enhance our understanding of cave ecosystems but also to serve as a valuable tool for identifying and preserving fauna diversity in other caves.

MATERIALS AND METHODS

Study area

The research was conducted in December 2023 at Somopuro Cave, Bungur Village, Tulakan Sub-district, Pacitan District, East Java, Indonesia (Figures 1 and 2). The research survey was conducted on 2 December 2023 and sampling at the research location was from 8 to 10 December 2023. Tulakan, Pacitan District, is located between 200 and 700 meters above sea level, approximately 25 km eastern of Pacitan capital district, and is classified as a topography dominated by highlands, karst mountain areas, and limestone mountain areas. The geographic coordinates of Somopuro Cave are 8°10'44"S and 111°16'53" E.

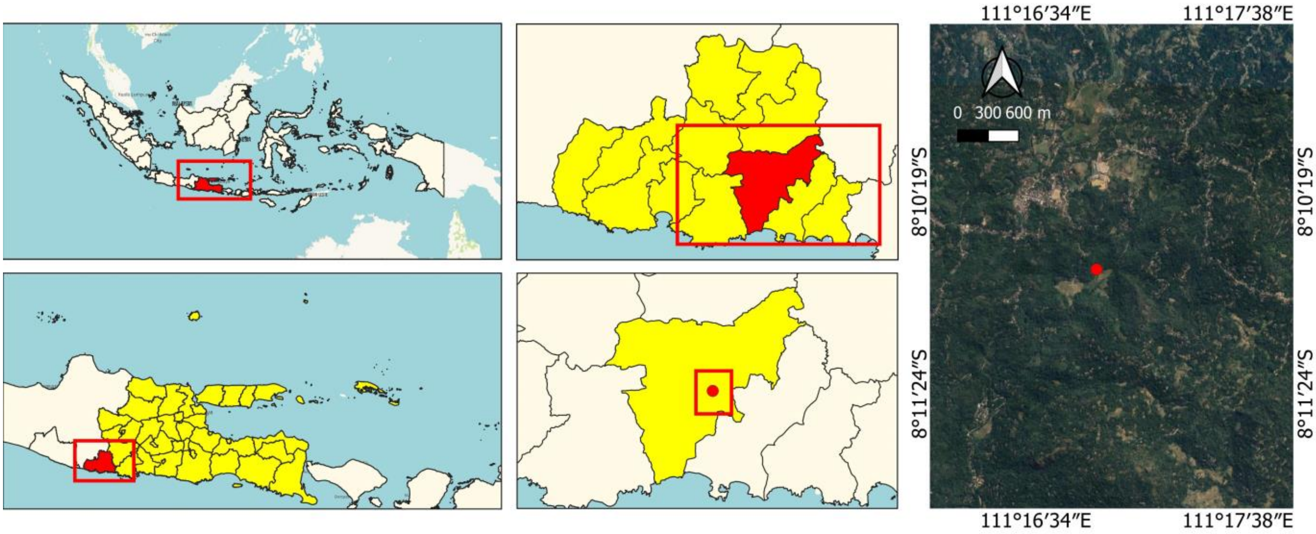


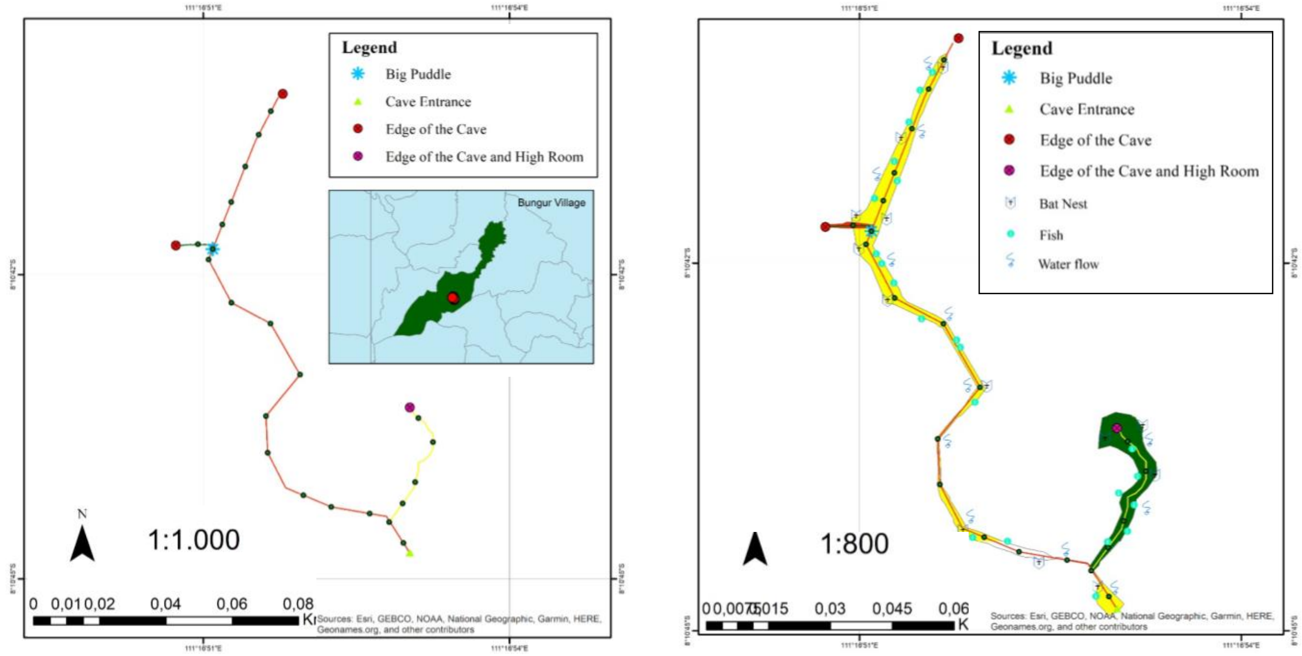
Figure 1. Map of Somopuro Cave, Bungur Village, Tulakan Sub-district, Pacitan District, East Java, Indonesia

