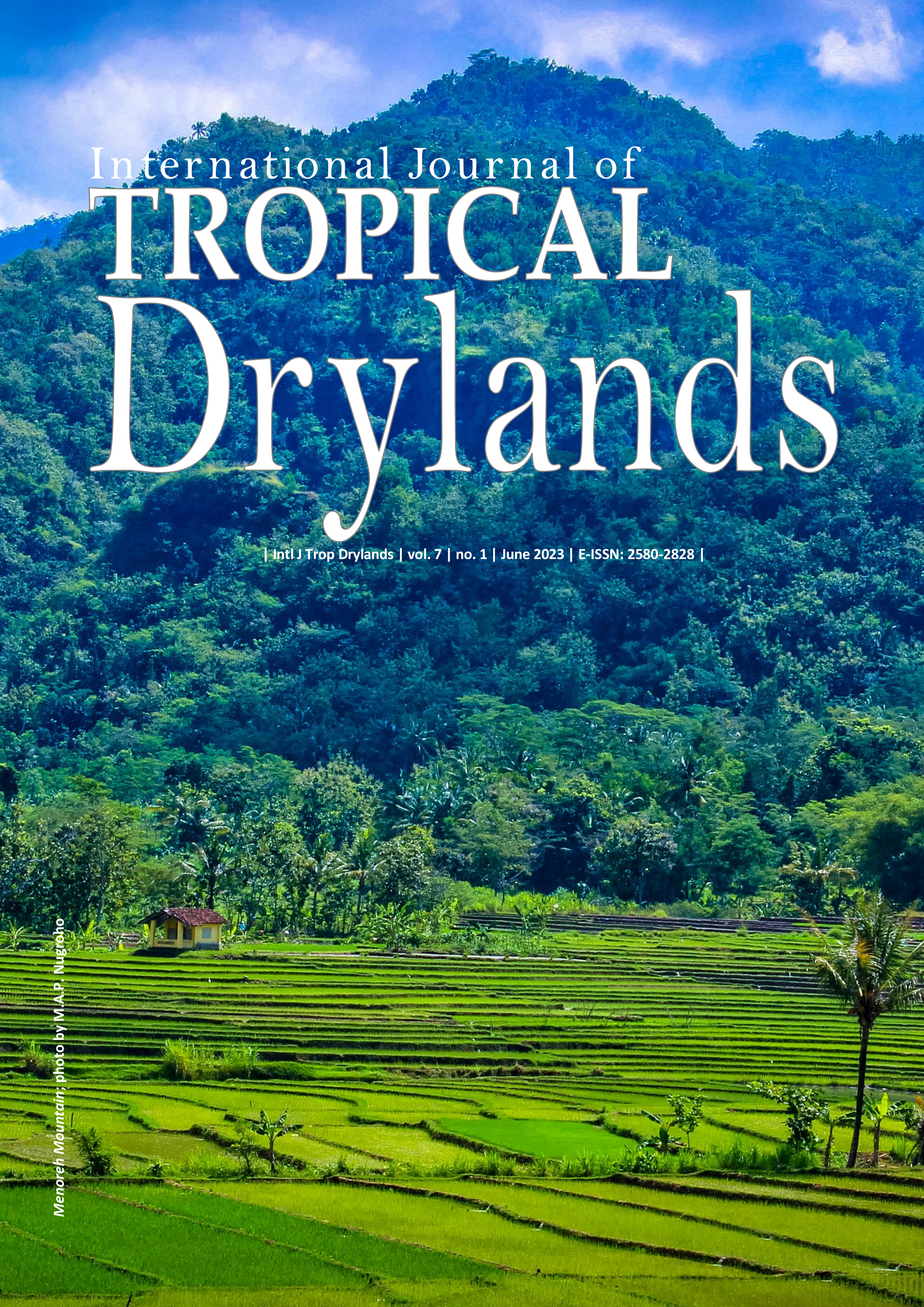

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Menoreh Mountain; photo by M.A.P. Nugroho

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Abstract A concise abstract is required (about 200 words). The abstract should be informative and state briefly the aim of the research, the principal results and major conclusions. An abstract is often presented separately from the article, thus it must be able to stand alone (completely self-explanatory). References should not be cited, but if essential, then cite the author(s) and year(s). Abbreviations should be avoided, but if essential, they must be defined at their first mention. **Keywords** are about five words, covering scientific and local name (if any), research themes, and special methods used; and sorted from A to Z. **Abbreviations** (if any): All important abbreviations must be defined at their first mention there. **Running title** is about five words.

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

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

References Preferably 80% of it comes from scientific journals published in the last 10 years. In the text, give the author names followed by the year of publication and arrange from oldest to newest and from A to Z; in citing an article written by two authors, both of them should be mentioned; however, for three and more authors only the first author is mentioned followed by et al. For example, Saharjo and Nurhayati (2006) or (Boonkerd 2003a, b, c; Sugiyarto 2004; El-Bana and Nijs 2005; Balagadde et al. 2008; Webb et al. 2008). Extent citation should be avoided, as shown with the word "cit." Reference to unpublished data and personal communication should not appear in the list but should be cited in the text only (e.g., Rifai MA 2007, pers. com. (personal communication); Setyawan AD 2007, unpublished data). In the reference list, the references should be listed in alphabetical order. Names of journals should be abbreviated. Always use the standard abbreviation of a journal's name according to the **ISSN List of Title Word Abbreviations** (www.issn.org/2-22661-LTWA-online.php). Please include DOI links for journal papers. The following examples are for guidance.

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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A case study of the Handeni District (Tanzania) examining drought coping strategies and risk management among pastoralists based on livestock

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Abstract. *Mwakalonge HL, Chingonikaya EE. 2023. A case study of the Handeni District (Tanzania) examining drought coping strategies and risk management among pastoralists based on livestock. Intl J Trop Drylands 7: 1-11.* A case study was done to learn more about how pastoralists in the Handeni District, Tanzania, cope with drought. Drought poses a serious threat to pastoralists' way of life globally. The purpose of this research was to analyze and record data on the efficacy of livestock-based risk management and coping mechanisms in mitigating the negative consequences of drought. Despite the common belief that pastoralists can't make a living without their animals, there is a lack of information on how to make pastoral communities more resistant to drought and other dangers, information that is essential for any system of sustainable management. Many efforts have been made to deal with the drought, but it continues to worsen. Therefore, a cross-sectional research strategy was adopted to learn more about cattle risk management and coping strategies. Questionnaires, focus groups, and interviews with key informants were used to gather socio-economic information from 160 herders. Frequencies and percentages were calculated using a statistical software package for social sciences. A regression model was used for inferential statistics to establish a connection between the socio-economic status of pastoral households and the independent variable of interest. A negative correlation with age was found (β = -0.451; p = 0.808), a positive correlation with education (β = 43.821; p = 0.497), a positive correlation with family size (β = 3.379; p= 0.50), a negative correlation with marital status (β = -53.979; p = 0.847), and a positive correlation with the land area (β = 58.898; p = 0.004). Herd mobility positively influenced the socio-economies of pastoral households (β =91.749; p = 0.01), as did the availability of an early warning system (β =; 316.537; p = 0.00) and the timely availability of a market (β = 11.516; p = 0.021). A total of 3.666 animals out of 57,785 were lost due to the effects of the drought. The death rate was 6.34%.

Keywords: Drought, information, pastoral, socio-economies

INTRODUCTION

Drought seriously harms pastoral communities' ability to make a living (FAO 2001). People in low-income nations are four times more likely to die as a result of natural disasters such as drought, as shown by the research of Hardley (2006), Al-Rousan et al. (2014), Arouri et al. (2015), Hashim and Hashim (2015), Mohamed (2017), Zorn (2018), Barnes et al. (2019), Fatema et al. (2019), and Onuma et al. (2021). The researches show that the impacted region will double from 25% to 50% by the end of this century (Gaiha and Thapa 2006). Changing weather patterns look likely to increase the frequency and intensity of unfavorable weather events in low-income nations, as shown by the findings of the Munich (2006) and IPCC (2007) reports. It includes increased extreme climate events like droughts and floods (Christensen et al. 2007; Sunardi and Wiegleb 2016; Fang et al. 2019; Asadullah et al. 2020). Turner (2000) asserts that pastoral households' access to cattle as a source of wealth significantly impacts their ability to prepare for and respond to drought and other threats. Economically, livestock can act as a buffer against food shortages brought on by drought, as the proceeds from selling animals are often used to buy food for human use.

Livestock is socially and economically vital to rural livelihoods, according to studies by ILRI (2006) and UNDP (2006), making it imperative to prioritize the sustainable use of the natural resource base that supplies them. Therefore, pastoralism is pictured as the most economically, culturally, and socially appropriate strategy for sustainable communities in dryland landscapes. That is because it is the only strategy capable of providing stable incomes, protecting ecosystem services, fostering wildlife conservation, and respecting cultural values and traditions simultaneously.

Tanzania's economy is highly dependent on pastoralism and agro-pastoralism. Pastoralists and agro-pastoralists provide most of the country's meat and milk, as evidenced by Homewood and Rodgers (1991) and Scoones (1992). According to the 2005 National Livestock Census, Tanzania is home to about 17 million cattle, 12.5 million goats, and 3.6 million sheep, making it the third most populous country in Africa south of the Sahara. Pastoralists and agro-pastoralists own over 98% of the national herd, or 16.7 million cattle. Tanzania slaughters approximately 1,500,000 cattle, 2,500,000 goats, and 555,000 sheep annually, yielding an estimated 335,000 tons of meat for the local market. Many live animal exports to nearby countries go unrecorded.

Only 3% of Tanzania's 3.7 million households are strictly pastoralists, whereas 7% are agro-pastoralists. It equates to roughly 370,000 houses or 2.2 million individuals. The resulting personal, economic, and environmental costs are unknown if these individuals were coerced out of pastoral production.

IPCC (2001) states that a fundamental factor of poverty, food insecurity, and environmental health in pastoral areas is the lack of effective risk management. Therefore, it is recommended that risk management be considered an essential aspect of a comprehensive approach to progress. Furthermore, for a risk management strategy to be successful, it needs to be integrated or linked to other initiatives aimed at rural development, food security, environmental preservation, and the reduction of poverty. Although the information on how to better prepare pastoral communities to deal with drought and mitigate associated risks is still few, it is essential to advance long-term drought management strategies (Benson and Clay 1998). Therefore, gaining insight into local community expertise, risk management practices, and drought coping strategies is crucial. Therefore, this research aims to evaluate and record data on drought-reduction strategies involving livestock-based risk management and coping mechanisms.

Even though various methods have been devised to mitigate the consequences of drought, they have had little success in the research region. Climate change, which will impact the region and, in particular, other parts of Africa and the world, is the root cause of the problem and is predicted to exacerbate it in the years ahead. Understanding the nature and dynamics of sensitivity to drought shocks in pastoral and agro-pastoral systems, as well as identifying livestock-based interventions (technical, political, and institutional) to reduce and cope with the crisis, will be aided by this study.

The goals of this study are as follows: (i) to locate areas of high risk due to drought's impact on livestock; (ii) to identify the socio-economic effects of drought; (iii) to investigate drought-response mechanisms and strategies; (iv) to evaluate the mechanisms and factors affecting the socio-economics of pastoral households; and (v) to evaluate the mechanisms' long-term viability.

MATERIALS AND METHODS

Study area

The Handeni District, Tanzania, served as the site of the study (Figure 1). The region was chosen because it had a high concentration of pastoralists and because there had been fewer studies on them than in other parts of Tanzania. The study included eight villages with four wards and two divisions.

Location

The Handeni District is located in Tanga's southwestern region. It is situated at an altitude of 600 to 1,000 meters above sea level and spans an area of 6,433 km^2. There were 248,633 people in the country per the national population census in 2002, with a 3.3% annual growth rate. It was predicted that 332,024 people would live there in 2011/2012. One of Tanzania's eight districts, Handeni, is surrounded by the Pwani Region to the south, the Kilindi District to the west, the Korogwe District to the north, and the Pangani District to the east. Administratively, the Handeni District is divided into 112 villages, seven divisions, and 19 wards.

Most people live in poverty despite having enough land with the potential for high agricultural productivity, a generally favorable climate, sufficient rainfall, and a sizable labor force. It results from low levels of knowledge, technological advancements, insufficient infrastructure, unstable sources of irrigation water, a weak cash-selling network, and a dearth of dependable, cooperative organizations.

Socio-economic profile

Agriculture serves as the district's population's primary source of income. Around 93.1% of households, as per local government monitoring data from 2010, rely on agriculture for income, whether in cash or kind of it.

Agriculture

309,356 ha (48% of the district's total area) of the 643,300 ha total are potentially arable. Out of this, 92,809.5 ha are currently being used for crop production. Maize, beans, cassava, millet, cotton, sunflower, pigeon pea, oranges, coconut, bananas, and vegetables are among the crops farmed. A total of 3,124 ha of large farms having title deeds and 1,620 ha that have not been surveyed are also present. The primary crop grown on the estate is sisal. Crop markets can be found at Arusha, Tanga, and Dar es Salaam.

Livestock

There are 99,670 indigenous cattle, 735 improved cattle, 180,138 goats (of which 6,161 are improved breed), 17,728 sheep, 1,696 donkeys, 24,520 pigs, and 439,509 chickens in the district, making livestock the second most important production activity (11,099 are improved breed). The estimated 33,943 ha of potential range land can support 140,580 animal units per year based on the Handeni carrying capacity of 2 ha/AU/Year. The current population of Handeni is estimated to be 122,790 animal units, which does not include wildlife. Natural features include a mix of savannah woodlands and riverbank forests.

Environment

There are 37 forest reserves in the district, of which six are Local Authority Forests (LAFR), covering an area of 31,290.4 hectares, and 31 are Central Government Forests (CGRF), covering an area of 21,970.2 ha. Of the 37 forest reserves, 25 (43, 779.2 hectares) are active, while 13 (9,481 ha) are designated protected forests. However, the woodland region is in danger of disappearing because of unauthorized harvesting, widespread bushfires, mining, excessive grazing, and shifting farming.

Investment opportunities

Fruit farming, cattle ranching, sheep herding, beekeeping, honey processing, and mineral exploration are the primary areas of opportunity. The Zigua make up the majority (66.1%), followed by the Nguu (18.1%). The Maasai, a pastoralist people, is one of the other ethnic groups in the area, although their population estimate is not included in the documentation.

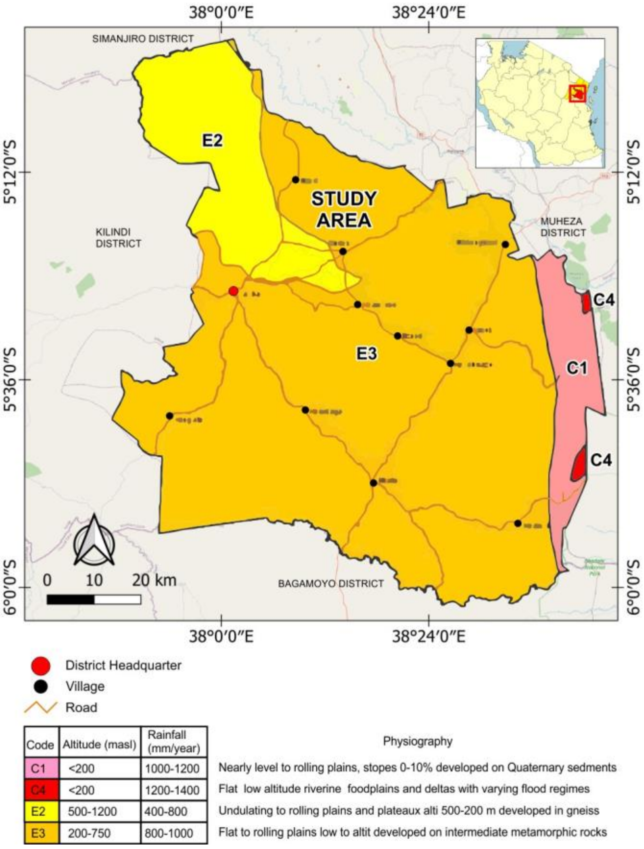

Figure 1. Map of Handen district in Tanzania region showing the location of the study villages

Research design

All of the information for this study came from a single point in time, making it a cross-sectional study. This approach was chosen due to time, labor, and material constraints. Still more crucial because of the aims of the research.

Sampling procedure

The study included data from 160 randomly chosen pastoralists. The formula below, recommended by Kothari (1993), was used to estimate the appropriate size of the sample for the study.

$n = Zpq/e^2$ Where:

Where:

n = Desired sample size (where the proportion is greater than 10,000)

Z is the standard normal deviate set at 1.96 (in a sample at 2.0), corresponding to a 95% confidence interval

p is the proportion in the largest population estimated to have particular characteristics

q = 1.0- p

e^2 = degree of accuracy desired, usually set at 0.05 or occasionally at 0.01

Therefore, the total number of samples needed was $((1.96)^2*0.1*(1-0.1))/(0.05)^2 = 134$. However, to ensure the reliability of the data, 160 households were chosen randomly. The household was chosen with the help of the local record. Households were used as the sampling unit.

Sampling technique

Two divisions, Chanika and Sindeni, were chosen at random within the district. Chanika, Kibaoni, Misima, and Sindeni are the four predetermined wards in the chosen division. Selected wards included Banju, Kilimila, Konje, Malezi, Msomera, Mbagwi Nzeri, and Sindeni, eight villages. Divisions, wards, and villages were selected based on their proximity to a large population of pastoralists. Twenty pastoralists were randomly picked from each community using a simple random selection procedure.

Data collection

Primary data

Primary and secondary data were compiled. Household surveys, focus groups, and key informant interviews were used to gather primary data. Household heads were given a questionnaire with open-ended and closed-ended items (Appendix 1). Each chosen village hosted two separate focus groups. Seven to twelve people of varying ages and sexes made up each group. A predetermined set of discussion questions served as a framework for the conversation. Key informants interviews are a phase of data collecting used to verify the accuracy of survey responses by speaking with community leaders, extension officers, and other village experts. After the questionnaire was distributed, we immediately began interviewing important informants. Preliminary testing was done to ensure that responders could comprehend the questionnaire and that it answered the research questions. After conducting preliminary tests, improvements were implemented.

Secondary data

This information was compiled from various resources, including the Handeni District Administration, published works about pastoralists, and village registries.

Data analysis

Analysis of the data was conducted using both quantitative and qualitative techniques. Descriptive and inferential statistics were employed for the numerical data. Descriptive statistics were applied to study socio-economic data. Descriptive statistics provided a snapshot of the outcomes by calculating percentages and frequency distributions. Furthermore, a regression model was used for inferential statistics to determine the connection between the socio-economic status of pastoral households and the inferred background variables' characteristics, management, and coping techniques. We postulate that some determinants positively affect the socio-economic status of pastoral households.

Following is a summary of the regression model:

SE(PHH) = ßo + ß1(AGEHH) + ß2(EDULHH) + ß3(FSPHH) + ß4 (MSPHH) + ß5(SPHH) + ß6(LOPHH) + ß7(MEPHH) + ß8(PSPHH) + ß9(MPPHH) + e_i

Where:
SE (PHH): the Socio-economies of pastoral households (Measured as the number of animals possessed)
ß1 (AGEHH): Age of the head of household (in years)
ß2 (EDULHH): Education level of head of household (in years spent in school)
ß3 (FSPHH): Household size (measured in the number of families in the household)
ß4 (MSPHH): Marital status (1 married, 2 Single, 3 Divorced)
ß5 (SPHH): Sex of interviewed head of household (1 male and 2 female)
ß6 (LOPHH): Land ownership (measured in the size of the land owned in acres)
ß7 (MEPHH): Management practices (1 sedentary system and 2 nomadic)
ß8 (HMPHH): Herd mobility (measured in the number of pastoralists migrated)
ß9 (MAPHH): Market availability (Number of the available market in a specified year
ß10 (AEPHH): Availability of early warning system (1 available and 2 not available)
ß(1-10): coefficient of the independent variables
e_i: random error

The SPSS software package was used to analyze the quantitative data statistically. After the data was analyzed, it was coded and prepared for use in achieving the desired goals. Focus groups and key informant interviews were used to gather qualitative data, which was then analyzed using structural content analysis.

RESULTS AND DISCUSSION

Household characteristics

Age, sex, education level, marriage status, and family size are just some of the household demographics covered here (Table 1).

Respondents' level of education

Findings showed that while 33.1% of respondents had completed primary school, 66.9% had only completed informal education. In this sample, no one who had completed secondary education responded (Table 1). The majority of respondents (66.9%) have only received an informal education. Yet, it does not prevent them from being aware of the issue of drought and its impact on their daily lives. Findings also showed that most people were aware of drought's root causes, warning signs, and preventative measures.

Nonetheless, many researchers have stressed the value of education as a tool for development. For instance, Bray (1996) found that people's awareness, attitude, and values improved with higher education levels, which could encourage them to manage natural resources sustainably. Education and training in natural resource management also boost productivity on the job. In addition, Adell's (2002) research found that education is crucial for alleviating poverty and ensuring full participation in political life. Even though modern society relies on diverse skills, pastoralists are falling behind in education, and girls are particularly at risk. Adell's (2002) research suggests that pastoralists face unique obstacles to their educational participation due to mobility and isolation. Therefore, nations with considerable pastoralist populations that fail to invest adequately in their youth through education will fail to achieve the Millennium Development Goals they set for themselves and may face economic stagnation and even political unrest. Thus, it may be instructive for policymakers to devise novel approaches to elementary and secondary education and all fields of study that better prepare pastoralists for modern life and the fight against poverty. Countries with large pastoralist populations are less likely to meet their Millennium Development Goals; national economic development is slowed; rural economic diversification is impeded; and political unrest increases if pastoralist enrollment rates remain low and dropout rates remain high. The report also noted that education could help alleviate poverty by equipping pastoralists with the knowledge and skills necessary to expand their businesses and increase their income.

Economic development, improved child health, lower mortality rates, and democratic governance are all strongly correlated with higher levels of education. However, pastoralists cannot increase their productivity in the field or diversify their livelihoods beyond their habits, trapping them in a cycle of poverty. That is difficult to break free of without education. In addition, a lack of education exacerbates gender inequality in the wider society.

In a world where poverty and insecurity are the norms, growing marginalization of pastoralists has already translated into political unrest. Therefore, strategies are required for all levels of education, learning, and skill acquisition that help pastoralists deal better with economic diversification, rising productivity, and the state. Furthermore, a comprehensive plan like this must consider the differences between the sexes, not just in age, and address the needs of both children and adults (Krätli 2000).

Percentage of male and female respondents

As seen in Table 1, the vast majority of respondents (85.0%) were male, while only 15.0% were female. It demonstrates that most women were engaged in other pursuits at the time. Niamir-Fuller (1994) argues that women's views, experiences, and needs are often overlooked in decision-making. Despite their significant contributions to pastoralism in areas such as childrearing, household management, disease treatment, animal care, water management, and the provision of building materials, fuel wood, and other resources.

Distribution of respondents by marital status

More than ninety-nine percent (99.4%) of those who responded were married, while only 0.6% were single (Table 1). This finding suggests that most people living in the study area were of adult age.

Table 1. Socio-demographic characteristics (n=160)

Variables	Freq.	Percent
Respondents' level of education		
Informal education	107	66.9
Primary level	53	33.1
Secondary level	0	0.0
Percentage of male and female respondents		
Male	136	85.0
Female	24	15.0
Marital status of the respondent		
Marriage	159	99.4
Single	1	0.6
Divorced	0	0.0
Family size of pastoral household		
1-4	13	8.1
5-9	59	36.9
10 and above	88	55.0
Age categories		
Below 20	1	0.6
21-40	61	38.1
41-50	42	26.3
Above 50	56	35.0
Land ownership		
Yes	102	63.75
No	58	36.25
Justification of the land		
Owned with title deed	84	52.5
Owned without a title deed	76	47.5

Family size of the household

About 36.9% of all households contained 5-9 people, while 8.1% comprised only 1-4 people. The remaining 55% of households consisted of 10 or more people. The average number of people living in a home was 10.76 (Table 1). An average of 4.8 was recorded in 2007's version of the household budget survey, so this is significantly higher (URT 2007). One possible cause of diversity is human migration.

Age of respondents

It was found that 38.1% of respondents were between the ages of 21 and 40, and 26.3% were between the ages of 41 and 50. About a third, or 35.0%, were aged 50 and up. Very few (0.6%) were in the 18-20 age range (Table 1). As a result, there should not be a shortage of people to help with livestock risk management initiatives, as most household members are of working age.

Legal land ownership

According to the findings, 63.75% of those surveyed own land, while 36.25% do not. The data also shows that 52.5% of landowners have a title deed issued by their village, while 47.5% do not (Table 1). In support of this view, Nori et al. (2008) contend that local institutional structures and governance have historically prevented a "tragedy of the commons" on most pastoral lands.

Identification of livestock-based risk areas associated with drought

Livestock based- risk areas

According to the results, 11.9% of respondents attribute livestock losses to a rise in deaths and inadequate feed resources in the risk areas. In comparison, 6.3% attribute an increase in poverty and conflicts between humans and wildlife to these factors. The remaining 45.6% indicates an increase in sickness and resource scarcity. Table 2 shows that the remaining 36.3% of respondents consider livestock losses, inadequate feed resources, human-wildlife conflicts, and increasing poverty the most significant livestock-based risks associated with drought. According to a study conducted by the International Livestock Research Institute (ILRI) in 2006, risk management in the livestock business necessitates a mix of risk reduction and financial techniques. In light of this, it is essential to supplement Pastoral and herd management with financial mechanisms that give herder households access to quick cash in the aftermath of a disaster.

Livestock-based risk absorption mechanisms

Half of the respondents think there should be a system for setting aside grazing land to be used in times of extreme poverty and splitting up huge herds into smaller groups. While another 20% think there should be a system ready to alert pastoralists of developing drought conditions. Five percent more say insurance should be used instead. Twenty-five percent of respondents suggested using all three approaches together (Table 2).

A 2006 study by the International Livestock Research Institute (ILRI) found that it takes a combination of risk mitigation and financial approaches, such as providing credit (providing liquidity after the disaster) and insurance against livestock death due to drought, to manage risks associated with livestock effectively. As a result, it seems reasonable to propose that a combination of risk avoidance, risk management, and risk adaptation strategies is necessary for an efficient livestock-based risk absorption mechanism.

The two most important reasons to keep track of their livestock are disease prevention and the ability to save grazing land in the event of a severe drought. Both of these highlight the need to register their livestock as a form of risk management. In addition, better drought-mitigating treatments and institutionalization of local, national, and regional livestock early warning systems can be informed by identifying livestock-based solutions in risk management and dealing with climate shocks, as shown by Gaiha and Thapa (2006). It will enable pastoral and agro-pastoral households to protect their animals and climate shocks better.

Table 2. Livestock based-risk areas (n=160)

Variable	Freq.	Percent
Livestock based-risk areas		
Livestock losses and insufficient feed resources	19	11.9
Human-wildlife conflicts and increased poverty	10	6.3
Increased diseases and competition in resource use	73	45.6
Everything mentioned above	58	36.3
Livestock-based risk absorption mechanisms		
Conservation of grassland and separation of herds	80	50
Provision of early warning, timely market	32	20
Insurance	8	5
Everything mentioned above	40	25

Socio-economic effects of drought

Out of 57,785 animals owned by respondents across villages, 3,666 reported died that year due to drought, or an average of 22.91 animals per family. The range for the number of animals reported dead was between 3 and 110. The death rate was 6.34% (Table 3).

Cattle losses per household per year

Table 4 shows that 60.6% of cattle deaths occurred when more than 15 animals were in a home, 12.5% when 11-15, and 26.9% when there were 1-10 deaths annually. Therefore, the expected loss of income due to mortality was calculated as 41,949,000 TAS. That amount is equivalent to what would have been created if animals had not perished because of drought effects.

Distance tranced in looking for water and pasture

The results suggest that 39.1% of pastoralists traveled more than 10 kilometers in search of pasture and water, while 24.2% traveled between six and ten kilometers. The remaining 36.0% traverse between 1 to 5 km (Table 4).

Availability and affordability of health services during drought

Regarding the availability and affordability of health care, around 71.4% indicated that services were available but expensive, while 26.1% indicated that treatments were neither available nor affordable. 1.9% of respondents stated health services were accessible and cheap (Table 4).

