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Full Length Research Paper

Aquatic macro invertebrate contribution in leaf litter breakdown in tropical mining area streams (Côte d'Ivoire, West Africa)

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The aim of the study was to determine how mining operations affected the health of aquatic ecosystems. The investigation was carried out in the diamond, gold, and manganese mining areas of Tortiya, Hiré, and Lauzoua. Leaf litter bags were used to assess breakdown. To further identify macro-invertebrates in the laboratory, leaves from emerged large-mesh bags were preserved in 70% alcohol. The results showed that there was no statistically significant difference in lost masses between small mesh nets and large mesh nets for a foliar species at the same station. The breakdown rates of *Alchornea cordifolia* in large mesh nets at N'Teko station were significantly higher ($p<0.05$) than in small mesh nets (0.017 j^{-1}). The majority of the macro-invertebrates found in leaf litter bag were insects and gastropods, with proportions exceeding 50%. Insects dominated the macroinvertebrate group involved in leaf litter decomposition in Lauzoua (91% of associated species) and Hiré (56.5%), whereas gastropods (Mesogastropoda and Basommatophora, 77% of related organisms) were most abundant in Tortiya. The functional feeding groups of macro-invertebrates involved in the breakdown of leaf litter were dominated by predators (46% of species) and scrapers grazers (27% of taxa). Shredders made up only 1% of the species associated with leaf litter. Macro-invertebrates' contribution was significantly higher (Mann -Whitney test, $p<0.05$) at Bou 1 station. Insects and gastropods made up the majority of the macro-invertebrates involved in litter decomposition. Breakdown rates were relatively low at all stations.

Key words: Macro-invertebrates, contribution, breakdown rates, mining areas, streams.

INTRODUCTION

Leaf litter breakdown is a process involving biotic (macro-invertebrates, micro-organisms) and abiotic (physicochemical and chemical parameters). Aquatic macro-invertebrates are part of the invertebrate fauna visible to the naked eye. They carry out at least part of their life cycle in an aquatic environment and are larger

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than 0.5 mm. These organisms make it possible to establish a much more precise portrait of the integrity of an ecosystem according to the groups of communities that live there (Yoder and Rankin, 1995).

Among the macro-invertebrates, macro-invertebrate shredders are selective organisms which play important role in breakdown fluxes of leaf litters (Sena et al., 2020). Under natural conditions, streams litter is made up of leaves of various plant species. Leaf selection by shredders seems to impact their growth while taking into account the quality of the leaves (Tenkiano and Chauvet, 2017). Leaf selectivity by macro-invertebrates can be based on toughness, nutrient content and the presence of secondary plant components such as chemical defenses (Divekar et al., 2022). Leaf toughness could be a physical barrier to feeding of invertebrates, since harder leaves are probably more difficult to puncture than soft leaves (Barton et al., 2019). Consequently, some genera of macro-invertebrates at younger stage of development are unable to feed on hard leaves. The nutrient content of the leaves is a very important factor for the organisms that feed in the litter (Arias-Real et al., 2018). Finally, secondary compounds, involved in plant defenses are known to remain active after leaf senescence (Barton et al., 2019). These compounds can be toxic, disrupt digestion or give off bitter taste and act as food deterrents. Streams, whether forest or savannah, receive significant inputs of organic debris. These ecosystems are generally heterotrophic. In these ecosystems, allochthonous contributions generally exceed primary production (Golubkov et al., 2017) ; the amount of sunshine being limited by the presence of the canopy. Allochthonous organic matter such as leaf litter from riparian vegetation is, therefore, an important source of energy for these ecosystems (Mutshekwa et al., 2020). Leaf litter breakdown is therefore, a central process in the balance of organic matter in these ecosystems (Bista et al., 2017). Once in the watercourses, this organic matter is broken down and transformed by stream shredders to fine particles that can be consumed by detritivorous macroinvertebrates (González and Graça, 2020).

In this regard, shredder macro-invertebrates play an important role in decomposing organic matter (Augusto et al., 2019). Macro-invertebrates exclusion, which are the main actors in leaf litter breakdown, would thus reduce the loss of mass of litter (Classen Rodriguez et al., 2019). Given their importance in the functioning of aquatic ecosystems, it is important to assess the contribution of macroinvertebrates in leaf litter breakdown process. Very few studies on leaf litter breakdown have been carried out in West Africa (Tenkiano and Chauvet, 2017), especially in Côte d'Ivoire where no study has been carried out on the role of aquatic macroinvertebrates in the process of leaf litter breakdown in streams. The objectives of this study were (a) to assess leaf litter lost masses and breakdown rates, (b) to determine the contribution of macroinvertebrates involved in the leaf litter decomposition process, and (c) identify the macroinvertebrates involved in the leaf litter breakdown process.

MATERIALS AND METHODS

Study sites and sampling stations

The study was conducted in three mining areas in Côte d'Ivoire namely: Tortiya in the north (diamond mining), Hiré (gold mining) and Lauzoua (manganese mining) in the south of the country between 6 and 11 weeks during 8 campaigns. The choice fell on the mining areas because of the multiplicity of mining activities in Côte d'Ivoire. Seven streams were selected (Figure 1).

One sampling station was defined on each stream except in stream Bou were two stations were defined. The sampling station is a very precise place with known geographical coordinates where samples are taken, where an experiment can also be carried out. Among the 7 stations (Table 1) the Bou 1 (locality of Tortiya) and N'Téko (locality of Lauzoua) stations stand out from the others since they are not found in the mining area. Indeed, they have been defined as reference station. In Hiré, no reference station could be defined because of the mining activities that take place near all the streams there.

This experiment has limitations, as there is a possibility of leaf loss. However, it is the only one carried out presently in small streams to highlight the role of certain organisms in the litter decomposition process. Its purpose is to illustrate the role of certain organisms in the functioning of aquatic ecosystems.

To carry out the experiment, the dominant plant species encountered near the study stations were used. Indeed, these species are those which are found in the rivers once it detaches from the nearby trees. Their use made it possible to better perceive the rate of decomposition of litter. Two families of leaf species were used, Euphorbiacea (genus *Alchornea cordifolia*) and Leguminosae (genera: *Pueraria phasoloides*, *Lonchocarpus sericeus* and *Leptoderris brachyptera*).

Leptoderris brachyptera (station Bou 1) and *Pueraria phasoloides* (station Bou 2) were the two species used in Tortiya. Species *Lonchocarpus sericeus* (stations Gbloh and Tributary Gbloh) and *Alchornea cordifolia* (Tchindegri station) were used in Hiré. In Lauzoua stations (Dougodou, Tributary Dougodou and N'Téko), *Alchornea cordifolia* was used.

The geographical characteristics of stations are listed in Table 1.

Leaf litter lost masses and breakdown rates

Once in the laboratory, 100 g of each type of leaves were dried in an oven at 67.5°C for three days until a fixed mass was obtained. The dry leaves are used because they facilitate the action of the decomposers. For each type of leaf litter, 5 g (± 0.05) of dried leaves were incorporated into two types of litter net: Fine mesh (FM) (250 µm of mesh) and large mesh (LM) (0.5 cm of mesh) in order to differentiate the activity of micro-organisms and that of macro-invertebrates (Benfield, 1996). The FM litter net was used to exclude invertebrates, whereas a LM litter net was used for invertebrate colonization. Each litter bag was labeled, kept closed and held by large stones at the bottom of the various streams to ensure stability. A total of 40 LM nets and 40 FM nets with leaf species were laid down during the study. Litter nets were removed carefully from each location. They were immediately and individually placed in labeled jars containing water from the corresponding stream and kept in a cooler.

In the laboratory, leaf litter were rinsed with water over fine mesh (0.5 mm) sieved to remove sediments and invertebrates from large mesh litter bags. Fine mesh Litter bags were rinsed according to the same process. In these bags, there were no invertebrates. The leaves were cleaned and dried for three days in an oven at 65°C. The mass losses were determined for further analyses.

Contribution of macro-invertebrates involved in the leaf litter breakdown process

The contribution of macro-invertebrates in the decomposition process of leaf litter made it possible to determine the proportion of leaves decomposed under their action for each type of litter at the stations concerned.

Macro-invertebrates involved in the leaf litter breakdown process

To identify the macroinvertebrates involved in the process of leaf litter breakdown, macroinvertebrates from large mesh litter bags were identified to the lowest possible taxonomic level using a stereomicroscope Olympus SZ (40× magnification) and a series of identification keys (Monod, 1966; Déjoux et al., 1981; Day et al., 2001a; Day et al., 2001b; De Moor et al., 2003a; De Moor et al., 2003b; Stals and De Moor, 2007; Tachet et al., 2010). After identification, each taxon was allocated to a class and a functional feeding group according to the trophic category as assigned by Tachet et al. (2010).

Data analysis

Litter mass losses were determined in the different station. They are generally assessed using the litter bag technique, which has been widely used by many authors including Bärlocher (2005). The difference between the initial dry mass (before immersion in water) of the litter and the final dry mass (after immersion in water) of the litter corresponds to the amount of decomposed leaves (mass lost) during the experimental period. This difference is made for both types of litter bags. The mass losses are then converted into percentage. Following this calculation, the mass losses are used to calculate the breakdown rate of leaf litter according to the type of litter taken from the different water-courses.

Leaf litter breakdown rates (k) were estimated according to the exponential model:

$$\mathrm{K(day^{-1})} = \frac{1}{\mathrm{t}} \ln\left(\frac{\mathrm{M_0}}{\mathrm{M_t}}\right)$$

where M_t is final mass of leaf litter (g), Mo is initial mass of litter at the beginning of the experiment, and t the exposure time (days).

Macro-invertebrates contribution in decomposition process was isolated from microbial activity by subtracting fine mesh mass lost (microorganisms) to large mesh mass lost (Boulton and Boon, 1991). Macro-invertebrates abundance, taxa, classes and functional feeding group (FFG) were determined.

The statistical significance of lost masses in different nets, macro-invertebrate contribution and leaf litter breakdown rates were evaluated using a Mann-Whitney and Kruskal-Wallis test.

RESULTS

Lost masses of leaf litter and breakdown rates

The variation of lost masses in FM nets and LM are presented to Figure 2A.

In Hire, the percentage variations of lost masses for *Lonchocarpus sericeus* species was most important in Tributary Gbloh station. In FM nets the variation in lost masses was between 2 and 9% while it was between 10 and 18% in LM nets. In this same locality (Tchindegri station) the variation of the lost masses for *Alchornea cordifolia* species varied between 5 and 20% (FM nets) and oscillated between 7 and 28% (LM nets).

In Lauzoua, the variation of the lost masses for *Alchornea cordifolia* in FM nets oscillated between 0.8 (station Dougodou) and 20.2 (station Affluent Dougodou). The variations of lost masses for *Pueraria* species was between 0.2% (Dougodou station) and 40% (station N'Téko).

In Tortiya, the variation of lost masses for *Pueraria phasoloides* (station Bou 2) was between 6 and 18% (FM nets), also between 20 and 25% (LM mesh).

The statistical test (Mann-Whitney test, $p > 0.05$) showed that there was no significant difference between lost masses in FM nets and LM nets for a foliar species at the same station.

Leaf litter breakdown rates in the two types of nets (LM and FM) are shown in Figure 2B. In Hiré, breakdown rates in the FM nets were between 0.032 j^{-1} (Tributary Gbloh station, *L. sericeus*) and 0.04 j^{-1} (Gbloh station, *L. sericeus*) while those of the LM nets were between 0.05 and 0.07 j^{-1} at these same stations.

In Lauzoua, *Alchornea cordifolia* species breakdown rates ranged between 0.017 j^{-1} (N'Teko station) and 0.034 j^{-1} (Dougodou station) in the FM nets while those of the LM nets were between 0.035 j^{-1} (Affluent Dougodou station) and 0.043 j^{-1} (N'Teko station). At N'Teko station, the breakdown rates in LM nets were significantly higher (Mann-Whitney test, $p < 0.05$) than those obtained in FM nets.

In Tortiya, breakdown rates in the FM nets were between 0.025 j^{-1} (station Bou 2, *Pueraria phasoloides* specie) and 0.029 j^{-1} (station Bou 1, *Leptoderris brachyptera* specie) ; those of the LM net oscillated between 0.031 and 0.037 j^{-1} at these same stations.

Contribution, classes and functional feeding group of macroinvertebrates involved in the process of leaf litter breakdown

The contribution and *functional feeding group* of macroinvertebrates in the process of leaf litter breakdown are shown to Figure 3A.

In Tortiya, their contribution oscillated between 4% (Bou 2 station, *Pueraria phasoloides*) and 32% (Bou 1 station, *Leptoderris brachyptera*). Their contribution was significantly higher (Mann -Whitney test, $p < 0.05$) at Bou 1 station.