Figure 2. Front gate of Somopuro Cave, Bungur Village, Tulakan, Pacitan District, East Java, Indonesia

Several abiotic, biotic, and cultural factors in Somopuro Cave are always related to form a balanced karst environmental composition. Sompuro Cave is one of the karst natural features whose abiotic factors are in the form of karst hills, air from rivers, and karst springs with relatively sufficient light intensity. Somopuro Cave is a type of elongated horizontal cave (Figure 3.A). The mouth of the cave faces southeast, with a width of 8.34 meters. This cave has two directions of corridors that are divided into two separate parts (Figure 3.B). The left cave corridor has a water source and passes through an underground river and is a habitat for air and land fauna. At the same time, the right corridor has no water source and is usually used by the community for traditional ceremonies. The left corridor system has a length of 184 meters, with the cave walls relatively damp and slippery. In this left corridor system, many stalagmites, stalactites, and fauna are found in it. In addition, there is no light intensity at all in the inside of this corridor. The river flow at the entrance to the left cave corridor has a depth of up to 187 cm, but the flow after it towards the water source is at a depth of 35-47 cm. Researchers managed to explore the deepest end of the cave until they found a source of flowing water at the end of the cave, which then flowed into the water body of the Somopuro Cave. Meanwhile, the right corridor is dominated by quite large stalactites and stalagmites, but the distance between the mouth of the cave and the inside reaches 42.6 meters. The fauna found in the right passage is not that much and is usually used by residents for meditation. Local residents meditate on the highest karst rocks towering to the roof of the cave, approximately 7-8 meters. Hence, the position of meditation is quite close to the roof of the Somopuro Cave in the right passage system (Figure 3). In addition, the soil conditions are relatively fertile, resulting in many plants and animals being able to grow and develop around the cave. This potential creates an opportunity for local communities to cultivate their land for agricultural, plantation, and livestock sectors.

Procedures

The methods used in the study are descriptive, quantitative, and qualitative. Field data search by means of observation. The sampling technique used is a combination of data collection with trapping methods and direct calculations. Local wisdom information is obtained through interviews with sources or caretakers (*juru kunci*) of Somopuro Cave directly. The interview method used is the In-depth interview technique in order to obtain information from participants and informants that the researcher has determined. Then, the interview was conducted in a semi-structured manner by asking questions about the objects and data needed by the researcher to the informant. The indicator data studied include abiotic factors, aquatic fauna, terrestrial fauna, and local wisdom.



A B

Figure 3. Somopuro Cave, Pacitan District, East Java, Indonesia. A. Schematic map; B. Corridor system and sampling points

Environmental factor sampling technique

Moreover, the data collection on water quality with parameters Total Dissolved Solids (TDS) (ppm), water temperature (°C), Dissolved Oxygen (DO) (%), and pH are calculated using the TDS meter, pH meter, and DO meter. TDS measurements are carried out by dipping the TDS meter into the solution to be measured to a depth of 2-3 cm. The final value can be read quickly, and the number is stable. The TDS and temperature readings are collected from these meters (Wang 2021). pH measurements are carried out by inserting a pH meter into the water in Somopuro Cave. Monitoring water pH is important to determine whether water quality is good or bad. Water with poor quality can have a negative impact on the health of aquatic biotas and cause various diseases (Rahmanto et al. 2020). The DO measurement refers to Uddin et al. (2014). All results are recorded and then compiled for analysis. The pH meter correlates with physical, chemical, and biological water factors to closely relate to water quality (Supriatna et al. 2020). Water quality is important to measure because it can affect life in the area (Astuti 2014).

Aquatic and terrestrial fauna sampling technique

The research's specification method combines hand collection with trap methods and direct count (Setiawan et al. 2018). The fauna in Somopuro Cave was captured using trap nets, and then data on numbers was collected (Safitri et al. 2016). Sampling was conducted from 08.00 am to 1.00 pm which was conducted 3 times in 3 days of research. The number of teams involved in this research was 5 researchers and 1 caretaker who accompanied the data collection. Of the 5 people, 1 of them made observations regarding cave conditions and abiotic parameter measurements. At the same time, 4 of them focused on sampling aquatic and land fauna using nets, and each person was equipped with a headlamp. The technique used in this sampling was to combine hand collection with trap and direct count methods, where the fauna found was directly captured, and the number of individuals was counted at that time. The tools used in capturing aquatic fauna species use nets with a width of 25 cm, meshes with holes of 1 and 2 mm accompanied by a 1.5 m pole for the handle, a headlamp as a light when capturing species, a 100 mL sample bottle, and a 108-megapixel cellphone camera. Aquatic and land fauna found directly were captured using nets and documented. Each sample was put into a sample bottle with 4% formaldehyde in water that had been brought for further identification. The search for animals using nets was carried out directly on all river flows in the cave and the bottom, sediment, walls, and ventilation, which were documented with a camera. Complementary data regarding existing fauna and strong local wisdom were obtained by conducting direct interviews with the caretaker of the cave. In addition, collecting data using the exploratory method involves observing or taking samples directly from the observation location (Gunarno 2021).

Identification of aquatic and terrestrial fauna in the Actinopterygii class refers to Kottelat and Whitten (1996) and Tamsil et al. (2021), while the crustacean class refers to Zupo (2022), in the mollusca class using Graham (1988), the amphibian group is identified refer to MEF & IIS (2019), bats group is identified refer to Taylor (2019) and the arthropod group is identified with Thorp (2009).