The abovementioned condition affected the number of deaths, leading to income loss and other socio-economic and cultural effects. It is corroborated by research conducted by Rothauge (1998), who found that drought significantly impacts the socio-economic conditions of pastoralists. Furthermore, according to another study conducted by IPCC (2001) and URT (2003), the mortality of vast numbers of livestock owing to a shortage of water and pasture has been a recurring event in Tanzania over the past few years, jeopardizing the livelihood of the country's pastoralists.

Pastoralist vulnerability to drought

About 74.4% of respondents think pastoralists are more vulnerable to drought than the general population. It is because drought has a profound impact on both animals and humans, leading to high rates of animal mortality, decreased milk production, and increased food insecurity. About 10% of respondents reported being vulnerable to severely affecting animals and humans, and another 15% reported being vulnerable to animal deaths, decreased milk production, and subsequent food instability (Table 4). The research of Patrick (2003) lends credence to this idea since he found that a population's sensitivity to a decrease in its standard of living when a change in the productivity of the area's natural resources was directly proportional to the degree to which the people relied on those resources.

The socio-economic value of pastoralism

Concerning the socio-economic values, the findings revealed pastoralist activities are the main source of income from livestock and meat, skin, hide, and milk sales (6.3%). Furthermore, for social and cultural values (14.4)% and the rest of the respondents (79.4%) reported that pastoralist activities were the source of income and could be used as social and cultural values. Only 14.4% of respondents said they relied on money from pastoralist activities for social and cultural purposes, but the remaining 79.4% said the same (Table 4).

Consequences of drought effects

Respondents indicated drought had led to the deaths of 1.9% of animals, 11.9% of people going hungry, and 5.6% of humans getting sick. The remaining 80.6% stated that the consequences of drought include animal deaths, human hunger, food insecurity, and the spread of animal and human diseases (Table 4).

Reasons for keeping animals

Furthermore, 7% of respondents said they kept animals for subsistence (milk, meat, and blood), and 11% said they kept animals as a form of capital. While 23% said livestock is an important store of wealth and insurance, 56% said they kept animals for all three reasons (Table 4).

Hogg's (1997) research, which found that pastoralists preserve animals for various reasons, gives credibility to these conclusions. In addition to serving as a source of food (milk, meat, and blood), transportation (cattle, donkeys, and camels), and a valuable financial and security asset, livestock constitutes a sort of productive capital. Because they are vulnerable to drought and illness impacts, they may not be a perfect type of insurance. To many herding families, however, it is the only type of insurance available due to the lack of alternatives, particularly in financial markets and organizations. Animals may be slaughtered for food, but they are typically sold to generate income to purchase grain and other staples. Social institutions like marriage and inheritance reflect the storage of capital/wealth in animals. A man's wedding is the largest exchange of livestock they will make in his lifetime. Therefore, livestock is a status symbol and a means of participating in intricate social duty and reciprocity networks that reduce vulnerability (particularly for poorer households).

Table 3. Amount of cattle owned and amount of cattle that died due to drought (n=160)

	Amount of cattle owned	Amount of cattle that died due to drought
N = 160	160	160
Mean	361	23
Median	220.00	20.00
SD	356.024	17.071
Variance	126753.051	291.426
Minimum	30	3
Maximum	2000	110
Sum	**57785**	**3666**

Table 4. Socio-economic effects of drought (n=160)

Socio-economic variables	Freq.	Percent
Cattle lost in amount per household per year		
1-10	43	26.9
11-15	20	12.5
above 15	97	60.6
Distance traced in looking for water and pasture (km)		
1-5	58	36.0
6-10	39	24.9
>10	63	39.1
Pasture availability in terms of quality		
Available but dry	69	42.9
Not available at all	91	57.1
Availability and affordability of health services		
Not available and not affordable	42	26.1
Available but not affordable	115	71.4
Available and affordable	3	2.5
Pastoralist vulnerability to drought		
Both animals and Human beings are severely affected	16	10.0
The animal dies, and low milk production hence food insecurity	25	15.6
Everything mentioned above	119	74.4
The socio-economic value of pastoralism		
Livestock and meat sales (income)	10	6.2
Social and cultural values	23	14.4
Everything mentioned above	127	79.4
Consequences of drought effects		
Death of animals	3	1.9
Hunger and food insecurity	19	11.9
Diseases to animals and human beings	9	5.6
Everything mentioned above	129	80.6
Reason for keeping animals		
Provide for subsistence (milk, meat, and blood)	12	7.5
Form of productive capital	19	11.9
Serve as an important store of wealth and insurance	38	23.8
Everything mentioned above	91	56.9

Examining coping mechanisms and strategies against drought

Respondent's response on drought management and coping mechanism

According to the findings, every responder had felt the drought's effects. More than 86% of responders indicate that drought conditions remained from October to January annually. Roughly 66% of pastoralists attribute the drought to negligent farming and the felling of trees for charcoal and other purposes. Respondents predicted it using indicators such as dry riverbeds, dams, and tree foliage (63.9%). The data also shows that 95% of herders considered the absence of rain, well water, dam water, and pasture signs of a drought.

The results show that 13.1% of pastoralists looked at a wide variety of drought-tolerant plant trees, 3.8% forecast drought by examining leaves in selected trees, and 20% predict drought when there is a severe dry spell during the short rain season (Table 5).

Coping mechanism adopted

About 66.9% of respondents engaged in Nomadic pastoralism as a means of survival, whereas 1.2% separated large herds of animals into smaller ones and dispersed them to different areas. The remaining 31.9% used migration and subdividing their animal populations (Table 5). Research by Ndikumana et al. (2000), who stated that Pastoralists routinely migrate with their livestock in search of pasture and water, is consistent with these findings. It is also claimed that traditional pastoral mobility led to the most efficient use of available natural resources by taking advantage of seasonal and geographical differences in the rainfall pattern and forage availability and selecting areas where the forage was most nutritious. As a result, climate-dependent hazards like drought and disease or insect outbreaks can be avoided, making this a useful risk management tool. Additionally, pastoralism helped to avoid the overexploitation of natural resources by reducing the concentration of livestock in one area. That would lead to biodiversity conservation. As a result, pastoralists and their livestock require a great deal of resource utilization mobility to respond to temporal and spatial variation in the distribution and quantity of rainfall and forage (Homewood and Rodgers 1991). Finally, the ability to move around helps pastoralists control the spread of disease by allowing them to avoid areas of infestation (Shem et al. 2005).

Limitations of the adopted mechanism

It was discovered that 63.1% of respondents found the mechanism to be limited because it leads to social disputes with farmers, 16.3% found it to be limited in their ability to access social services, and 2.5% found it to be limited in their ability to own land. In addition, some 18.1% of respondents said the process has drawbacks, such as escalating tensions between farmers, making it hard for them to access social assistance, and making land ownership problematic (Table 5).

Pastoral system practiced

For the pastoral system practiced by the respondents in keeping animals, 33.8% reported practicing the Nomadic system, while 66.2% reported practicing the sedentary system. No respondent practiced the transhumance system. The finding indicates that 87% of the respondents reported that the nomadic system has the advantage that it optimizes the available resources and avoids over-exploitation of the land. However, the system adopted was reported to have the disadvantage of resulting in social conflict with farmers (63.1%), difficulty in owning land (2.5%), and limited acquisition of social services because of mobility (16.3%). The rest, 18.1%, indicates that the system had a disadvantage because it resulted in conflicts with farmers, difficulty in owning land, and limited acquisition of social services (Table 5).

This finding is supported by the study by Shem et al. (2005). They argue that increasing poverty due to reduced mobility, lack of alternative livelihoods, confused and competing rights and entitlements, poor provision of basic needs, and increasing human and livestock populations aggravate conflicts. For example, surveys (by Shem et al. 2005) in his study show that the number of cattle in Tanzania has already surpassed the normal carrying capacity in most areas. In addition, increasing land scarcity and conflicts of interest between land users in these and other areas have implied that many people have migrated in search of arable land and pastures elsewhere.

Table 5. Respondent's response on drought management and coping mechanism (n=160)

Experience of drought	Freq.	Percent
Yes	160	100
No	0	0.0
Causes of drought reported by the respondent		
Clearing of forest cover for charcoal production and other purposes	51	31.9
Ineffective methods of farming	10	6.3
Everything mentioned above	99	61.8
Drought signs, as indicated by the respondent		
Drying up of water sources such as rivers, reservoirs, and wells	54	33.8
Dry tree leaves	4	2.5
Everything mentioned above	102	63.7
Perception of drought as reported by the respondent		
One year without rainfall	1	0.6
When rainwater, wells, and dams are dry	60	37.5
When pastures are dry	7	4.4
When 2 and 3 apply	92	57.5
The most common month of drought in a year		
October to January	138	86.2
Other time	22	13.8
The reason why pastoralists are more vulnerable to drought		
Both animals and Human beings are affected	16	10.0
Death of animals, low milk production hence food insecurity	25	15.6
Everything mentioned above	119	74.4
Local knowledge used by pastoralists in predicting drought		
Scheduling of leaves in some plant trees	6	3.8
Heavy dry spell during Vuli season	32	20.0
All 1 and 2 above	101	63.1
Identification of a wide variety of tolerant plant	21	13.1
Coping mechanism adopted		
Migrating to look for pasture and water	107	66.9
Splitting of animals into smaller groups	2	1.2
Everything mentioned above	51	31.9
Limitations of the adopted systems		
It can result in social conflict with the farmer	101	63.1
Difficult in owning land, predators	4	2.5
Limited acquisition of social services because of the system	26	16.3
Everything mentioned above	29	18.1
Pastoral system practiced by the respondents		
Sedentary	106	66.2
Nomadic	54	33.8
Transhumance system	0	0.0
Advantages of the Nomadic system		
Possible to optimal utilize the available resources	61	38.1
It avoids over-exploitation of the land	2	1.3
It exploits different areas of vegetation types and productivity	10	6.3
Everything mentioned above	87	54.3
The disadvantage of the Nomadic system		
It can result in social conflict between farmer	101	63.1
Difficult in own land	4	2.5
Limited acquisition of social services	26	16.3
Everything mentioned above	29	18.1
Assistance from the government		
Receiving assistance from the government	44	27.5
Not receiving assistance from the government	116	72.5
Is a financial institution has anything to play?		
Yes	160	100
No	0	0.0
The role needed to play		
Provision of credit to pastoralists	115	71.9
Insuring pastoralists when a situation of drought occurs	45	28.1
Pastoralists' opinion on local institutions		
Community-based pastoral associations are established	159	99.4
Others	1	0.6

Additionally, the growth of the livestock population has led to increased movement of large herds of livestock to areas that traditionally had a few livestock, such as Mbeya, Iringa, Morogoro, Rukwa, and Coast Regions, creating serious land use conflicts. Worse, as they lose their land, some pastoralists become sedentarized. In contrast, others migrate to new areas often occupied by crop farmers, resulting in conflict and sometimes violence, particularly over the allocation of land and water resources.

In addition, Shem et al. (2005) argue that sedentarisation, for whatever reason, without good planning and transfer of appropriate livestock management techniques, extension services, and good livestock marketing systems, tends to affect pastoralists and the environment negatively.

Government interventions

On government interventions in assisting pastoralists during drought seasons, the results indicated that 72.5% of the respondents didn't receive any assistance from the government, while only 27.5% reported getting assistance in the construction of check-dams and wells (Table 5).

These results show that the government takes little effort to assist pastoralists with drought. A study by Thompson (1992) stated that it is the role of government to support in movement of livestock, provision information where forage is available, and management of conflicts concerning access to key resources (water points, forage), support the marketing of livestock to ensure purchasing power and avoid waste of assets; provision of food aid to relieve pressure on food prices and supply grain directly to pastoral populations; subsidies and price control, and to ensure pastoralist a minimum of purchasing power in the context of selling animals, buying food, health, and nutrition support, and to control disease outbreaks and to protect the nutrient status of vulnerable groups. Furthermore, the study pointed out that the government should put more emphasis on conducting veterinary campaigns to avoid large-scale livestock deaths due to outbreaks of contagious animal diseases during drought. The study concluded by saying there is a need to build a successful program to reduce pastoral risk and vulnerability by creating new strategies to enhance the ability of herders and herder communities to manage risk.

Financial Institutions interventions

On financial institutions aspects, all (100%) of the respondents reported that financial institutions had a great role to play in improving the livelihood of pastoral households. About 71.9% of the respondents said the role financial institutions need to play is to provide them with credit. In comparison, 28.1% of the respondents said financial institutions need to assist in ensuring pastoralists when drought occurs (Table 5).

Toulmin's (1995) research corroborates this idea by showing that governments should investigate the most effective means of establishing and administering emergency funds for natural disaster relief, such as readily available stand-by funds. To further expand agricultural banks, microfinance programs, private financial institutions, and financial incentives for risk management, he explains that the government should establish an economic and legal climate and institutional support that is friendly to their development. The need for central government and donors to assist is reduced, self-reliance is encouraged, and dependence is reduced if pastoral groups can create formal or informal savings and/or insurance.

Katani (1999) noted the importance of understanding national policies and legal frameworks for credit union development and micro-finance in the African pastoral context, as well as whether or not NGOs and CBOs pastoral associations are interested in or involved with developing credit, finance, and savings institutions and providing management and training. In India and Bangladesh, for instance, microfinance is successful for livestock production, and extremely low-income households (typically headed by women) prefer to invest their loans in livestock rather than crops. Investment in livestock has been shown to result in the growth of other assets in the long run. Therefore, to lessen the effects of drought and finance post-drought recovery, more research on the prevalence of informal banking and credit arrangements is necessary, as is an increase in the potential for the formation of savings clubs and micro-credit. Investigate herd dynamics to learn if there is a surplus of unproductive animals in the years between droughts, and check if conventional savings accounts can grow fast enough to compete with livestock output (over the drought cycle). Before banking and credit can be safely brought to these societies, a more nuanced understanding of ownership, wealth, and private, communal, and commercial assets among pastoral households is required.

Local institutions

About 99.4% of respondents agreed they would feel more represented and empowered if local institutions were created (Table 5). Davies (1993) found that establishing local institutions that use a bottom-up risk management planning mechanism was an essential first step in meeting the needs of herders and communities. This method would supplement the predominant top-down planning approach. As a result, the planning process for risk management should include input from herder's representatives, community leaders, and representatives of herder cooperatives.

Impacts of the mechanisms and factors influencing socio-economies of pastoral household

The analysis found that age had a negative effect on the socio-economics of pastoral houses (β= -0.451; p = 0.808), while education level had a positive but insignificant effect (β= 43.821; p = 0.497), family size had a positive but insignificant effect (= 3.379; p= 0.50), marital status had a negative effect (β= -53.979; p = 0.847), and the land area had a positive. Additionally, the results show that early warning systems (β= 316.537; p = 0.00), the availability of timely markets (β= 11.516; p = 0.021), and herd mobility all have a positive and significant effect on the socio-economics of pastoral households. Positive and statistically significant is the pastoralist system (β= 316.537; p = 0.00). The findings imply that demographic factors such as age, education, marital status, and family size do not influence drought risk management strategies or coping mechanisms. Drought risk management and adaptation mechanisms depend on land area, herd mobility, pastoral system, timely market access, early warning system, and insurance (Table 6).

According to the data, herd mobility improved the total number of animals, which helps more animals make it through drought by better using the available resources. It also helps lessen the likelihood of disease outbreaks and prevents the wasteful concentration of livestock in any given area. When pastoralists are aware of the drought situation, they can unload the unproductive stock by selling them at good prices, ensuring that they are financially stable in terms of income, food security, and the affordability of social services. So it is because the results for the availability of the market and early warning information show a strong relationship between the two (p = 0.021). Access to pasture, water, animal health, market, credit, and education are crucial to pastoral communities' overall socio-economic well-being.

According to the results, pastoral risk management is a coping strategy that can improve environmental health, increase food security (meat, milk, and cash), and decrease poverty due to income from livestock sales and other byproducts (reduce land degradation). In addition, maximizing livelihood from pastoral livestock production through risk management can do so without jeopardizing the long-term viability of the resource base. Therefore, reducing poverty, ensuring adequate nutrition, and protecting the environment are all directly linked to effective risk management for pastoralists. Furthermore, the analysis shows the following strengths of the adopted mechanism: it is possible to manage disease risks by avoiding infested areas, and it effectively utilizes marginalized land (arid and semi-arid land); the mechanism reduces the loss of animals because of the effective utilization of resources, taking temporal and spatial variation in the distribution and quality of rainfall and forage into account, as well as the nutritional status of forage; however, the analysis also indicated that there is a trade-off between these strengths. However, with the ability to sell animals, people now have access to much-needed funds to meet basic social needs such as paying for tuition or medical bills.

The research also found that better product pricing and distribution are linked to higher incomes. The study also discovered that improving the quality of extension services could lead to higher pastoral income thanks to better animal health. The research also indicated that women might spend less time looking for water if they conserved it, freeing them up to participate in other income-generating activities and improve their living standards.

Assessment of the sustainability of mechanism on the socio-economies of pastoral households

Land ownership, market access, financial institution availability, information availability, and technological adoption were the metrics used to determine the long-term viability of the mechanisms. Approximately 70% of respondents evaluated the chosen mechanism as not sustainable due to issues with land rights, market access, information accessibility, trustworthiness with financial institutions, and technological accessibility. In comparison, 30% rated it sustainable due to its positive effects on the environment and animal survival (Table 7).

These findings are consistent with those of Ganya et al. (2004), who argued that sustainable development goals could only be attained if pastoralism is founded on a set of good pastoral management practices that combine policy consideration, management tools, and economic and financial instruments. Furthermore, for example, integrating indigenous knowledge, innovation, and practices; securing land right; forecasting technology to improve market access for sustainable development; and so on.

Results from the focus group discussion and key informants

The qualitative data was gathered from people who shared similar thoughts and attitudes. Women and children were identified as the most vulnerable category in the focus group because they are forced to travel large distances in search of water for domestic use and because youngsters cannot consistently attend school due to mobility.

Loss of animals, inaccessible grazing areas, and a lack of watering holes were other negative outcomes of the drought. The created groups agreed that preventing poverty, which can result in food insecurity and environmental degradation, is best achieved by carefully managing pastoral risk. Almost all those who participated in the survey said that government assistance in the form of check-dams and other water sources would help reduce water scarcity in the area under investigation. Most respondents also agreed that if pastoralism is well managed, it may help enhance pastoralists' livelihoods and cut poverty.

Moreover, to add insult to injury, the majority demanded that the government find legitimate places for herders to graze and farmers to plant crops. They believe this will lessen the tensions between pastoralists and farmers over scarce land. According to the data gathered from our key informants, drought is getting worse in comparison to previous years. Therefore, all agree that the following actions should be implemented. First, however, the majority recommend spreading information about drought's origins and the steps that can be taken on a personal and societal level to mitigate its consequences. In addition, the vast majority agreed that legitimate grazing and farming property should be strategically located using sustainable land management practices.

Governments, with the assistance of extension officials, should establish a system for calculating the carrying capacity of land concerning the stocking rate, which would prevent overgrazing and the subsequent depletion of natural resources. They also advocated for the education of pastoralists on the significance of limiting the number of animals following the available terrain to maximize output.

Table 6. Impacts of the mechanisms and factors influencing socio-economies of pastoral households (n= 160)

Variables	Unstandardized coefficients	BETA error	t	P value
(Constant)	-377.035	325.884	-1.157	0.249
Herd mobility	91.749	26.821	3.421	0.001
Pastoral systems	316.537	60.252	5.254	0.000
Age of respondent	-.451	1.854	-0.243	0.808
Marital status of the respondent	-53.979	279.482	-0.193	0.847
Education level of the respondents	34.821	51.113	0.681	0.497
Ownership of land	58.898	69.971	0.842	0.401
Size of the land	2.854	0.970	2.942	0.004
Number of the family of the respondent	3.379	5.002	0.676	0.500
Timely market, early warning system, and insurance	11.516	23.266	0.495	0.021

Note: SS = 202228571.445; MS = 995904.383, df = 9; F = 13.261 $P<0.05$), R^2 = 44.3

Table 7. Assessment of mechanism in terms of sustainability (n= 160)

Assessment of mechanism in terms of sustainability	Frequency	Percentage	Ranking
Land right, market, financial institutions, information, and technology	112	70.0	Not effective
Land right, market, financial institutions, information, and technology	48	30.0	Effective

Several measures were taken at the District level to mitigate the consequences of the drought, including more Chaco dams being built (Lambo). A total of 30 dams have been built, using materials sourced from various settlements and livestock dips around the district. Another tactic was to educate pastoralists on land use management and land tenure systems and resolve conflicts with farmers. That was reportedly supported by Care International's Pastoral Management Project and Enviro-care. The community agreed that a policy of herd reduction based on carrying capacity should be implemented.

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Short Communication: Comparison of the water environment aspects and production of Nile tilapia (*Oreochromis niloticus*) between biofloc and conventional aquaculture systems in tropical dryland region

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Abstract. *Halla PTHB, Lalel, H, Santoso P. 2023. Short Communication: Comparison of the water environment aspects and production of Nile tilapia (*Oreochromis niloticus*) between biofloc and conventional aquaculture systems in tropical dryland region. Intl J Trop Drylands 7: 12-15.* The study aimed to compare the water quality of two aquaculture systems (i.e., conventional system and biofloc technology system) used to cultivate Nile tilapia (*Oreochromis niloticus* Linnaeus, 1758) in tropical dry land areas. This study used a survey method using seven samples for each aquaculture system. The results of the Kruskal-Wallis test showed that there was a significant difference ($P<0.05$) in the content of ammonia (NH_3) between the two aquaculture systems, while the content of nitrate (NO_3), phosphate (PO_4), dissolved oxygen (DO) and pH was not significantly different ($P>0.05$). Although the value of ammonia (NH_3) in the biofloc aquaculture system is higher than in the conventional aquaculture system, it is still below the quality standard of the aquatic environment. Conversely, the specific growth rate (SGR), relative growth rate (RGR), survival rate (SR), and production of fish between the two aquaculture systems showed significant differences ($P<0.05$). Where the value of SGR, RGR, and survival rate in conventional ponds is higher than that of biofloc ponds, on the contrary, the value of fish production in biofloc ponds is higher than in conventional ponds.

Keywords: Aquaculture, biofloc, environment, fish, freshwater, production

INTRODUCTION

The development of freshwater fish farming in tropical dryland areas is limited by freshwater availability, especially in the dry season. Therefore, appropriate technological innovations, especially to overcome the limitations of freshwater, are needed to increase freshwater fish production in this area. The biofloc system may be an alternative that can be applied in producing freshwater fish culture in tropical dryland areas.

The application of fish aquaculture systems, both intensive and semi-intensive, is faced with the problem of decreasing water quality caused by waste in the form of metabolite waste (feces and urine) and uneaten feed residue. The waste increases the content of inorganic nitrogen compounds, namely ammonia (NH_3), nitrite (NO_2), and nitrate (NO_3). However, feed with a high protein content is only used by fish by 20-30%, and the rest will be disposed of in aquaculture media in the form of urine and feces. The accumulation of these metabolites results in the formation of toxic compounds for fish, mineralization of nutrients that produce organic nitrogen, and high oxygen absorption, thereby accelerating the decline in water quality which impacts fish survival (Shin et al. 2016; Palupi et al. 2021).

Heterotrophic bacteria can convert nutrients from feed residues and waste metabolites into potential biomass for forming natural feed. If this process takes place effectively, the waste of metabolites in the aquaculture media will be resolved. As a result, heterotrophic bacterial communities will form floc that can be used as a source of natural fish food. Technology for activating heterotrophic bacteria under anaerobic conditions is known as the biofloc system (Ahadiftita et al. 2016; Kunindar et al. 2018).

The application of the biofloc system is based on the manipulation of the C: N ratio; if the ratio is 15-20 or there is a sufficient supply of additional carbon, such as glucose, sucrose, and starch in the pond, the inorganic nitrogen component will be converted into effective bacterial biomass. In principle, the biofloc system can change organic compounds in the nitrogen cycle in the aquaculture system through the enrichment of heterotrophic microbial growth that can reduce nitrogen waste (Kunindar et al. 2018).

The quality of the aquatic environment is one factor that affects fish's growth, survival, and production (Koniyo and Juliana 2018; Asriyana et al. 2021). On the other hand, biofloc technology has the opportunity to be an alternative solution to the problem of the quality of the aquatic environment in closed-system aquaculture. Based on these considerations, a comparative study has been carried out on aspects of the aquatic environment and production of tilapia (*Oreochromis niloticus* Linnaeus, 1758) in conventional and biofloc aquaculture systems in tropical dryland areas.

MATERIALS AND METHODS

Study area

The research was conducted in Oinlasi Village, South Mollo Sub-district, South Central Timor District, East Nusa Tenggara Province, Indonesia. Water quality analysis is carried out at the Fisheries Field Laboratory, UPT. *Laboratorium Lapangan Terpadu Lahan Kering Kepulauan* (Integrated Field Laboratory of Archipelagic Dryland), Universitas Nusa Cendana, Indonesia. In addition, water quality analysis is carried out at the Laboratory of Fisheries, Faculty of Marine Science and Fisheries, University of Nusa Cendana.

Procedures

The study used a survey method, with a variety of water, environmental parameters (ammonia, nitrate, phosphate, dissolved oxygen, and pH), and tilapia production in 2 (two) different groups of aquaculture ponds, namely ponds with biofloc systems and ponds with conventional systems respectively, each with a capacity of 10 m^3. Before the research, the ponds with the biofloc system had been treated with calcium hydroxide ($Ca(OH)_2$), cruciferous salt, granulated sugar, and aquaenzyme™ (containing bacteria *Bacillus subtilis*, *B. megaterium*, *B. polimyxa* each with a density of $5x10^9$ CFU). These materials are put into aquaculture water, then aerated.

The tilapia used weighs 10 grams. The density of tilapia in each conventional pond is 1,000 fish/pond, while in biofloc ponds, it is 2,000 fish/pond. Commercial feed was given at a dose of 5% by weight of biomass in the first month and 5% by weight of biomass in the following month, with a frequency of feeding three times a day. As a result, water changes in conventional pond systems are carried out every week as much as 30%, while in biofloc ponds, there are no water changes.

Water quality samples in NH_3, NO_3, and PO_4 were taken 7 times, and laboratory tests were carried out in the Field Laboratory of Fisheries, Universitas Nusa Cendana. In contrast, other water quality parameters were tested every week in the morning and evening.

Data analysis

Specific growth rate

$$SGR = \frac{(\ln W_t - \ln W_0)}{t} X\ 100\%$$

Where:
SGR : specific growth rate (%/day);
W_t : average weight of fish on day t (g);
W_0 : average weight at the beginning of the study (g)

Relative growth rate

$$RGR = \frac{W_t - W_0}{W_0 \times t} \times 100\%$$

Where:
RGR : relative growth rate;
W_t : fish biomass for the final test (%/day);
W_0 : fish biomass for the initial test;
t : length of the study.

Survival rate

$$SR = \frac{(N_0 - N_t)}{N_0} X\ 100\%$$

Where:
SR : survival rate (%);
N_0 : the number of fish at the beginning of the study;
N_t : the number of fish at the end of the study.

Biomass production

$$P = W \times N$$

Where:
P : biomass production,
W : individual weight at the end of the study,
N : number of live fish at the end of the study.

Statistical analysis

This study used the statistical analysis by the Kruskal Wallis test using the software SPSS VER 24 (Statistical Package for the Social Sciences version 24).

RESULTS AND DISCUSSION

Results

The mean values of environmental parameters in conventional ponds are ammonia 0.04 mg/L, nitrate 1.96 mg/L, phosphate 0.08 mg/L, dissolved oxygen 5.57 mg/L, and pH 7.9. Meanwhile, in the biofloc ponds, ammonia 0.04 mg/L, nitrate 1.33 mg/L, phosphate 0.12 mg/L, dissolved oxygen 5.31 mg/L, and pH 8.21 (Figure 1). The results of the Kruskal-Wallis Test showed that the ammonia value in conventional ponds was significantly different ($P<0.05$) compared to biofloc ponds. In contrast, nitrate, phosphate, dissolved oxygen, and pH values did not show significant differences ($P>0.05$), where the value of ammonia (NH_3) in biofloc ponds is higher than in conventional ponds.

The observations on tilapia in conventional ponds obtained the following results: specific growth rate (SGR) of 0.82 %/d, relative growth rate (RGR) of 3.59 %/d, a survival rate of 89.46%, and fish production of 95.67 kg. Meanwhile, tilapia in biofloc ponds obtained SGR of 0.78%/d, RGR of 3.15%/d, a survival rate of 85.86%, and fish production of 896.66 kg (Figure 2). The results of the Kruskal-Wallis Test showed that the values of SGR, RGR, survival rate, and fish production in conventional ponds were significantly different ($P<0.05$) compared to biofloc ponds. Where the value of SGR, RGR, and survival rate in conventional ponds is higher than that of biofloc ponds, on the contrary, the value of fish production in biofloc ponds is higher than in conventional ponds.