In Hiré the lowest (0.25 %) and highest (14%) values were observed in Tributary Gbloh station for *L. sericeus.*

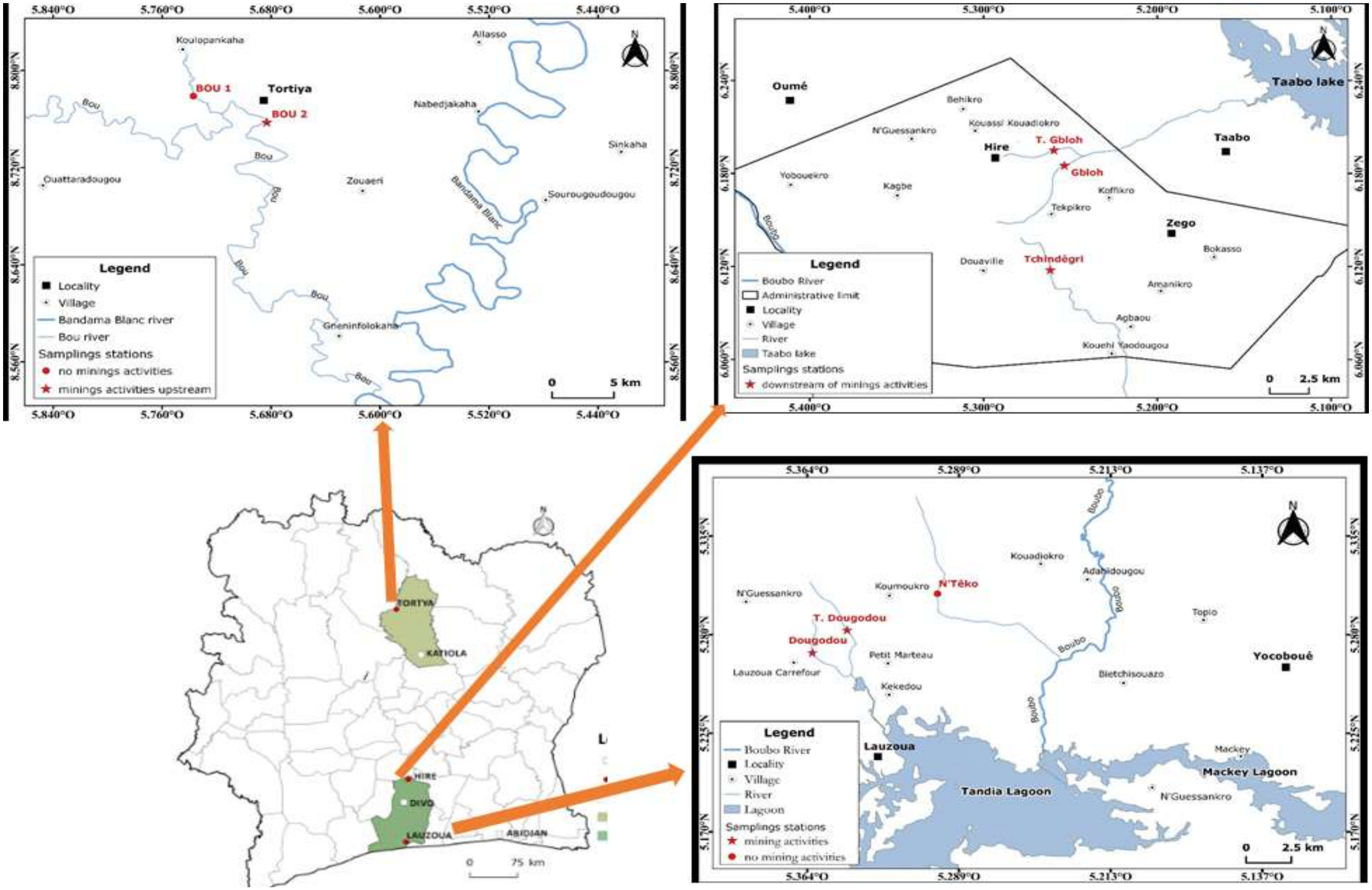

Figure 1. Geographic location of sampling stations in streams studied in three mining areas.
Source: Administrative limits data of Côte d'Ivoire, CNTIG, 2018. CNTIG: National Center for Remote Sensing and Geographic Information of Côte d'Ivoire "https://cntig.net/index.php/produits/produits-services-cntig/cartes-atlas"
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Table 1. Location and characteristics of stations used for the leaf litter breakdown experiment.

Location	Stations	Codes	Latitude (UTM)	Longitude (UTM)	Altitude (m)
Tortiya (diamond area)	Bou 1	B 1	200619	970058	300
	Bou 2	B 2	387252	595637	343
Hiré (Gold area)	Gbloh	G	250551	684486	191
	Tributary Gbloh	TG	249927	685437	168
	Tchindégri	Tg	200615	970060	189
Lauzoua (Manganese area)	N'Téko	Nt	245176	546616	4
	Tributary Dougodou	TD	240225	584411	1
	Dougodou	D	238101	582993	4

Source: The geographical coordinates of the stations of each locality were determined using a GPS

In Lauzoua, their contribution varied between 0.37% (N'Teko station) and 48% (Tributary Dougodou station) for *A. cordifolia*. Among the macro-invertebrates associated with leaf litter, insect class was predominant in Lauzoua (91% of associated organisms) and Hiré (56.5%) compared to Tortiya where gastropods (77% of associated organisms) were the most abundant (Figure 3B).

The functional feeding groups of macro-invertebrates associated with leaf litter were dominated by predators (46% of taxa associated) and scrapers grazers (27% of taxa associated). Shredders accounted for only 1% of taxa associated with leaf litter (Table 2).

DISCUSSION

Assessing the relationships between aquatic organisms and leaf litter decomposition is a key process in the functioning of waterways (Jabiol, 2010). This experiment made it possible to evaluate the contribution of macroinvertebrates at different trophic levels in the decomposition of leaf litter. Decomposition rates differ depending on the plant species. This finding would highlight the impact of the nature and quality of the plant species in the process of litter decomposition. These results corroborate those of Dangles (2004) on two plant species with different decomposition rates at similar periods of immersion. This fact would illustrate the influence of litter quality on the activity of the organisms involved in this process. This specificity essentially results from the structure and the chemical composition of the leaves, in particular in lignin and in nitrogen (Swan and Palmer, 2006). Leaf senescence could also explain the variability in decomposition rates. According to Gessner et al. (2002), decomposition rates are influenced by leaf senescence regardless of the plant species considered, especially in mining environments. During the experimental period, leaf litter decomposition rates were relatively low at all stations studied. Several studies have shown that leaf litter decomposition rates are slower in streams affected by mining activities. This result could be explained by the scarcity of grinders and shredders which play a very important role in this process. Indeed, mining activities are likely to lead to changes in the physico-chemical parameters of water. Thus the conditioning of litter by micro-organisms (bacteria and hyphomycetes) could be influenced. This situation would therefore reduce the appetite of chewing macro-invertebrates for litter, thus reducing the masses lost and the rates of decomposition. Baudoin et al. (2008) showed that micro-organisms are significantly affected by mining activities having impacts not only on nutrient intake (Cross et al., 2005) but also on protein and lipid intake essential for growth and development of macro-invertebrates (Larrañaga et al., 2010). Indeed, the micro-organisms condition the leaves in such a way that macro-invertebrates are attracted to them for food. In this study, macro-invertebrate communities associated with leaf litter were dominated primarily by predators and scraper-grazers. Macro-invertebrates are organisms that have a broad spectrum in terms of diet. In Tortiya, the contribution of macro-invertebrates was significantly high at the Bou 1 station. This result could be explained by the abundance of scraper-grazers at this station. These organisms are likely to replace the role of grinders in the leaf litter decomposition process (Graça, 2001). The contribution of macro-invertebrates differs depending on the locality and the nature of the leaves. In Lauzoua, it fluctuates between 0.37 and 48% for the species *A. cordifolia*. In Tortiya, this contribution fluctuates between 4 and 32%. In Hiré, it varies from 0.25 to 14%. Overall, the contribuion of macro-invertebrates is greater in Lauzoua and Tortiya and weaker in Hiré. These results reflect the importance of these organisms in the decomposition process and allow us to deduce that gold activities have a greater influence on the role of macro-invertebrates in this process compared to diamond and

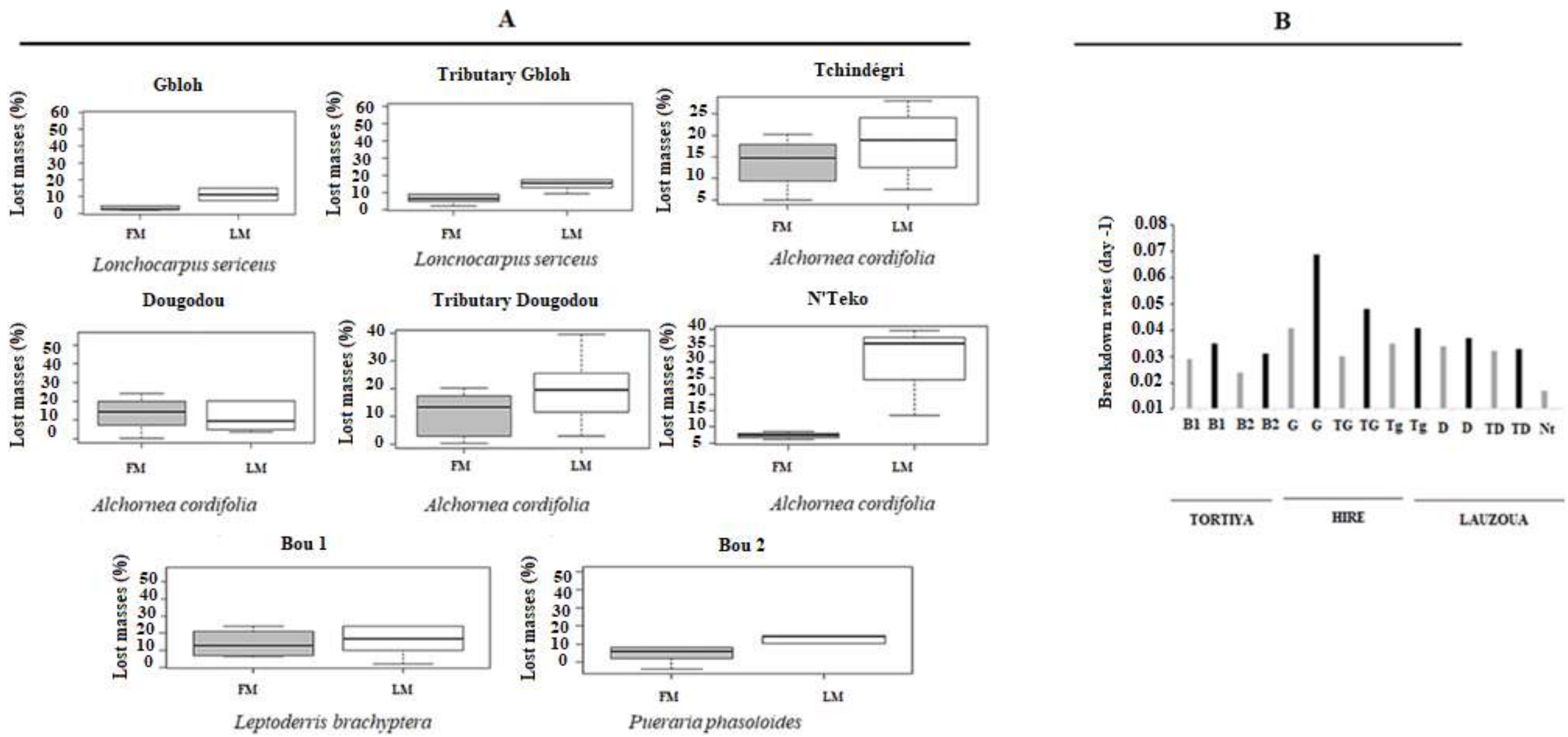

Figure 2. A: Lost masses in leaf litter nets (FM: fine mesh net, LM: large mesh net) at all stations; B: Leaf litter breakdown rates at all stations (grays bars: fine mesh, blacks bars: large mesh).
Source: Author

manganese exploitation. To reduce the impact of mining activities on the functioning of aquatic ecosystems, it would be necessary to carry out water quality assessment checks and ensure that the actors involved in mining activities comply with environmental protection standards. Periodic assessments should also be made of the impacts of these activities on the fauna of the rivers involved by listing organisms in order to identify changes in aquatic communities and to remedy them as soon as possible.