Local wisdom sampling technique

Information regarding the local wisdom of Somopuro Cave was obtained through in-depth interviews directly (using the Focus Discussion Group/FDG scheme) with the five key informants, one of whom is Somopuro Cave's senior caretaker. The other informants had been determined by the researcher as suggested by the head of the community to represent the area used for research. Then, the interview was conducted in a semi-structured manner by asking questions about the objects and data needed. Key informants become a source of information in helping the research process. This FDG is an interview scheme with a model of gathering together and asking questions about Somopuro Cave, both from history, abiotic, biotic, cultural elements, fauna species found, and local wisdom around the cave. This is done using the local language (Javanese) to create a clearer and more communicative language and easier for informants to understand. The interview was conducted at the key informant's house and the cave. Then, the research team recorded and documented all local wisdom information in Somopuro Cave. The results of the interview were identified to be more communicative and analyzed, then published based on the permission given by the informants when the interview was conducted.

Data analysis

Environmental factor analysis (abiotic parameters)

Water quality parameters, including TDS, temperature, DO, and pH, were tested on the underground river water of Somopuro Cave and then analyzed using the Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. The results of river water measurements are compared to these regulations so that their compliance with the applicable river water quality standards in Indonesia can be determined.

Aquatic and terrestrial fauna analysis

The Shannon-Wiener formula was used to calculate the diversity index by analyzing the abundance and distribution of species found in Somopuro Cave. According to Jhingran (1989), the formula and value of the Shannon-Wiener diversity index are as follows:

$$H' = -\sum_{i=1}^{s} \left(\frac{ni}{N}\right) ln\left(\frac{ni}{N}\right)$$

Where:
H': Diversity Index Pi: ni/N
ni: Number of species i
N: Total number of individuals
S: Number of all individuals

The categories of the results of the diversity index are as follows:

H'<1: Low diversity

$1<H'<3$: Medium diversity
$H'>3$: High diversity

Apart from the diversity index, the Evenness Index is also calculated using the formula made by Shannon-Wiener (Heip 1974):

$$E = \frac{H'}{LnS}$$

Where:
E: Evenness Index
H': Diversity Index
S: Number of all species

Categories from the results of the evenness index (evenness) are as follows:

$0<E\leq 0.4$: Low evenness

$0.4<E\leq 0.6$: Medium evenness

$0.6<E\leq 1$: High evenness

Calculation of the dominance value of the species found is calculated and analyzed using the formula made by Simpson (Zuhry et al. 2020; Merly et al. 2022):

$$C = \sum \left(\frac{ni}{N}\right)^2$$

Where:
C: Dominance Index
ni: Number of individuals of the i-th species in each plot
N: Number of individuals of species i in all plots

The categories of species dominance index results are as follows:
$C<0.5$: Low dominance
$0.5<C<0.75$: Moderate dominance
$0.75<C<1$: High dominance

The species Richness Index is calculated and analyzed using the formula made by Margalef (Latumahina et al. 2020; Mulya et al. 2021):

$$R = \frac{S-1}{Ln\,N}$$

Where:
D: Species Richness Index
S: Number of all species
N: Number of individuals of species i in all plots

The categories of the species richness index results are as follows:
$D<2.5$: Low species richness
$2.5>D>4$: Medium species richness
$D>4$: High species richness

Local wisdom analysis

The results of the Somopuro Cave local wisdom interview (through the Focus Discussion Group scheme) by surrounding people were analyzed by abstracting raw information into more general insights (Rachmawati 2007). Then, the data was presented descriptively.

RESULTS AND DISCUSSION

Abiotic factor in Somopuro Cave

The water quality parameters checked in Somopuro Cave River, i.e: TDS, temperature, DO, and pH. Based on Table 1, TDS parameter shows 224 ppm or 223.74 mg/L with a range (1,000-2,000 mg/L); the water temperature parameter shows 18.9°C with a range (15-28°C); the Dissolved Oxygen (DO) parameter shows 18% or 1.67 mg/L with a range (1-6 mg/L); and the pH parameter shows 7.02 with a range (6-9). The water quality in Somopuro Cave is then compared with the Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management. It is known that the quality standards for Somopuro Cave in TDS are included in classes 1-3 with a quality standard limit of 1,000 mg/L. The temperature parameter has a range between 15-28°C or follows a standard deviation of 3. DO class 4 with a minimum quality standard limit of 1 mg/L and a pH acidity level of class 1-4 with a quality standard limit of 6-9.

Aquatic and terrestrial fauna in Somopuro Cave

The total number of individuals found at the location reached 438 individuals. Some animals that, according to respondents, live in this cave but were not found in this study are *Anguilla celebesensis*, *Tachysurus fulvidraco*, and *Lutrinae perspicillata*. Specifically, *L. perspicillata* only found its tracks in this study. The presence of animals in Somopuro Cave can be caused by parameter factors such as water quality, which can support species living in the cave (Khatri and Tyagi 2015), as well as human disturbance. No animals were found in the cave due to the community's excessive exploitation that indirectly threatened the species living in it (Veress 2020). These findings underscore the need for further research to understand the dynamics of the cave ecosystem fully.

Table 2 shows the species found in Somopuro Cave which consist of several animal families including Cypirinidae, Poeciliidae, Channaidae, Palaemonidae, Gecaricinidae, Pachychilidae, Dicroglossidae, Vespertilionidae, Rhaphidophoridae, Gerridae, Dicroglossidae, and Phrynidae. This family of animals falls into the categories of actinopterygii, crustaceans, molluscs, amphibians, mammals, and anthropods. Mammals in the form of bats, actinopterygii, crustaceans, and molluscs dominate the presence of animals in Somopuro Cave. Based on the results of the research, the species found in the Actinopterygii class are *Barbodes binotatus*, *Poecilia reticulata*, *Barbonymus gonionotus*, and *Channa striata*, in the Crustacea class are *Penaeus merguiensis* and *Cardisoma carnifex*, in the Mollusca class is *Faunus ater*, in the Amphibia class are *Fejervarya cancrivora* (rice field frog and tadpole), in the Mammal class is *Eonycteris spelaea*, in the Arthropods class are *Diestrammena heinrichi*, *Phrynus exsul*, and *Limnogonus fossarum*. The highest number of individuals belonged to *Eonycteris spelaea* species, with 278 individuals, while the fewest species were *Chana striata*, *Cardisoma carnifex*, and *Fejervarya cancrivora*, with only 1 individual found each.