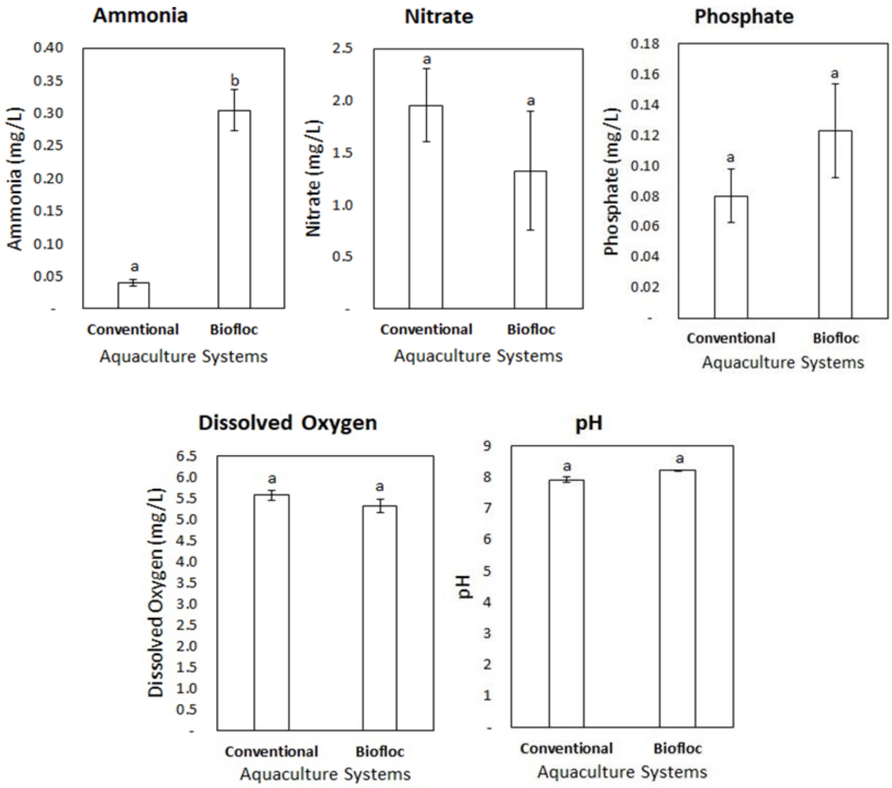

Figure 1. Graph of water environment parameters

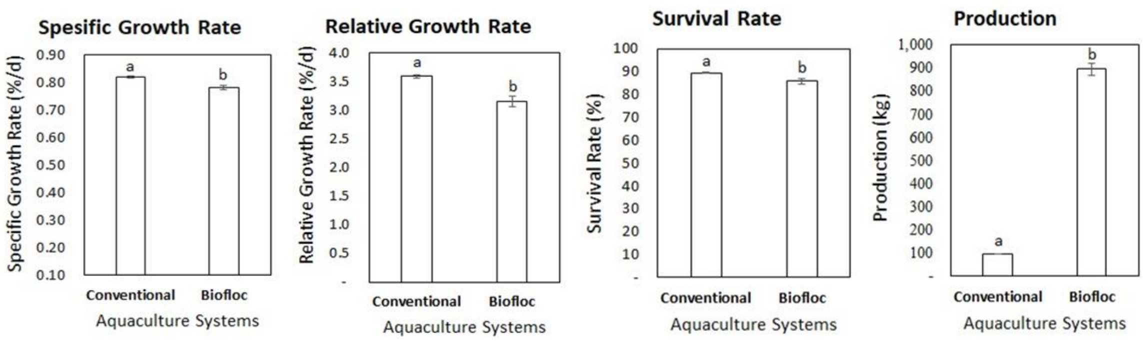

Figure 2. Graph of growth (SGR and RGR), survival rate, and fish production

Discussion

The high content of ammonia in the biofloc aquaculture system in this study was due to this system being run without water changes until the end of the study. That allows the accumulation of ammonia in the waters due to the ineffective reduction of ammonia in the biofloc formation process in this system. The results of previous studies also showed that soil ponds produced lower ammonia content (Mustapha and Akinshola 2016). In aquaculture systems, ammonia comes from the decomposition of organic matter from food residue or dead plankton and the excretion of metabolic products through the kidneys and gill channels (Ahadiftita et al. 2016).

Ammonia concentrations above 0.2 mg/L in fish ponds threaten fish life (Ogbonna and Chinomso 2010). The ammonia value for rearing tilapia in calm water is 0.02 mg/L level. If the ammonia concentration is more than 0.08 mg/L, it will reduce the appetite and growth of fish (Panggabean et al. 2016). Ammonia content will poison fish if it is 0.06-2 mg/L (Effendi 2016). Increased ammonia can increase fish leukocytes and reduce erythrocytes, hematocrit, and hemoglobin. Ammonia as a stressor can reduce the specific growth rate (SGR), reduction of feed intake, disturbance in metabolism, and harm the health of tilapia (Zeitoun et al. 2016). In addition, an increase in ammonia in fish ponds will trigger other reactions that can increase the concentration of other physicochemical parameters, namely TDS, Calcium, Electrical Conductivity, chloride, and nitrite (Ogbonna and Chinomso 2010).

Ammonia oxidation is carried out by aerobic chemoautotrophic bacteria (Nitrosomonas and Nitrobacter, primarily) to produce nitrite and nitrate (Camargo et al. 2005). Nitrite is toxic to fish because it disrupts several physiological functions, namely osmoregulation, respiratory, cardiovascular, endocrine, and excretory (Kroupova et al. 2015). Although nitrate is not toxic to fish, at too high concentrations, it can cause hypoxia in fish (Isaza et al. 2021). Nitrates in water are reduced by phytoplankton and aquatic plants for nitrogen assimilation (Ahadiftita et al. 2016).

Phosphate values in conventional aquaculture systems are not different from those in biofloc aquaculture systems. That is because both aquaculture systems are closed systems, so the source of phosphate in aquaculture media comes from the same source, namely fish feed. In addition, the presence of phosphate in the waters is related to stocking density, residual feces, and food residue that fish do not eat. Therefore, phosphate values in aquaculture systems occur in line with an increase in fish density, metabolic waste, and feed waste that fish do not eat (Kunindar et al. 2018; Piranti et al. 2018). However, both in conventional and biofloc aquaculture, the phosphate values in this study were still below the phosphate quality standard, which was <2 mg/L (Effendi 2016; Putri et al. 2019).

Dissolved oxygen values in conventional aquaculture and biofloc systems also did not show significant differences. Although the biofloc aquaculture system is equipped with an aeration system to supply oxygen to the air, the oxygen consumption in this system is also high because this system applies a high fish density. Therefore, the dissolved oxygen concentration in these two cultivation systems is in the range following the quality standard, which is >4 mg/L (Effendi 2016; Kunindar et al. 2018).

The pH values in this study did not differ between the biofloc system ponds and conventional ponds. However, the results of this study showed that the pH value in the second cultivation system showed a range that followed the quality standard for aquaculture, which was between 6-9. In water, the pH value is related to ammonia; if the ammonia is high, then the pH also increases (Effendi 2016; Putri et al. 2019).

Specific Growth Rate (SGR), relative growth rate (RGR), and Survival Rate (SR) in conventional aquaculture systems were higher than in biofloc aquaculture systems. Fish production in aquaculture systems is higher than in conventional aquaculture systems. Fish production in the biofloc aquaculture system is higher because the farmed fish receives the feed in the form of biofloc in addition to artificial feed. Biofloc is a microorganism that forms floc, a natural food for cultured fish (Kunindar et al. 2018). The Survival Rate (SR) in the biofloc aquaculture system is lower due to competition for oxygen. Although this system is equipped with an aeration system, the high concentration of floc causes competition for oxygen between the floc community and fish fry in the cultivation media of the biofloc system (Ahadiftita et al. 2016).

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Species diversity, richness, and conservation status of Pteridophyta in the karst ecosystem of Donorejo Forest, Kaligesing, Purworejo, Indonesia

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Abstract. *Pramudita DA, Armando MF, Rahmayani D, Afifah FN, Putri NRA, Hartanti AN, Safira RN, Mahajoeno E, Indrawan M, Nazar IA, Buot Jr IE, Setyawan AD. 2023. Species diversity, richness, and conservation status of Pteridophyta in the karst ecosystem of Donorejo Forest, Kaligesing, Purworejo, Indonesia. Intl J Trop Drylands 7: 16-25.* Pteridophyta is often used as an environmental bioindicator. It can be found anywhere because of its cosmopolite ability. Karst ecosystem is one type of Pteridophyta habitat and roles as a pioneer plant. This study aims to determine Pteridophyta's biodiversity and conservation status in Donorejo Forest, Kaligesing, Purworejo, Central Java, Indonesia. The data collection of Pteridophyta species was carried out by survey method. Furthermore, the species found were analyzed using the Shannon-Wiener species Diversity Index (H'), Margalef Species Richness Index (Dmg), and Evenness Species Index (E). The research found 1387 individuals from 14 families and 34 species. Then, from the analysis that has been carried out using the calculation of tree indices, the following results are obtained; Shanon-Wiener Index (H') = 2.53, Margalef Species Richness Index (Dmg) = 4.56, Evenness Species Index (E) = 0.72. *Selaginella plana* (Desv. ex Poir.) is the most dominant in the area. From its conservation status, there are two species in LC (Least Concern) under IUCN conservation status, namely *Pteris vittata* L. and *Sphaeropteris glauca* (Blume) R.M.Tryon., while the rest are in NE status (Not Evaluated). Moreover, the CITES found one species under Appendix II status, *S. glauca*. Those biodiversity indices showed that Donorejo Forest has a stable, productive, and complex ecosystem with moderate biodiversity, a high value for Margalef Species Richness Index (Dmg), and an Evenness Species Index (E). At the same time, it faces threats from dominant species and local community activity. This study result can be used for diversity assessment, especially karst land ecosystems, and for further research to make the appropriate conservation strategy.

Keywords: Biodiversity, conservation, Donorejo, karst, Pteridophyta

INTRODUCTION

Indonesia has a karst area of 15.4 million hectares (Setyawan et al. 2015). There are differences between karst vegetation and non-karst vegetation. The karst ecosystem has a vegetation composition different from other areas because the karst area is formed from karst and has specific hydrological characteristics, so the vegetation is unique (Suhendar et al. 2018). The vegetation in karst is highly dependent on the local environmental conditions in which it grows (Setyawan et al. 2015). Pteridophyta is one of the typical flora of the karst region (Najib 2019). The differences between Pteridophyta in karst and non-karst forests are lower diversity, unique species, and average species richness per transect (Phoutthavong et al. 2019). Pteridophyta is a flora with a high diversity and wide distribution. This Pteridophyta plant belongs to the crypto game plant, which means that this plant is vascular but does not have flowers but spores. This plant can be found in terrestrial and aquatic habitats or propagates on its host or epiphytes. The function of these spores is as a propagation tool for the Pteridophyta itself in the regeneration process (Atho et al. 2020). These spores are located in a spore box called a sporangium; a collection of these spore boxes is called a sorus. Pteridophyta, which are cosmopolitan; that is, they can grow in all areas, both in the highlands and lowlands, is one of the reasons these plants have high diversity (Salsabila et al. 2021). Based on their habitat, Pteridophyta is classified into three habitats: lithophytes, epiphytes, and terrestrial (Priambudi et al. 2022).

Pteridophyta in Indonesia is a group of plants with high diversity. Pteridophytes plants in Indonesia, according to

Murniningtyas et al. (2016), there are around 2,197 species or about 22% of Pteridophyta plants that grow in the world, and around 630 species are on the island of Java. Pteridophyta is planted in an area that can be an environmental indicator (Kurniawati et al. 2016). The diversity of Pteridophyta in an area can be an indicator of the environmental conditions of that area. The existence of Pteridophyta is an environmental component that indicates whether the environment supports the life of an organism or not because it has a reciprocal relationship and is interdependent with its environment. Habitat for Pteridophyta in Indonesia is usually in a humid place which is a habitat for terrestrial, epiphytic, and aquatic (Ramadhan and Sianturi 2022). The substrate of Pteridophyta is also one of the influential biotic factors, especially in the type of host tree epiphytic habitat, which is an important factor in the life of ferns (Majid et al. 2022). Even though they are on the same host tree, each type of epiphytic fern can have different morphological characteristics. The Polypodiaceae family has a characteristic form of leaves that are not ventilated, while the Aspleniaceae family has a characteristic feature of leaves with a stiff texture (Listiyanti et al. 2022).

Pteridophyta conservation is necessary because Pteridophyta has a role in life, providing a source of food or medicine for humans, filtering poisons such as heavy metals, and thus providing bioindicators for the health of an ecosystem. Pteridophyta is endangered due to climate change and is near extinction. Protection of Pteridophyta is not enough to restore the population, and conservation efforts are needed without any disturbance from climate change (Wang et al. 2016). The selection of Donorejo Forest as a research location was based on several reasons. First, Donorejo is a karst forest with a different vegetation composition from other forest types. The distinctions between Pteridophyta in karst and non-karst forests are lower diversity, unique species, and average species richness per transect (Phoutthavong et al. 2019). The karst ecosystem in Donorejo is still quite beautiful and well-maintained, so it is estimated that the biodiversity, especially Pteridophyta, in this area is still relatively high. In addition, there has yet to be any research on Pteridophyta's diversity, richness, and conservation status in the Donorejo Forest. The results of this study can be used as a reference for further research. Therefore, Donorejo Forest was chosen as the research location. This study aims to determine Pteridophyta's biodiversity and conservation status in the Donorejo Forest, Kaligesing, Purworejo, Central Java, Indonesia.

MATERIALS AND METHODS

Study area

Sampling in this study was conducted in November 2022 in the forest of DonorejoVillage, Kaligesing Sub-district, Purworejo District, Central Java Province, Indonesia. Donorejo Village is at coordinates S 07°45'53.07", E 110°06'15.45". Donorejo is a village in the highlands with an area of ±597.3730 ha. According to BPS (2022), Donorejo Village has an average rainfall of around 2,391 mm/year with an average daily temperature of 29°C. This village is included in the Jonggrangan karst formation of the Menoreh Mountains. The village's location, which is in the highlands with an altitude of 740 m asl., makes Donorejo Village have high species diversity (Figure 1). Donorejo Forest has heterogeneous vegetation. Located close to residential areas, at the Donorejo forest can be found many fruticultural species such as *Citrus* sp. (orange), *Cocos nucifera* L (coconut), *Artocarpus heterophyllus* Lam. (jackfruit), and *Coffea* sp. (coffee).

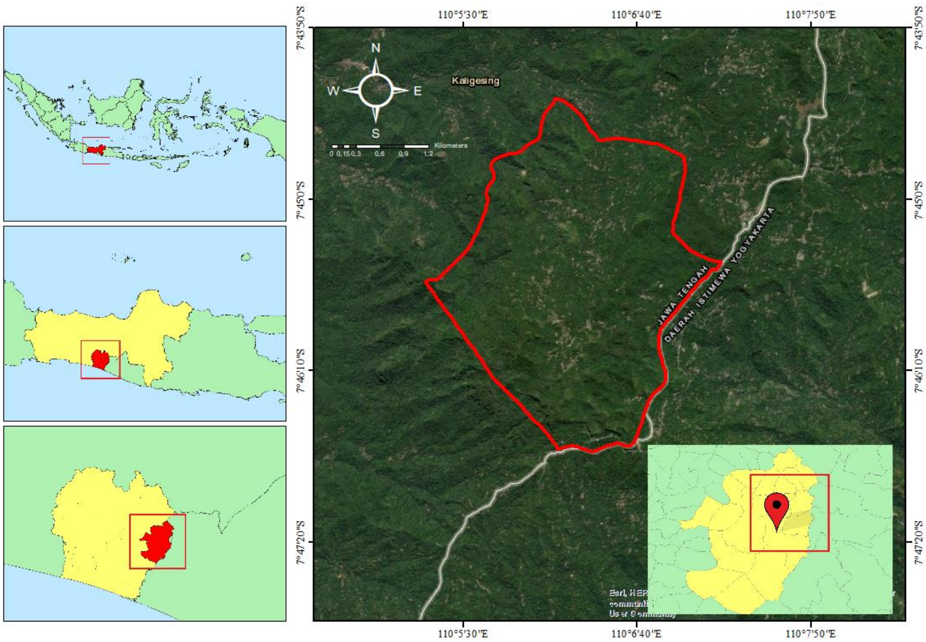

Figure 1. Pteridophyta research area in Donorejo Forest, Kaligesing, Purworejo, Central Java, Indonesia

Sampling technique

This study uses a qualitative analysis method and field observations using the survey method (Palupi et al. 2015) by purposive sampling based on the presence of Pteridophytes. The survey method by purposive sampling means that sampling was carried out by tracing the Donorejo Forest in areas that match the characteristics of the Pteridophyta habitat. Data collection was carried out by recording on a tally sheet with presumptive species names, number of individuals, morphological characters, habitat, and habitus of Pteridophytes. Sampling is also carried out by collecting Pteridophyta's generative and vegetative organs for further preservation. That preservation includes storing and drying them in newspapers and giving an identity in the form of a collection number, collector's name, and presumptive species name (Lestari and Nindira 2021).

Identification

Identification is made directly and indirectly. For unknown Pteridophyta species, the names will be identified using Hoshizaki and Moran (2001), Mehltreter et al. (2010), and Callado et al. (2016). The detailed morphological generative (spore) and vegetative (leaf, stem, rhizome, hair/scale) organs were documented for each species found (Priambudi et al. 2022). Name validation is carried out by checking the scientific name on the website of the Global Biodiversity Information Facility (GBIF) (https://www.gbif.org/).

Data processing

Then the primary data obtained will be included in the calculation of the diversity of Pteridophyta using the biodiversity indicators, namely Shannon-Wiener Index (H'), Evenness Species Index (E), and Margalef Species Richness Index (Dmg) (Priambudi et al. 2022). While secondary data were obtained from literature studies to support field findings, namely IUCN Redlist and CITES for the conservation status

Data analysis

Data analysis was performed by calculating the Shannon-Wiener Diversity Index, Margalef Species Richness Index, and Evenness Species Index, as well as identification of conservation status.

Shannon Wiener's Diversity Index

The diversity of Pteridophyta was analyzed using the Shannon-Wiener Index. A formula calculates the Shannon wiener index:

$$H' = - \sum pi \ln pi$$

Where :
H' : Shannon-Wiener Diversity Index
ni : Number of individuals of the i-th species
n : Total number of individuals of all species
pi : ni/n

From the calculation results (H' value), it can be determined whether the area's species diversity level is high or low. Alwi et al. (2021) divide the level of species diversity where if:

H'<1: Low species diversity.
1≤H'≤3: Moderate species diversity
H'>3: High species diversity

Margalef Species Richness Index

Pteridophyta species richness was analyzed using the Margalef Species Richness Index. The Margalef Species Richness Index of Margalef was calculated using the formula :

$$Dmg = \frac{S - 1}{lnN}$$

Where:
D : Margalef Species Richness Index
S : Number of species in the habitat
N : Total number of individuals of all species in the habitat

From the calculation results will be known the level of species richness. According to Wardhana et al. (2022), the criteria for the level of species richness are as follows:

D < 2.5: Low species richness level
2.5> D > 4: Moderate species richness level
D > 4: High species richness level

Evennes Species Index

Evenness analysis of Pteridophyta was carried out using the evenness species Evenness Index. This index is calculated to determine the distribution of the number of individuals in each species (Salami and Akinyele 2018). The formula calculates the even species Evenness Index:

$$E = \frac{H'}{\text{In S}}$$

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

The Evenness Index value of the evenness type ranges from zero to one. The lower the value, the more unequal the number of individuals in each species. Conversely, the higher the value, the number of individuals distributed among species are even. Based on Rudianto et al. (2022), the species evenness category is based on the Evenness Index value, that is:

E<0.4: Small population uniformity
0.4<E<0.6: Average population uniformity
E>0.6: High population uniformity

RESULTS AND DISCUSSION

Donorejo Forest is one of the karst areas in the Purworejo District. The ecosystem is relatively well maintained even though villages surround it. Sarwanto et al. (2017) stated that limestone mountains are landscapes that have important values for the environment, such as water resources, biodiversity, and tourism. However, the typology of karst soil causes a lack of water in the soil and limited nutrient content (Yuslinawari et al. 2022). Pteridophytes are a group of plants commonly found on the forest floor. Plants on the forest floor live under forest stands, including shrubs, herbs, and pteridophytes (Andika et al. 2017). The presence of forest floor plants is useful as a provider of organic matter, which can increase water absorption capacity (Afriana et al. 2022). Thus, the presence of Pteridophytes can act as a provider of nutrients for surrounding plants. Pteridophyta is a group of plants that have a role as pioneers. The characteristics of Pteridophytes that make them pioneers are their adaptability and wide distribution due to their light spores being carried by the wind so that they can colonize large numbers of degraded areas (Dwisutono et al. 2019). In Donorejo Forest found 34 Pteridophytes species, as documented in Figure 2.

Discussion

Diversity

The research showed that in the Donorejo Forest, 14 families of Pteridophytes were found from 34 species and 1,397 individuals of Pteridophytes (Table 1). The Pteridophyte plant with the highest relative abundance value is *Selaginella plana* (Desv. ex Poir.) Hieron, which is 524 individuals (37.78%). According to Ismawan et al. (2015), this value is classified as high abundance. In comparison, the other 34 species belong to low abundance because they have a value of less than 15%. The six most dominant species in the Donorejo Forest area are *S. plana* with 524 individuals found; *Cyclosorus interruptus* (Willd.) H.Itô. 188 individuals (13,46%); *Adiantum capillus-veneris* L. 86 individuals (6.16%); *Amphineuron immersum* (Blume) Holttum. 50 individuals (3.58%); *Selaginella ornata* (Hook and Grev.) Spring. 50 individuals (3.58%); and *Tectaria angulata* (Willd.) Copel 40 individuals (2.86%). Two species with the lowest distribution were found: *Sphaeropteris glauca* (Blume) R.M.Tryon Copel. and *Lycopodium cernuum* L., where only two individuals were found for each species.

Table 1. Identification of Pteridophyta in this study

Family	Species	Habitats	n	Conservation status	
				IUCN	CITES
Aspleniaceae	*Asplenium nidus* L.	E	14	NE	N/A
Athyriaceae	*Deparia petersenii* (Kunze) M.Kato	T	15	NE	N/A
Blechnaceae	*Blechnum orientale* L.	T	25	NE	N/A
Cyatheaceae	*Sphaeropteris glauca* (Blume) R.M.Tryon	T	2	NE	Appendix II
Davalliaceae	*Davallia denticulata* (Burm.fil.) Mett. ex Kuhn	E	5	NE	N/A
Dryopteridaceae	*Dryopteris sparsa* (D.Don) Kuntze	T	29	NE	N/A
	Arachniodes spectabilis (Ching) Ching	T	10	NE	N/A
Gleicheniaceae	*Dicranopteris linearis* (Burm.fil.) Underw.	T	10	NE	N/A
Lycopodiaceae	*Huperzia phlegmaria* (L.) Rothm.	E	13	NE	N/A
	Lycopodium cernuum L.	T	2	NE	N/A
Nephrolepidaceae	*Nephrolepis acutifolia* (Desv.) Christ	T	8	NE	N/A
Polypodiaceae	*Drynaria quercifolia* (L.) J.Sm.	E	34	NE	N/A
	Goniophlebium percussum (Cav.) Wagner and Grether	E	26	NE	N/A
	Lepisorus mucronatus (Fée) Li Wang	E	16	NE	N/A
	Platycerium bifurcatum (Cav.) C.Chr.	E	9	NE	N/A
	Microsorum membranifolium (R.Br.) Ching	T	4	NE	N/A
	Pyrrosia nummularifolia (Sw.) Ching	E	3	NE	N/A
Pteridaceae	*Adiantum capillus*-veneris L.	T, L	86	NE	N/A
	Adiantum diaphanum Blume	T	46	NE	N/A
	Adiantum philippense L.	T	25	NE	N/A
	Pteris vittata L.	T	25	NE	N/A
	Pityrogramma calomelanos (L.) Link	T	18	NE	N/A
	Adiantum caudatum L.	T	8	NE	N/A
	Pteris ensiformis Burm.	T	5	NE	N/A
Selaginellaceae	*Selaginella plana* (Desv. ex Poir.) Hieron.	T	524	NE	N/A
	Selaginella ornata (Hook and Grev.) Spring	T	40	NE	N/A
Tectariaceae	*Tectaria angulata* (Willd.) Copel.	T	40	NE	N/A
	Tectaria dissecta (G.Forst.) Lellinger	T	15	NE	N/A
Thelypteridaceae	*Cyclosorus interruptus* (Willd.) H.Itô	T, L	188	NE	N/A
	Amphineuron immersum (Blume) Holttum	T	50	NE	N/A
	Macrothelypteris torresiana (Gaudich.) Ching	T	34	NE	N/A
	Cyclosorus sparsisorus Ching ex K.H.Shing	T	29	NE	N/A
	Christella dentata (Forssk.) Brownsey and Jermy	T	20	NE	N/A
	Christella subpubescens (Blume) Holttum	T	9	NE	N/A

Note: E: epifit, NE: not evaluated, n: number of individuals, L: litofit, LC: least Concern, T: terrestrial, N/A: not available


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Figure 2. Species of Pteridophyta in this study: 1. *Asplenium nidus* L., 2. *Deparia petersenii* (Kunze) M.Kato, 3. *Blechnum orientale* L., 4. *Sphaeropteris glauca* (Blume) R.M.Tryon., 5. *Davallia denticulata* (Burm.fil.) Mett. ex Kuhn, 6. *Dryopteris sparsa* (D.Don) Kuntze, 7. *Arachniodes spectabilis* (Ching) Ching., 8. *Dicranopteris linearis* (Burm.fil.) Underw., 9. *Huperzia phlegmaria* (L.) Rothm., 10. *Lycopodium cernuum* L., 11. *Nephrolepis acutifolia* (Desv.) Christ, 12. *Platycerium bifurcatum* (Cav.) C.Chr., 13. *Microsorum membranifolium* (R.Br.) Ching, 14. *Lepisorus mucronatus* (Fée) Li Wang, 15. *Drynaria quercifolia* (L.) J.Sm., 16. *Goniophlebium percussum* (Cav.) Wagner and Grether, 17. *Pyrrosia nummularifolia* (Sw.) Ching, 18. *Adiantum capillus*-veneris L., 19. *Pteris vittata* L., 20. *Adiantum philippense* L., 21. *Adiantum diaphanum* Blume, 22. *Pityrogramma calomelanos* (L.) Link, 23. *Pteris ensiformis* Burm., 24. *Adiantum caudatum* L., 25. *Selaginella plana* (Desv. ex Poir.) Hieron, 26. *Selaginella ornata* (Hook and Grev.) Spring, 27. *Tectaria angulata* (Willd.) Copel., 28. *Tectaria dissecta* (G.Forst.) Lellinger, 29. *Cyclosorus interruptus* (Willd.) H.Itô., 30. *Macrothelypteris torresiana* (Gaudich.) Ching, 31. *Amphineuron immersum* (Blume) Holttum, 32. *Christella dentata* (Forssk.) Brownsey and Jermy, 33. *Christella subpubescens* (Blume) Holttum, 34. *Cyclosorus sparsisorus* Ching ex K.H.Shing

Selaginella plana are known as the most dominant Pteridophyta in Donorejo Forest. Research by Gabi et al. (2021) shows that the species of *S. plana* also dominates the forest floor in burnt forest areas in North Sulawesi. That indicates *S. plana* have an ecological function as a pioneer plant in the succession process of an ecosystem. Since *S. plana* are cosmopolitan and can grow in various climates and soil, *S. plana* also have rhizome roots and function as a ground cover (Kurniasih 2019). Therefore, the existence of dominant species affects the stability of the ecosystem, as the dominance of certain species can decrease the value of diverse species. It could explain why the Pteridophyta species diversity values in the Donorejo Forest were at a moderate level, while the Evenness Species Index (E) and Margalef Species Richness Index (Dmg) values were at a high level.