Conclusion

In conclusion, we can affirm that the macroinvertebrates participate weakly in the process of decomposition of the leaf litter at the different stations studied. These relatively low degradation rates show that the ecosystem functioning of the waters of the stations studied is impacted by mining activities, thus causing a change in the functional structure of the macro-invertebrates of the streams studied.

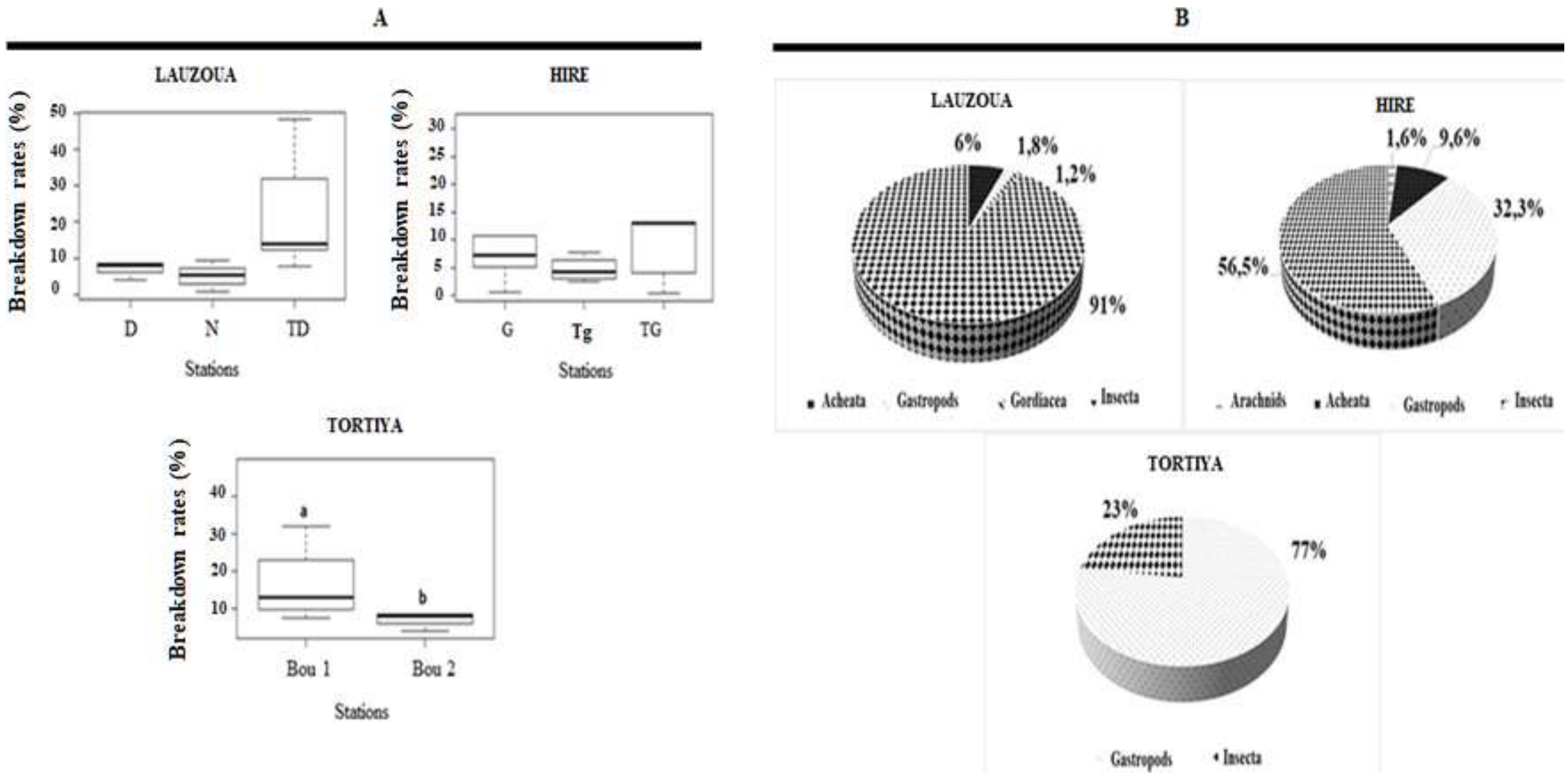

Figure 3. A. macro invertebrates' contribution in leaf litter breakdown rates. B= Percentage of macroinvertebrates classes involved in leaf litter breakdown process.
Source: Author

Table 2. List of taxa of macroinvertebrates associated with leaf litter in the target streams.

Class	Order	Family	Taxa	FFG	Lauzoua			Hire			Tortiya	
					D	TD	NT	G	TG	Tg	B1	B2
Acheata	Rhynchobdelliformes	Glossiphoniidae	*Glossiphonia* sp.	Parasites				*				
			Helobdella sp.	Parasites				*				
Arachnids	Trombidiformes	Hydrachnidae	*Hydrachnella* sp.	Predator	*	*					*	*
Bivalves	Unionoida	Corbuliidae	*Corbula gibba*	Filter			*				*	

Table 2. Cont.

Gastropods	Basommatophora	Physidae	*Physa marmorata*	Scraper grazer				*				
		Planorbidae	*Biomphalaria pfeifferi*	Scraper grazer		*						
			Indoplanobis exustus	Scraper grazer								
	Mesogastropoda	Bithyniidae	*Gabiella africana*	Scraper grazer								
		Thiaridae	*Melanoides tuberculata*	Scraper grazer	*		*		*		*	*
		Curculionidae	*Pseudobagous Longulus*	Scraper grazer				*				
Insectes	Coleoptera	Elmidae	*Limnius* sp.	Scraper			*		*			
		Hydrophilidae	*Berosus* sp.	Predator			*					
Insecta	Diptera	Ceratopogonidae	*Bezzia* sp.	Predator	*							
		Chioronomidae	*Ablabesmyia* sp.	Predator	*				*			
			Crptochironomus sp.	Predator	*	*		*			*	*
			Nilodorum sp.	Predator	*	*		*				
			Polypedilium sp.	Predator	*	*		*			*	*
			Stictochironomus sp.	Predator	*	*		*	*	*	*	*
			Chironomus sp.	Predator	*	*	*	*	*	*	*	*
			Tanypus sp.	Predator	*							
		Tabanidae	*Tabanus* sp.	Predator		*						
Malacostracea	Decapoda	Atyidae	*Caridina africana*	Shredder			*					

Stations codes: TD= Tributary Dougodou, D= Dougodou, NT= N'Téko, TG= Tributary GBloh, G= Gbloh, Tg= Tchindégri, B1= Bou 1, B2= Bou 2, *= taxa present at station, FFG= feeding functional group.
Source: Author

CONFLICT OF INTERESTS

There is no conflict of interest.

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Pare's people perception influences on conservation of wild plant diversity in protected areas in Kilimanjaro Region, Northern Tanzania

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This study was designed to assess Pare people's perception about the role of protected areas in biodiversity conservation. Viewpoints on factors causing biodiversity loss, related consequences and people's participation in forest husbandry activities were also investigated. Data were collected from Same and Mwanga Districts using semi structured interview. Results indicated generally that majority of people in the two districts regardless of sex have positive perception on the role of protected areas (p<0.01). However, consequences of biodiversity loss are more serious in Same than in Mwanga District. This contradicts the general perception. Factors that cause biodiversity loss were scored less serious in Same District and only less that 50% of people participate in forestry husbandry activities. The need to understand people's perception prior to establishment of protected areas is emphasized. Where the general perception is positive, ascertain existence of supportive evidence as it may be misguiding as observed in Same District.

Key words: Conservation of forest biodiversity, perception of Pare people, role of PAs, consequences of biodiversity loss.

INTRODUCTION

Convention on Biological Diversity (CBD) considers protected areas (PA) to be the cornerstone of biodiversity conservation. As defined by Dudley (2008), protected area is a clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve long-term conservation of nature with associated ecosystem services and cultural values (Dudley, 2008). In theory, PA should offer economically valuable goods and services that benefit society and secure livelihoods. However, policies and management strategies of PAs (e.g. forest reserves, game reserves and national parks) in many developing countries including Tanzania, keep humans away from these areas using laws or by- laws. These strategies have not been welcomed and in some places have led to hatred between protected area managers and local communities due to

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negative perception developed by local people on the role of PA (Rao et al., 2002). The reason of the hatred is not only the exclusion but the consequences of the exclusion. People no longer enjoy the environmental benefits they used to enjoy before creation of protected areas and their environmental incomes are low compared to what is typically found in such rural areas (Vedeld et al., 2012). In such a situation, management of protected areas has been expensive and sometimes counterproductive (Leimgruber et al., 2005). In the Congo basin, 34 protected areas in five countries have failed to attain their objectives due to tensions and negative perceptions held by local communities towards protected areas management (Pyhälä et al., 2016). Ntuli et al. (2019) showed that in Southern Africa if people see the rules of the park in a negative way, then they are less likely to conserve it. The author concluded that local communities' perceptions of PAs are important determinants of the success of conservation efforts. Thus, understanding people's perception is important because the attitudes and perceptions of local people towards the role of PAs are important for their long-term survival and a key to improve protected areas–people relationship (Weladji et al*.,* 2003; Htun et al., 2012).

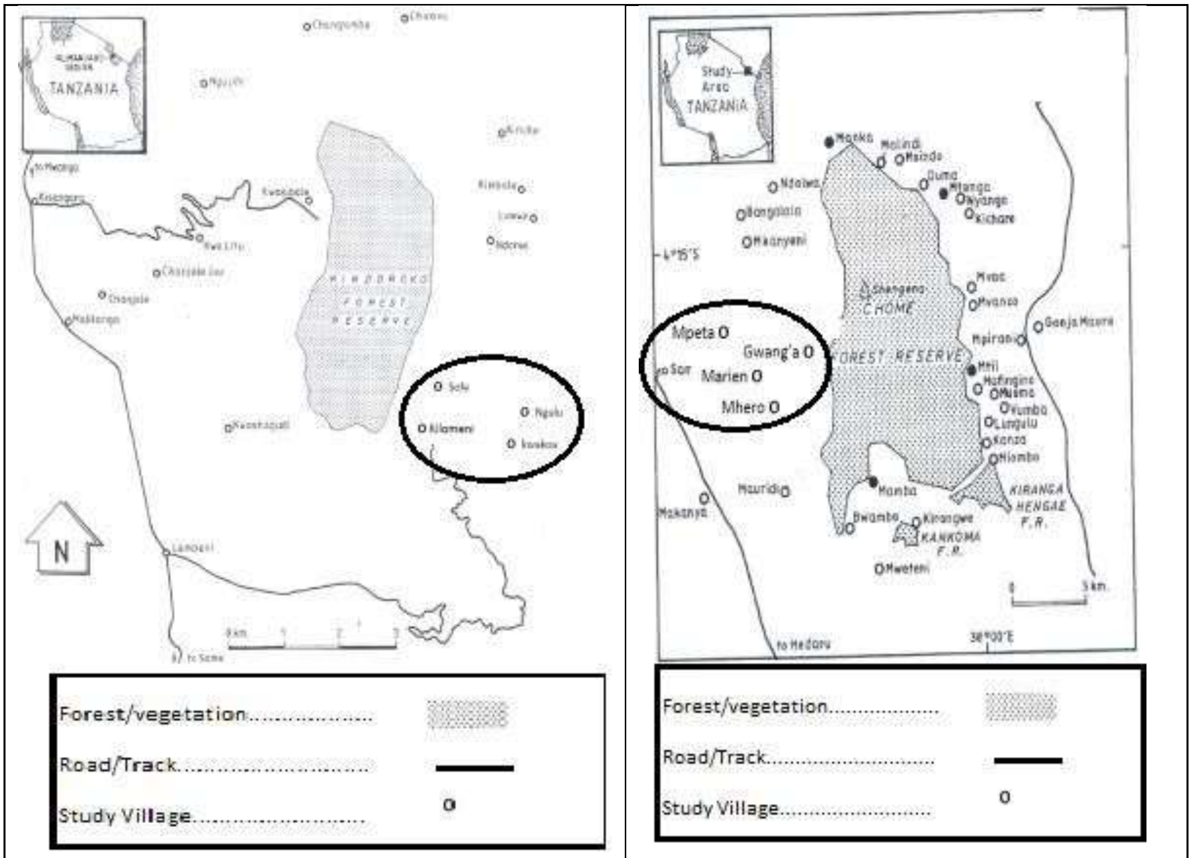
Many factors influence the perceptions of the role of protected areas held by residents living in their periphery. Some of these are history of the areas management, degree of awareness of protected areas existence among people (Ormsby and Kaplin, 2005) and the education level (McClanahan et al*.,* 2005). Others are reference to future generation (Bauer, 2003), sex and ethnicity (Gillingham and Lee, 1999; Mehta and Heinen, 2001). In Pendjari National Park, in Benin (West Africa), Bale National Park in Ethiopia and Popa Mountain Park in Myanmar what influenced people's perception were the type of management offered by the PAs and/or socioeconomic gains (Ormsby and Kaplin, 2005; Htun et al., 2012; Mamo, 2014). In Pakistan gender, crop damage, livestock predation, and total livestock holding shaped the people's perception to PAs respondents who had suffered crop damage or livestock predation by wild animals exhibiting negative attitudes toward wildlife conservation.