Accumulation of fauna diversity values in Somopuro Cave

Based on the results of the fauna research in Somopuro Cave, it was then analyzed using the ecological diversity value consisting of the diversity index, evenness index, dominance index, and species richness index. The diversity index (H') shows a value of 1.26, which indicates the medium species diversity category (Ren et al. 2021). The evenness index (E) shows a value of 0.45, which indicates medium species evenness (Ren et al. 2021). The dominance index (C) shows a value of 0.44, which indicates a low dominance category (Ren et al. 2021). The Species Richness Index (D) shows a value of 2.46, which indicates low species richness (Wahyuningsih et al. 2019). Therefore, various unique species are found in Somopuro Cave because the water parameters mutually support each other species in the cave.

Table 1. Water quality parameters in Somopuro Cave

TDS		DO		Temperature (°C)	pH
(ppm)	(mg/L)	(%)	(mg/L)		
224	223.74	18	1.67	18.9	7.02

Table 2. Fauna species found in Somopuro Cave

Common name (Local name)	Family	Scientific name	Category	Total individuals
Spotted barb (*Ikan Wader*)	Cyprinidae	*Barbodes binotatus* (Valenciennes 1842)	Actinopterygii	84
Guppy (*Ikan Cethol*)	Poeciliidae	*Poecilia reticulata* (Peters 1859)	Actinopterygii	11
Silver barb (*Ikan Bader*)	Cyprinidae	*Barbonymus gonionotus* (Bleeker 1849)	Actinopterygii	3
Striped snakehead (*Ikan Gabus*)	Channidae	*Channa striata* (Bloch 1793)	Actinopterygii	1
Banana prawn (*Udang Jerbung*)	Palaemonidae	*Penaeus merguiensis* (De Man 1888)	Crustacea	19
Brown land crab (*Kepiting Darat Coklat*)	Gecarcinidae	*Cardisoma carnifex* (Herbst 1796)	Crustacea	1
Black devil snail (*Kerang Sumpil*)	Pachychilidae	*Faunus ater* (Linnaeus 1758)	Mollusca	14
Rice field frog (*Katak Sawah*)	Dicroglossidae	*Fejervarya cancrivora* (Gravenhorst 1829)	Amphibia	5
Bat (*Kelelawar*)	Vespertilionidae	*Eonycteris spelaea* (Dobson 1871)	Mammals	278
Cave-cricket (*Jangkrik Gua*)	Rhaphidophoridae	*Diestrammena heinrichi* (Ramme 1943)	Arthropods	9
Water striders (*Anggang- Anggang Air*)	Gerridae	*Limnogonus fossarum* (Fabricius 1775)	Arthropods	10
Tadpole (*Kecebong*)	Dicroglossidae	*Fejervarya cancrivora* (Gravenhorst 1829)	Amphibians	1
Whip spider (*Laba-Laba Cambuk*)	Phrynidae	*Phrynus exsul* (Harvey 2022)	Arthropods	2
Totals				438

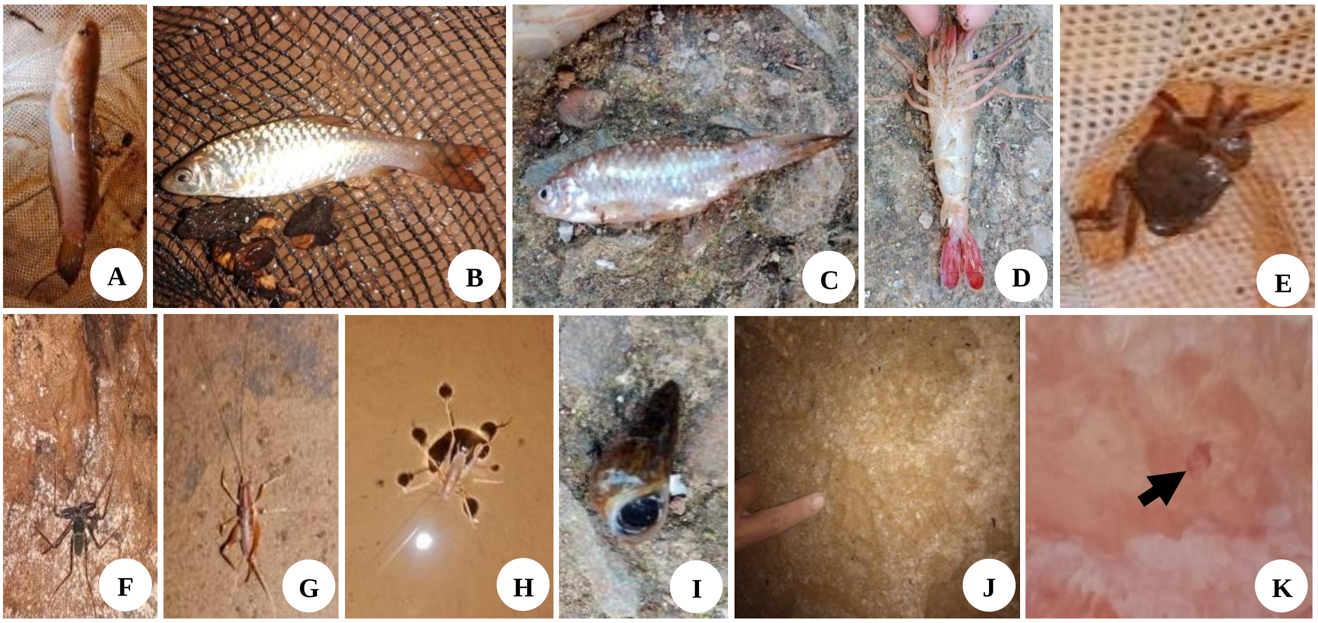


Figure 4. Some documentation of animals found in Somopuro Cave, Pacitan District, East Java, Indonesia. A. Snakehead (*C. striata*); B. Silver barb (*B. gonionotus*); C. Spotted barb (*B. binotatus*); D. Banana prawn (*P. merguiensis*); E. Brown Land Crab (*C. carnifex*); F.