Pteridophytes found in this study were analyzed for diversity through three indicators, namely the Shannon-Wiener Index (H'), Margalef Species Richness Index (Dmg), and Evenness Species Index (E) (Figure 3). From the analysis that has been carried out, the results show that the Shannon-Wiener Index owned by Pteridophyta in Donorejo Forest is 2.53, which means it is in moderate condition. This Shannon-Wiener Index shows the level of diversity within a community. The higher level of domination of a species in a place, the less diversity. That can make it easier to know a species' diversity in a particular community. One research related to Pteridophytes carried out in karst areas is from Press (2021). It states that the Diversity Index of Pteridophytes found is 1.37-2.36, which means they are in the moderate category. Hoshur (2022) state high values of the Shannon-Wiener Index (H') indicate a greater number of species sharing more or less equally. Therefore, the lower Diversity Index could be due to the dominance of a few species. Furthermore, most of the Pteridophytes in karst were calcium-preferring species (Ren et al. 2021), such as *Selaginella* spp., *Adiantum philippense* L, *Pteris vittata* (Kumar et al. 2016), and *A. capillus-veneris* (Hoshizaki and Moran 2001). Based on the Pteridophyte species mentioned above, it is known that this Pteridophyte calcium-preferring species was also found at the study site.

The results of the analysis of Pteridophyta in the Donorejo Forest using the Evenness Species Index obtained that E = 0.72. These results indicate that the value of E >0.6 means that the evenness distribution of individuals numbering Pteridophyta species in the Donorejo Forest is high. This condition is supported by the heterogeneous condition of the Donorejo Forest with diverse vegetation variations, which can potentially become hosts for Pteridophyta to grow. In addition, the geographical conditions of the Donorejo Forest, located in the highlands, make the soil in the Donorejo Forest relatively humid. That supports high biodiversity, including the Pteridophyta itself. Research from Press (2021) conducted in the Sangkulirang-Mangakalihat karst area, East Kutai Regency, East Kalimantan, also found that the overall Evenness Index of Pteridophyte species was at a value of >0.6, which means it was also in the high category.

The Margalef Species Richness Index determines the number of species present in a community, where the number of species will be directly proportional to the Margalef Species Richness Index. Suppose the number of species in a community is high; then the Margalef Species Richness Index value of that species is high. Vice versa, if the number of species found is low, the Margalef Species Richness Index is also low. The wealth index value owned by Pteridophyta in Donorejo Forest is 4.56. The Margalef Species Richness Index value is more than 4, meaning that Pteridophyta's species richness in the Donorejo Forest is in the high category. The high value of species richness, especially Pteridophyta, indicates that the ecosystem in the research area, namely the Donorejo Forest, is in good condition. That is why Pteridophyta has a role as environmental bioindicators. This result has a higher Margalef Species Richness Index than Priambudi et al. (2022) in Belitung Island, which showed the Margalef Species Richness Index value of Pteridophytes in the heath forest (low category 1.29) and tropical rain forest (moderate category 3.36) was below the species richness in karst ecosystems. According to (Ansari et al. 2017), several plants from different divisions of the plant kingdom, such as chlorophyta, Bryophyta, and Pteridophyta, can be used to monitor and assess water quality in freshwater or marine, lentic or lotic, wetlands and coastal aquatic ecosystems.

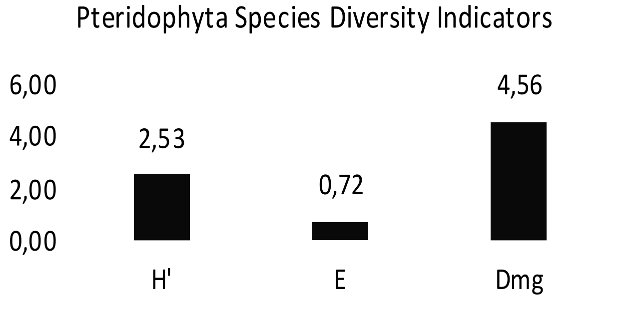

Figure 3. Biodiversity indicators of Pteridophytes species including Shannon-Wiener Diversity Index (H'), Evenness Index (E), Margalef Species Richness Index (Dmg) in this study

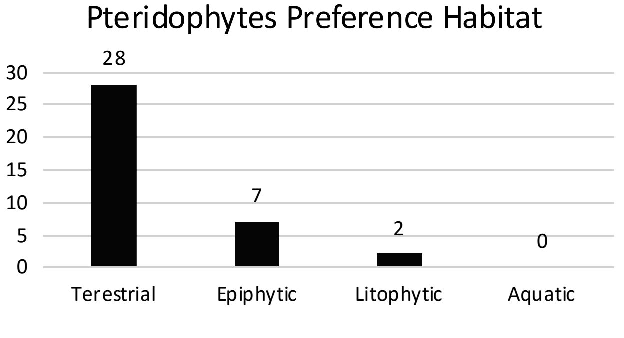

Figure 4. Pteridophytes habitat found for each species in karst ecosystem Donorejo Forest, Purworejo, Central Java, Indonesia

Pteridophyta habitat

Pteridophyta lives in terrestrial, epiphytic, lithophytic, and aquatic habitats. Pteridophyta is usually found in lowland subsoil, beaches, mountain slopes, and humid areas with an altitude of about 350 meters above sea level. On the other hand, there are Pteridophyta whose lives float in water, for example, *Azolla pinnata* R.Br. and *Marsilea crenata* C.Presl.

The observations showed that Pteridophytes were found in Donorejo Forest, namely Pteridophyta, which live in terrestrial habitats. Many Pteridophyta is found in terrestrial habitats because some Pteridophyta lives in moist and shaded soil, both in the highlands and lowlands, making terrestrial habitats suitable due to their humidity, temperature, light intensity, and rainfall (Kurniawati et al. 2016).

Observation found as many as 28 species compared to epiphytic and lithophytic habitats (Figure 4). Uniquely, the physical conditions of karst habitats result in a limited supply of moisture and restrictions to nutrient access in this ecosystem (Liu et al. 2020). Based on their habitat, Pteridophytes live as epiphytes or are attached to host trees. Pteridophytes are terrestrial living on soil substrates, and lithophytes are attached to rock substrates. This research found seven species of Pteridophyte plants that live as epiphytes, namely *Asplenium nidus* L., *Davallia denticulata* (Burm.fil.) Mett. ex Kuhn, *Huperzia phlegmaria* (L.) Rothm., *Platycerium bifurcatum* (Cav.) C. Chr., *Lepisorus mucronatus* (Fée) Li Wang, *Drynaria quercifolia* (L.) J.Sm., *Goniophlebium percussum* (Cav.) Wagner and Grether, and *Pyrrosia nummularifolia* (Sw.) Ching. The host trees of the epiphytic Pteridophytes found included *Citrus* sp. (orange), *C. nucifera* (coconut), *A. heterophyllus* (jackfruit), and *Coffea* sp. (coffee). In comparison, the types of Pteridophyta that live in lithophytes or rock crevices are *A. capillus-veneris* and *C. interruptus*, which are also found to live terrestrially while the rest live terrestrially. Rambey et al. (2021) state that Pteridophytes with terrestrial habitats are more commonly found in karst areas than in urban areas. The existence of epiphytic Pteridophytes ecologically acts as a habitat for several types of insects. Their presence is also used as a bioindicator in a humid environment (Lestari et al. 2019). However, epiphytic Pteridophytes prefer rough stems to stick their fibrous roots easily. Moreover, conditions under the canopy also determine the growth of epiphytic Pteridophytes (Sirami 2015). In the Donorejo Forest area, a karst area, more Pteridophyte species live terrestrially than epiphytes. Many Pteridophyta is found in terrestrial habitats because some Pteridophyta lives in moist and shaded soil, both in the highlands and lowlands, making terrestrial habitats suitable for humidity, temperature, light intensity, and rainfall (Kurniawati et al. 2016).

Environmental factors

Pteridophyta in Indonesia is a group of plants with high diversity. According to Murniningtyas et al. (2016), around 2,197 species, or 22% of the Pteridophyta plants, grow worldwide, and around 630 are on Java Island. Pteridophyta is planted in an area that can be an environmental indicator (Kurniawati et al. 2016). Therefore, the diversity of Pteridophyta in an area can be an indicator of the environmental conditions of that area. The existence of Pteridophyta is an environmental component that indicates whether the environment supports the life of an organism or not because it has a reciprocal relationship and is interdependent with its environment. Habitat for Pteridophyta in Indonesia is usually in a damp place, such as near a waterfall which is a habitat both terrestrial, epiphytic, and aquatic (Ramadhan and Sianturi 2022).

Environmental factors influence the diverse types of Pteridophyta. The higher the place, the higher the humidity in the air, causing the temperature to be low and the intensity of sunlight received by the plants to be minimal, which causes the plants not to be able to live. The abiotic factor of the Pteridophyta was in a soil moisture condition of 5.25% (Table 2). That is due to the soil structure in the karst ecosystem, which is composed of limestone so that it stores relatively less water. Wahyuningsih et al. 2019 stated that the optimal soil moisture conditions for Pteridophyte growth were 8-68%, so the types of Pteridophyta found had tolerance to relatively low soil moisture. While other conditions, with air humidity at 85%, soil pH 6.75, soil temperature at 25°C, and air temperature at 27°C, are already in optimum conditions (Lubis 2009; Permana 2017). In addition, the heterogeneous and dense vegetation in the Donorejo Forest means that the intensity of sunlight needs to reach the forest floor optimally. This condition is ideal for shade-loving Pteridophytes.

Conservation status

Based on the IUCN Red List, of the 34 species of Pteridophyta found, there are two species with IUCN's most minor concern conservation status, and the rest are not evaluated. The not evaluated status means that the species has not been included in the evaluation of the IUCN Red List, which may be due to a need for more data regarding the species. That is unfortunate because initial data is needed for conservation efforts, especially for Pteridophyta. Meanwhile, the species included in the most minor concern category are *P. vittata* and *S. glauca*. The minor concern category means that the species has a low risk. According to Saputro and Utami (2020), a minor concern category is a category in which the species has a limited distribution but has been evaluated and is not included in the upper category. Then, based on CITES, of the 34 species found, 1 type of Pteridophyta is included in the Appendix II category, while the others are included in the not protected category (Table 1)

Table 2. Abiotic factor in this study

Abiotic factor	Average score
Soil moisture (%)	5.25
Air humidity (%)	85
Soil pH	6.75
Soil temperature (°C)	25
Height (masl)	735
Air temperature (°C)	27
Light intensity (lux)	8100

The not protected category means that the species is not a protected species. The type of Pteridophyta found in the Appendix II category is *S. glauca*. Appendix II category means that the species is not endangered, but while it is traded continuously without binding regulations or limits, it can result in the extinction of the species. Thus, species included in the Appendix II category may only be traded in particular situations, specifically for the use of non-detriment findings, and have been included in the determination of harvesting allowances. The data above shows that data collection related to Pteridophyta species, especially those found in research locations, still needs to be examined to determine their conservation status. In addition, some species need further attention, such as *P. vittata* and *S. glauca*. Although these two species are included in the low-risk category according to the IUCN Red List, even *S. glauca* are included in the Appendix II category according to CITES. Therefore, those two species still need to be given more attention to prevent these species' extinction.

Other species that have not been evaluated or are still not protected must also be maintained so that the diversity and richness of Pteridophyta in the Donorejo Forest remain good. According to Phoutthavong et al. (2019), the diversity of Pteridophyta in karst areas cannot be protected simply by preserving several habitat patches. Because each patch plays a very important role in the diversity of Pteridophyta, therefore, just the loss of one habitat patch can cause the extinction of local or endemic species. In addition, humans can use Pteridophyta as a source of food and medicine, materials for handicrafts, ornamental plants, and growing media in plant cultivation (Syukur 2019). For example, *P. vittata* is helpful as an ornamental plant for the heavy metal mercury hyperaccumulator and a source of antioxidants (Nurcahyani 2021). Then, *Dryopteris sparsa* (D.Don) Kuntze can be used as a medicine for worms (Nikmatullah et al. 2020). The *S. glauca* are also widely used as a planting moderate (Suryana et al. 2018). Even though the extensive use of Pteridophyta can threaten their sustainability, excessive utilization without regard to the environment can lead to their extinction. In addition, land conversion or pollution as a result of human activities can also damage the Pteridophyta habitat.

In conclusion based on the research, it can be concluded that the diversity of Pteridophyta species in the Donorejo forest consists of 34 species and 14 families. The Shannon-Wiener Species Diversity Index (H') is in the moderate category, while the Evenness Species Index (E) and Margalef Species Richness Index (Dmg) are in the high category. That means the current condition of the Donorejo Forest is in stable condition, but the existence of the dominant species (*S. plana*) could be threatening the biodiversity of Pteridophyta. Moreover, from their conservation status, out of 34 species, there are two species in LC (Least Concern) under IUCN conservation status, namely *P. vittata* and *S. glauca*, while the rest are in NE status (Not Evaluated). In addition, of the 2 LC species, one is included in Appendix II, *S. glauca*, which means that special attention is needed to conserve this species so that its existence is maintained. Further research is needed regarding the ethnobotanical of Pteridophyta by the community to develop appropriate conservation strategies, especially in the karst ecosystem, both in nature and in vitro.

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Woody species diversity, composition, structure and carbon storage of a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania

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Abstract. *Mwakalukwa EE, Mwakisu A, Maliondo SMS. 2023. Woody species diversity, composition, structure and carbon storage of a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania. Intl J Trop Drylands 7: 26-36.* The biodiversity status of flora and fauna of many forests found on small protruding and isolated hills in most parts of dry areas in Tanzania is largely less studied. Their contribution to climate mitigation options also remains largely unknown. This study assessed the woody species diversity, composition, structure and carbon stocks potential of a dry evergreen montane forest of Essimingor Nature Forest Reserve in Tanzania. The vegetation data were collected from 23 concentric sample plots of 5m, 15m, and 20m radius laid systematically across the entire forest area of 6,100 ha. A total of 54 trees and shrubs species belonging to 29 families were identified. Diversity indices indicated the forest to have a high diversity of woody species. The most important species were *Cassipourea malosana, Diospyros abyssinica* and *Drypetes natalensis*. Stand structure comprised 288±173 stems ha^{-1}, basal area of 11.47±7.23 m^2ha^{-1} and standing volume of 27.3±16.3 m^3ha^{-1}. The mean above-ground and below-ground carbon stocks were 56.93±34.60 Mg C ha^{-1} and 34.71±19.72 Mg C ha^{-1}, respectively. The observed high species diversity and carbon density signify the importance of conservation efforts bestowed in this reserve. Quantification of other carbon pools for estimation of the total carbon stock potential of this forest is recommended.

Keywords: Biodiversity, climate change, humid forest, Monduli, REDD+

INTRODUCTION

The role of forest ecosystems in the conservation of soil, water and biodiversity and in mitigating climate change is well acknowledged (Burgess et al. 2007; Pan et al. 2011; Lewis et al. 2013; Ashagre et al. 2014; Spracklen and Righelato 2014; Apguaua et al. 2015; Kacholi et al. 2015; Mauya et al. 2019; Kendie et al. 2021; Biadgligne et al. 2022; Nugroho et al. 2022; Rawal and Subedi 2022). Forests contain most of the terrestrial biodiversity and are estimated to store about 289 Gt of biomass carbon (Apguaua et al. 2015; FAO 2022). The terrestrial vegetation alone is estimated to store approximately 450-650 Gt of carbon (Daba et al. 2022). Forests also support life of many living organisms on earth and are a source of livelihood for more than 1.4 billion people worldwide (Kendie et al. 2021). Dryland forests specifically, and other woodlands found in Africa are estimated to meet a large part of the needs of more than 320 million people (Haddad et al. 2021). According to Chidumayo and Marunda (2010), these requirements include rain-fed agricultural cultivation, animal farming, and the collection of timber and non-timber forest products, all of which boost regional enterprises.

Despite their potential, forest ecosystems are threatened by anthropogenic activities, mainly from deforestation and forest degradation (Hansen et al. 2013; Kideghesho 2015; Doggart et al. 2020; Biadgligne et al. 2022). Food and Agriculture Organisation (FAO) (2020) estimated that between 1990 and 2020, around 420 million ha of forest had been deforested and converted to other land uses. More specifically, about 10 million ha of forest were lost per year between 2015-2020. Studies have indicated that deforestation contributes to 18-20% of Anthropogenic Greenhouse Gases (GHGs) emissions globally (Baccini et al. 2012; Biadgligne et al. 2022). About 20% of GHGs emission is caused by deforestation from Africa (Leon et al. 2022). Although dryland ecosystems have been estimated to store about one-third of the global carbon stock, contributing significantly to land-based carbon sinks (Trumper et al. 2008; Lal 2019), the contribution of dry land forests, especially dry evergreen montane forests in Tanzania in carbon sinks is not well studied.

According to estimates, Tanzania loses between 372,816 and 469,420 ha of forest cover annually (MNRT 2015; URT 2017). This suggests that Tanzania's forest resources and biodiversity are in danger (Newmark and McNeally 2018), leading to higher GHG emissions. It is imperative to stop additional deforestation for this reason. According to Karki et al. (2017), deforestation prevention has been generally accepted as a promising mitigation strategy for mitigating climate change through carbon negotiation mechanisms like REDD+ (reduced emission from deforestation and forest degradation, plus forest conservation, sustainable forest management, and enhancement). REDD+ was devised under the United

Nations Framework Convention on Climate Change (UNFCCC) to combat CO_2 emissions (Houghton 2012; Daba et al. 2022). However, for a participating country to benefit from the carbon credit market, a precise and verifiable estimate of carbon stock data from the major carbon pools is necessary (Corbera and Schroeder 2011; Daba et al. 2022). Understanding available carbon stocks in different forest ecosystems is also important for estimating potential carbon losses through deforestation and forest degradation (Mauya et al. 2019; Manyanda et al. 2019).

Therefore, this study was intended to provide baseline data on species composition, diversity and structural attributes and carbon storage potential of a relatively undisturbed forest reserve of Essimingor Nature Forest Reserve (ENFR) in Tanzania. The isolated forest on top of a hill is part of broader distribution of dry evergreen montane forests surrounded by open savanna (forest-savanna mosaic) in Eastern Africa (Greenway 1973; White 1983). ENFR is among many forests found on small protruding and isolated hills in most parts of dry areas in Tanzania with high biodiversity values (Lovett and Pocs 1993; Sitati et al. 2014; Sitati et al. 2016; Kayombo et al. 2022) and carbon storage potential (Swai et al. 2014; Mwaluseke 2015) but is less studied. This information is important to aid the preparation of strategies for successful management of the forest reserve and planning for Ecotourism. Specifically, the study aimed to; (i) determine woody species composition and diversity of all trees and shrubs found in reserve, (ii) determine the structure of the forest (stem density, basal area and volume) of trees and shrubs with diameter > 5 cm in reserve, and (iii) estimate carbon stocks of the reserve in both above-ground and below-ground components.

MATERIALS AND METHODS

Study area

Essimingor Nature Forest Reserve (ENFR) is situated in the North East Tanzania between 36° 03' to 36°08'E and 3° 21` to 3° 26`S. It is located 60 km from Monduli, 90 km from Arusha townships and 10 km from the Arusha to Dodoma Road (Lovett and Pocs 1993) (Figure 1). ENFR is owned by Central Government and was first declared as forest reserve in 1954. The forest reserve covers about 6,100 hectares with a boundary length of 28 km. Due to its high biodiversity value; it was upgraded to Nature Forest Reserve in 2020 by Government Notice No. 691 of 28/08/2020. The ENFR is characterized by ragged and steeply dissected Essimingor Mountain from an elevation range of 1520-2195 m.a.s.l. The soils are characterized by brown volcanic soils. Over volcanic rock occupy about 32% of the Monduli District (Lovett and Pocs 1993). The forest reserve is bordered by seven villages namely, Essimingor, Selela, Eslalei, Makuyuni, Mbuyuni, Mbaashi and Repruko. The main ethnic group in the locality is Masai who are mainly pastoralist. The major economic activities are extensive livestock keeping and agriculture (Lovett and Pocs 1993).

ENFR is dominated by orographic rainfall from the nearby Lake Manyara with continental temperatures. Rainfall ranges from 750-1000 mm/year on the lower slopes but higher than 1500 mm/year with mist effect on the higher altitudes on the upper slopes. Dry season is from June to October with temperatures of 15.4°C in December and 11.5°C in July at lower altitudes. According to Lovett and Pocs (1993), the vegetation distribution is clearly changes with elevation such that, in the lower slopes are dominated by grassland with scattered trees. On the upper slopes from 1675 to 2195 m, dry montane forest with fire-maintained grassland dominates. Closed forest is mostly concentrated at higher elevation with high humidity and dense canopy cover (Lovett and Pocs 1993; Holmes 1995). The forest is reserved as water catchment and contributes to ground water supplies below the mountain, and some are piped from the eastern side to farms on the lower slopes.

The forest has experienced minimal human disturbances that resulted into existence of wild animals such as Buffalo, Elephants and others. The ENFR alongside other forest reserves such as Burko and Monduli forest reserves serve as a corridor by linking movement of wild animals in three National Parks namely Tarangire, Manyara and Ngorongoro. The reserve is potentially a breeding site for Buffaloes. There is an increase in number of wild animals in ENFR during dry season due to favorable condition (fodder and water). Formerly it served as a hunting block under the Wildlife Division. The common genus of tree species found in the wooded grassland area include *Acacia* sp., *Combretum* sp., *Dombeya* sp., and *Euphorbia* sp. Tree species from dry montane forest area include *Albizia gummifera*, *Calodendrum capense*, *Cassipourea malosana*, *Catha edulis*, *Cussonia arborea*, *Ekerbergia capensis*, *Fagaropsis angolensis*, *Nuxia congesta* and *Olea capensis* (Lovett and Pocs 1993).

Data collection

In order to conduct the field survey, which took place in August and September 2014, a total of 23 concentric sample plots with a 5 m (0.0079 ha), 15 m (0.0707 ha), and 20 m (0.1257 ha) radius were strategically placed across the 6,100 hectare forest. Each of the 23 plots contained the following parameters: within a 5 m radius, all small trees and shrubs with Diameter at Breast Height (DBH) <1 cm was counted, and their species were recognized; medium-sized trees and shrubs with DBH ≥1 cm but <5 cm were identified, and their diameters were measured. All large trees and shrubs with DBH ≥5 cm within a 15 m radius had their species identified and their diameters measured. At 1.3 m above-ground, a diameter tape/caliper was used to measure the tree's DBH. In addition, three stems (with small, medium and large DBH) in a plot were selected and measured for height using Suunto hypsometer. Altitude was recorded at the plot center using GPS and slope was measured from the centre of the plot facing the direction of the slope using suunto clinometer.

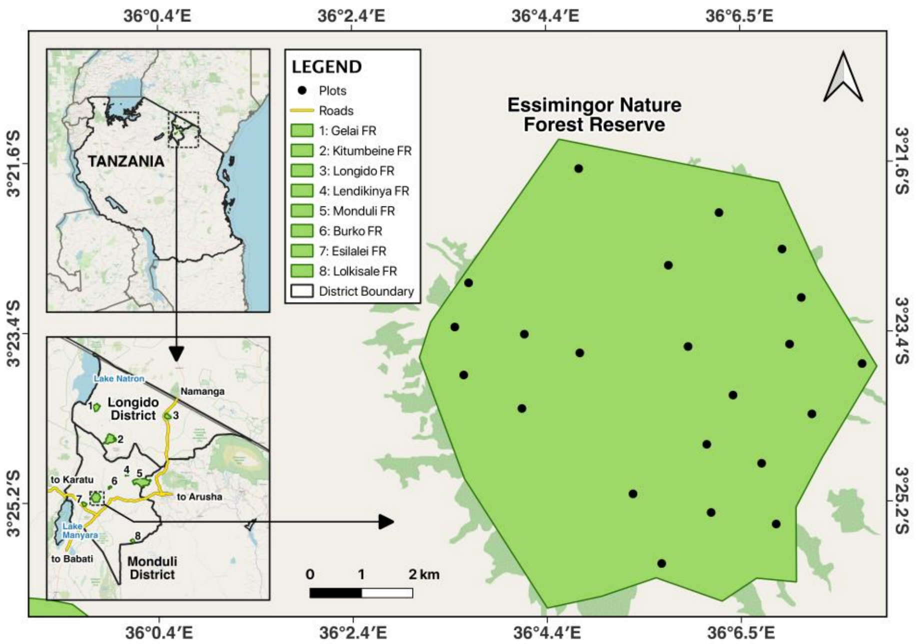

Figure 1. The map of Tanzania showing the location of Essimingor Nature Forest Reserve in the Monduli District and the surveyed sample plots

Data analysis

The collected data were analyzed for species richness, number of stems ha^{-1}, basal area ha^{-1}, volume ha^{-1} and biomass ha^{-1} (Kent 2012). Data on diameter at breast height (DBH) was used to estimate biomass using the developed equations and hence estimate of above-ground and below-ground carbon stocks potential of the forest. The models developed by Masota et al. (2016) for lowland and humid montane forests were used to estimate volume and biomass content (both for above-ground and below-ground) of the forest and after that converted to carbon content per ha of the forest:

Tree height (m) = $2.2936 \times DBH^{0.1225}$ (n = 39, RMSE = 0.434, R^2 = 0.95, DBH range 1.70-56.6 cm).
Total tree volume (m^3) = $g \times ht \times (1.414741-0.21174 \times \ln(DBH))$ (n = 60, RMSE (m^3) = 1.343, R^2 = 0.91, MPE (%) =-0.9).
Total tree above-ground biomass (kg) = $0.9635 \times DBH^{1.9440}$ (n = 60, RMSE (kg) = 1020.3, R^2 = 0.80, MPE (%) = 0.0).
Total tree below-ground biomass (kg) = $7.5811 \times DBH^{1.16801}$ (n = 29, RMSE (kg) = 312.7, R^2=0.71, MPE (%) = 2.0).

Where, g is the tree basal area (m^2), DBH is Diameter at Breast Height (cm), RMSE is root mean square error and R^2 is coefficient of determination. Carbon stock was estimated by multiplying with a conversion factor of 0.49 and presented per hectare (Mg C ha^{-1}) (Manyanda et al. 2020). All data were entered in Excel spreadsheet and analyzed using R (version 4.2.0).

RESULTS AND DISCUSSION

Species richness

Including all size categories (small individuals of DBH < 5 cm and large individuals of DBH ≥ 5 cm) a total of 54 species (29 plant families) of trees and shrubs were identified in the Essimingor Nature Forest Reserve (ENFR) (Table 1). Trees contributed 91% (26 plant families) and shrubs 9% (4 plant families) of the species. Generally, tree and shrub species from the family Euphorbiaceae contributed the most (11%) number of species, followed by those from the families Rutaceae (9%) Rubiaceae (6%) Oleaceae (6%), Meliaceae (6%) and Araliaceae (6%). For trees alone, the greatest number of species was found in Euphorbiaceae family (10) followed by Rutaceae family (10%), Araliaceae (6%), Meliaceae (6%), Oleaceae (6%) and Rubiaceae family (6%), whereas 40% of the shrub species were from the family Anacardiaceae.

Considering different size categories and including both trees and shrubs (small sizes, DBH<5cm and large sizes, DBH ≥ 5cm), a total of 46 species (25 families) were found among large sizes (DBH ≥ 5cm), with Euphorbiaceae (13%), Rutaceae (9%), Meliaceae (7%), Oleaceae (7%) and Rubiaceae (7%) being the most species-rich plant families, while among the small sizes (DBH < 5cm), a total of 25 species (17 families) were observed, with Euphorbiaceae (16%), Rutaceae (12%), Ebenaceae (8%), Malvaceae (8%) and Mimosoidea (8%) contributing the greatest number of species (Table 1). In general, the average number of species per plot was 4 species (range 0-9 species per plot). The species accumulation curve (Figure 2) indicates the rate of encountering new species. Species initially increased rapidly up to the 15th plot and increased slowly up to the 20th plot. However, since only 23 plots were sampled, the later result implies that any further increase in sample size might have included additional new species. The sample size was, considered sufficient to provide baseline information necessary in understanding the composition and diversity of the species in ENFR.