The contribution of income from the environment to rural people in developing countries ranges from 6-44% of their total annual income (Angelsen et al., 2014). According to Angelsen and Wunder (2003), income from the environment supports household consumption and acts as a fall back support in response to shocks. In addition it is considered to be a gap filling in case of seasonal shortfalls and a means to accumulate assets; thus an alternative way for families to get out of poverty. Before understanding and accommodating the need of the people living on the periphery, managing Pendjari National Park was often characterized by conflict between local people and forest administration (Tiomoko, 2007). In Gabon, communities said parks were responsible for their poverty (Pyhälä et al., 2016).

Residents' positive perceptions towards the role of PAs makes it possible to create place-based management strategies that uphold positive perception and help to mitigate any negative perceptions (Rao et al., 2002). The current move of tilting protection policies towards creation of PAs for poverty alleviation and putting a management emphasis on livelihood-based approaches and social safeguards as seen in Madagascar (Gardner et al., 2013; Gardner et al., 2018) reflects the need of understanding the people. In Cambodia households bordering the PAs are significantly better off due to greater access to markets and services (Clements, 2014).

In Tanzania forest reserves are managed under the Forest Act No 14 (URT, 2002). Under this protectionist model, after official gazzetment, most local people's activities that used to be without restrictions are criminalized or require permit from government authorities. Example of such restricted activities include, grazing, cutting fodder or roofing grass, fishing and making new paths or roads. Others are cutting of construction poles and ropes by debarking live trees, harvesting forest products for sale, and harvesting bee products (URT, 2002). There are twelve government forest reserves in the area; most of them were created in the past decade as a measure to control increased loss of biodiversity outside clan forests and status of some have been raised to nature reserves. As in other places where PAs have been used creation of these forest reserves has resulted into exclusion of people as residents, prevented consumptive use, and minimized other forms of human impacts. Mariki (2001) showed that some people living near Pas in Tanzania were poorer than national average.

Much has been written about Pare people. They range from history and religion, how they conserve biodiversity, biodiversity richness in traditional forests, forest and tree symbolism and conservation and fragmentation of indigenous forest and loss of indigenous knowledge within the young generation (Kimambo, 1969; Kimambo and Omari, 1972; Mshana, 1992; Mwihomeke et al., 1998; Newmark, 1998; Persha, 2003; Ylhäisi, 2004; Jones, 2013). However, there is limited information on Pare's perceptions towards the role of protected areas to conserve forest biodiversity in their area. Pares still maintain clan forest managed under indigenous knowledge; however, the reason why there is continuous forest loss and disturbance has not been fully explained. Specifically, this study was thus designed to answer the following questions: 1) What is the perception of Pares about the role of protected areas in biodiversity conservation in relation to location (Mwanga and Same) and gender; 2) What are the factors that lead to forest biodiversity loss; 3) What are the main consequences of



Selected villages around Kindoroko Forest Reserve – Mwanga District (37°25′-37°58′ E; 3°25′-3°55′ S).	Selected villages around Chome Forest Reserve - Same District (4°15'0" S and 37°55'0" E).

Figure 1. Map of Mwanga and Same districts in Tanzania showing the study sites in circles.
Source: Geography Department University of Dar e s Salaam.

forest biodiversity loss; and how do people participate in selected forest husbandry activities.

MATERIALS AND METHODS

Study area and sampling

Pare mountain forest blocks are wholly confined to Same and Mwanga Districts in Kilimanjaro Region. It is situated between 40 10' and 4024' South and 370 53' and 380 00' East. It reaches up to 2,463 m altitude. Most of the lands outside the government reserves are villages and traditionally managed forest patches in farmlands. Existence of both traditional managed forest and government forest reserves in the same areas made this area ideal for this study. The study was carried out in Same and Mwanga Districts. In each district, 4 villages were systematically selected: two villages located close to the forest reserve and two villages away from the forest reserve. The villages were: Mhero, Marieni, Gwanga and Mpeta from Same District and Sofe, Kilomen, Ngulu and Kwakoa from Mwanga District (Figure 1). In each village, 30% of households were included in the study; from Same District, Mhero village, 95; Marieni village, 98; Gwanga village, 108 and Mpeta village, 84 households. From Mwanga district were Sofe village, 112; Kilomen village, 86; Ngulu village, 129 and Kwakoa village, 49 households. Total sample size was thus 761 households.

In each village households were selected systematically where every fourth household was picked. In case where the selected household had no people the next household was included. In each household either a male or a female was interviewed in an alternating order. During data collection, it was also ensured that people interviewed were of different ages, levels of education and sex. Data on youths from below 18 years of age were obtained from secondary schools. Figure 1 provides the names and locations of the systematically elected villages around Kindoroko Forest Reserve in Mwanga District and around Chome Forest Reserve in Same District.

Data collection and analysis

Data from household members were collected using semi structured interview. An interview questionnaire was designed to cover all issues that were intended for this study. Data from youths were collected from school students during working hours. On general perception interviewees were asked how they perceived the use of forest reserve to conserve forest biodiversity and the expected answer was whether they had a positive or negative

Table 1. General perception of Pareson use of PAs to conserve diversity of wild plants.

District	Those with positive perception						Those with negative perception					
	Male		Female		Total		Male		Female		Total	
	Count	%	Count	%	Count	%	Count	%	Count	%	Count	%
Same	190	49.4	147	38.2	337	87.6	26	6.8	22	5.7	48	12.4
Mwanga	167	44.4	163	43.4	330	87.8	26	6.9	20	5.3	46	12.2

Source: Authors

Table 2. Rating percentage index on activities that cause loss of forest biodiversity.

District	Habitat loss (%)	Over exploitatation (%)	Poor management (%)	Forest fire (%)	Logging (%)	Mining (%)
Same	46	43	50	36	32	46
Mwanga	44	44	42	40	41	44

Source: Authors

perception. It was assumed that their perception could be influenced by knowledge of factors that causes loss of forest biodiversity in the area and the consequences. The participants were also asked which activities they thought were more important causes of biodiversity in the area and what the important resulting consequences were. Responses to these questions were selected from prepared list of known causes of biodiversity loss and their possible consequences. The causes of biodiversity loss and consequences were those that have been reported in the area by other workers and forest authorities. It was also thought that how they participated in forestry husbandry activities was a reflection of how they understood the consequences of forest biodiversity loss and showed their readiness took initiatives to counter the problem.

The collected data were sorted and analyzed using Statistical Package for Social Science (SPSS) for windows version 16. Attitude of people towards the role of FRs to conserve biodiversity was also tested statistically using Analysis of Variance (ANOVA) of the software INSTAT 3. Tukey post hoc test was run to confirm where the differences between groups occurred following the differences observed under ANOVA to be significant. Other data were compared ranked based on percentage using Rating Percentage Index calculated with the formula,

$$= \quad (WP*0.25) + (OWP*0.50)$$

Where WP = Percentage of acceptance and OWP =percentage of rejection and 0.25 and 0.5 are constants. The lower the value of RPI the more the acceptance is.

RESULTS

Table 1 presents general perception of Pare people of Mwanga and Same districts on the use of Forest reserves to conserve biodiversity. Results are presented as number of people (real count and percentage. This table showed that 87.6% of all people interviewed in Same District generally had positive perception towards the role of Pas, that is, forest or nature reserve to conserve wild biodiversity in the area. Males constituted 49.4% and females, 38.2%. Only 12.5% of all people interviewed, 6.8% males and 5.7% females had negative perception towards the role of FRs as a strategy to conserve wild plants diversity in Same District.

This pattern was not different from the pattern observed in Mwanga District. In Mwanga 337 people which are 87.8% of all people interviewed generally had positive perception towards the role of FRs to conserve diversity of wild plant in Mwanga District. This percentage was made up 167 males (44.4%) and 163 females (43.4%). Only 46 people (12. 2% of all people interviewed had negative perception. Of these 6.9% were males and 5.3% were females.

Though the number of males with positive perceptions was higher in each district compared to number of females in both districts the differences observed were not statistically significant ($p>0.05$). This pattern was similar to the one observed between males and females with negative perception within each district. On the other hand, the number of females or males with positive perception was higher than females or males with negative perception within each district and across districts and these differences were highly significant ($p<0.01$).

Factors that causes loss of forest biodiversity

Table 2 presents Rating Percentage Index (RPI) scores for each activity in each district and Figure 2 presents results on what Pares of Mwanga and Same consider to be causes of loss forest biodiversity in their area.

The percentage of people that agree that habitat loss through agriculture, over exploitation of forest products, poor forest management, forest fires, timber harvesting

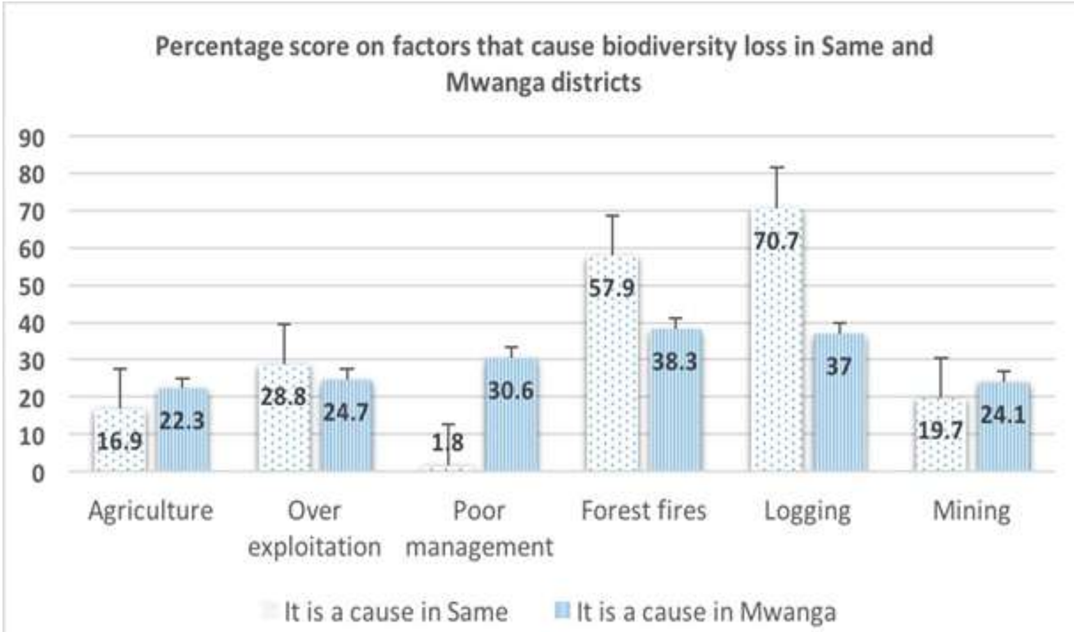


Figure 2. Pares percentage score per activity known to cause forest biodiversity loss. Whisker on bars represent standard errors.
Source: Authors

Table 3. Rating percentage index scores on consequences of forest biodiversity loss in the study area.

District	Unreliable rainfall	Drying of water source	Diminishing source of firewood	Wildlife unavialability	Loss of herbs	Drought
Same	37	36	44	49	36	34
Mwanga	41	41	44	44	39	33

Source: Authors

(logging) and mining has caused loss of forest biodiversity in Mwanga District were below 40% of all (22.3 to 38.3%) the people interviewed. The results for Same District almost compare with those in Mwanga District. People who considered habitat loss, overexploitation, mineral exploitation and poor management to be causes of loss of forest biodiversity in Same District were below 30% of the people interviewed.

The exception of the above observation was that in Same District 70 and 54% of people interviewed agreed that logging and forest fires cause forest biodiversity loss in their district. Based on Rating Percentage Index, timber harvesting and forest fire overexploitation of resources were the activities that were rated higher in the two districts but seemingly to have more effects in Same than in Mwanga. Poor forest management was rated the least contributor in Same District whereas in Mwanga it was habitat loss through agricultural expansion, over exploitation of resources and mining.