Whip Spider (*P. exsul*); G. Cave-cricket (*D. heinrichi*); H. Water striders (*L. fossarum*); I. Black devil snail (*F. ater*); J. Otter tracks (*L. perspicillata*); K. Bat (*E. spelaea*)

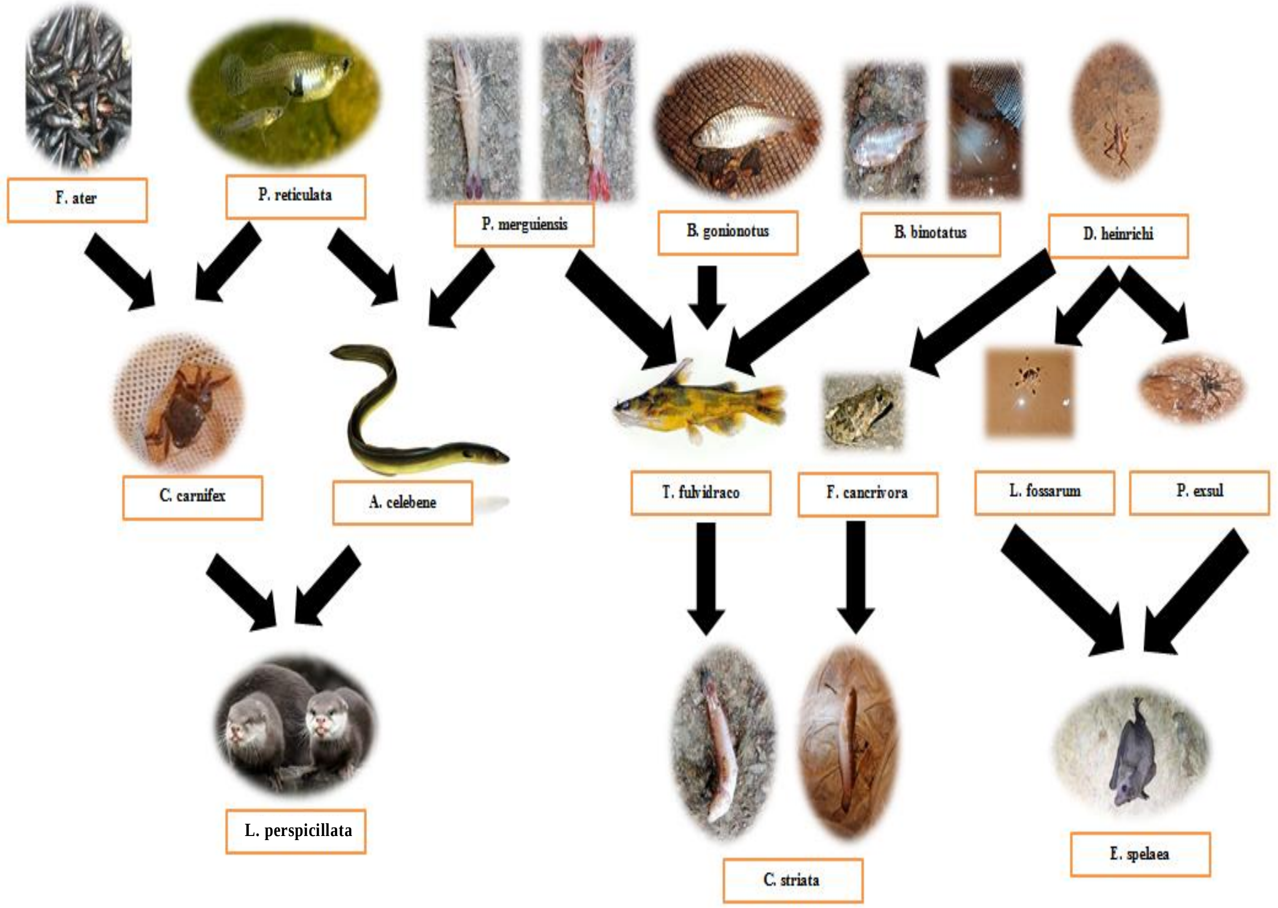


Figure 5. The composition of the aquatic and terrestrial fauna food chain in Somopuro Cave, Pacitan District, East Java, Indonesia