Table 1. Checklist of tree and shrub species identified in Essimingor Nature Forest Reserve (ENFR), Tanzania, showing frequency (%), density (mean±SE), basal area (mean±SE), Dispersion index (DI), Importance Value Index (IVI), stand volume (mean±SE), Above-ground Carbon (AGC) (mean±SE), and Below-ground Carbon (BGC) (mean±SE) for trees and shrubs with a minimum DBH 1 cm (plot size = 15 m radius)

Botanical name	Family	Habit /Life form	Frequency (%)	Density (Stems/ha)	Basal area (m^2/ha)	IVI	DI	Stand volume (m^3/ha)	AGC (Mg/ha)	BGC (Mg/ha)
Cassipourea malosana (Baker) Alston	Rhizophoraceae	Tree	52	52 ±17	2.35±0.77	35.6	8.83	5.73±1.87	11.74±3.85	7.29±2.35
Diospyros abyssinica (Hiern) F.White	Ebenaceae	Tree	30	34±13	1.30±0.55	18.1	8.28	3.21±1.34	6.50±2.73	4.35±1.75
Drypetes natalensis (Harv.) Hutch.	Euphorbiaceae	Tree	17	57±33	1.40±0.73	17.3	31.26	5.00±2.29	10.12±4.60	7.38±3.46
Combretum molle R.Br ex G. Don	Comretaceae	Tree	9	3±2	0.09±0.07	11.3	2.49	0.21±0.18	0.43±0.37	0.31±0.23
Dombeya krkii Mast.	Malvaceae	Tree	4	2±2	0.01±0.01	10.5	3.00	0.03±0.03	0.05±0.05	0.08±0.08
Steganotaenia araliace Hochst.	Araliaceae	Tree	4	1±1	0.02±0.02	10.5	1.00	0.06±0.06	0.12±0.12	0.09±0.09
Teclea nobilis Del.	Rutaceae	Tree	39	22±8	0.43±0.15	8.4	4.53	1.10±0.39	2.17±0.78	1.82±0.63
Drypetes gerrardii Hutch.	Euphorbiaceae	Tree	13	27±21	0.94±0.66	8.4	25.61	0.79±0.65	1.60±1.31	1.03±0.83
Albizia gummifera (J.F.Gmel.) C.A.Sm.	Mimosoidea	Tree	9	6±5	0.58±0.44	7.7	6.65	1.32±1.00	2.83±2.14	1.31±1.01
Ficus lutea Vahl	Moraceae	Tree	4	2±2	0.07±0.07	6.8	3.00	0.18±0.18	0.36±0.36	0.25±0.25
Fagaropsis angolensis (Engl.) H.M.Gardner	Rutaceae	Tree	4	1±1	0.46±0.46	6.0	2.00	0.85±0.85	2.14±2.14	0.57±0.57
Rhus vulgaris Meikle	Anacardiaceae	Shrub	4	3±3	0.02±0.02	5.8	5.00	0.05±0.05	0.09±0.09	0.13±0.13
Catha edulis Forssk.	Celasteraceae	Tree	9	2±2	0.45±0.42	4.8	2.43	0.91±0.84	2.14±1.99	0.73±0.64
Croton megalocarpus Hutch.	Euphorbiaceae	Tree	13	5±3	0.40±0.22	4.6	2.51	0.91±0.51	1.95±1.10	0.96±0.53
Calodendrum capense (L.f.) Thunb.	Rutaceae	Tree	13	9±6	0.42±0.25	4.1	5.79	1.01±0.60	2.10±1.24	1.25±0.75
Ekebergia capensis Sparrm.	Meliaceae	Tree	13	3±2	0.25±0.20	3.7	1.65	0.57±0.44	1.21±0.96	0.60±0.41
Dombeya rotundifolia (Hochst.) Planch.	Malvaceae	Tree	13	2±1	0.02±0.02	3.1	0.91	0.07±0.04	0.13±0.08	0.13±0.08
Olea europaea L.	Oleaceae	Tree	4	2±2	0.46±0.46	2.5	4.00	0.97±0.97	2.19±2.19	0.79±0.79
Celtis africana Burm.f.	Urmaceae	Tree	13	3±2	0.16±0.12	2.1	2.07	0.36±0.26	0.76±0.57	0.41±0.25
Commiphora africana (Rich.) Engl.	Burseraceae	Tree	4	1±1	0.02±0.02	2.1	1.00	0.05±0.05	0.10±0.10	0.08±0.08
Cussonia arborea Hochst. Ex A. Rich	Araliaceae	Tree	4	3±3	0.16±0.16	2.0	5.00	0.39±0.39	0.78±0.78	0.49±0.49
Maytenus senegalensis (Lam.) Exell	Celasteraceae	Tree	4	4±4	0.18±0.18	2.0	7.00	0.44±0.44	0.91±0.91	0.55±0.55
Mystroxylon aethiopicum (Thunb.) Loes	Melastomataceae	Tree	9	9±8	0.13±0.12	1.8	12.06	0.35±0.30	0.68±0.60	0.62±0.55
Clausena anisata (Willd.) Hook.f. ex Benth.	Rutaceae	Tree	4	2±2	0.01±0.01	1.5	4.00	0.02±0.02	0.05±0.05	0.08±0.08
Rhus natalensis Bernh.ex Krauss	Anacardiaceae	Shrub	4	1±1	0.00±0.00	1.5	1.00	0.01±0.01	0.01±0.01	0.02±0.02
Acacia hockii De Wild.	Mimosoidea	Tree	4	1±1	0.00±0.00	1.4	1.00	0.01±0.01	0.01±0.01	0.02±0.02
Lepidotrichilia volkensii (Gürke) Leroy	Euphorbiaceae	Tree	4	1±1	0.19±0.19	1.4	1.00	0.40±0.40	0.93±0.93	0.29±0.29
Pschotria sp.	Rubiaceae	Tree	9	5±4	0.04±0.04	1.4	6.17	0.12±0.11	0.23±0.22	0.26±0.24
Bersama abyssinica Fresen.	Melianthaceae	Tree	4	2±2	0.01±0.01	1.4	4.00	0.02±0.02	0.04±0.04	0.08±0.08
Ficus thonningii Blume	Moraceae	Tree	4	1±1	0.14±0.14	1.3	2.00	0.31±0.31	0.67±0.67	0.32±0.32
Turraea robusta Gürke	Meliaceae	Tree	4	1±1	0.20±0.20	1.2	1.00	0.41±0.41	0.95±0.95	0.30±0.30
Ilex mitis (L.) Radlk.	Aquifoliaceae	Tree	9	5±4	0.13±0.09	1.2	4.86	0.32±0.23	0.64±0.46	0.50±0.37
Denbolia borbonica Scheff.	Sapindaceae	Tree	13	3±2	0.03±0.02	1.1	2.07	0.08±0.06	0.16±0.11	0.18±0.12
Olea capensis L.	Oleaceae	Tree	4	3±3	0.05±0.05	1.1	5.00	0.14±0.14	0.26±0.26	0.25±0.25
Prunus africana (Hook.f.) Kalkman	Rosaceae	Tree	4	1±1	0.07±0.07	1.0	1.00	0.17±0.17	0.36±0.36	0.17±0.17
Senna sp.	Caesalpinioideae	Tree	9	1±1	0.05±0.04	0.7	0.95	0.11±0.09	0.23±0.19	0.15±0.12
Casearia battiscombei R.E.Fr.	Flacortiaceae	Tree	4	1±1	0.05±0.05	0.7	2.00	0.13±0.13	0.25±0.25	0.17±0.17
Vangueria infausta Burch.subsp.*infausta*	Rubiaceae	Tree	4	1±1	0.02±0.02	0.7	1.00	0.04±0.04	0.08±0.08	0.07±0.07

Schrebera alata (Hochst.) Welw.	Oleaceae	Tree	4	1±1	0.12±0.12	0.6	2.00	0.29±0.29	0.60±0.60	0.30±0.30
Memecylon sp.	Melastomataceae	Tree	4	1±1	0.03±0.03	0.5	2.00	0.08±0.08	0.15±0.15	0.12±0.12
Rinorea illicifolia (Welw. Ex Oliv.) Kuntze	Violaceae	Tree	9	1±1	0.01±0.01	0.4	0.95	0.03±0.02	0.05±0.04	0.06±0.05
Turraea holstii Gürke	Meliaceae	Tree	4	1±1	0.01±0.01	0.4	1.00	0.02±0.02	0.04±0.04	0.04±0.04
Xylopia sp.	Annonaceae	Tree	4	1±1	0.00±0.00	0.3	1.00	0.00±0.00	0.01±0.01	0.02±0.02
Margaritaria discoidea (Baill.) Webster	Euphorbiaceae	Tree	4	1±1	0.00±0.00	0.3	1.00	0.01±0.01	0.01±0.01	0.02±0.02
Erythrococca sp.	Euphorbiaceae	Shrub	4	1±1	0.01±0.01	0.2	2.00	0.03±0.03	0.06±0.06	0.07±0.07
Vangueria sp.	Rubiaceae	Tree	4	1±1	0.00±0.00	0.1	1.00	0.00±0.00	0.01±0.01	0.02±0.02
Apodites dimidiata E.Mey. ex Arn.	Icacinaceae	Tree	+							
Commiphora schimperi (O.Berg) Engl.	Burseraceae	Tree	+							
Euclea divinorum Hiern	Ebenaceae	Tree	+							
Grewia similis K. Schum.	Tiliaceae	Shrub	+							
Harrisonia abyssinica Oliv.	Simaroubaceae	Shrub	+							
Premna sp.	Verbenaceae	Tree	+							
Schefflera volkensii (Engl.) Harms	Araliaceae	Tree	+							
Vepris simplicifolia (Verd.) Mziray	Rutaceae	Tree	+							
Total (all species			**417**	**288±173**	**11.47±7.23**	**200**		**27.29±16.32**	**56.93±34.60**	**34.71±19.72**

Note: +: Indicates species identified among smaller individuals within 5m radius plots (DBH<5cm), Mg/ha: Megagram per hectare

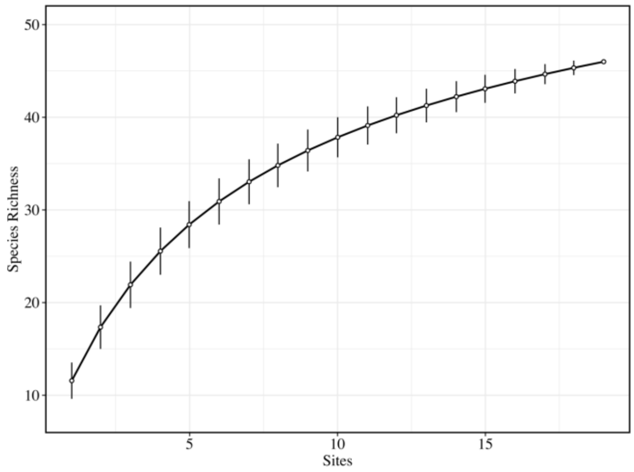

Figure 2. Species accumulation curve in Essimingor Nature Forest Reserve (ENFR), Tanzania

The species richness of 54 different trees and shrubs and 29 plant families reported in this study using 23 sample plots of 0.071 ha is lower when compared to other studies from other tropical forests. For instance, Sitati et al. (2014) found a total of 75 tree and shrub species from 100 plots of 0.02 ha established in a dry evergreen forest of Gelai Forest Reserve located in Longido District in Tanzania; Mwaluseke (2015) found a total of 79 tree and shrub species from 56 concentric sample plots of 0.071 ha established in a dry evergreen forest of Lendikinya Forest Reserve in Monduli District, Tanzania; Kayombo et al. (2022) found a total of 84 tree species from 60 plots of 20 m × 20 m established in a dry evergreen forest of Monduli Mountain Forest Reserve in Tanzania; Boz and Maryo (2020) from Ethiopia reported a total of 76 woody species representing 40 families in a dry semi-evergreen Afromontane forest from 64 (0.04 ha) sample plots; Masresha and Melkamu (2022) reported 19 values of different species richness ranging from 55-122 tree species from dry evergreen Afromontane forest patches in Ethiopia; Erenso et al. (2014) found a total of 95 species from a dry evergreen forest in Ethiopia, and Daba et al. (2022) recorded a total of 68 tree and shrub species and 33 families from 100 plots of 20 m × 20 m from the moist Afromontane forest of South-western Ethiopia.

However, compared to other studies, the species richness of 54 was relatively higher despite the smaller sample size used in this study (23 plots). For instance, Sitati et al. (2016) found a total of 43 tree and shrub species from 77 plots of 0.071 ha established in a dry evergreen forest of Ketumbeine Forest Reserve located in Longido District in Tanzania; Masresha and Melkamu (2022) in Ethiopia reported seven different values of species richness ranging from 36-50 tree species; Mialla (2002) reported species richness of 42 trees and shrubs from 48 sample plots of 0.071 ha; Dugilo (2009) reported species richness of 42 species from 28 sample plots of 0.071 ha; Feroz et al. (2016) reported 40 species (in 0.16 ha) in tropical wet evergreen forest in Bangladesh; Sutomo and van Etten (2023) reported 20 tree species (in 19 genera and 13 families) from 25 sample plots of 0.25 ha in a seasonally dry tropical forest of Baluran National Park (BNP), located in the Situbondo Regency, East Java Province, in Indonesia and Kacholi et al. (2015) reported six different values of species richness ranging between 17-52 from seven individual tropical wet forests of Uluguru forests in Tanzania.

The species richness found in this study falls within the range of species commonly found in miombo woodland of 40-229 species (Mwakalukwa et al. 2014; Jew et al. 2016). This shows that ENFR has a relatively large number of forest plant species, stressing the significance of its conservation. The higher values found elsewhere could be attributed to greater sampling effort (total area, number of sample plots and sizes) employed by other studies as compared to this study. For example, Erenso et al. (2014) apart from using 60 sample plots also conducted additional opportunistic sampling in selected microhabitats. However, the studies also included liana and epiphytes, but if liana and epiphytes are excluded, the total number of species is reduced to 76.

Species diversity

Shannon-Wiener diversity indices for large (DBH ≥5cm) and small (DBH <5cm) individuals were 2.70 and 2.93, respectively, and the Simpson index for large individuals was 0.13 and that of small individuals was 0.07. The following species were observed to have the greatest contribution to the Shannon-Wiener diversity index of large individuals (DBH ≥5cm): *Drypetes natalensis* (0.35), *C. malosana* (0.31), *Diospyros abyssinica* (0.25), *Teclea nobilis* (0.19), *C. capense* (0.10), *Mystroxylon aethiopicum* (0.10), and *Drypetes gerradii* (0.09). For smaller ones (DBH < 5cm), the greatest contributions were from *Pschotria* sp. (0.28), *Clausena anisata* (0.23), *A. gummifera* (0.19), *Combretum molle* (0.19), *Dombeya rotundifolia* (0.19), and *D. natalensis* (0.17). The index of dominance (1-D) for large individuals was 0.87 and for smaller individuals was 0.93; the index for evenness or equitability (J) for large individuals was 0.71 and for smaller individuals were 0.91.

In terms of frequency of occurrence for large sizes standing individuals, *C. malosana* was the most frequent species (52% of plots), followed by *T. nobilis* (39%) and *D. abyssinica* (30%), while for small sizes *C. anisate* (22%), *C. molle* (13%), and *D. natalensis* (13%) were the most frequent species. The Importance Value Index (IVI) for large individuals (DBH ≥ 5cm) shows that *C. malosana* (35.6), *D. abyssinica* (18.1), and *D. natalensis* (17.3) were the most important species. These tree species resemble those earlier reported from this forest (Lovett and Pocs 1993).

The values of the Shannon-Wiener index (*H´*= 2.70) for trees and shrubs in the present study are lower than those documented in other tropical forests. For instance, Sitati et al. (2014) reported a *H´* value of 2.848 from a dry evergreen forest of Gelai Forest Reserve in Tanzania; Mwaluseke (2015) reported a *H´* value of 3.46 from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania; Boz and Maryo (2020) from Ethiopia reported an average *H´* value of 3.38; Kacholi et al. (2015) found an overall *H´* value of 4.03 from the Uluguru forests in Tanzania; and Tynsong et al. (2022) reported a *H´* values ranging from 3.74-3.95 (mean 3.85±0.06) from the tropical evergreen forests in India. However, *H´* values in this study are much higher than those documented by Sitati et al. (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania (*H´* value of 2.3616); Kayombo et al. (2022) reported a *H´* value of >1.5 from Tanzania, Sutomo and van Etten (2023) reported *H´* values ranging from 0.6-1.9 (mean 1.4) from seasonally dry tropical forest in Indonesia; Erenso et al. (2014) reported *H´* value of 1.79 and Dugilo (2009) reported *H´* value of 1.298. However, the *H´* value of 2.70 in this study falls in the range of *H´* value commonly found in other dry evergreen Afromontane forest patches as in Ethiopia where Masresha and Melkamu (2022) reported 18 different *H´* values ranging between 1.31-3.35 and in miombo woodland where values ranging from 1.05-4.27 were reported (Shirima et al. 2011; Mwakalukwa et al. 2014; Jew et al. 2016). According to Magurran (2004) and Mwakalukwa et al. (2014), the *H´* values normally varies between 1.5 and 4.5 and rarely exceeds 5, and a threshold value of 2 has been mentioned to be the minimum value, above which an ecosystem can be regarded as medium to highly diverse. Therefore, the value of 2.70 found in this study implies that the ENFR has high diversity in tree and shrub species. High diversity might be attributed to relatively low levels of disturbance experienced in the forest as there were no signs of tree cutting happening in the reserve as observed by Lovett and Pocs (1993) and during this study.

Spatial distribution

Table 1 lists the dispersion indices (DI) for each species. The values of the dispersion index range from 0.91, which indicates nearly complete spatial randomness or slight underdispersion, to 31.26, which indicate significant overdispersion and suggests a patchy or clustered distribution. Out of 46 species, 31 species (67%) had DI > 1, 12 species (26%) had DI = 1, and 3 species (7%) had DI <1, indicating that the majority of species have patchy distributions within the forest. The *D. rotundifolia* (0.91) had the species with the lowest estimated DI, and *D. natalensis* had the highest estimated DI (31.26). The most prevalent species are severely overdispersed, and these include *D. natalensis* (DI = 31.26), *C. malosana* (DI = 8.83), *D. abyssinica* (DI = 8.28), and *D. gerradii* (DI = 25.61).

Stand density

Large individuals with DBH ≥5cm had a total mean stem density of 288±173 stems ha^{-1}, while small individuals with DBH <5cm (including those with DBH 1cm) had a total mean stem density of 736±621 stems ha^{-1}. The *D. natalensis* (19.8% of 288 stems ha^{-1}) was the most prevalent species among large individuals, followed by *C. malosana* (17.9%), *D. abyssinica* (11.9%), and *D. gerradii* (9.4%). *Pschotria* sp. (14.3 of 736 stems ha^{-1}) was the species with the highest abundance among the smaller individuals, followed by *C. anisata* (9.8%), *A. gummifera* (7.5%), *C. molle* (7.5%), and *D. rotundifolia* (7.5%). The distribution of trees to size classes generally exhibited the typical reverse J shape (Figure 3).

The stem density of 288±173 stems ha^{-1} for the woody species with DBH ≥ 5 cm reported in this study is lower than that documented by Dugilo (2009) from dry evergreen forest of Selela village forest reserve in Tanzania who reported a mean density of 310 stems ha^{-1}; Sitati et al. (2014) from a dry evergreen forest of Gelai Forest Reserve in Tanzania reported a mean density of 377 stems ha^{-1}; Sitati et al. (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania reported a mean density of 435 stems ha^{-1} and Gebeyehu et al. (2019) from five forests in Ethiopia reported a range of 365.6-664.1 stems ha^{-1} with a mean of 636.5 stems ha^{-1}. Kacholi et al. (2015) from seven tropical wet forests in the Uluguru forests in Tanzania reported an overall mean density of 390 stems ha^{-1}.

The stem density of 288±173 stems ha^{-1} is ten times lower than those reported by Mialla (2002) from Monduli Forest Reserve a dry evergreen mountain forest in Tanzania, who reported a mean density of 1,822 stems ha^{-1}, Mwaluseke (2015) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania reported a mean density of 1,398±679 stems ha^{-1}; Atomsa and Dibbisa (2019) reported a mean density of 1,453 stems ha^{-1} from Ethiopia, Boz and Maryo (2020) reported the total density of 1,745.3 stems ha^{-1} from Ethiopia whereas Tynsong et al. (2022) reported a mean density of 2,005±48.01 trees ha^{-1} with a range from 1944 to 2100 trees ha^{-1} in the tropical evergreen forests of the North-East India.

However, mean stems density values of 288±173 stems ha^{-1} from this study fall in the range of density value found in miombo woodland of 281-1,521 stems ha^{-1} (Shirima et al. 2011; Mwakalukwa et al. 2014). This implies that ENFR is among the highly stocked dry evergreen montane forests in Tanzania and other forests in the tropical countries. The higher density reported in other studies might be attributed to the influence of microclimate which creates favorable conditions for the growth of more species. Presence of wildlife animals such as elephants could have affected the density of species in the ENFR. The density distribution (Figure 3) indicated a dominance of small trees depicting the normal reversed "J" shape which indicates strong regeneration status and recruitment of the forest, a tendency normally observed in the natural mixed species of different ages.

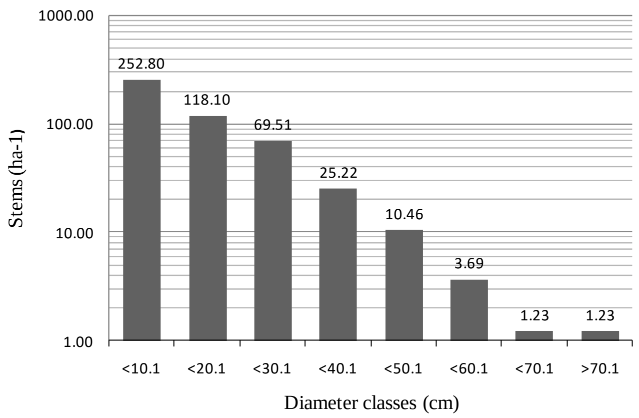

Figure 3. Density of trees ≥1cm DBH by diameter class in the Essimingor NFR (n = 23). NB: logarithmic scale on vertical axis

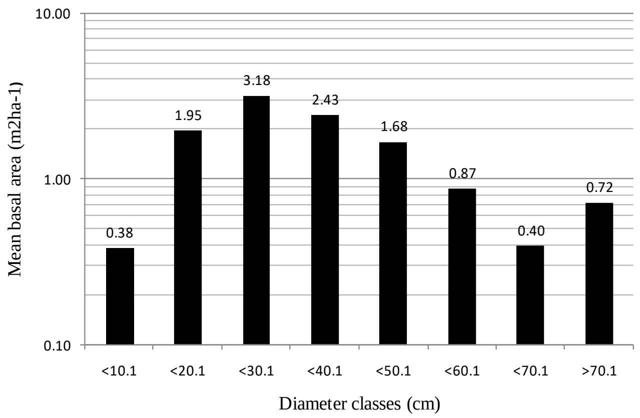

Figure 4. Distribution of basal area per hectare for trees ≥1cm DBH by diameter classes in the Essimingor NFR (n = 23). NB: logarithmic scale on vertical axis

Basal area

The mean basal areas for large (≥5cm DBH) and small individuals (<5cm DBH) found in Essimingor Nature Forest Reserve (ENFR) were 11.47±7.23 m^2ha^{-1} (Table 1, Figure 4) and 0.13±0.10 m^2ha^{-1}, respectively. The species contributing most to the basal area of large individuals were *C. malosana* (20.5%), *D. natalensis* (12.2%), *D. abyssinica* (11.3%), and *D. gerradii* (8.2%), while those contributing most to the basal area of smaller individuals were *C. anisate* (23.3%), *D. natalensis* (22.9%), *Erythrococca* sp. (19%), and *Margaritaria discoidea* (16.9%).

The mean basal area of 11.47±7.23 m^2ha^{-1} determined in this study is much lower than that documented in other mountain forests which normally range between 20-60 m^2ha^{-1} (Sitati et al. 2016). For instance, Sitati et al. (2014) reported a mean basal area of 26.87 $m^2ha^{-1}$from a dry evergreen forest of Gelai Forest Reserve in Tanzania; Sitati et al. (2016) from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania reported a mean basal area of 30.49±2.3; Mialla (2002) reported a mean basal area of 69.3±1.6 $m^2ha^{-1}$from Monduli dry evergreen mountain forest in Tanzania; Kacholi et al. (2015) from Uluguru mountain forests reported a mean basal area of 24 m^2ha^{-1}; and Tynsong et al. (2022) reported a range from 52.26 to 68.05 m^2ha^{-1} (mean 61.72±4.82 m^2ha^{-1}) in the tropical evergreen forests in India. The basal area determined in this study is ten times lower than a mean basal area of 114.64 m^2ha^{-1} reported by Erenso et al. (2014) from Ethiopia, and a mean basal area of 126.47 m^2ha^{-1} from lowland dry semi-evergreen forest in Ethiopia (Boz and Maryo 2020). Siraj and Zhang (2018) recorded a total basal area of 454.52 $m^2{\cdot}ha^{-1}$ from a dry Afromontane forest in Ethiopia. However, the mean basal area reported in this study is higher than 11.42±5.41 m^2ha^{-1} reported by Mwaluseke (2015) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania.

The mean basal area found in this study is within the range of values commonly found in other forests including miombo woodland of 3.9-16.7 m^2ha^{-1} (Backeus et al. 2006; Dugilo 2009; Mwakalukwa et al. 2014). The low basal area obtained in this study could be due to low stem density observed in the reserve. The higher basal area observed in other studies could be associated with the presence of high stem density of individuals in the higher DBH classes as compared to other forests.

Stand volume

The mean standing volume per hectare for individuals with diameter (≥5cm DBH) found in the ENFR was 27.3±16.3 m^3ha^{-1} (Table 1, Figure 5). The species contributing most to the standing volume of large individuals were *C. malosana* (21% = 5.73±1.87 m^3ha^{-1}), *D. natalensis* (18.3%), *D. abyssinica* (11.7%), *A. gummifera* (4.8%), and *T. nobilis* (4.0%). Their diameter classes distribution is presented in Figure 5. In general, the distribution of standing trees with diameter ranging from 20.1-50.1 cm contributed most to the mean total standing volume in the forest.

The total mean volume of 27.3±16.3 m^3ha^{-1} reported in this study for trees and shrubs with DBH ≥ 5 cm was considered lower than 40.03±11.21 m^3ha^{-1} reported by Dugilo (2009) from Selela village forest reserve and a value of 54.47±24.1 m^3ha^{-1} from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania (Mwaluseke (2015) while Sitati et al. (2016) reported a much higher value of 395.07±14 m^3ha^{-1} from a dry evergreen forest of Ketumbeine Forest Reserve in Tanzania. However, the volume reported in this study is within the range of 16.7 to 92.17±39.0 m^3ha^{-1} commonly reported in other forests including miombo woodland (Mwakalukwa et al. 2014; and at least two recent reports e.g., Chamshama et al. 2004 [76.1m^3ha^{-1}]; Maliondo et al. 2005 [54.0 m^3ha^{-1}]; Sawe et al. 2014 [32.6 m^3ha^{-1}]). The lower volume reported by this study might be caused by the presence of many small-sized trees and shrubs in the forest which contributed less to the total volume since large size woody plants were few. The scarcity of large trees in this study was attributed to microclimate condition (Sitati et al. 2016) and presence of wild animals like elephants which limit the growth of trees to large diameter classes.

Biomass and carbon storage

The mean above-ground biomass and potential carbon stocks of the forest reserve for trees and shrubs with diameter ≥5cm were 116.19±70.61 Mg ha^{-1} and 56.93±34.60 Mg C ha^{-1} respectively, while the mean below-ground biomass and potential carbon stocks of the forest reserve for trees and shrubs with diameter ≥5cm were 70.84±40.24 Mg ha^{-1} and 34.71±19.72 Mg C ha^{-1}, respectively (Table 1, Figure 6). Tree species which had high contribution to the observed above-ground carbon density were *C. malosana* (11.74±3.85 Mg C ha^{-1}), *D. natalensis* (10.12±4.60 Mg C ha^{-1}), *D. abyssinica* (6.50±2.73 Mg C ha^{-1}), *A. gummifera* (2.83±2.14 Mg C ha^{-1}), *Olea europaea* (2.19±2.19 Mg C ha^{-1}), *T. nobilis* (2.17±0.78 Mg C ha^{-1}), *C. edulis* (2.14±1.99 Mg C ha^{-1}), *F. angolensis* (2.14±2.14 Mg C ha^{-1}) and *C. capense* (2.10±1.24 Mg C ha^{-1}). On the other hand, species with high contribution to the observed below-ground carbon density were *D. natalensis* (7.38±3.46 Mg C ha^{-1}), *C. malosana* (7.29±2.35 Mg C ha^{-1}), *D. abyssinica* (4.35±1.75 Mg C ha^{-1}), *T. nobilis* (1.82±0.63 Mg C ha^{-1}), *A. gummifera* (1.31±1.01 Mg C ha^{-1}), *C. capense* (1.25±0.75 Mg C ha^{-1}), and *D. gerradii* (1.03±0.83 Mg C ha^{-1}).