What Pare people consider main consequences of loss of forest biodiversity in their area

About what Pares considered to be major consequences of loss of forest biodiversity in their area are unreliable rainfall, drying of water sources, diminishing of firewood, unavailability of wildlife, loss of useful herbs and drought. Results in this case are presented in Table 3 (PRI scores per activity in each district are presented) and Figure 3.

In Same District, majority of the people (51.8 to 62.3%) agreed that four of the six consequences of loss of forest biodiversity studied namely; unreliable rainfall, drying of water sources and loss of useful herbs and drought were evident consequences of loss of forest biodiversity. Diminishing of firewood and unavailability of wildlife were not considered by majority to be consequence of loss of forest biodiversity in Same District. In Mwanga District almost all factors listed were considered to be consequences of forest biodiversity loss only by less than 40% of people interviewed (that is 22.6-36%). The

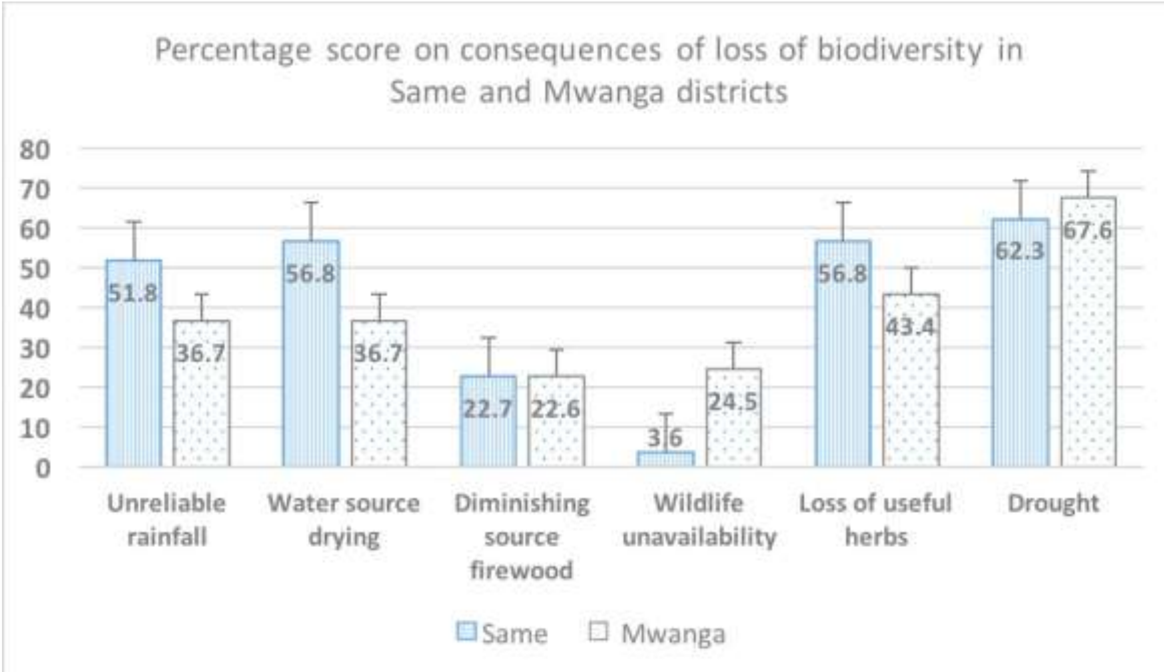


Figure 3. Scores of Pares people on consequences of forest biodiversity loss in their area. Whisker on bars represent standard errors.
Source: Authors

exception was only drought which was considered a consequence by 67.7% of Pares interviewed in Mwanga. The RPI for drought was closer for the two districts. Based on Rating Percentage Index in Same District drought was rated first followed by drying of water sources; loss of useful herbs were rated equal, followed by unreliable rainfall, diminishing source of firewood and lastly unavailability of wildlife. In Mwanga District as in Same District drought was rated first, followed by loss of useful herbs, unreliable rainfall and drying of water sources were rated same and similarly diminishing source of firewood and wildlife unavailability were rated same. With exception of diminishing of firewood sources which was rated equally in both Same and Mwanga districts and wildlife unavailability all other consequences were rated to have lower consequences in Mwanga than in Same.

Participation in forestry husbandry activities

Figure 4 presents results on the participation of Pare people on selected forest husbandry activities. These are activities that directly or indirectly contribute to serve forest biodiversity and their services; they are planting trees, conserving water catchment, controlling forest fire, and observing forest resource conservation regulations. Table 4 presents results on RPI scores.

Results on the participation of Pares in the two districts on the four selected forest husbandry activities were not comparable contradicting the results on general perception in Table 1. In Mwanga District, the percentage of people who said they participate in the four forest husbandry activities ranged from 58.8 to 88.1%. The highest percentage was on controlling forest fires and the lowest being on planting trees. Observing forest resource conservation regulations and conserve water sources were at 60.1 and 63.5%, respectively. Since engagement on these four forest husbandry activities supports conservation of forestry diversity, Mwanga results agree with general perception of Pare people. On the contrary, results on how Pares in Same District participate in the four selected forest husbandry activities gave a different picture. The percentages of people participating in each of these activities were lower than 50% (range from as lower as 11.7 to 41.5%). The highest percentage for Same District was not on controlling forest fires as in Mwanga but on planting trees, controlling forest fires was lowest of all in Same District.

Based on Rating Percentage Index (Table 4), people in Same participated mostly in controlling fires, followed by conserving water sources, whereas planting tree and observation of forest regulations rate last and equal. On the other hand, in Mwanga District what was rated highly was tree planting and observation of forest regulations (RPI 40 each) followed by conserving of water sources and lastly controlling of fires. Observation indicates also

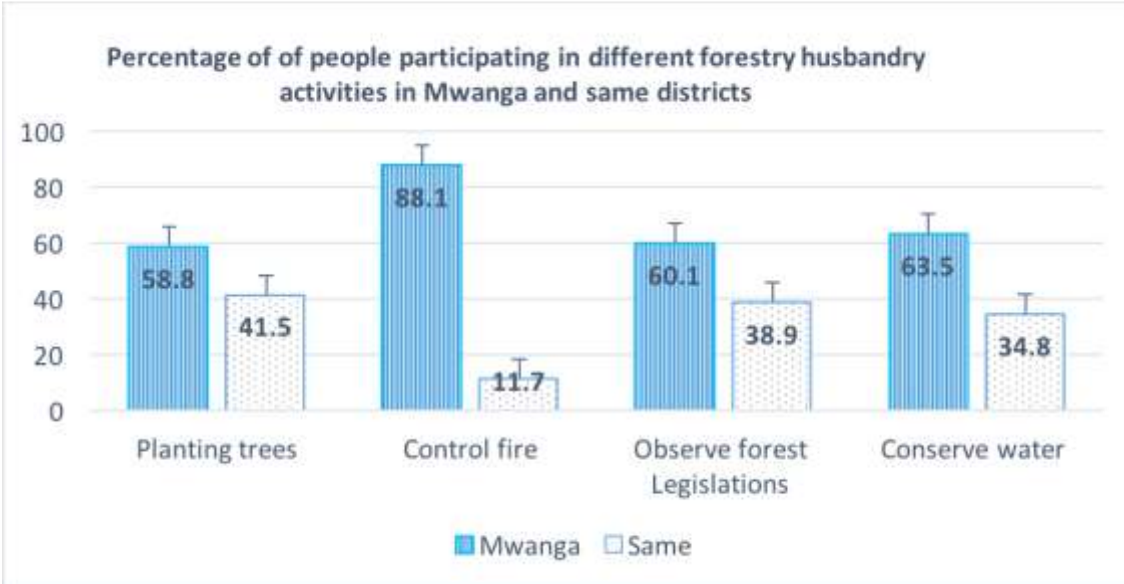


Figure 4. Percentage of Pares that participate on selected forest husbandry actions. Whisker on bars represent standard errors.
Source: Authors

Table 4. Rating Percentage Index scores on forest husbandry activities in the study area.

District	Tree planting	Control forest fires	Observe forest legislations	Conserve water sources
Same	35	28	35	34
Mwanga	40	47	40	41

Source: Authors

that comparatively each activity was rated higher in Same District than in Mwanga.

DISCUSSION

Local community's perception on the role of PAs on the conservation of forest biodiversity

The Pare person with positive perception on the role of forest reserve to protect forest diversity was significantly higher than those with negative perception regardless of their sex. This suggests generally that majority of Pares in Mwanga and Same districts regardless of their sex perceive the role of forest reserve to conserve diversity of plant species positively. Conserving forests biodiversity is not new to Pares as they themselves maintain sacred forest that are protected under indigenous regulations and in fact, are more protected than government reserves.

Although the positive perception recorded by Pares may be taken to indicate that they have accommodated the presence of forests reserves such as Kindoroko, Kamwala I and II, Minja and Mramba in Mwanga district (North Pare) and Chome Nature Reserve, Kwamwenda, Chambogo and Mwala in Same districts (South Pare) the real situation is different. A study on carbon losses caused by deforestation between 1980s and 2000 and between between 1999/2003 and 2010/2011 depicted a gloomy picture. For example, Chome Nature Reserve was found to be among reserves in the eastern Arc Mountains that showed a higher carbon loss than other protected forests of similar protection status such as Magamba NR, Kilombero NR and Udzungwa scarp NR. Carbon loss per year of these later protected areas was only in few hundreds whereas that of Chome NR was 1,692.88 t/year. In fact, other protected areas like Uluguru NR and Udzungwa Mountains National Park recorded no carbon loss at all (URT 2010). Ylhäisi (2004) reported that between 1982 and 1997 Pare Mountains lost 37% of all types of forest.

This indicates that the rate of deforestation was higher in Chome than in the other mentioned protected forests of the same status. This is sad because South Pare

Mountains host 10% of the all 554 plant taxa endemic to the Eastern Arc Mountains and two of six endemic taxa of plants namely *Pentas hindsioides var. parensis* and *Streptocarpus parensis* which are restricted to Chome Nature Reserve (URT 2010). This observation was not new. The Division of Forestry and Beekeeping (FBD 2005) concluded that protected forests in Same and Mwanga districts were highly disturbed by human activities being more so in the earlier than the later. This observation contradicts Andam et al. (2008)‘s conclusion that PA was a major means of reducing deforestation.

Positive perception has been considered an important condition towards success of protected areas. Allendorf et al. (2007) in Bateman (n.d) have argued that ―management effectiveness of protected areas is dependent on the actions of people living in close proximity to their borders‖. In addition, local people are unlikely to support PAs if they have negative perceptions and attitudes toward them (Alkan et al., 2009). Local communities‘ behaviour towards the role of PAs in conserving biodiversity is shaped by the perceived benefits (Vodouhê et al., 2010). This could be the reason why some workers like Newmark and Hough (2000) proposed use of incentives to win local communities‘ support of PAs and mitigating negative perception towards the role of PAs in biodiversity conservation.

Positive perception serves as an entry point towards establishing positive relationships between PAs managers and the local residents (Hayes and Ostrom 2005). Engaging Indigenous people more effectively in conservation of biodiversity represents a win win situation due to that most of the world‘s major biodiversity centres coincide with areas occupied or controlled by indigenous people (Sobrevila, 2008).

Evaluation of causes of forest biodiversity loss by Pares in Mwanga and Same districts

Factors that are known to cause forest biodiversity loss that were evaluated are habitat loss through agriculture, over exploitation of forest products, poor forest management, forest fires, logging and mining. Majority (63-77.9%) of people interviewed in Mwanga District did not consider these factors to be major causes of forest biodiversity loss in their area. Similarly, only two of the six causes assessed namely logging and forest fires were considered to cause forest biodiversity loss in Same District but not habitat loss through agriculture, over exploitation of forest products, poor forest management, and mining. Some of these observations however contradict earlier findings. Between 1982 and 1997, North Pare where Mwanga District is located increased the cultivated area by 68% (Ylhäisi, 2004). There are three catchment forests reserves and three more being proposed in Mwanga District and nine forest reserves in Same District and three more being proposed. Most of these forest reserves have biodiversity value that is comparable to other eastern Arc mountains (Wass, 1995). Generally, forest reserves are created only where threats to forest biodiversity are evident. According to the Forest Policy, creation of protected areas is the main official mechanism of protecting forest biodiversity in Tanzania. That means having all these forest reserves and proposing more indicate that forest biodiversity in such areas is threatened. The situation on the ground depicts a similar picture too. In order to attract more funds for conservation from a global NGOs for protection and conservation, the government of Tanzania in 2010 (URT 2010) proposed nine protected forests to be included in the UNESCO‘s World Heritage sites. Chome Nature reserve was one of them and was proposed based on UNESCOs criteria ix and x. These two criteria reflect the status of threats and level of taxa endemism. In addition, assessment of effectiveness of management of forest reserve based on management effectiveness tracking tool (METT) showed that Chome forest reserve was only averagely managed. Although based on this observation Chome forest reserve is not managed as expected, 98% of people interviewed considered poor management not to be a factor that is contributing to loss of biodiversity in Same District where Chome forest reserve is. Same District lost 25 ha of forest between 2000 and 2010; Mwanga District did not record any loss. In order to increase level of protection, Chome Forest Reserve was elevated to Nature Reserve.