Discussion

Karst Somopuro Cave in Pacitan

Karst is the result of the weathering process of limestone material from the activity of groundwater flows in the Earth so that over a long period, up to millions of years, large holes were created (Goldscheider et al. 2020). The dissolution process is called true karst (Singh et al. 2020). The similar ecosystems formed by lava flows are called pseudokarst (Wood et al. 2023). Somopuro Cave is a type of horizontal cave that has a river flowing in it. This cave describes two directions at once, as seen in Figure 3. The left cave passage, or the one with the water source and passed by the underground river flow, is a place for aquatic and land fauna to live. While the right passage does not have a water source and is usually used by the community for traditional ceremonies and only a few terrestrial faunas are found at this point, when the research was carried out, animal footprints were also found, such as *L. perspicillata*. According to Veress (2020), karst is a form of the Earth's surface with closed features and caves. Somopuro Cave is formed from karst rock type material, carbonate rock type from the dissolution process. On the other hand, the Somopuro Cave ecosystem is muddy; there are lots of small rocks, slippery rocks, rivers, and dark and no light entering the cave. Somopuro Cave is used as a habitat for several animals, especially bats. Similar research by Sasmito et al. (2019) states that the bats use the cave as their nest. Somopuro Cave has an underground river; part of Tikung River flows upstream to downstream of Gede River. Somopuro Cave has two common types of mineral formations, i.e., stalactites with a pointed shape, such as ice on the cave ceiling, and stalagmites rising from the cave floor. Karst material has a health benefit for making toothpaste because it contains calcium carbonate (Solang et al. 2021). Apart from the types of rocks such as limestone and dolomite stone, 13 species were found in Somopuro Cave, and 3 additional species were obtained from interviews with local people. Of the many animal species in Somopuro Cave, there are not too many except for spotted barb (*B. binotatus*), banana prawn (*P. merguiensis*), black devil snail (*F. ater*), guppy (*P. reticulata*), and bats (*E. spelaea*). Animals can adapt quickly to new environments, with minimal genetic diversity, as in cave environments (Carneiro and Lyko 2020); therefore, their color is white because they are not exposed to sunlight from the outside. Research by Straka et al. (2020) states that the color change in animals when they are inside the cave and outside is due to exposure to reflected light from the sun or lighting. In the cave, a flow path is directly connected to an underground river, and they experience differences with animals outside the cave. The water inside the cave will increase, leaving traces of water flowing on the cave floor and seeping into the walls while raining. Various animal species were raised when the water increased due to the absorption process from tree roots, and they entered the various holes of Somopuro Cave. The form of the food chain in Somopuro Cave is spotted barb (*B. binotatus*), banana prawn (*P. merguiensis*), black devil snail (*F. ater*), guppy (*P. reticulata*), tadpole (*F. cancrivora*), cave-cricket (*D. heinrichi*) and silver barb (*B. gonionotus*). There are many predatory levels as follow: (level I producer) → yellow catfish (*T. fulvidraco*), rice field frog (*F. cancrivora*), brown land crab (*C. carnifex*), eel (*A. celebesensis*), water striders (*L. fossarum*) and bats (*E. spelaea*) (level II producer) → snakehead fish (*C. striata*), otter (*L. perspicillata*) and whip spiders (*P. exsul*) (level 1 predator). Predators such as snakehead fish are dangerous for other animals because they are carnivores, so the existing animals' birth rate will be drastically reduced to their juveniles (Rahayu et al. 2021). Even so, Somopuro Cave is a place whose ecosystem is still preserved due to the local wisdom of the local community.

Abiotic factors found in the underground river of Somopuro Cave Pacitan

The underground river in Somopuro Cave is the outlet river leading downstream (Septiasari et al. 2021), formed from springs, water droplets from cave rocks, and upstream of the river. The streams connect with the Tikung River to the downstream Gede River. In the middle of Somopuro Cave, a branching river leads to villages and agricultural land. The water quality of the underground river in Somopuro Cave has a Total Dissolved Solid (TDS) parameter of 224 ppm or 223.74 mg/L, a water temperature of 18.9°C, the Dissolved Oxygen (DO) content is 18% or 1.67 mg/L, and the pH acidity level is 7.02 (Table 1). Somopuro Cave materials such as limestone and dolomite stone possibly pollute the water quality because limestone contains iron, manganese, magnesium, and lead, while dolomite is a carbonate of calcium and magnesium (Lamare and Singh 2016); if the water contains a lot of calcium and magnesium, it will impact negatively on health if drunk (Bouderbala 2017) and also animal feces can risk contaminating the water quality and introducing pathogens (White et al. 2016). Comparison of data on the water quality of the Somopuro Cave underground river with river water quality standards based on Government Regulation of the Republic of Indonesia Number 22 of 2021, it is known that the river water quality standard limits that follow the data are TDS including class 1-3 with a quality standard limit of 1000 mg/L. The mixing of rainwater also influences the high TDS value in the Somopuro Cave river water. This is because the research was conducted during the rainy season. So the results will affect the high and low TDS values, DO including class 4 with a minimum quality standard limit of 1 mg/L, and pH acidity levels are class 1-4 with a quality standard limit of 6-9. The underground river water of Somopuro Cave has the characteristics of lower water temperatures due to the lack of sunlight and its location in the highlands; low DO is influenced by calm water currents, low levels of aquatic plants, and relatively high levels of aquatic animals; water pH is influenced by water temperature and dissolved oxygen levels in the water (Khatri and Tyagi 2015), while TDS is influenced by runoff from the soil, rock weathering, and anthropogenic influences (Rinawati et al. 2016). The advantage of Somopuro Cave's underground river compared to ordinary river water is that it is able to accommodate groundwater and store rainwater; limestone correlates with small to medium continuity of underground water and limited availability of underground water; slow underground water flows can store water reservoirs for three to four months after the rainy season (Aprilia et al. 2021). The absence of sunlight results in no evaporation of the water, as well as providing a habitat for unique living creatures to live. Apart from that, the water quality of the underground river at Somopuro Cave is clear. Still, suspended solids such as sediment, sand, clay, and mud are in large quantities and large masses in river beds. Similar Research by Piccini et al. (2019) showed that Apuan Alps Karst Aquifers had suspended solids like fine sands and mud.