The total mean aboveground carbon stocks of the trees and shrubs with DBH ≥ 5 cm of 56.93±34.60 Mg C ha^{-1} determined in this study is lower than that documented from other tropical forests. For instance, Asrat et al. (2022) reported two values of 180.18±17.19 t·C ha^{-1} and 106.71±7.64 t·C ha^{-1} from dry evergreen Afromontane forests in Ethiopia; Mauya and Madundo 2021 reported a range of 88.5 Mg C ha^{-1} to 436 Mg C ha^{-1} with an overall average of 175.54 Mg C ha^{-1} from mountain forests in Tanzania; Wondimu et al. (2021) reported a value of 332.69±37.42 t C ha^{-1} from a dry evergreen Afromontane forest in Ethiopia; Gebeyehu et al. (2019) reported a mean value of 191.6±19.7 Mg C ha^{-1} from five different dry Afromontane forests in Ethiopia and Daba et al. (2022) reported a value of 203.80±12.38 t·C ha^{-1} from moist Afromontane forest in Ethiopia. From a tropical dry forest in India, Naveenkumar et al. (2017) reported a range of 99 to 216 t·C ha^{-1}, and Rawal and Subedi (2022) reported a value of mean carbon stock of 59.55 t C ha^{-1} from one of the community forests in Nepal.

In contrast, the total mean aboveground carbon stocks found in this study is higher than that reported by Mwaluseke (2015) from a dry evergreen forest of Lendikinya Forest Reserve in Tanzania who reported a value of 16.04±7.7 t C ha^{-1}; Biadgligne et al. (2022) reported two values of 14.84±1.27 t C ha^{-1} and 3.49±0.66 t C ha^{-1} from two community forests from Ethiopia; Solomon et al. (2017) who reported a mean carbon stock of 40.99±0.40 t·C ha^{-1} from dry forests in Ethiopia; Biadgligne et al. (2022) from Ethiopia reported a mean carbon stock density of 43.72±3.79 t C ha^{-1}; Swai et al. (2014) reported a mean carbon stock of 48.4±8.0 t C ha^{-1} from Hanang mountain forest in Tanzania; Shirima et al. (2015) reported a value of 54.30±5.84 Mg C ha^{-1} from several montane sites in Tanzania and Jew et al. (2016) reported a mean carbon density of 14.6 t C ha^{-1}. from one site of miombo vegetation in Tanzania. Elsewhere, Rawal and Subedi (2022) reported a value of mean carbon stock of 51.86 t C ha^{-1} from one of the community forests in Nepal. However, very few studies have reported estimates of below-ground carbon density (MNRT 2015; Mauya et al. 2019).

The high value reported by several authors could be due to differences in climatic conditions of these sites in terms of rainfall received and the presence of many large trees which had significant contribution to the total mean carbon density than the presence of many small trees reported in this study (Mauya and Madundo 2021). According to Mauya and Madundo (2021) climate, topography as well as estimation methods particularly the selection of allometric models is also key factors when it comes to accurate estimation of AGB and AGC in the different study sites.

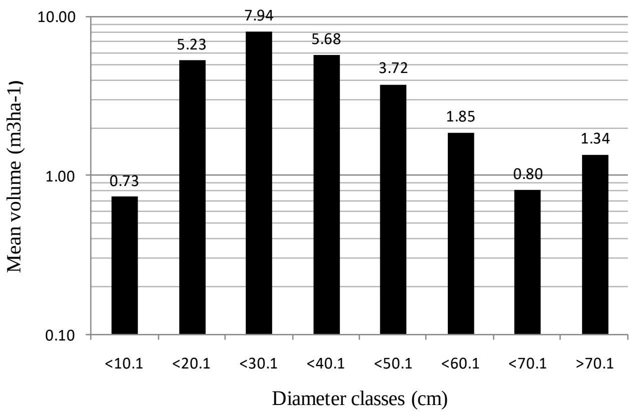

Figure 5. Distribution of mean volume per hectare for trees ≥5cm DBH by diameter classes in the Essimingor NFR, Tanzania (n = 23). NB: logarithmic scale on vertical axis

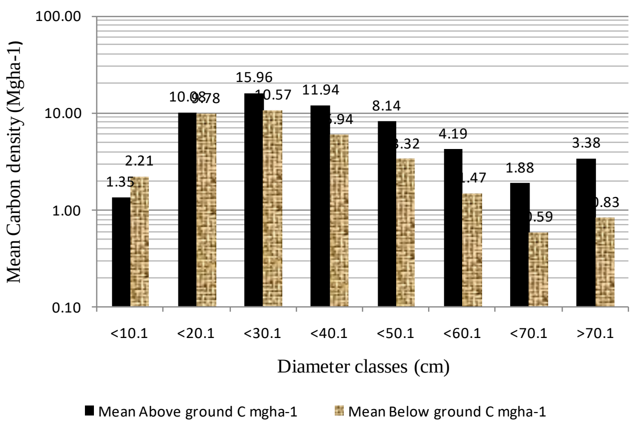

Figure 6. Distribution of both above-ground and below-ground mean carbon density of tree species with diameter ≥ 5cm by diameter classes in the Essimingor NFR, Tanzania (n = 23). NB: logarithmic scale on vertical axis

In this study we used models developed for lowland and humid montane forests (Masota et al. 2016) to estimate volume and biomass content (both for above-ground and below-ground) of the forest as there were no models developed specific for these vegetation types (Holmes 1995). These models were selected due to the fact that the climatic conditions of the area where the models were developed resemble with the condition of the study site especially on the amount of rainfall received in the study area. According to Lovett and Pocs (1993) rainfall in ENFR ranges from 750-1000 mm/year on the lower slopes but higher than 1,500 mm/year with mist effect on the higher altitudes on the upper slopes. According to Masota et al. (2016) their study site receives an annual rainfall ranging between 1,800 and 2,200 mm. The slight differences in the amount of rainfall could have slightly affected the total observed estimates.

In conclusion, the results showed that ENFR has relatively rich diversity of woody species (54 species), and high species diversity values (*H*'=2.70) as compared to many of dry evergreen montane forests of Tanzania and other tropical forests. Tree density and basal area are lower in our studied area as compared to other tropical forests. The above-ground carbon stock was relatively lower compared to those reported in other studies from dry evergreen montane forests. However, this study is among the few studies to report estimates on below-ground carbon density from dry evergreen montane forests in Tanzania and elsewhere. These data on carbon stock obtained provides baseline data for the possibility of future payment schemes on REDD+ project implementation in Tanzania. Quantification of other carbon pools such as in soil, dead wood and surface litter should be considered for estimation of the total carbon stocks potential of this forest.

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Bowen ratio and evapotranspiration dynamics of oil palm

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Abstract. *Asyura MF, June T, Salmayenti R. 2023. Bowen ratio and evapotranspiration dynamics of oil palm. Intl J Trop Drylands 7: 37-45.* To optimize its biophysical processes, plant needs water and this requirement can be quantified as Evapotranspiration (ET). There are various methods for estimating ET from a vegetated surface, and Bowen ratio is one method commonly used for agricultural purposes. We use Bowen ratio method to estimate ET from oil palm (Elaeis guineensis Jacq.) plantation in PT. Perkebunan Nusantara VI, Batang Hari, Jambi Province, Indonesia for the period 2014-2015 using observed micrometeorology data and looked at the strength of micrometeorological components in influencing the daily and diurnal patterns, which include net radiation (Rnetto), heat fluxes (latent LE and sensible H), actual vapor pressure (ea), soil moisture (SM), wind speed (WS), air temperature (Ta), ground heat fluxes (G), and LE-H. We found that the daily pattern of Bowen ratio was strongly influenced by LE-H, LE, H, SM, shown by a correlation coefficient of -0.85, -0.75, 0.84, -0.58, respectively. The diurnal pattern of Bowen ratio was affected by ea with a correlation coefficient of -0.52, while daily ET was strongly influenced by Rnetto, LE-H, H, Bowen ratio with a correlation coefficient of 0.85, 0.95, -0.63, -0.75 respectively. WS, Ta, Rnetto, G, ea, RH and LE-H affected diurnal ET with a correlation coefficient of 0.72, 0.72, 0.96, 0.89, 0.51, -0.64 and 0.9, respectively. Within this period of 2014-2015 there were 7 months where rainfall was greater than ET (wet period December 2014 to April 2015, November 2015) and 5 months where rainfall was lower than ET (dry period May 2015 to October 2015). During this long dry period of 2015, caused by strong El Nino events, oil palms became vulnerable to drought.

Keywords: Latent heat fluxes, net radiation, sensible heat fluxes, temporal analysis ET, water requirement

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq.) is a plant species belonging to the subfamily Cocoideae from tropical region of South America. The first industrialization of oil palm in Indonesia was when the dutch colonial in 1848 brought these plants to Kebun Raya Bogor (Benny et al. 2015). These days oil palm has a major contribution to Indonesia's GDP because the Crude Palm Oil (CPO) product from plants is used in many industries such as food, cosmetics and pharmacy (Apriyanto et al. 2020; Darkwah et al. 2020). Indonesia has an area of oil palm plantations, approximately 11,67 million hectares, with the largest parts in North Sumatra and Riau. Total oil palm production in Indonesia could reach 33,50 million tonnes annually (Sirait 2020). Solar radiation is crucial for growth and development, especially visible light with a 400-700 nm wavelength for carbon assimilation, photosynthesis, and respiration to grow and produce the best quality fruit (Suryadi et al. 2013). According to Evizal et al. (2020), oil palm is categorized into 5 ages: ages 3 to 8 are young, ages 9 to 13 are juvenile, ages 14 to 20 are mature, ages 21 to 24 are old and more than age 25 is vulnerable. Oil palm could grow in regions where sunshine duration is about 5 to 7 hours long, which suits most tropical regions like Indonesia (Putra et al. 2017).

Abundant solar radiation throughout the year in tropical regions due to earth's relative position to the sun makes Indonesia have 2 seasons: the rainy and dry seasons, with 2 transition seasons in between. This complex and dynamic phenomenon also makes Indonesia had 3 main rainfall patterns which are monsoonal, equatorial and lokal pattern (Molle and Larasati 2020). Rainfall pattern significantly impacts growth and palm oil development because it is sensitive to water stress, especially in dry season, and requires tremendous water resources for optimum growth (Wagino et al. 2018). One of the natural factors that makes water loss in a plant is the evapotranspiration process. Evapotranspiration is a combined process between plants transpiration and surface evaporation. The evaporation process is caused by surrounding micrometeorological conditions such as air temperature, wind speed, humidity, solar radiation, actual vapor pressure and sunshine duration. Evapotranspiration is crucial for water resources management in order to make more effective and sustainable agricultural practices (Singh et al. 2018). Estimating the evapotranspiration rate could be done with various methods such as aerodynamics, Penman-Monteith, and Bowen ratio (June et al. 2018), but this research focuses on the energy balance method using Bowen ratio calculation. Bowen ratio, by definition, is between sensible and latent heat flux.

According to Xuanlan et al. (2021), research shows that the Bowen ratio value is influenced by a complex interaction between micrometeorological variables, vegetation and soil characteristics but the dominant factors are air temperature, humidity and albedo. Bowen ratio calculation needs micrometeorological data such as air temperature, net radiation, ground heat flux, and psychrometric constant, with two minimum elevations to quantify energy transfer vertically. Bowen ratios have different values for various land cover, and according to Kuang et al. (2015), urban populated, dense areas had a bigger value of Bowen ratio compared to a rural area with a high concentration of vegetation cover. Bowen ratio and evapotranspiration on various land cover need to be reviewed for temporal analysis if there's an influence of seasonal and daily cycles. These two variables could be varied within the same land cover in a certain period.

MATERIALS AND METHODS

Study area

This research is conducted on site of PT. Perkebunan Nusantara VI in Batang Hari District, Jambi Province, Indonesia. Geographically PTPN VI is located at 01° 41' 35'' S and 103° 23' 29'' E. There are five land cover types, but study site is mostly covered with tropical rainforest and plantations shown by green color. A black rectangle box marks PTPN VI in Figure 1.

Jambi Province is a central production of good quality oil palm because the location is agglomerated for the specialization of oil palm commodities due to soil characteristics that suit growth and development (Wahyudi 2022). Batang Hari District is 11,59% of the total area in Jambi Province where this district continues to develop oil palm plantation areas, indirectly caused by local farmers and the private sector because this commodity is economically profitable compared to others. Farmers and the private sector also realized that oil palm relatively has fewer pests thus, the operational cost is low and profit could be maximum (Anggreany et al. 2013).

PTPN VI has a 2025 Ha area of oil palm plantation mostly covered by ultisol soil where nutrient content is low but could hold a high water concentration, thus it suits for oil palm characteristics (Adriadi et al. 2012). The optimal vegetation density for oil palm in PTPN VI is 120 plants per hectare and each tree is approximately 9 meters apart. If oil palm is too dense, the sunlight cannot reach individual trees optimally and tree will also compete for other resources and make businesses less profitable. Compared to the rainforest, where trees compete each other, the density of oil palm is lower thus Bowen ratio value is usually higher (Kuang et al. 2015). Two patterns influence rainfall in Jambi Province: on the eastern side is dominated by monsoonal while the western side is dominated by equatorial (Pradiko et al. 2016). PTPN VI is located in Batang Hari District, which are the eastern side of Jambi Province, thus monsoonal pattern has dominated this region.

Procedures

Calculate actual vapor pressure and gradient of actual vapor pressure

Micrometeorological data from PT. Perkebunan Nusantara VI, Batang Hari, Jambi is observed by climate tower at six different heights: 22m, 16.3m, 12.3m, 8.1m, 2.3m and 0.9m. Data used to calculate actual vapor pressure and the gradient of actual pressure (Upreti and Ojha 2018; Walls et al. 2020):

$$ea = 0.6108 \left\{exp\left(\frac{17.27\,Tzi}{Tzi + 237.3}\right)\right\} * Rh/100$$

$$\frac{\partial ea}{\partial z} \approx \frac{0.6108\left\{\exp\left(\frac{17.27\,T1}{T1 + 237.3}\right) * Rh1 - \exp\left(\frac{17.27\,T2}{T2 + 237.3}\right) * Rh2\right\}}{z1 - z2}$$

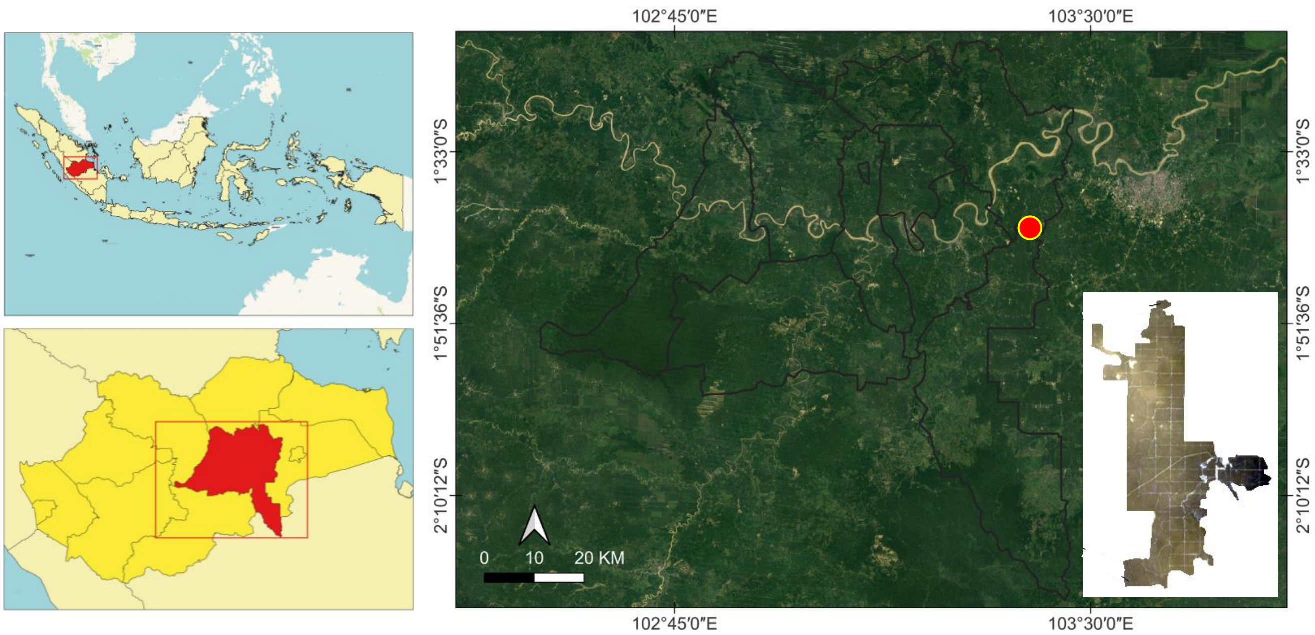

Figure 1. Location of PT. Perkebunan Nusantara VI, Batang Hari District, Province of Jambi, Indonesia

Calculate gradient of air temperature

Calculation of air temperature gradient could be done directly from observational micrometeorological data (Schilperoort et al. 2018):

$$\frac{\partial T}{\partial z} \approx \frac{T1 - T2}{z1 - z2}$$

Calculate latent heat vaporization (λ) and psychrometric constant (γ)

Latent heat of vaporization and psychrometric constant also could be done directly from observational data, using equations (4) and (5) (Allen et al. 1998):

$$\lambda = 2.501 - (2.361 \, x \, 10^{-3})Tmean$$

$$\gamma = \frac{Cp \, P}{\varepsilon \, \lambda} = 0.665 \, X \, 10^{-3} \, P$$

Calculate Bowen ratio

Bowen ratio (β) value is calculated after we obtained psychromentric constant (γ), gradient of air temperature and gradient of actual vapor pressure.

$$\beta = \frac{H}{LE} = \gamma \left(\frac{\partial T / \partial z}{\partial ea / \partial z} \right) = \gamma \left(\frac{\partial T}{\partial ea} \right)$$

Calculate latent heat flux (LE) and sensible heat flux (H)

$$LE = \frac{Rn - G}{1 + \beta}$$

$$H = \frac{Rn - G}{1 + (\frac{1}{\beta})}$$

Calculate Evapotranspiration (ET)

Evapotranspiration calculation could be done after we obtained latent heat flux (LE) divided by air densities times psychrometric constant.

$$ET = \frac{LE}{\rho \lambda}$$

Calculate micrometeorological correlation coefficient

In order to see the relationships between evapotranspiration, Bowen ratio to other micrometeorological variables, we used Pearson's correlation equation (Bruce et al. 2020).

$$r = \frac{\sum_{i=1}^{n}(xi - x)(yi - y)}{\sqrt{\sum_{i=1}^{n}(xi - x)^2} - \sqrt{\sum_{i=1}^{n}(yi - y)^2}}$$

Data analysis

The tools used in this research are Microsoft Excel for data calculation process and Python 3.9 using Jupyter Notebook IDE (Integrated Development Environment) for data visualization and exploratory data analysis. The materials used in this research are micrometeorological data measured at the climate tower in PTPN VI, Batang Hari, Jambi, from December 2014 to November 2015. We split the data based on 4 season, which is wet season (DJF), transition season I (MAM), dry season (JJA), and transition season II (SON).

RESULTS AND DISCUSSION

Daily micrometeorological correlation matrix

Figure 2 shows the matrix correlation between micrometeorological variables daily from December 2014 until November 2015 in PTPN VI, Batang Hari District. This research focuses on Bowen ratio (β) and evapotranspiration (ET), the last two lines in Figure 1. Micrometeorological components consist of rainfall (CH), air pressure (P), wind speed (Ws), relative humidity (Rh), air temperature (Ta), soil temperature (Tsoil), soil moisture (SM), net radiation (Rnetto), ground heat flux (G), actual vapor pressure (ea), sensible heat flux (H), latent heat flux (LE), LE-H, Bowen ratio (β) and evapotranspiration (ET). These data were obtained from measurements in study site using various instruments such as sap flow sensors, soil chamber, and automatic weather stations every thirty minutes. Pearson's correlation coefficient estimates each relationship between variables.

Figure 2 shows the correlation matrix of micrometeorological variables daily, where the yellow color represents the highest possible value of 1. As the color starts to get darker, the correlation value becomes smaller. The axis of x and y both represent the micrometeorological variables, where the main diagonal in yellow shows a perfect correlation because it's the same variable. Rnetto strongly influenced ET and LE-H by positive correlation coefficients of 0.85 and 0.95, while H and β influenced ET negatively, shown by a correlation coefficient of -0.63 and -0.75, respectively. LE has a perfect relationship with ET, shown by one correlation coefficient, this is caused by LE divided by water density (ρ) and latent heat vaporization (λ) that has a constant value. β is strongly influenced by H shown by the positive correlation coefficient, which is 0.84, while SM, LE-H and ET have a negative influence on β shown by a correlation coefficient of -0.58, -0.85, and -0.75, respectively. A high positive correlation between β and H shows that biophysically if the Rnetto is allocated more to H, it will decrease ET processes since H is used for heating up surrounding air temperature, while LE biophysically used by the ecosystem to transform water that is available into vapor, that is why LE – H had strong positive correlation coefficient with ET. The correlation coefficient also shows that net radiation is allocated more to LE rather than H, this indicates that in PTPN VI, the energy available is prioritized to transform water into vapor rather than heating up surface air temperature, thus water availability in the region is sufficient.

Scatterplot of evapotranspiration and Bowen ratio

Figure 3 shows a scatterplot between evapotranspiration (ET) and Bowen ratio (β) from December 2014 to November 2015 at PTPN VI, Batang Hari, Jambi. The correlation coefficient between these two variables based on Figure 1 is -0.75, where green dots represent the wet season (December, January, February), orange dots represent transition season I (March, April, May), purple dots represent dry season (June, July, August) and pink dots represent transition season II (September, October, November).

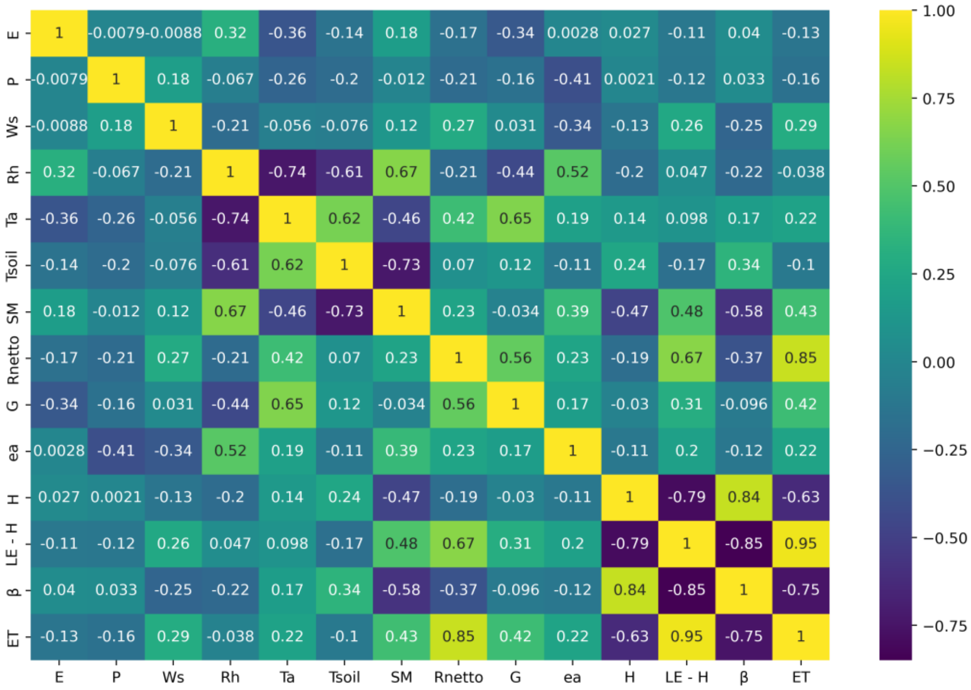

Figure 2. Daily micrometeorological variables correlation matrix in PTPN VI, Batang Hari, Jambi Province, Indonesia for December 2014 – November 2015 period

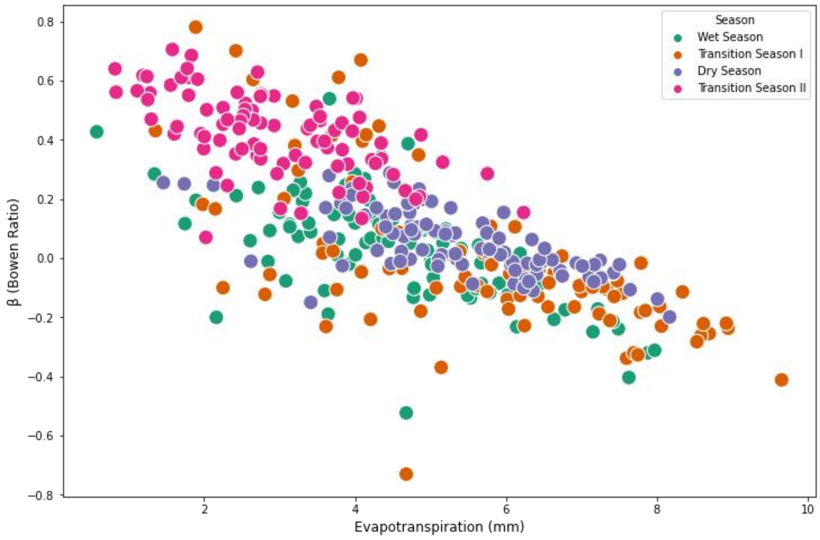

Figure 3. Scatterplot of daily evapotranspiration and Bowen ratio in PTPN VI, Batang Hari, Jambi Province, Indonesia for December 2014 – November 2015 period

The x-axis of Figure 3 represents the evapotranspiration (ET) value in millimeters, while the y-axis represents Bowen ratio value (β) and the dots represent those two variables values on daily scale. The colors represent different season, the green one represents wet season (December, January, February), the orange one represents transition season I (March, April, May) which is between wet and dry season, the purple one represent dry season (June, July, August) and the pink one represent transition season II (September, October, November) which is between dry and wet season. ET value at the lowest with average 2.95 mm showed by transition season II and the β value is relatively bigger than others. Transition season II indicates that the amount of net radiation received in PTPN VI is mostly allocated to sensible heat flux (H) compared to another season, thus ET is low due to latent heat flux (LE) deficiency. Dry season showed β value mostly within the range of -0.2 to 0.2 with an average ET of 5.33 mm. Wet season and transition season I had relatively wider ranges of ET and β values compared to dry season and transition season II, which had more clusters and narrower interval values. Wet season and transition season I have an average ET 4.56 mm and 5.63 mm, respectively.

A negative value of β indicates that LE and H move in an opposite direction vertically, this usually happens during the night when atmospheric condition is stable, thus H moving towards surface while ET process still happens. A negative value of β also could happen in midday caused by vertical advection due to stable atmospheric conditions (Neog et al. 2005). LE and H are crucial components for local hydrological cycles that could estimate vapor transfer from surface into the atmosphere (June et al. 2018).

A higher β value indicates that more net radiation energy is allocated to H where this component is used by ecosystem to heat up surrounding surface air temperature, thus the higher β, the higher air temperature, which can lead to drought stress (Göckede et al. 2017). Transition season II is transition from dry to wet season, but in 2015 there was an enormous wildfire triggered by a strong El Nino event where the amount of hotspots increased from 1,152 in 2014 to 1,654 in 2015 mostly from July to October (Saharjo and Velicia 2018). The phenomenon of this wildfire causes longer drought, thus obstructing natural precipitation and hydrological cycle and affecting plant's water availability.

Diurnal micrometeorological variables correlation matrix

Figure 4 shows diurnal Pearson's correlation value between micrometeorological variables for 24 hours cycle from December 2014 to November 2015 at PT. Perkebunan Nusantara VI, Batang Hari, Jambi. This research focuses on evapotranspiration (ET) and Bowen ratio (β) correlation with other diurnal micrometeorological variables shown by the last two lines in Figure 4.