This pattern is not unique to Chome Nature Reserves but a study by Nigel and Sue (1999) on effectiveness of protected areas in Eastern Arc Mountain forests concluded that only 10 of these areas were effectively protected and the rest lacked the necessary infrastructure to monitor and control causes of biodiversity loss. Failure of protected areas is now being reported from several places in Africa. According to respondents the major causes of forest biodiversity in Same are logging and forest fires. This collaborates with URT (2010) which concluded that the two were the major causes of forest biodiversity loss in Chome Nature Reserve which is in Same District. For Mwanga District forest fires and poor management of forest reserves were scored higher. Rating Percentage Index for different activities that cause forest biodiversity loss in Mwanga rated logging and forest fires (RPI=41 and 40, respectively). This was in line with URT (2010)‘s findings too.

In the present study only less than 20% of people in Same and at least 24% in Mwanga considered mining to be a cause of biodiversity loss. This is not in line with Eastern Arc Mountains Conservation Endowment Fund study findings (EAEF 2013) that showed mining was one of the major causes of forest degradation in Same. Though not widely distributed mining is practiced in Same and not in Mwanga.

Consequences of forest biodiversity loss

In our discussion a consequence is considered evident in the area if it is scored by at least 50% of respondents otherwise is considered less serious. Similarly, people participating in a forest husbandry activity are considered to be majority if more than 50% participate otherwise are considered to be minority. Since unreliable rainfall, drying of water sources, loss of herbs and drought were scored by more than 50% of participant interviewed in Same District, these are thus serious consequences. In this line only loss of sources of firewood and unavailability of wildlife are not serious consequences. On the other hand, that almost all consequences in Mwanga district scored less than 50% with exception of drought, suggests that these consequences were not serious in Mwanga District. Drought is the only serious consequence in Same and Mwanga districts, in fact the most serious of all. It is thus more evident that of the two districts Same District experiences consequences related to loss of forest biodiversity more than Mwanga District.

Participation in selected forest husbandry activities

Majority of the people were considered to be participating in in forest husbandry activity if more than 50% of the people interviewed participated in that activity; otherwise it was considered that only minority participated. Since only 11.7 to 41.5% of people in Same participated in three of the four forest husbandry activities, it can be concluded that with exception of controlling forest fires, majority of the people did not participate in forest husbandry activities in this district. This observation, however, gives a different picture. The later indicates that, although there are more serious consequences as a result of biodiversity loss in Same than in Mwanga District, minority of people in Same do participate in forest husbandry activities. In Mwanga District, majority of people participate in planting trees, controlling of forest fires, conserving of forest by observing forest legislations and conserving water sources; whereas in Same, it is the minority. This observation was not expected for Same District. The present study and other studies (URT, 2010) show that forest fires and timber harvesting are the major management challenges for Chome Nature Reserve which is in Same District. According to Ylhäisi (2004) in North Pare, fires have damaged a quarter of closed forest in recent years. Generally, the named factors cause some of the said consequences; this is why corresponding forestry husbandry actions have been proposed to control them. For example, according to FORCONSULT-SUA and TAFORI (n.d) Mwanga District was one of the districts in the Eastern Arc areas where use of bylaws, anti-fire campaigns, proper forest management plans, and maintenance of sacred forests that engage residents in the quest for solutions have proved effective in both preventing and controlling wild fires.

Part IX section 70 of Forest Act 2002 prohibits setting up of fires. Part 2 reads: ―Any person who willfully and unlawfully sets fire to any forest reserve, forest plantation, standing trees, sapling or shrubs, whether indigenous or not, commits an offence and upon conviction shall be liable in accordance with the provisions of section 321 of the Penal Code‖. This means where fire is one of the major threats to forest biodiversity this regulation is observed by minority. In the present study 88.1% of people in Mwanga District participate in controlling forest fires but only 11.7% do so in Same District. On the other hand, Forest Act 2002 Part IX section 71 gives power to require persons to assist in extinguishing fire. Para 3 of this section reads, ―Any person in the vicinity of a fire has the obligation whether called upon do so or not, to attempt or assist in extinguishing such fire which he has reasonable cause to believe is not under control or may become dangerous to life or property but no person shall be obliged to take any action which a reasonable person or firm disposition would consider likely to endanger his life or cause him injury‖. That only less than 12% of Pares in Same participate in extinguishing forest fires indicate most likely that majority of residents of this area do not observe this regulation whereas in Mwanga majority (88%) do. In several places in Africa, Europe and Asia it has been shown that success on controlling fires was only achieved through Community-Based Forest Fire Management Program that accommodated both the interest of communities and the need to conserve the natural resources (Mengistu (n.d); Goldammer et al. (n.d)).

Conservation of biodiversity trends and lessons that can be learnt

It is well established that people‘s perception towards the role of PAs is key to their success as methods of conserving among others forest biodiversity. However, based on the present study, it is also important to understand what the general perception decodes in real terms. The current study indicates that majority of people in the two districts have positive perception towards the role of protected areas to conserve forest biodiversity. However, as evidenced, protected areas in the two districts are threatened, the situation being more serious in Same District. On factors that are known to cause loss of forest biodiversity in the area only minority considered them to be serious in the in their area; though in the group as indicated in the literature, the study areas fall in one of the areas in Tanzania where forests are threatened by human activities. Yet, when it comes to consequences of biodiversity loss in the two districts, majority of people in Mwanga District indicate that unreliable rainfall, drying of water sources, diminishing source, unavailability of wildlife and loss of useful herbs are not taking place in their areas though these are said to be serious in Same District. This is confusing because the two districts border each other and there are no external factors that explain the observed differences. Consequences of biodiversity loss are mitigated by performing forest husbandry activities and observing forestry legislations. Though there is more loss of biodiversity consequences in Same District majority of the people in this district do not participate in forest husbandry activities. While this is the state, on the ground, loss of forest biodiversity continues in protected which raises the question whether protected areas have the ability to conserve biodiversity. As a matter of fact, while national protected forests such as Chome Nature Reserve and Kindoroko Forest Reserve are highly disturbed, the fairly protected are clan forests protected under indigenous beliefs. The reported success of village forest reserves such the Duru-Haitemba Babati District in Tanzania cannot also be explained by the protected areas model. Village forest reserves work because villagers are empowered to be managers and not merely users or beneficiaries (Wily, 2002). According to Brockington and Igoe (2006) local people‘s displacement to allow establishment and enforcement of protected areas makes the relationships between conservationists and rural groups in many parts of the world unfavorable. In such a situation, it is most likely that the belief that protected areas are the cornerstone for biodiversity conservation can no longer stand the test in every situation.

Conservation measures that allow human use and access to resources in PAs or models that are not rooted in conservationists‘ priorities are disputed (Redford et al., 2000; Brockington, 2007). However, Nigel and Sue (1999); WWF (2004) and Bruner et al. (2001) have shown that protected areas are not sufficient to protect biodiversity by themselves. Similarly, a study of 34 protected areas in five countries in Africa namely; Cameroon, Central African Republic, Democratic Republic of Congo, Gabon, and Republic of Congo) concluded that protected areas are failing to reach their own conservation objectives (Pyhälä et al., 2016). On the other hand, IUCN (2017) affirmed among others the following: ―1) Conservation needs the capacities, concerns and engagement of society as a whole, not of expert professionals or government officials only; 2) More attention must be paid to the crucial ties between biological and cultural diversity, as well as the conditions that allow indigenous peoples and local communities to be empowered for conservation. Muhumuza and Balkwill (2013) suggest that future conservation approaches in protected areas e.g. National Parks in Africa should place more emphasis on the human dimension of biodiversity conservation than purely scientific studies of species and habitats in National Parks. Some workers e.g. Volunteer for Africa (VA, 2009) have proposed community based conservation as an alternative. Our argument here is that for the role of PAs to be a success, the commitment of local people which is mostly shaped by their needs should be taken aboard. According to Hayes and Ostrom (2005), where residents do not believe that the government has the right to regulate their resource use, they will often find ways to resist or sabotage park regulations. In that case the role of PAs will fall short of their expectations. In fact, according to Hoffman et al. (2010) and Butchart et al. (2010), PAs coverage alone will not prevent all losses of forest biodiversity or reduce the increased threats.

Conclusion

The positive perception of Pares in Mwanga and Same districts towards the role of PAs to conserve forest biodiversity especially in Same DISTRICT is contradictory. The extent of biodiversity loss in Same District is comparatively higher; higher consequences of biodiversity loss and the participation in forestry husbandry activities are lower. Thus despite the existence of protected areas, forest biodiversity continues to be threatened by human activities whereas clan forests are comparatively well protected. This probably suggests that although general perception seems to be supportive, in actual fact, in Same District people have not fully supported the role of PAs. In other places similar situations have led to sabotage or resistance of local people to PA authorities which have led to their failures. Therefore, deeper understanding and accommodating the need of people in ensuring success of PAs is crucial. On the other hand, criminalizing or restricting all human activities in PAs in the midst of needy people may not necessary work for PAs. We thus strongly recommend that establishment of PAs should foremost obtain the commitment of the people founded on genuine understanding.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Effect of heavy metals and physicochemical parameters on diversity of plants at a gold mine tailings dam in Ghana

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This study focuses on the impact of physicochemical parameters and heavy metals concentrations in soil on abundance, richness and diversity of plants at Marlu tailings dam located near Bogoso, Ghana. The concentrations of heavy metals (mg/kg) in soil at the study area are as follows: Fe (10,528.9 - 7,873.0), Cu (224.9 - 177.4), Zn (51.6 - 42.7), Cd (3.0 - 2.6), As (2.4 - 1.7) and Mn (78.3 - 57.1). Soil nutrient levels (nitrate, phosphate and sulphates) were relatively low with most sites having acidic soils (6.4 - 5.3). A total of 2,055 plants composed of eighteen (18) different species were observed at the study area. *Pennisetum purpureum* was the most abundant plant species (46.8%), and Poaceae and Asteraceae were the predominant families with percentage abundance of 37 and 28.8%, respectively. Diversity of plants measured using Simpson and Shannon indices at sampling sites varied significantly between the different sampling sites but are relatively low compared to other similar sites in Ghana. Species richness and diversity of plants correlated positively with the low nutrient levels and soil acidity. Low plant abundance, species richness and diversity correlated with increased Copper (Cu) levels in soil. Cadmium (Cd) levels were correlated with low abundance of plants belonging to families Asteraceae and Fabaceae. The presence of heavy metals at concentrations above regulatory limits negatively impacted on abundance and diversity of plants at the decommissioned mine tailings dam. Increased concentrations of heavy metals and low nutrient levels in soil could account for reduced plant abundance, species richness and diversity at the mine tailings dam.

Key words: Plant diversity, mine tailings dam, heavy metals, physicochemical parameters.

INTRODUCTION

Gold mining is considered as one of the economic activities known to cause ecological disturbance in spite of its contribution to economic growth of many developing countries (Aboka et al., 2018). The generation of processed mineral wastes known as tailings has become one of the adverse remnants of mining activities due to the difficulty and costly nature of its treatment (Ahmadpour et al., 2012; Ghosh and Singh, 2005). The remediation of gold mine tailings containing heavy metals using conventional methods is an economically

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challenging activity but phytoremediation is a low cost and environmentally friendly alternative and has already been used in many countries including Ghana (Bansah and Addo, 2016; Keller et al., 2003). The aim of the remediation process is to return mined lands to productive status after which they could be released to indigenous communities. Heterogeneous spatial distribution of contaminants and unstable physical composition of mine tailings dams present as formidable challenge for phytoremediation (Huang et al., 2012; Mensah, 2015).