Diversity of aquatic and terrestrial fauna

The results of identifying the types of animals found in Somopuro Cave have significant implications for our understanding of biodiversity and cave ecosystems. The findings are divided into 5 groups: Actinopterygii, Mammals, Crustaceans, Arthropods, Amphibians, and Molluscs (Table 2). In the Actinopterygii class, it is known that there are spotted barb (*B. binotatus*), guppy (*P. reticulata*), silver barb (*B. gonionotus*), snakehead fish (*C. striata*), eel (*A. celebesensis*), yellow catfish (*T. fulvidraco*). Types of crustaceans are brown land crabs (*C. carnifex*) and banana prawn (*P. merguiensis*). Animals belonging to the Arthropod class in Somopuro Cave are water striders (*L. fossarum*), Whip Spiders (*P. exsul*), and cave crickets (*D. heinrichi*). Amphibians are animals that can live in water and on land. The animal class found was frogs (*F. cancrivora*). Mammals are all animals that suckle (Francis 2019). These mammals are bats (*E. spelaea*) and otters (*L. perspicillata*). Mollusks are soft-bodied, non-segmented animals; their bodies consist of muscular legs, a head, a visceral mass containing organ systems, and a fleshy mantle that secretes a calcareous shell (Pyron and Kenneth 2015). The class of mollusks found in Somopuro Cave are black devil snail (*F. ater*). These species also have an important role in freshwater quality because they are often used as bioindicators of water pollution so that pollutant substances enter and automatic changes in water quality occur (Lige et al. 2022). According to research by Xu et al. (2021), animals that live in caves and then are consumed will risk developing diseases in their bodies due to gene differences between animals inside and outside the cave. Genetic changes in several animal birth rates are smaller in the living habitat in a cave. Species in Somopuro Cave experience changes in body color when exposed to light because the sensory nerves in their bodies respond to receiving light (Souto-Neto et al. 2023). According to research by Kurniawati et al. (2022), the habitat of various animals in the cave has an average temperature parameter of 18-38°C and a pH of 7.

The diversity index of aquatic and terrestrial fauna

The research results of Ren et al. (2021) show that the calculation of the diversity index ranges from 1.03 to 2.13, which is included in the medium species diversity category. On the other hand, various species are also found in it. The large number of species that live in caves can be due to environmental quality parameters that are still supportive. The analyses of the results of diversity calculations using the Shannon-Wiener formula show 16 total animal species and 6 classes, including Actinopterygii, Mammals, Crustaceans, Arthropods, Amphibians, and Mollusca. The most dominant animals are bats, with 278 species (Table 3). However, there are *B. binotatu*s (84), *P. reticulata* (11), *B. gonionotus* (3), *C. striata* (1), *P. merguiensi*s (19), *C. carnifex* (1), *F. ate*r (14), *D. heinrich*i (9), *L. fossaru*m (10), *F. cancrivor*a (5), *P. exsul* (2) and *F. cancrivora* (1). Animal species that were not found include *A. celebesensis*, *T. fulvidraco*, and *L. perspicillata*. *Eonycteris spelaea* is often found in Somopuro Cave because it has become its habitat. *Anguilla celebesensis* and *T. fulvidraco* were discovered through interviews with local people who had caught the animal. *L. perspicillata* is known through footprints on the cave floor in muddy conditions during the research. But, in calculating the diversity index value, it is not included quantitatively. The H' value is a diversity index value to determine the high level of diversity of a species in the area to be studied. The diversity index obtained from Somopuro Cave included moderate diversity with a value of 1.26 (Table 3). There is moderate diversity in Somopuro Cave because it was once used as a tourist attraction by the local community, so over time, when it was no longer a tourist attraction, various animal species entered Somopuro Cave. According to research by Syukri et al. (2018), animals' movement into caves was due to places that were no longer used, such as tourist attractions, and were far from human activity. Compared to Ren et al. (2021), the Somopuro Cave ecosystem is still relatively good and well-maintained.

The evenness index (E) is the composition of the mixture of each species contained in one community. The calculation results show that the evenness index in Somopuro Cave is 0.45, categorized into medium evenness (Table 3). Therefore, compared to Ren et al. (2021), the average value per cave is 0.42 to 0.77 and is included in the medium and high categories; these values still have similarities with the results of the evenness calculation values in Somopuro Cave. The balance of species distribution in a community can be determined through the results of the evenness index so that the results will be inversely proportional to the results of the diversity index (Sirait et al. 2018). However, the diversity index and evenness index values in Somopuro Cave tend to be moderate because there are several species whose existence is threatened due to human hunting. Interviews with local people show that some of the animals that are often hunted are *D. heinrichi*, *B. binotatu*s, *T. fulvidraco*, *A. celebesensis*, *P. merguiensi*s, *P. reticulata*, and *B. gonionotus*. Therefore, several animal species were not found or had been hunted during data collection. The results of this analysis, compared by Ren et al. (2021), show that the evenness index is medium in Somopuro Cave when the ecosystem conditions are quite good, and the distribution of individuals of each species is relatively even. Therefore, the high or low evenness index results are more influenced by physicochemical and biological parameters, including temperature, pH, and dissolved oxygen. Species behavior also influences things such as adaptation to environmental conditions.

The results of calculating species dominance using the Simpson formula there are 16 animal species, with 5 species from the most individuals, i.e., *E. spelaea* with 278 individuals, *B. binotatu*s with 84 individuals, *P. merguiensi*s with 19 individuals, *F. ater* with 14 individuals, and *P. reticulata* with 11 individuals. Based on individual data, it can be known that *E. spelaea* has a very high number of 278 individuals, followed by *B. binotatus*, which has 84 individuals. However, the dominance of species in an ecosystem can be determined after calculating the dominance index using the Simpson formula. Based on Table 3, it is known that the dominance index (C) value is 0.44. The dominance level influences competition between species that depend on the same ecological and management principles (Adeux et al. 2019). The dominance level in Somopuro Cave between species is low to maintain ecosystem balance. Similar research by Núñez-Novas et al. (2016) about studying Simpson's species dominance index at some caves during the wet and dry seasons showed that the total species dominance index in the rainy and dry seasons in Honda de Julián is 0.27, La Chepa is 0.26, Los Patos 0.41, and Pomier #4 is 0.36 which are all in the low dominance category.