Figure 4 shows the correlation matrix of micrometeorological variables on a diurnal basis, where the dark green color represents the highest possible value of 1. As the color gets brighter, the correlation value becomes smaller and eventually becomes negative as the color turns red. The axis of x and y both represent the micrometeorological variables, where the main diagonal in dark green shows a perfect correlation because it's the same variable. WS, Ta, Rnetto, G, and LE-H have a strong positive influence on ET diurnal pattern shown by correlation coefficients 0.72, 0.72, 0.96, 0.89 and 0.9, while RH and ea have a moderate negative influence, with correlation coefficients -0.64 and -0.51. Variables like CH, P, Tsoil, sm, H and β have a minor influence on ET. Micrometeorological variables like CH, P, WS, RH, Ta, Tsoil, Rnetto, G, and LE also have a minor influence on diurnal pattern of β shown by a correlation coefficient less than 0.4. Variables like sm, ea and LE-H have a moderate negative correlation coefficient of -0.4, -0.52, and -0.43, while H has a moderate positive correlation coefficient of 0.44 with β. Evapotranspiration processes are generally limited by four factors: energy availability that mostly comes from incoming solar radiation, water availability, plant physiology and surface vapor lifting. It is crucial to understand that these four limiting factors interact with each other formed by surface-atmospheric heat and water exchange.

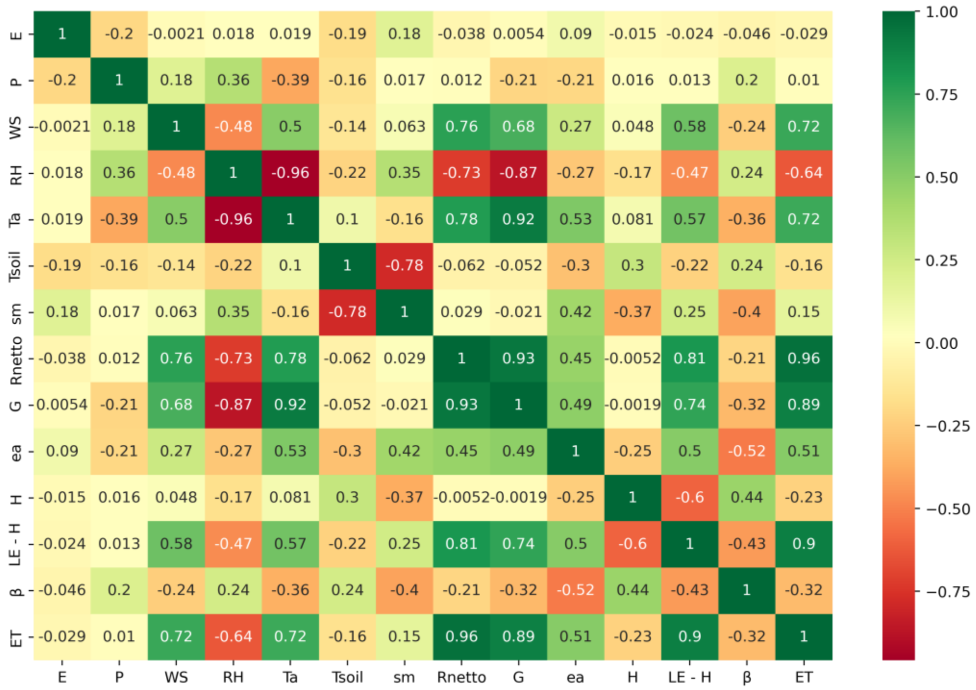

Figure 4. Diurnal micrometeorological variables correlation matrix in PTPN VI, Batang Hari, Jambi Province, Indonesia for December 2014 – November 2015 period

Diurnal Rnetto directly influenced ET, shown by a strong correlation of 0.96. variation of diurnal Rnetto pattern causing an imbalance in surface energy budget and heat exchange between day and night (Kleidon and Renner 2017). Heat exchange between surface and lower atmosphere affects surface air temperature, vapor pressure, and wind speed, which are driving factors of diurnal ET process (Van Heerwaarden et al. 2010), which is why these variables strongly correlate with ET. Rnetto is a dominant factor of LE and H partition, which is influenced by factors like vapor pressure deficit, air temperature, actual vapor pressure and soil moisture that affect vapor transport from terrestrial ecosystem into the atmosphere (Chen et al. 2020). LE allocation has a major role in the amount of carbon plants absorb. The optimal ET process will lead to good regulation between CO_2 and H_2O through plant's stomata (June 2002).

Diurnal evapotranspiration pattern

Figure 5 shows a diurnal pattern of ET in each season from December 2014 until November 2015. Dynamics of diurnal ET are relatively stable throughout the season at night until dawn before sunrise. The maximum ET for all seasons mostly occurred midday, around 12 o'clock.

The diurnal ET pattern differs for each season, especially during midday. ET in wet season starts to vary around 10 o'clock and has a different maximum ET at its peak. December, January and February have maximum ET of 18 mm, 20 mm and 16 mm, respectively, with an average ET of 5.08 mm in wet season. Transition season I relatively have a higher maximum ET than other seasons, especially in April, where ET could reach 30 mm while March and May are 25 mm and 22 mm, respectively. Diurnal average of ET in transition season I is 6.55 mm. Dry season especially June, has a bigger maximum ET of 25 mm, while July and August had 17 mm and 14 mm, respectively. The diurnal average of ET in dry season is 4.84 mm.

Transition season II relatively had a low maximum ET compared to other seasons, with an average 3 mm. November had a maximum ET of around 17 mm, while September and October had a maximum ET of 10 mm and 8 mm, respectively. ET at night until dawn shows a negative value for all seasons, indicating the reversed process of ET, condensation. The condensation process occurs when plants capture moisture and vapor in atmosphere and turn it into liquid water. Low ET on transition season II caused by a strong El Nino event in 2015 led to increasing hotspots. Figure 3 implicitly explains the low value of daily ET in transition season II, caused by El Nino events.

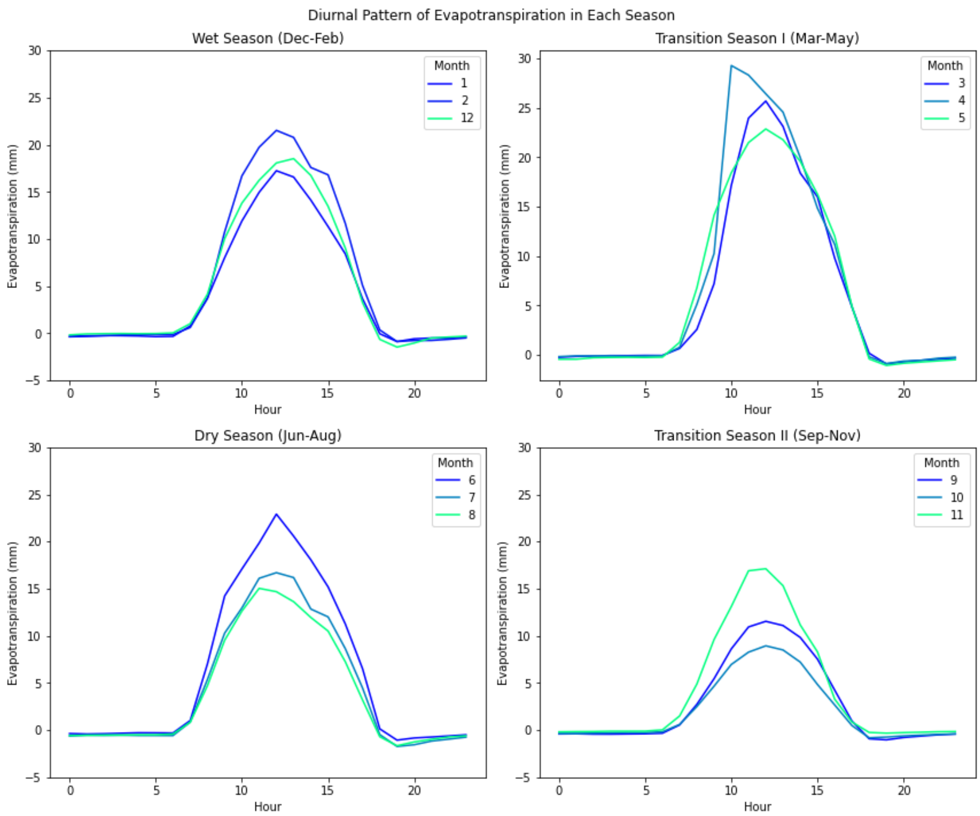

Figure 5. Diurnal evapotranspiration (ET) pattern for each season in PTPN VI, Batang Hari, Jambi Province, Indonesia for December 2014 – November 2015 period

Diurnal Bowen ratio pattern

Figure 6 shows a diurnal pattern of β in each season from December 2014 until November 2015. Dynamics of diurnal Bowen ratio is high throughout the season in 24 hours cycle. A positive β value shows the movement of LE and H within the same direction, while a negative β value indicates that LE and H are moving in opposite directions vertically. The diurnal β value in wet season has a similar pattern for December and February, while January has a relatively stable pattern. There is a gradual increase of β value from midnight until 06.00 and a decrease after sunrise until 10:00. After 10:00, the β value is relatively stable for December and February. The maximum and minimum values of β in wet season are 0.83 and -0.47. During transition season, I have a uniform pattern each month. Still, more fluctuation compared to other seasons where from midnight to morning around 07:00, β gradually increases. There is a sudden decrease until 09:00. The sudden decline indicates that within this time interval, atmospheric condition is stable thus, the H is moving towards surface while LE is still moving upward. β value remains stable until 20:00, and the Bowen ratio gradually increases until midnight. The maximum and minimum values of β in transition season I are 0.91 and -0.7.

Dry season also had a uniform diurnal pattern of β for each month but not fluctuating as much as transition season I. There are 2 peaks and 2 valleys, where β value increases at midnight until 06:00, then decreases until 10:00. Then, β value increases again after 10:00 until 15:00 and gradually decreases until 20:00. Maximum and minimum values of β in dry season are 0.44 and -0.41. Transition season II had a relatively higher value of β with a uniform pattern for September and October, while November's pattern is slightly different. The sudden decline of β value happened at 07:00. The Bowen ratio pattern for September and October is relatively stable with gradual changes. The maximum and minimum values of β in transition season II are 0.74 and 0.05. Gradual decline in β value mostly during sunrise throughout the season, which indicates that net radiation allocated more to LE to transform water into vapor in PTPN VI while on night until dawn β value is relatively high in most of the season where this indicates that the leftover of net radiation is used to heating up surface air temperature.

Monthly rainfall and evapotranspiration

Figure 7 shows a histogram between monthly observational rainfall (blue bar) and estimated evapotranspiration (orange bar) using the Bowen ratio calculation method from December 2014 to November 2015 at PT. Perkebunan Nusantara VI, Batang Hari, Jambi. Table 1 show statistic between rainfall and estimated evapotranspiration using the Bowen ratio method.

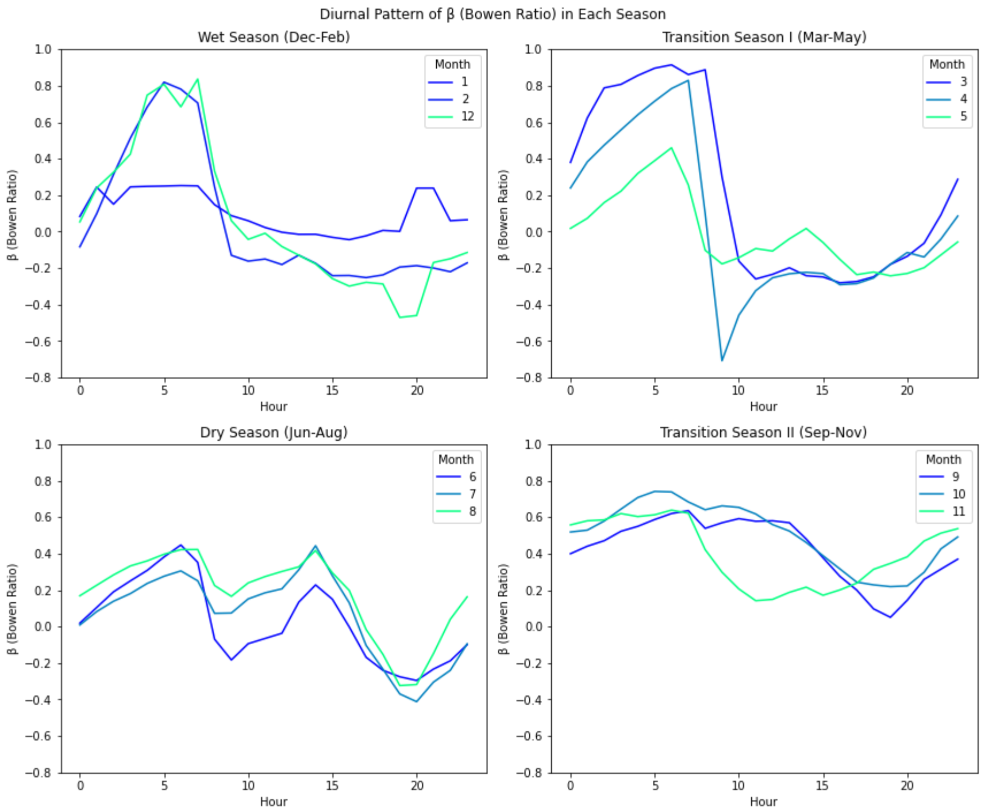

Figure 6. Diurnal Bowen ratio (β) pattern for each season in PTPN VI, Batang Hari, Jambi Province, Indonesia for December 2014 – November 2015 period

Table 1. Statistic between rainfall and evapotranspiration in PTPN VI, Batang Hari District, Province of Jambi, Indonesia

	Mean	Std	Min	25%	50%	75%	Max	Total
Rainfall	161.05	115.73	23.95	61.51	145.63	260.73	352.1	1932.6
Evapotranspiration	140.68	37.69	68.81	123.6	145.33	164.06	197.02	1688.17

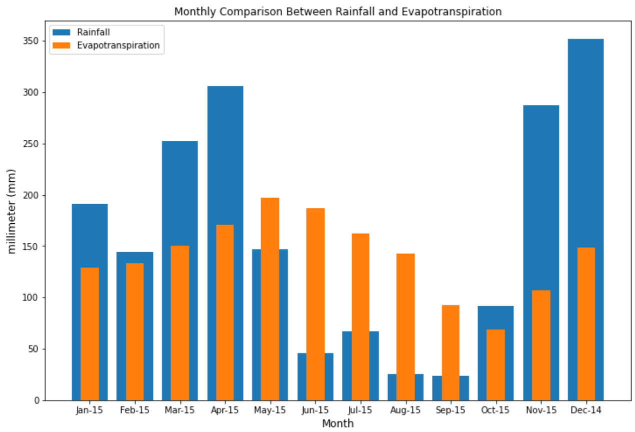

Figure 7. Histogram of monthly rainfall and evapotranspiration in PTPN VI, Batang Hari, Jambi Province, Indonesia for December 2014 – November 2015 period

Monthly ET in the wet season has a lower value than rainfall, whereas, in December, January, and February, it has a surplus of rainfall of 203 mm, 62 mm and 11 mm, respectively. Monthly rainfall in transition season I show a surplus of 101 mm and 135 mm in March and April, while in May, there is a deficiency of 49 mm rainfall shown by higher ET due to the El Nino phenomenon that started to occur. On the other hand, dry season shows low monthly rainfall compared to ET; in June, July, and August, the water supply deficiency is 141 mm, 94 mm, and 116 mm, respectively. Transition season II also has a deficit of 68 mm of rainfall in September, while in October and November, the rainfall exceeds ET by 22 mm and 179 mm, respectively. The monsoonal rainfall pattern is due to Intertropical Convergence Zone (ITCZ) caused by earth's relative position to the sun, thus the amount of radiation received varies at higher altitudes compared to lower ones (Ilfan and Arwin 2019). High variation of radiation received caused high gradient of air pressure between northern and southern hemispheres, causing air mass moving from high pressure to low pressure. Two air masses with different characteristics then converge in the equator in December, January, and February causing a wet season in Indonesia.

Strong El Nino events in 2015 obstructed Indonesia's natural monsoonal rainfall patterns, causing longer drought and significantly reducing monthly rainfall known by declining SOI index (Pradiko et al. 2016). A long drought, water supply deficiency, and dry spells of more than 20 days in terms of oil palm could cause the malformation of fruits, obstruct CO2 assimilation processes and interfere with nutrient absorption, could decrease productivity significantly on economic scale (Syarovy et al. 2015). The average value of rainfall in Figure 6 is 161,1 mm, while for ET is 140,7 mm which indicates water surplus on an annual scale but distributed unequally per month where this phenomenon precisely could make oil palm and topsoil more vulnerable due to extreme rainfall conditions from the dry period to wet period transition.

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Assessment of soil health in uncontrolled grazing areas in the Administrative Post of Luro, Lautem, East Timor

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Abstract. *Da-Costa D. 2023. Assessment of soil health in uncontrolled grazing areas in the Administrative Post of Luro, Lautem, East Timor. Intl J Trop Drylands 7: 46-54.* Uncontrolled grazing practices have been judged as the main cause of soil degradation in grassland areas. This study was conducted to provide baseline information on soil health in uncontrolled grazing areas in the administrative post of Luro, municipality of Lautem, East Timor (Timor Leste). Furthermore, 40 soil samples were collected from eight uncontrolled grazing areas using the core method; five points sampling per each site (four in corners and one in in the center) sampling points distances were 100 to 150 m apart, and each point represented three different soil layers (0-5 cm, 5-10 cm, and 10-20 cm). All soil samples were transported to the laboratory of the Faculty of Agriculture, Universidade Nacional Timor Lororsae, East Timor. Samples preparation and analysis followed the procedure and guidelines of McKenzie et al. (2002) and Liu et al. (2019) for physical properties, while Soil Organic Matter (SOM) analysis used Loss-On-Ignition (LOI) adopted from Nakhli et al. (2019). In addition, all soil chemical properties were analyzed using Kjeldhal and Bray-1 method following the soil analysis guidelines of JICA (2014). The study showed that soil physical properties in the uncontrolled grazing areas in Luro are characterized by high bulk density, poor porosity, and low organic matter content. Furthermore, soil pH remains neutral in areas where uncontrolled grazing is practiced but with very low nitrogen and potassium levels. In contrast, phosphorus is very high in the Cotamuto and Lakawa but very low in the Afabubo areas. Furthermore, low literacy levels and livelihoods are key socioeconomic factors that directly influence uncontrolled grazing practices. Hence, promoting sustainable grazing methods among communities towards raising livestock for their livelihood is recommended.

Keywords: Agriculture development, ecological risk, livestock

INTRODUCTION

Soil health is the fitness of the soil to sustain the growth, development, and yield of vegetation: crops, grasses, shrubs, and forests (Sopialena et al. 2017; Tahat et al. 2020). In contrast, soil degradation means adverse changes in soil properties and processes can be set in motion by disturbing the dynamic equilibrium of soil with its environment by natural or anthropogenic (human) perturbations over time (Lal et al. 2003).

The soil's physical properties are the components that greatly influence the texture, structure, porosity, and pore space fraction of soil (Gray et al. 2011; Fu et al. 2022). Chemical properties include soil pH, exchange capacity, salt-affected soil, and calcareous soil, while biological properties include soil biota, flora, and fauna (McCauley et al. 2005). The physical properties of soil include texture, bulk density, porosity, moisture, and erosion. Soil texture is the particle-size distribution that determines the soil's coarseness or fineness. The physical and chemical weathering process of rocks and minerals results in a wide range of sizes, such as stones, gravel, sand, silt, and very small clay particles, simultaneously (Ellis and Foth 1997; Mahilum 2004; Schoeneberger et al. 2012).

Aside from soil's physical and biological properties, soil pH range is important in soil productivity as it determines the availability of other nutrients for crop uptake. For example, nitrogen availability is maximum between pH 6 to 8 because this is the most favorable range for the soil microbes to mineralize the nitrogen in organic matter and organisms to fix nitrogen symbiotically. In addition, maximum phosphorus availability is within the range of 6.5 to 7.5, while potassium is widely available in alkaline soil (Ellis and Foth 1997). UNEP (1992) reported the degree of soil degradation by sub-continental regions, which indicates that 15% of the total area in the world has degraded, with Africa and Asia dominating the list. Even in Asia, soil degradation has increased to about 18%.

Land degradation was estimated to begin in East Timor when the general process of commencing mercantilism and economic reforms occurred due to sandalwood (*Santalum album* L.) exploration in 1718 (Sousa 2018). It resulted in massive deforestation and loss of biodiversity (McWilliam 2003). As a result, land cover changes have been observed, and the most critical changes are in woodland; from 1989 to 1999, woodland has been reduced from 7% to 22%, followed by forest from 6% to 7%, while agriculture land decreased from 26% to 24% of total area (Bouma and Kobryn 2004). In addition, 30% of forests were lost from 1972 to 1999, based on analysis of satellite images (MAF 2007). Most people are involved in shifting cultivation, uncontrolled grazing, uncontrolled forest fire, slash-and-burn and firewood collection. Moreover, the primary sources of livelihood are agriculture, livestock production, and forestry, which are directly associated with the land's quality and resources (NAP 2008).

Approximately 3,600 ha of the grassland areas are being utilized by the community under uncontrolled grazing practices for grazing cattle, buffalo, horses, goats, and sheep. In addition, burning practices are customarily done by herders in grassland during the dry season to give space for the next grass to grow when the wet season comes (IWMPR 2012). Environmental degradations in the country have been noticed and cited in several important documents on uncontrolled grazing practices that have initiated a sequence of environmental degradation. The general opinion is that soil degradation in uncontrolled grazing areas is associated with poor livestock raising management, lack of knowledge, weakness of policies, land ownership issues, and other socioeconomic problems (NBSAP 2011; MAF 2018; NDC 2022).

A series of studies on uncontrolled grazing and grazing management effects on soil health have been conducted in other places (Yong-Zhong et al. 2005; Savadogo et al. 2007; Maitima et al. 2009; Piñeiro et al. 2010; Matano et al. 2015). However, no study has been conducted on uncontrolled grazing influences on soil health in Luro administrative post. Therefore, this study was conducted with three main objectives, namely to: assess soil physical, chemical, and biological properties in uncontrolled grazing areas; assess the socioeconomic conditions of farmers who practice uncontrolled grazing; and find the association between socioeconomic characteristics and soil degradation to identify important parameters for policy-making that will ensure the soil for agriculture and livestock production sustainability.

MATERIALS AND METHODS

Study area

The study was conducted during the dry season in the Lautem municipality of Cotamuto, Lakawa, and Afabubo Villages, East Timor in 2022. These villages geographically are located between latitude 8°33'07.13"S and longitude 126°48'27.33"E with an elevation from 119 to 782 meters above the sea level (masl) (Figure 1). The wet season is between November and May, with a range of 92 mm to 237 mm, and the dry season is from June until early November, with an average rainfall of 30 mm to 108 mm (Figure 2). Three soil types are found in the study area: Entisols, Inceptisols, and vertisols (IWMPR 2012).

Methods

Soil health measurement

Moreover, 40 soil samples were collected randomly in 8 uncontrolled grazing areas; two in the village of Cotamuto, two in the village of Lakawa, and four in the village of Afabubo. The selections of uncontrolled grazing areas were based on the grazing intensities, sizes of grassland, and non-conflict areas. Soil samples were collected using the core method; five points sampling per each site (four in corners and one in in the center) sampling points distances were 100 to 150 m apart, and each point represented three different soil layers (0-5 cm, 5-10 cm, and 10-20 cm).

All samples were transported to the laboratory of the faculty of agriculture, Universidade Nacional Timor Lorosae, East Timor and continue with the analysis; soil physical properties analysis used the gravimetric method: soil moisture (Liu et al. 2019), soil porosity and bulk density (McKenzie et al. 2002). Furthermore, SOM was measured by the loss-on-ignition (LOI) method; determining organic matter involves the heated destruction of all organic matter in the soil or sediment (Nakhli et al. 2019). In addition, 45 households were interviewed for the socioeconomic factors, and data were analyzed using multiple regression.

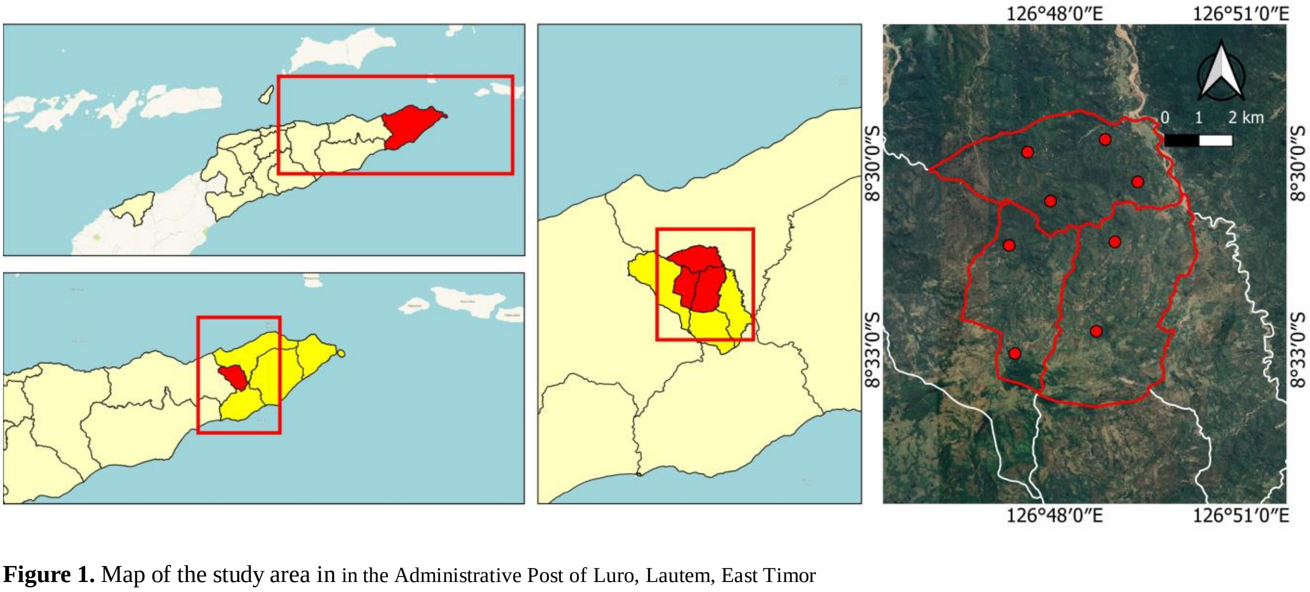

Figure 1. Map of the study area in in the Administrative Post of Luro, Lautem, East Timor

Determination of soil moisture content

The gravimetric method measured the moisture content by calculating the mass loss ratio after drying at 105°C (Liu et al. 2019).

$$\text{Soil Moisture} = \frac{(\text{wt of wet soil} + \text{ring}) - (\text{wt of dry soil} + \text{ring})}{(\text{wt of dry soil} + \text{ring}) - \text{ring}} \text{ x } 100$$

Determination of soil porosity

The percentage of pores was measured by specific gravity from then used to calculate porosity (McKenzie et al. 2002).

$$Porosity\ (\%) = 1 - \frac{\text{Bulk Density } g.cm^{-3}}{\text{Specific gravity } g.cm^{-3}}\ x\ 100\ \%$$

Determination of bulk density

The soil bulk density is the weight per unit volume of oven-dry soil, that is, the ratio of dry soil mass to total volume (McKenzie et al. 2002).

$$\text{Bulk density}(\frac{g}{cm^3}) = \frac{\text{weight of oven} - \text{dry soil (g)}}{\text{volume of soil } (cm^3)}$$

Soil Organic Matter (SOM): SOM was measured by the Loss-On-Ignition (LOI) method. Determining organic matter involves the heated destruction of all organic matter in the soil or sediment (Nakhli et al. 2019). Soil pH: Weigh about 10g of soil sample into the container. Add 50ml of distilled water to the soil and shake the container for about 2-3 minutes, then allow the soil to settle for 2 minutes. Next, measure the PH value of the water above the soil in the container. Finally, the soil nutrients (NPK): total soil nitrogen was measured by the nitrogen Kjeldhall method, and phosphorus and potassium (potassium the same as Kalium) were measured by the Bray-1 method (JICA 2014).