Ineffective remediation of gold mine tailings dams has resulted in erosion and leaching of contaminants into rivers, underground water and farm lands culminating in a reduction of agricultural produce and a rise in the incidence of terminal diseases in humans (Mensah et al., 2020). Heavy metals such as mercury, arsenic and cadmium cause irreversible cellular damage at minimal concentrations when absorbed by plants, and this poses serious health risks to other organisms at higher trophic levels which includes humans (Sarwar et al., 2017). Plants that grow naturally on mine tailings survive the harsh physical and chemical constraints, and establish stable communities are considered to be tolerant and/or able to accumulate these chemical contaminants. Chief among these chemical contaminants are heavy metals or metalloids (arsenic, cadmium, zinc, manganese, copper, mercury, iron and lead) most of which are partially degradable or non-degradable. Plants capable of accumulating high amounts of heavy metals in their tissues are referred to as hyperaccumulators. These plants often grow on soils with naturally high levels of heavy metals and heavy metal contaminated sites such as mine tailings dams than normal soils (Yoon et al., 2006). Changes in abundance and diversity of plant communities in many mining areas have been observed after introduction of heavy metal-rich wastes (Vangronsveld et al., 1996; Mukhopadhyay et al., 2017).Diversitymeasuressuchasthe Shannon index are used to assess plant community structure, and could be applied to evaluate the impact of mine tailings on plant communities growing on mine tailings dams (Pandey et al., 2014).

The Marlu tailings dam is located near Ghana's mining town of Bogoso which was in operation from the pre-colonial era until 1960 when it closed its mining operations. The concessional area has been operated by other mining companies who have engaged in remediation of the mine tailings dam left by the erstwhile company. This study focuses on the impact of heavy metal concentration and physicochemical parameters on the abundance, richness and diversity at the Marlu tailings dam, Bogoso in the Western Region of Ghana.

MATERIALS AND METHODS

Study area and sampling

The study site is located within coordinates 02°01'20"W – 02°01'32"W and 05°35'04"N - 05°35'14"N in the Forest Zone of Ghana, and forms part of the Ashanti gold belt which is known for its gold deposits (Figure 1).

The study area was used as a tailings dam and has been re-vegetated as part of reclamation efforts since halt of gold mining activities. The study area was divided into five zones using ArcGIS Pro (version 2.0) and a quadrat (1 m × 1 m) was used to randomly sample the established zones at the site. Plant samples were identified using digital and manual resources (Dokosi, 1998). Plant samples were obtained and preserved in a wooden press for further confirmation. The samples were sent to the Department of Theoretical and Applied Biology (KNUST) for further identification to confirm site identification. Furthermore, images of plants were also taken for digital identification using online tools, and manuals. Soil samples surrounding the root of plants were collected into sterile bags and kept at -4°C prior to further analysis.

Plant diversity estimation

Paleontological Statistics (PAST version 3.0) was used to calculate the abundance, species richness, dominance, evenness and diversity of plant species at five samplings plots of the study area.

Species richness (S)

Species richness is the total number of different species sampled and is considered the simplest estimate of biodiversity (Scheiner, 2012). This was estimated as the total number of different plant species observed at the mine tailings dam.

Shannon index (H' or $D_{Shannon}$)

The Shannon index was applied to measure plant diversity, and it incorporates species richness and evenness. It was estimated using the following equation: $D_{shannon} = -\Sigma\, p_i\, (\ln p_i)$, where p*i* is the proportion of species *i* relative to the total number of species observed at Marlu mine tailings dams. It assumes that sampling was conducted using the random method and all species were represented.

Simpson's diversity index (D_1)

The Simpson index also measures diversity but emphasizes the dominance of a particular species at mine tailings dam based on its estimates. This index estimates the probability that two individuals selected at random from a mine tailings dam are of the same species. It is calculated as follows: $D_1 = [\, 1-\Sigma(p_i)^2]$, where pi is the proportion of species *i* relative to the total number of species at the mine tailings dam.

Simpson's evenness ($E_{Simpson}$)

Evenness is a measure of how individuals are distributed among species at the mine tailings dam. This index facilitates the comparative estimation of how different the numbers of a particular species occur in different sites at the mine tailings dams. In this regard, mine tailings dams or communities with uniform evenness would have the same abundance of different species occurring in at the mine tailings dam.

The equation for estimating Simpson's evenness is as follows:

$E_{Simpson} = Ds/S$, where Ds represents Simpson's dominance index and S the species richness at a mine tailings dam.

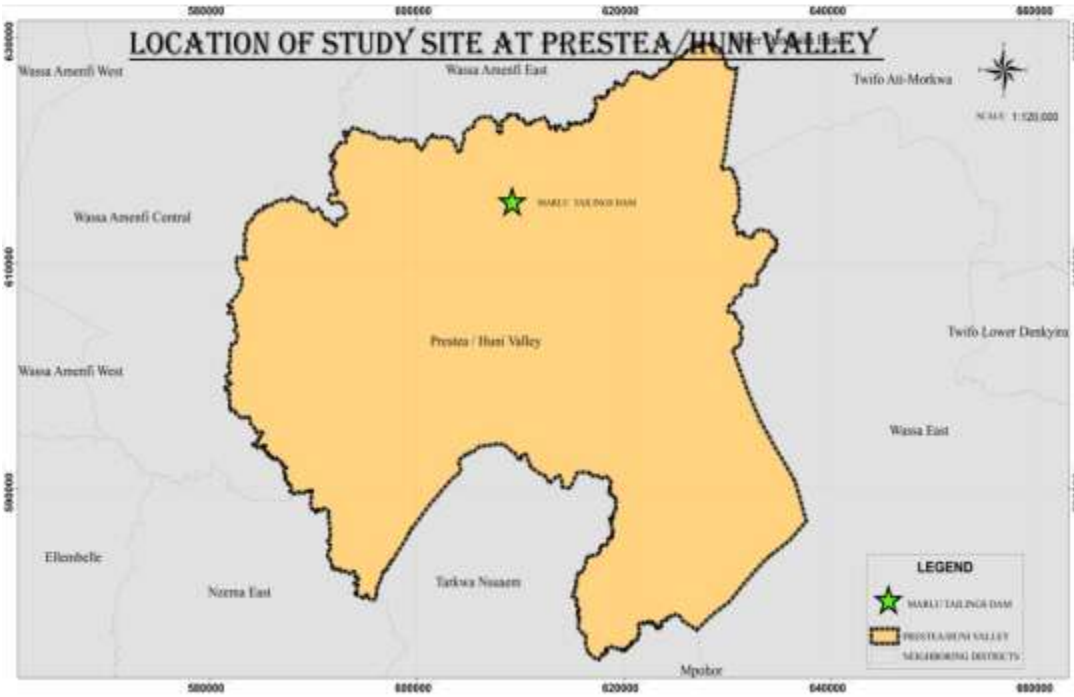

Figure 1. Map of the Marlu gold mine tailings dam in the Prestea-Huni valley district.
Source: Author

Simpson's dominance (D_2)

Dominance is an estimate of how few individuals in a sample or at mine tailings dams dominate in terms of abundance. It is the reciprocal of the original Simpson's index and estimated as follows: Ds = 1 / Σpi^2, where *pi* is the proportion of individuals at mine tailings dam.

Heavy metal and physicochemical analysis

Heavy metal analysis was conducted after acid digestion using flame atomic absorption spectrometry (FAAS, VGP Model 210, Buck Scientific Inc, USA) as described by Bansah and Addo (2016). Soil samples were dried in an oven at 50°C until a uniform weight was obtained. A mixture of perchloric, nitric, and hydrochloric acids (1:2:3) was used to digest soil samples on a hot plate at a 80 to 100°C. The residue is decanted and refilled with deionised water to a volume of 100 ml before heavy metal determination. Physicochemical parameters (pH, conductivity, total dissolved solids) were determined using a bench-top sension-plus probe (HACH, USA). Levels of nitrate-nitrogen, sulphate and available phosphate were measured using Kjeldahl method, Bray No. 1 method and Barium chloride titration method, respectively.

Statistical analysis

Data analysis was conducted using the Statistical Package for Social Sciences (SPSS version 20). Analysis of variance (ANOVA) and post-hoc (Tukey-b) analysis were conducted on replicated measures at 95% confidence interval while t-test was used for non-replicated measures. Spearman correlation was used to determine relationship between heavy metals, physicochemical parameters, plant abundance and diversity measures.

RESULTS

Abundance, species richness (S) and diversity of plants

A total of 2,055 plants comprising 18 plant species and 12 families were identified in this study (Tables 1 and 2). *Pennisetum purpureum*, *Pueraria phaseoloides* and *Mimosa pudica* were the most abundant plants species recording percentage abundance of 46.8, 7.4 and 6.77%, respectively (Figure 2). Poaceae (formerly Graminae) was the most abundant family while species richness varied significantly between sites with S1 (Site 1) being the most diverse (Table 3 and Figure 3). The Simpson and Shannon diversity indices indicated significant variation between the sampling sites in terms of site diversity (Figures 5 and 6). The evenness of plants varied significantly between the sampling sites and ranged from 0.33 to 0.82. The dominance varied significantly between sampling units and ranged from 0.19 to 0.65 (Table 3 and Figure 4). The highest abundance and highest diversity was observed at S1 (Site 1). Asteraceae and Fabaceae are among the six (6) plant families known to hyperaccumulate Cadmium (Cd) found in this study (Reeves et al., 2017). Low evenness and conversely high dominance was observed at S2 and S5 (Figure 7).

Heavy metals levels and physicochemical properties of soil

The concentration of heavy metals in soils at the

Table 1. Abundance of plant species at the Marlu Tailings Dam.

Plant	Site					Abundance	Relative abundance	Percentage abundance
	S1	S2	S3	S4	S5			
Psidium guavaja	54	0	0	3	12	69	0.034	3.36
Chromolaena odorata	95	0	25	0	0	120	0.058	5.84
Cyathea dealbata	75	0	0	0	0	75	0.037	3.65
Pennisetum purpureum	254	28	352	86	242	962	0.468	46.81
Mimosa pudica	114	8	15	0	0	137	0.067	6.67
Justicia flava	75	0	0	18	0	93	0.045	4.53
Scoparia dulcis	61	0	0	0	0	61	0.030	2.97
Pteris vittata	25	15	5	3	5	53	0.026	2.58
Ageratum conyzoides	0	45	0	0	12	57	0.028	2.77
Leucaena leucocephala	0	38	0	0	0	38	0.019	1.85
Pueraria phaseoloides	0	152	0	0	0	152	0.074	7.40
Tridax procumbens	0	16	0	0	5	21	0.010	1.02
Centrosema pubescens	0	0	8	0	0	8	0.004	0.39
Alchornea cordifolia	0	0	24	8	0	32	0.016	1.56
Nephrolepis biserrata	0	0	0	21	0	21	0.010	1.02
Nephrolepis cordifolia	0	0	0	22	0	22	0.011	1.07
Caulophyllum thalictroides	0	0	10	0	0	10	0.005	0.49
Phyllanthus amarus	0	0	0	0	124	124	0.060	6.03

Source: Author

Table 2. Abundance of plant families at the Marlu Tailings Dam.

Plant family	Site					Abundance	Relative abundance	Percentage abundance
	S1	S2	S3	S4	S5			
Acanthaceae	75	0	0	18	0	93	0.036	3.6
Asteraceae	95	611	25	0	17	748	0.288	28.8
Berberidaceae	0	0	10	0	0	10	0.004	0.4
Cyatheaceae	75	0	0	0	0	75	0.029	2.9
Dryopteridaceae	0	0	0	43	0	43	0.017	1.7
Euphorbiaceae	0	0	24	8	0	32	0.012	1.2
Fabaceae	114	192	23	0	0	329	0.127	12.7
Myrtaceae	54	0	0	3	12	69	0.027	2.7
Phyllanthaceae	0	0	0	0	124	124	0.048	4.8
Poaceae	254	28	352	86	242	962	0.370	37.0
Pteridaceae	25	15	5	3	5	53	0.020	2.0
Scrophulariaceae	61	0	0	0	0	61	0.023	2.3

Source: Author

sampling sites and maximum permissible limits of three countries namely United States, United Kingdom and Germany are shown in Table 4. The concentration of Iron (Fe) in soil ranged from 7,873.0 to 10,528.9 mg/kg, and S1 recorded the highest levels of Fe in soil (Table 4). The concentration of Copper (Cu) ranged from 177.4 to 224.9 mg/kg and was greater than permissible levels for agricultural soils in United Kingdom and Germany. The concentration of Zinc (Zn) ranged from 42.7 to 51.6 mg/kg and was lower than permissible levels of all selected countries. Cadmium concentrations were greater than permissible limits in Germany and United Kingdom and ranged from 2.6 to 3.0 mg/kg. The concentration of Arsenic (As) ranged from 1.7 to 2.4 mg/kg and was lower than permissible levels in the United Kingdom. The concentration of Manganese (Mn) ranged from 57.1 to 78.3 mg/kg with S1 recording the highest concentration.