Species richness often focuses on the quantity of animal species in a community, so the quantity in the field will determine the size of the richness index (Baderan et al. 2021). The species richness index is carried out by dividing the number of species by their natural function, where the number of species is inversely proportional to the increase in the number of individuals. The results of calculating the richness of animal species using the Margalef formula showed that there were 16 animal species, with the total number of animal species found in Somopuro Cave being 438 individuals. Table 3 shows that the species richness index (R) value is 2.46. Indicating a low species richness category. Based on this statement, a low species richness index indicates a low number of species in the community (Wahyuningsih et al. 2019). Comparing the species richness by Cardoso et al. (2020) shows that the results are high because environmental conditions are mutually supportive, and there is still no interference from outside. However, in Somopuro Cave, species richness is low because, when conducting interviews with local people, it was once a tourist spot for residents; after it was abandoned, new species entered Somopuro Cave, affecting their richness.

Table 3. Species calculation diversity in Somopuro Cave

Diversity Index	Evenness Index	Dominance Index	Species Richness Index

1.26	0.45	0.44	2.46

Local wisdom of value

Somopuro Cave in Tulakan Village, Pacitan, has the potency of historical, cultural, and local wisdom. According to Nurbaiti (2021), there are four versions of the Somopuro Cave story, including one like the one we got when interviewing the caretaker, that during the Dutch era around 1830 (after Java/Diponegoro War), Somopuro Cave was a place used to hide from Dutch pursuit. It is also told that Somo Adipuro, a descendant of royalty from Yogyakarta, the Islamic Mataram Kingdom, discovered the cave. Somo Adipuro fled from Dutch pursuit and then found a cave, which is now called Goa Somopuro, to hide and meditate in the cave for years. After leaving the cave, Somo Adipuro mingled with the community around the cave, namely Tulakan Village, and taught knowledge, including how to grow crops; therefore, the main local community's livelihood is farming and gardening. Then, the name Somopuro Cave was given to the cave discovered by Somo Adipuro because of the people around the cave's respect for Somo Adipuro (then summarized into Somo Puro or Somopuro). Until now, some people in the Somopuro Cave area believe in ancient traditions, namely carrying out the ritual of "*penance*" in Somopuro Cave.

According to Prabowo (2011), Javanese society at large gets to know the related attitudes of life with initiation in the form of asceticism. In the interview, the caretaker of Somopuro Cave informed that there is no rain while it is being used for meditation. Apart from *penance*, people usually do "*tapa mangsa*," which means meditating in a particular month (the sacred month, *Suro*, the first month of the Javanese calendar) to achieve their desired goals, called asceticism. This act of *'tapa mangsa'* is usually carried out within 40 days and 40 nights or, in most Javanese, called "*ngebleng*," meditating without lighting or crowds and eating in moderation. In this hermitage, a meditating person performs acts of worship to God, which they believe are a form of concern for a servant. A hermit will pray to remain peaceful for all their wishes, individual wishes, life, and the environment. Therefore, because of the local community's beliefs regarding Somopuro Cave, many people who enter the cave are more ethical and careful in their behavior. This is evidenced by the order from the caretaker, who requires every visitor who enters the cave to be prayed for and permitted by the caretaker first and is strictly prohibited from speaking badly and causing damage in Somopuro Cave. It has the same goal as conservation efforts in the karst environment in Somopuro Cave, namely to maintain the ecosystem and biodiversity found there. It is related to the local wisdom of Somopuro Cave. However, many local people still engage in these ascetic activities and think that they are normal. Therefore, many residents freely access the cave and utilize resources such as fish, shrimp, and other animals. The advancement of the times and the way people think logically about their respective religions have led to a decline in people's beliefs in local wisdom. This has caused the implementation of local wisdom to shift and has had an impact on the community being freer to explore and utilize the wealth of food sources in Somopuro Cave.

Furthermore, the existence of the Somopuro Cave-dwelling species is decreasing due to community activities that utilize these resources for food needs. It is indicated by the decline in species richness in the underground river of Somopuro Cave. People's habit of too many taking fauna from the cave freely has resulted in a decrease in the fauna. There are no special rules for residents not to exploit the cave's fish, shrimp, and other fauna. The local wisdom applied above will only limit the movement of people outside the area to exploit the Somopuro Cave but not inhibit the local people's activities. Steps that can be taken to increase the richness of species and diversity of fauna in the Somopuro Cave environment include providing a special ban on excessive exploitation of fauna in the cave, making the fauna of Somopuro Cave a local icon that is prohibited from being hunted, working with the relevant government to make this location a conservation site so that it is better managed, and there is continuous monitoring from both the caretaker, the community and the local government to keep Somopuro Cave sustainable and rich in the diversity of its fauna species.

In conclusion, the fauna found in Somopuro Cave consists of 13 species with as many individuals as possible of 438. The results of identifying animal species found in Somopuro Cave are divided into 6 groups, i.e., actinopterygii, mammals, crustaceans, arthropods, amphibians, and mollusca. The diversity index in Somopuro Cave is 1.26, which is included in the medium diversity. The evenness index (E) in Somopuro Cave is 0.45, which, according to the criteria, indicates medium. This dominance index (C) in Somopuro Cave is 0.44, which, according to the criteria, indicates low dominance). Furthermore, the diversity index for species richness (D) in Somopuro Cave is 2.46, which is in the category of low species richness. Based on these results, it can be concluded that a low level of dominance between species indicates that ecosystem balance is maintained. Apart from that, a low species richness index also indicates that the number of species in the community tends to be low. Many parameters cause this, such as local wisdom carried out by the surrounding community starting to decrease. The decreasing *tapa mangsa* or *ngebleng* culture is also an indicator that causes many residents to access the cave and freely carry out activities to exploit the resources within it. The low species richness is because there is no special prohibition for local people to take fish and shrimp in the cave so that the community can exploit the wealth of fish in the cave. Public trust in Somopuro Cave has the potential to increase visitor ethics and caution, supporting the goals of ecosystem and biodiversity conservation goals.

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