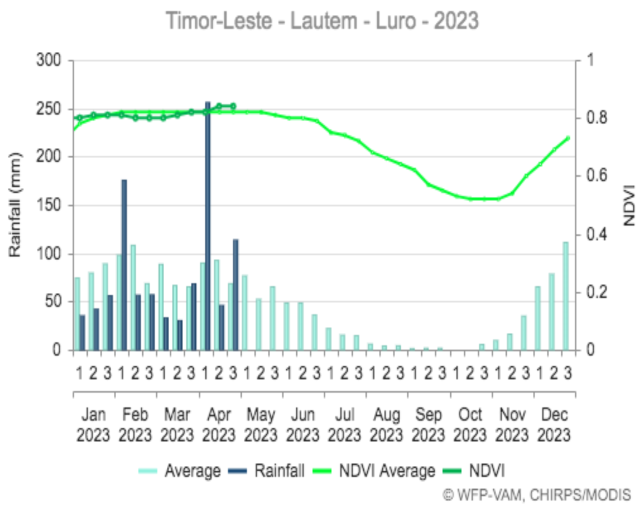

Figure 2. Rainfall and NDVI data of Luro Administrative Post, East Timor (Source: Online WFP-VAM)

Socioeconomic

Socioeconomic data were gathered through the survey and visits to farmers' houses that practice uncontrolled grazing in the study site. Purposive sampling was used to interview 45 household heads. Nexy, the descriptive analyses were used to analyze the socioeconomic status. (Education *(X_1)*, main livelihood*(X_2)*, main income *(X_3)*, and raising livestock *(X_4)*. Therefore, to determine the relationship between socioeconomic variables and soil degradation, multiple regression was used by function:

$$Y=a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + e$$

Where:

Y : Value of the Dependent variable (soil degradation)
a : Constant or intercept
b : Beta coefficient
X : independent variable (socio-economic variables)
e : residual error

Data analysis

Descriptive analysis was used to analyze the socioeconomic factors in the study. At the same time, inferential statistics and multiple regressions were used to analyze the relationship between socioeconomic variables and soil degradation. Therefore, the soil degradation was analyzed using descriptive and inferential statistics (complete random design). Moreover, Duncan's Multiple Range Test (DMRT) at 5% was used to determine the significance at each degraded site. In addition, the SPSS program and Excel software were utilized to process the data.

RESULTS AND DISCUSSION

Biophysical characteristics

Soil biophysical characteristics in grazing areas are measured by bulk density, soil porosity, and soil organic matter. In Cotamuto, there was no significant difference (DMRT 5%) between sites; bulk density value ranged from 1.27 to 1.59, soil porosity ranged from 38.37 to 50.85%, and soil organic matter percentage ranged from 3.26 to 3.99. In Lakawa, bulk density and soil porosity have no significant difference between sites; bulk density value ranged from 1.29 to 1.66, while soil porosity ranged from 35.95 to 50.21%. Overall, SOM in Cotamuto, Lakawa, and Afabubo were low fall under benchmarck, although highest SOM found in Cotamuto and lowest in Afabubo (Figure 3).

The soil biophysical properties in uncontrolled grazing areas are shown in Figure 3. In Cotamuto, soil organic matter, soil porosity, and bulk density are not significantly different among sites. Bulk density is not statistically different (DMRT 5%) but is slightly different from one site to another. High bulk density was found in site Cotamuto C (1.57 g/cm^3) and lowest in site Lakawa B (1.27 g/cm^3). The grassland's Bulk density is affected by the grazing intensity and the number of livestock grazing; the soil becomes compact if the intensity of grazing activity is increased. In addition, livestock grazing on ground cover continuously in the same area could affect grass growth. Grass would disappear if the number of livestock increased, but grazing areas would remain limited. Livestock movement by free grazing in the area led to the soil being compacted due to intense livestock trampling. These data of bulk density considered as compacted status is in line with the previous study conducted by Ellis and Foth (1997) revealed that bulk density for organic soil should be less than 1 g.cm$^{-3,}$ and for the optimum topsoil range is 1.3 g.cm^{-3}. Soil bulk density of more than 1.3 g.cm^{-3} indicates that the soil is compacted.

Moreover, soil with high bulk density has fewer pores. As shown in Figure 3, an increase in bulk density means low pores. Low porosity in soil could lead to low water absorption capacity during the rainy season. As a result, there is the possibility of high run-off instead of high water infiltration, less moisture, and also affects soil organisms. Fewer pores affects air circulation and soil moisture content to sustain soil organisms and soil health. These porosities can be drawn from an organic matter, whether high or low organic matter in the soil. The soil status can be considered low productivity due to the low porosity indicated in fewer pores and low organic matter. Moreover, less organic matter in the Cotamuto site led soil to low productivity, negatively affecting grass growth and harming livestock and farmers' livelihood. The recent study in Kenya and Tanzania by Matano et al. (2015) revealed that the high intensity of free grazing activities has contributed to the increasing bulk density and decreasing organic matter in grazing areas. Piñeiro et al. (2010) stressed that overgrazing activities might directly or indirectly affect the amount of C available for SOC formation by changing the proportion of Net Primary Productivity (NPP) allocated to below or aboveground organisms.

In Lakawa, bulk density and soil porosity are not significantly different among sites. Soil bulk density was slightly higher in Afabubo D (1.66 g/cm^3) while low bulk density was found in Afabubo B (1.29 g/cm^3). Most bulk densities were above 1.3 g/cm^3, which generally harms growing grass and makes it fragile to catch up to a wilting point as these sites have very low soil moisture. The reasons for slight differences in bulk density among sites in Afabubo are the differences in large grazing areas and the number of grazing livestock. In areas where livestock grazing is less, less effect was observed in short grazing periods, but if free grazing is continuously kept, soil compaction will result. Soil compacted by cattle grazing is susceptible to superficial erosion after rains due to its reduced capacity for water infiltration and greater surface run-off (Gray et al. 2011).

The soil porosity observation results have the same case with bulk density. The soil is less porous in Afabubo D (35.95%), while in Afabubo B, the soil has good porosity (50.21%). High porosity in Afabubo B was affected not by free grazing but by soil texture. In this site, the soil texture was sandy, and even the porosity was high, but not by organic matter. Sandy soils can be easily leached and remove nutrients and organic matter. Slopes exacerbate this and make it susceptible to erosion or run-off. Grass growth is very limited due to less moisture and compaction except in Afabubo B, but still, not much grass has grown due to less moisture. According to Ellis and Foth (1997), desirable soil for plant growth has a total porosity of 50%, one-half macro pore porosity, and one-half micro pore porosity. Such soil has a good balance between water retention for plant use and oxygen supply for root respiration.

Soil organic matter in Afabubo B is significantly higher in all sites, but organic matter is lower in Afabubo D. However, the organic matter in Afabubo A and C are found in adjacent points (DMRT 5%). The ground littered down and decomposed by microorganisms determines the organic matter in the soil cover. These components are interlinked to execute roles and functions in providing organic matter. The physical characteristics of soil have important roles in allowing the presence of microorganisms; microorganisms need soil moisture to decompose litter. High grazing frequencies in the same area affect grass to be extinct, less ground cover to low moisture, high run-off, and soil to be compacted, resulting in poor organic matter.

Intense grazing on the same land alters soil density, resulting in soil compaction due to the weight of animal movements and the mechanical forces of livestock grazing. This negatively impacts soil erosion, reduced rainfall infiltration rate, and degradation of vegetation cover (Matano et al. 2015). In addition, Savadogo et al. (2007) emphasized that less pore space can limit gas exchange and reduce root growth. Both mechanisms suggest that soil compaction reduces plant production and, thus, SOC storage.

Free grazing practices have affected soil biophysical properties in Afabubo. Soil organic matter is not significantly different (DMRT 5%) among sites as well as soil bulk density and porosity. Very low organic matter, high bulk density, and less porosity were the characteristics of soil found in the whole Afabubo grazing sites. Wiesmeier et al. (2019) found through their research that the compaction and poor soil structure in cultivated fields was attributed to loss of SOC, which averaged 46% less in cultivated A horizon than uncultivated A horizons and 35% less in cultivated B horizons compared to uncultivated B horizons, respectively.

Moreover, when the bulk density of soil is high, the soil tends to be more compact and heavier. This kind of soil is not suitable for growing any vegetation since the pores space for roots and moisture contents are not available. Topsoil could suffer compaction from any pressure, disturbing its pattern to accommodate an environmental preference for grasses. As a result, shallow grass rooting occurs and is vulnerable to reaching a permanent wilting point. According to Yong-Zhong et al. (2005), soil compaction under grazing is attributed to trampling by herbivores. Soil compaction reduces water infiltration, increases run-off under grazing conditions, and decreases water available for plant growth.

Soil porosity in grazing areas and bulk density in Afabubo are affected. Free grazing activity seemed to trigger degradation. Most cattle and sheep were freely grazing in that area. The soil will likely lose its pores and might be transformed into a compacted one (Figure 3). There was no significant difference among sites, as shown at DMRT 5%, but soils are poor in porosity on average, which could lead to worst conditions such as erosion, run-off, and siltation in watershed areas. These align with Blanco and Lal (2008), who stated that excessive grazing could degrade soil structure, reducing aggregate stability, pore-size distribution, macro-porosity, total porosity, and water infiltration rate. Meanwhile, Johnson and Matchett (2001) revealed that grazing could also change C allocation patterns affecting the amount of C entering the soil. Belowground biomass directly enters the soil and contributes more to SOM formation than aboveground tissues.

Soil chemical characteristics in an uncontrolled grazing area

Soil chemical properties measured are soil pH and macro-nutrients represented by nitrogen, phosphorus, and potassium level to estimate how fertile the soil is within an uncontrolled grazing area. Soil pH significantly differs between sites, with the highest pH in Afabubo and significantly lowest in Lakawa, while the pH in Cotamuto at the adjacent point. On the other hand, total nitrogen, phosphorus, and potassium availabilities have no significant difference; total nitrogen ranged from 0.11 to 0.18, and phosphorus availability ranged from 10.25 to 83.07, while potassium availability ranged from 0.23 to 0.26 (Table 1).

Soil chemical properties have no significant differences with total nitrogen, phosphorus availability, or potassium availability except soil pH. Soil pH in the grazing area showed a significant difference (DMRT 5%). Soil pH in Daudere is significantly lower pH found in Afabubo. However, soil pH in Lakawa and Cotamuto fell at adjacent points. Soil pH in Afabubo is relatively neutral in the whole area, but as pH increases, it tends to be alkaline due to overgrazing activities. Consequently, livestock left to freely graze in the area without keeping in paddocks have been raised. Several previous studies have shown that soil pH could increase to alkalinity status by overgrazing, as per the study by Wang and Batkhisig (2014). In addition, Yong-Zhong et al. (2005) found that overgrazing practices made soil slightly alkaline, with pH values of up to 8.72.

Total nitrogen in grazing areas is not significantly different (DMRT 5%) among sites; however, the total nitrogen is higher in Afabubo than in other sites. The grazing site in Cotamuto has a very poor nitrogen content (Table 1). The loss of nitrogen may be due to run-off triggered by overgrazing and made in soil-less porous and increased leaching during the rainy season. These findings align with Yong-Zhong et al. (2005), who concluded through their study that continuous grazing resulted in a considerable decrease in ground cover, accelerated soil erosion, and loss of soil organic carbon and nitrogen.

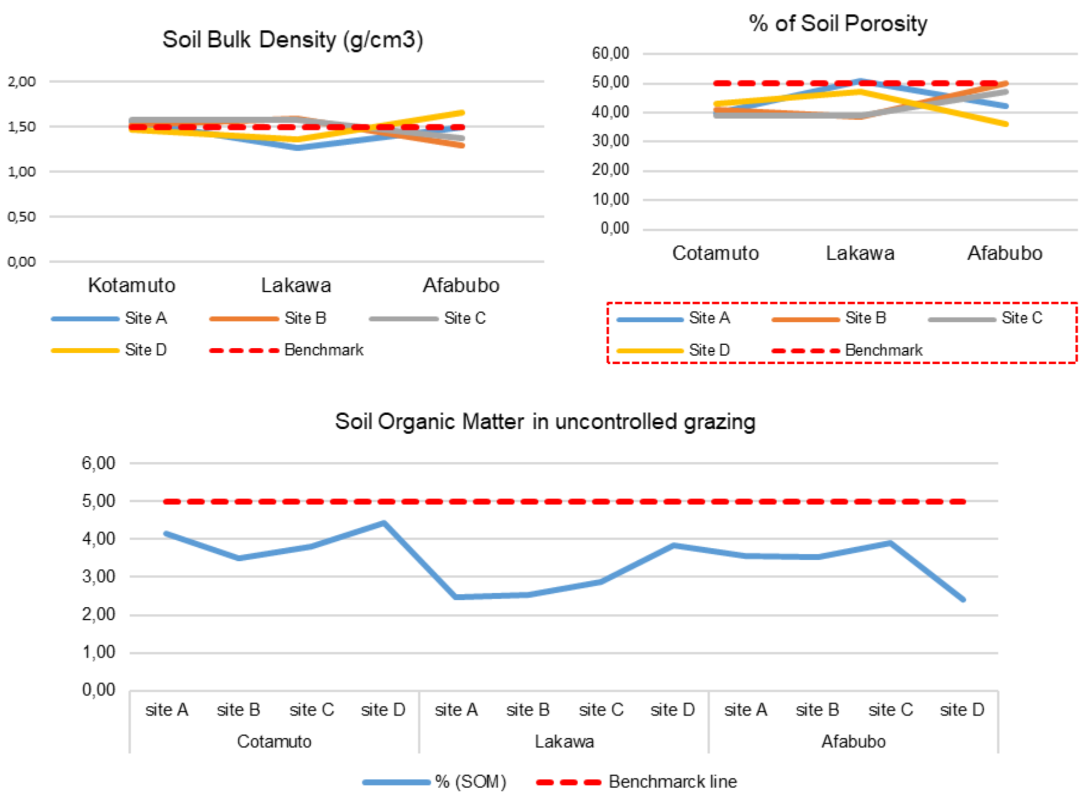

Figure 3. Soil bulk density, porosity, and organic matter

In grazing sites, phosphorous availability in Afabubo was less available (Table 1), but Cotamuto and Lakawa found abundance available. No significantly different (DMRT 5%) in terms of phosphorous availability among sites, but slightly different from one to another, with the highest in Cotamuto and lowest in Afabubo. Free grazing practices were found in the entire watershed, particularly during the dry season, because no garden crops are grown anywhere. Therefore, farmers felt free to leave their livestock to graze; however, these practices lead the soil in Luro Administrative Post to be in poor condition making it less productive. Maitima et al. (2009) reported that soil pH increased with overgrazing and organic matter, and essential macronutrients decreased.

Potassium availability was found at an optimum level in Cotamuto, while in two other sites of Lakawa and Afabubo, low level (Table 1). There were no significant differences (DMRT 5%) among sites. However, slight differences from one site to another, with the highest in Cotamuto and the lowest in Afabubo and Lakawa (0.23 Cmolc/kg). Chang et al. (2014) proved that overgrazing negatively impacted nutrient retention in the soil through a simulation model and concluded that overgrazing depletes soil organic carbon. In addition, they mentioned that more grassland degradation was caused by mismanagement of livestock keeping and free grazing methods.

Socioeconomic survey results

Socioeconomic variables consist of education level and main livelihood (Figure 4). Most farmers have big family sizes and are in their productive ages, but very few have attended school. Their sources of livelihood include farming, raising livestock, and a few firewood gatherings.

Education

In terms of education, more than half of the respondents had no formal education in the entire uncontrolled grazing area. That was aligned with the country's data (Census 2022) reported the education rate in the overall country was 70.1%; illiteracy of age ranged from 15 to 24. This study found that in Cotamuto and Lakawa, one-third of the respondents obtained their junior high school, while in Afabubo, 27% finished their primary education. Data suggests that most farmer-respondents in the study site did not have formal education, while for those who attended school, only a few obtained higher than junior high school.

Main livelihood

The households' main livelihoods were dominantly farming, while few engaged in livestock and hired labor (Figure 4). In Cotamuto, 73% of respondents were engaged in farming, while the remaining had hired labor and livestock raising as their main livelihood, with 13% each. In Lakawa, 71% of respondents engaged in farming and 29% engaged in livestock, but none of them had main livelihood from hired labour. In Afabubo, raising livestock was not their main livelihood, 80% of them had main livelihood from farming. These are inline with the national data in the 2010 census, Timorese are mainly agricultural people, with 63% of households engaged in agricultural production and 80% rearing many livestock. However, 20% are into hired labor but do farming during rest days. Moreover, farmers with limited and/or lack of knowledge are engaged in the worst land preparation practices and committed to destroying soil productivity, resulting in massive degradation, low yields, and household income. As suggested by Jha and Dang (2008), farmers head comprise 67% of the population of East Timor, of which 44% are poor, and nearly 42% are vulnerable to poverty.

Table 1. The chemical parameters in uncontrolled grazing areas

Site	pH (H_2O)	N Total (%)	P Ave. (ppm)	K Ave. (Cmolc/kg)
Cotamuto	6.93 ab	0.11 a	83.07 a	0.25 a
Lakawa	6.8 ab	0.17 a	59.29 a	0.23 a
Afabubo	6.71 b	0.18 a	10.25 a	0.23 a

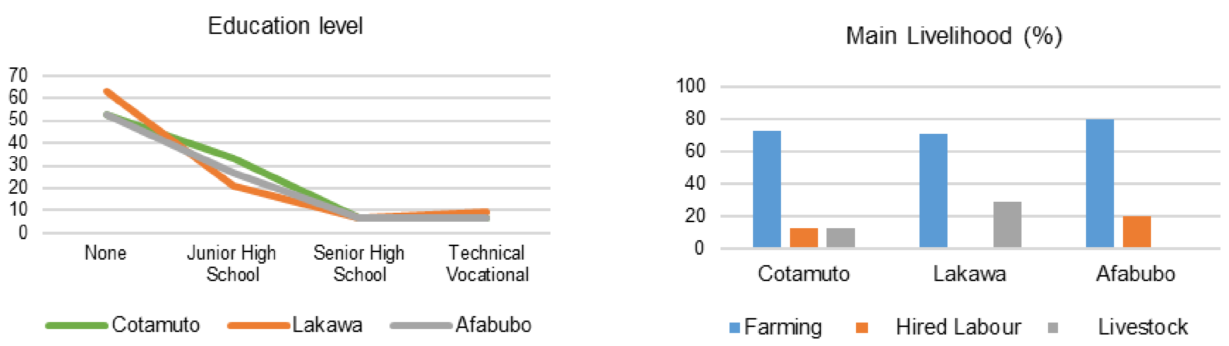

Figure 4. Education level and main livelihood

Raising livestock

Most farmers raise livestock, 93% in Cotamuto and 80% in Lakawa and Afabubo. Farmers in Cotamuto and Lakawa primarily own cattle, while sheep are mostly raised in Afabubo (Figure 5). In terms of the way they keep their livestock, all farmers in the Lakawa and Afabubo practiced uncontrolled grazing, while in Cotamuto mostly kept the animals fenced at night time and allowed them to graze in fallowed slash-and-burn areas (Table 2).

Livestock raising

A big proportion of the households in the study site are engaged in livestock production both as a main and alternative occupation. Raising livestock was highest in Cotamuto with 93.33% and slightly low in the Lakawa and Afabubo with 80% (Figure 5); these performances are common in Lautem municipality as have been reported by Ministry Economy and Development (MED) in 2011 that 84% of all household in Lautem municipality raise livestock; furthermore, Lautem municipality was the second biggest owner after Bobonaro municipality with 88.8% of households. All farmers mostly raised livestock because of the multipurpose reason they were raised. Livestock serves as household income, an asset for the future, and a social function for the wedding ceremony. Livestock also serves as cultural and ritual events, as an honored wealth to marry a woman, and for agricultural activities, particularly rice field tillage, instead of using modern agricultural machinery.

Besides the abovementioned value of livestock, it negatively impacts the soil if it grazes freely everywhere. Lack of grazing control and management leads livestock trumped on the ground with high intensity, and more frequently, could threaten soil productivity, grass sustainability, and other hydrological hazards. Through a field study in Mongolia, Wang and Batkhishig (2014) concluded that increasing the number of livestock in the same area would tend to overgraze affects soil water physical properties, top soil become more compact and decreasing soil moisture.

Livestock distribution

More than half (57.14%) of farmers in Cotamuto raised cattle and goats. A similar pattern was recorded in Lakawa but a slightly higher percentage (69.23%), while in Afabubo, the majority (92.31%) raised sheep (Table 2). Raising livestock is being opted as a traditional activity in East Timor as the report of MED 2011 and NSD 2011 mentioned that one of the most traditional activities of households in East Timor is raising livestock, for the overall country there are 80% raised livestock, and 23% are owned cattle in 2010, in addition in 2011 increased to 31% of household owned cattle mostly involved by rural/poor household.

Regarding keeping livestock, most (92.87%) of respondents living in Cotamuto kept their livestock in paddocks at night time and open grazing. However, more than half the place in them is in fallow burned areas. In Lakawa, all left their livestock in open grazing; a little less than half (41.67%) kept them in paddocks at night time. In Afabubo, all respondents placed their livestock in paddocks and grazing areas.

Data suggests that most farmers primarily utilize paddocks and grazing areas to keep their livestock. It was observed that free grazing without putting back in paddocks at night was practiced at the study site. Keeping in paddocks is usually practiced during wet or crop-growing seasons to avoid crop disturbance; these situations are practiced commonly by farmers. Waldron et al. (2015) described that way keeping cattle is commonly grazed for all or most of the year in open grassland and kept on the paddock at night, seasonally, or in some cases, not at all.

The relationship between socioeconomic factors and grazing area degradation

Multiple regression was used to determine the relationship between socioeconomic factors and soil degradation in watershed areas using socioeconomic data as independent variables and each soil properties data as dependent variables. This was done for three villages (Cotamuto, Lakawa, and Afabubo). First, the regression value in R^2 was used to interpret the relationship of both independent and dependent variables, followed by looking at coefficient values to determine either negative or positive effects in every single variable (Table 3).

The socioeconomic variables and soil degradation concerning free grazing in Cotamuto have a moderate relationship with physical properties and a strong relationship with biological and chemical properties with BD R^2 = 0.426, SP R^2 = 0.418, SOM R^2 = 0.496, N R^2 = 0.789, P R^2 = 0.375, and K R^2 = 0.716, respectively. In Lakwa, the relationship is low to moderate; the BD R^2 = 0.359, SP R^2 = 0.360, SOM 0.480, N R^2 = 0.385, P R^2 = 0.086, and K R^2 = 0.488. while in Afabubo, the relationship is moderate to a strong relationship. The BD R2 = 0.534, SP R^2 = 0.688, SOM R^2 = 0.903 N R^2 = 0.791 P R^2 = 0.559, and K R^2 = 0.529 (Table 3).

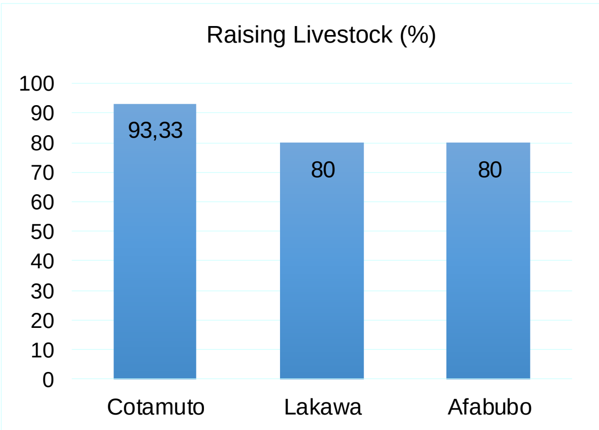

Figure 5. Percentage of raising livestock

Table 2. Livestock distribution and way of keeping

Area/village	Livestock distribution (%)			Way of keeping (%)		
	Cattle	Sheep	Goat	In paddock	Uncontrolled grazing	In fallowed/ burned area
Cotamuto	57.14	21.43	57.14	92.87	92.87	57.14
Lakawa	69.23	7.69	69.23	41.67	100.00	25.00
Afabubo	30.77	92.31	15.38	100.00	100.00	33.33

Table 3. The correlations between education and livelihood to physical soil quality

Site	Socioeconomic	BD	SP	SOM	N	P	K
Cotamuto	Education	0.068 ns	-2.711 ns	-1.238 ns	0.003 ns	-63.59 ns	0.002 ns
	Main Livelihood	0.425 ns	-16.218 ns	-1.174 ns	0.007 ns	-12.098 ns	-0.017 ns
	Livestock Raising	0.030 ns	-0.986 ns	3.211 ns	-0.048 ns	75.393 ns	0.009 ns
	Statistical	R^2 = 0.426	R^2 = 0.418	R^2 = 0.496	R^2 = 0.789	R^2 = 0.375	R^2 = 0.716
	Summary	F = 0.557	F = 0.539	F = 0.737	F = 2.957	F = 0.450	F = 1.894
Lakawa	Education	-0.022 ns	0.087	7.499 ns	-0.005 ns	-9.000 ns	0.107 ns
	Main Livelihood	0.315 ns	-11.45 ns	-1.540 ns	-0.005 ns	10.442 ns	-0.160 ns
	Livestock Raising	0.053 ns	-2.048 ns	-3.222 ns	-0.019 ns	-1.584 ns	0.061 ns
	Statistical	R2 = 0.359	R2 = 0.360	R2 = 0.480	R2 = 0.385	R2 = 0.086	R2 = 0.488
	Summary	F = 0.561	F = 0.562	F = 0.923	F = 0.627	F = 0.094	F = 0.952
Afabubo	Education	-0.001 ns	-1.946 ns	3.529 ***	-0.006 ns	108.940 ns	-0.049 ns
	Main Livelihood	0.226 ns	-11.022 ns	-0.943 ns	0.121 ns	-37.548 ns	-0.040 ns
	Livestock Raising	0.264 ns	-9.237 ns	-0.132 ns	-0.021 ns	9.120 ns	-0.022 ns
	Statistical	R^2 = 0.534	R^2 = 0.688	R^2 = 0.903	R^2 = 0.791	R^2 = 0.559	R^2 = 0.529
	Summary	F = 0.859	F = 1.656	F = 6.958	F = 2.844	F = 0.951	F = 0.843

Note: ns: Non-significant, * = 0.05, ** = 0.01, *** = 0.001, BD: Bulk Density, SP: Porosity, SOM: Soil Organic Matter, N: Nitrogen, P: Phosphorous, K: Potassium

Overall, the socioeconomic variables have no significant relationship with soil bulk density, porosity, and soil nutrients (Table 3), but grazing area degradation have widely reported in several studies has influenced by socioeconomic factors (Yong-Zhong et al. 2005; Chang et al. 2014). However, there is a moderate relationship instead. As a social relationship, soil degradation is widely recognized that no single factor is determining the quality and productivity of soil; anyhow, dynamic changes thru time and are affected by both socioeconomic and edaphology (agrology) factors. Agriculture practices ignoring agroecosystem stability have already posed more damage to nature than any other human activity (Balmford et al. 2012).

Unlike in Cotamuto and Lakawa, education level strongly relates to soil organic matter in Afabubo. This indicates farmers are not sensitive to the degradation because they lack awareness and do not value the grassland for their own life. Although knowledge of the importance of conservation is crucial, access to information, capacity building, and public awareness program would be equally important to improve farmers' awareness of managing grassland in sustainable ways (Wang and Batkhishig 2014).

Soil properties in uncontrolled grazing have a low to moderate relationship to the farmers' education level and livelihood; it may have been influenced by cultural or lack of information and policies (MAF 2018). Soil health problems can be caused by edaphic and climatic factors: soil type, structure, and soil formation process, including rainfalls, temperature, and land cover, contribute to soil property changes. The result mentioned a different view than other studies (Savadogo et al. 2007; Maitima et al. 2009; Piñeiro et al. 2010). Land ownership may influence soil degradation and uncontrolled grazing practices that this study does not assess. According to the National action program report for climate change, land tenure, and ownership trigger land degradation and low interest in conserving and protecting forests and grassland (NAP 2008).

Conclusions from the findings of the study, the following conclusions are drawn: (i) Uncontrolled grazing practices have directly affected soil productivity for livestock grazing and other purposes. Regarding soil biophysical properties, the soil became low in moisture content, very compacted, and less porous. The practice also removed the vegetation on the ground, which made the soil prone to a high evaporation rate, and increased soil moisture losses; it allowed for massive and continuous soil erosion. It also eliminated soil microorganisms that have important roles in decomposing organic matter. With continuous uncontrolled grazing practices, the balance in the ecosystem is affected. The soil health status in the study area is prone to high run-off, erosion, and loss of productivity. (ii) Across the study site, there are low levels of education and few alternative livelihoods; however, there is a moderate relationship between socioeconomic factors and soil degradation. Therefore, more studies on socioeconomic influences on uncontrolled grazing must be recommended to provide proper options for decision-makers and land users to promote conservative practices while utilizing land and other natural resources.

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