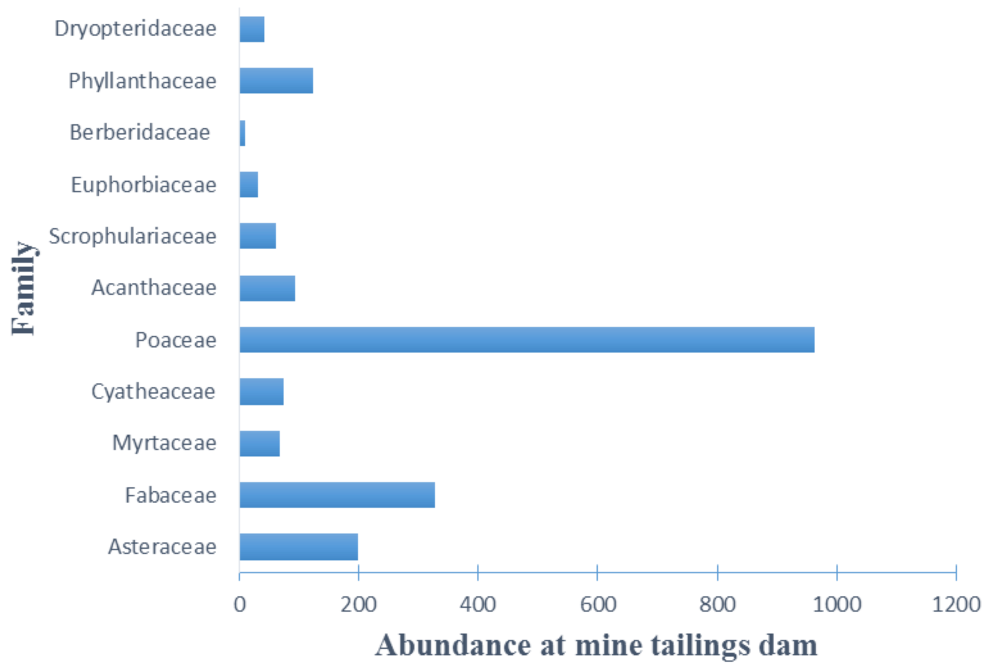

Figure 2. Abundance of plant families at Marlu Tailings dam.
Source: Author

Table 3. Abundance and diversity indices of plant species at the Marlu Tailings Dam.

Parameter	S1	S2	S3	S4	S5
Abundance	753	302	439	161	400
Richness	8.00[a]	7.00[b]	7.00[b]	7.00[b]	6.00[c]
Shannon	1.88[a]	1.51[b]	0.83[c]	1.42[b]	0.99[c]
Simpson	0.81[a]	0.69[b]	0.35[c]	0.66[b]	0.54[d]
Evenness	0.82[a]	0.65[b]	0.33[c]	0.59[b]	0.45[d]
Dominance	0.19[a]	0.31[b]	0.65[c]	0.34[b]	0.46[d]

Means in different rows with different alphabets vary significantly ($p < 0.05$).
Source: Author

The physicochemical parameters of soil at the different sampling sites are shown in Table 5. The soil was acidic and had pH values ranging from 5.3 to 6.4. Conductivity of soil ranged from 22.4 to 137.0 µS/cm, and total dissolved solids (TDS) ranged from 11.2 to 68.3. Soil nitrate, phosphate and sulphate levels ranged from 1.2 to 7.6, 0.03 to 0.5 and 3.0 to 48.7 mg/kg, respectively.

Relationship between heavy metals and plant diversity

Impact of heavy metal concentrations on abundance and diversity of plants was assessed using correlation matrix (Table 6). A strong and positive correlation was observed between plant abundance and heavy metals (Fe, Zn and Mn). This observation is associated with their role as micro-nutrients promoting growth and development of plants at low concentrations (Taiz and Zeiger, 2002). Shannon diversity index (H') and species richness (S) had strong and positive correlation with As and Fe concentration, respectively (Table 7). Abundance of grasses (Poaceae) correlated positively with concentrations of Fe, Zn, Cd, As and Mn indicating tolerance of plants in this family to different heavy metals (Table 8 and 9).

DISCUSSION

Abundance of plants growing on mine tailings has been observed to be relatively low and this has been attributed

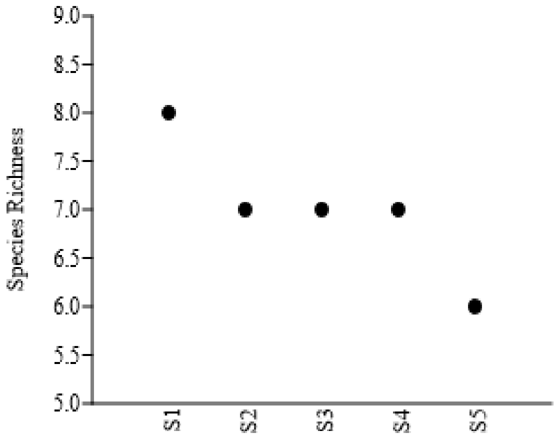

Figure 3. Species richness of plants at the Marlu Tailings Dam.
Source: Author

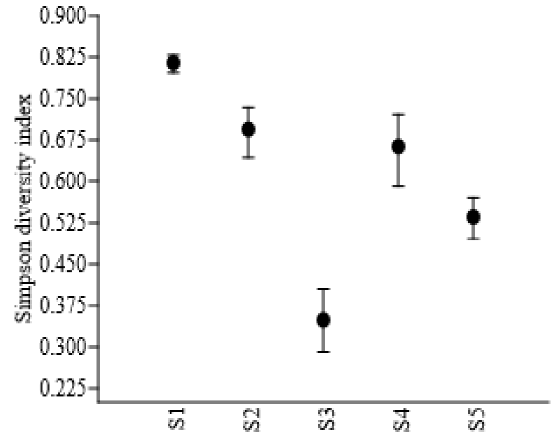

Figure 6. Simpson diversity index of plants at Marlu Tailings dam.
Source: Author

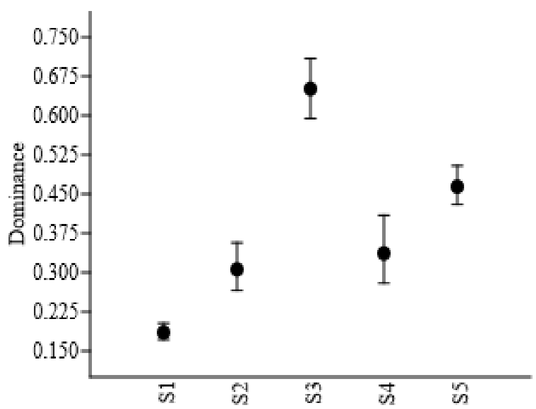

Figure 4. Dominance of plants at the Marlu Tailings Dam.
Source: Author

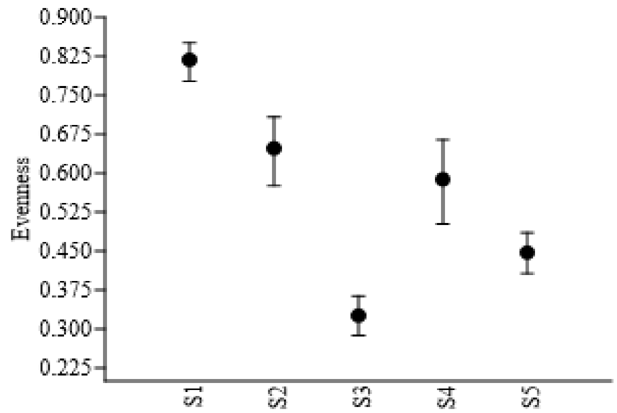

Figure 7. Evenness of plants at Marlu Tailings Dam.
Source: Author

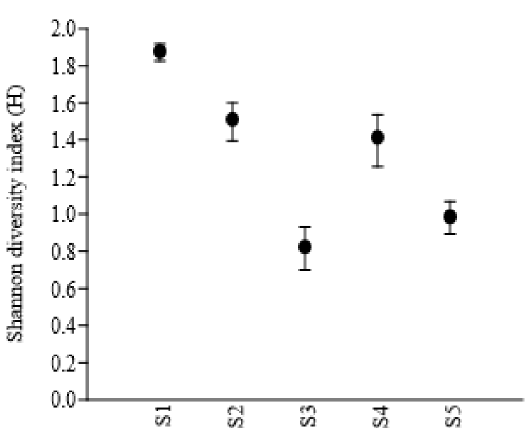

Figure 5. Shannon diversity index of plants at Marlu Tailings Dam.
Source: Author

to the 'complex' nature of contaminants and low nutrient levels (Petelka et al., 2019; Nkansah and Belford, 2017; Bansah and Addo, 2016). Although eighteen (18) plants were identified, most sites recorded seven (7) plant species which is comparatively lower compared to other similar studies in Ghana and other parts of the world (Bansah and Addo, 2016; Petelka et al., 2019). Specifically, the plant diversity observed at the Marlu tailings dam is lower than those reports from abandoned tailings dams and ponds in Chile, China, and Spain, and this could partly be associated with semi-arid conditions and high levels of heavy metals in mine tailings (Peng et al., 2007; Hernandez and Pastore, 2008). Consequently, Ginocchio et al. (2017) added that the presence fine soil particles and low nutrient levels in mine tailings are also factors that limit plant colonization of mine tailings. Occurrence of leguminous plants such as *Leucaena leucocephala* known to contribute above the 190 kg of

Table 4. Mean heavy metal concentrations in soil at different sites.

Site	Fe(mg/kg)	Cu(mg/kg)	Zn(mg/kg)	Cd(mg/kg)	As(mg/kg)	Mn (mg/kg)
S1	10528.9[d]	177.4[a]	50.1[c]	3.0[b]	2.3[c]	78.3[d]
S2	8079.7[b]	217.5[b]	42.7[a]	2.6[a]	2.4[c]	71.1[c]
S3	8980.1[c]	224.9[c]	45.6[b]	2.9[b]	1.7[a]	67.5[b]
S4	8059.2[b]	218.0[b]	43.4[a]	3.0[b]	2.0[b]	57.1[a]
S5	7873.0[a]	215.0[b]	51.6[c]	3.0[b]	2.2[c]	77.2[d]
US-EPA	**NA**	**750.0**	**1,400.0**	**20.0**	**NA**	**NA**
Germany	**NA**	**60.0**	**200.0**	**1.5**	**NA**	**NA**
United Kingdom	**NA**	**50.0**	**130.0**	**1.6**	**10.0**	**NA**

Figures in bold font represent maximum allowable concentrations of trace elements in agricultural soil in different countries. Values in the same column with different alphabets differ significantly ($p < 0.05$).
Source: Author

Table 5. Physicochemical parameters of soil at different sites.

Site	pH	Conductivity	TDS	Nitrate	Phosphate	Sulphate
S1	5.5[a]	22.4[a]	11.2[a]	2.1[bc]	0.40[c]	6.6[d]
S2	5.9[b]	133.6[d]	66.4[d]	7.6[d]	0.50[d]	7.4[e]
S3	6.4[c]	137.0[e]	68.3[e]	1.8[b]	0.03[a]	4.7[c]
S4	5.3[a]	69.0[c]	34.0[c]	2.3[c]	0.50[d]	4.0[b]
S5	5.9[b]	42.0[b]	20.0[b]	1.2[a]	0.32[b]	3.0[a]

Values in same columns with different alphabets differ significantly ($p < 0.05$).
Source: Author

Table 6. Correlation between heavy metals in soil, abundance, species richness (S) and Shannon diversity index (H').

Correlation	Fe	Cu	Zn	Cd	As	Mn	Abundance	Species richness (S)	Shannon (H')
Fe	1								
Cu	-0.829	1							
Zn	0.365	-0.527	1						
Cd	0.290	-0.322	0.615	1					
As	0.040	-0.505	0.168	-0.364	1				
Mn	0.424	-0.567	0.763	-0.012	0.523	1			
Abundance	0.896*	-0.821	0.669	0.269	0.199	0.770	1		
Species richness S)	0.848	-0.703	-0.133	0.000	0.127	0.045	0.569	1	
Shannon (H')	0.525	-0.786	-0.039	-0.082	0.688	0.167	0.368	0.748	1

*Correlation is significant at the 0.05 level (2-tailed).
Source: Author

Nitrogen per hectare annually could help improve nutrient levels in mine tailings (Mensah, 2015). More so, high relative abundance of elephant grass (*P. purpureum*) could be due its ability to tolerate low nutrients and heavy metal contaminated soils (Dhar et al., 2018; Singh et al., 2016). However, tolerance of plants to presence of heavy metals in soil may not result in accumulation of heavy metals (Verbruggen et al., 2009). That notwithstanding, Zhang et al. (2014) showed that *P. purpureum* accumulates more heavy metals when cultivated in soils with high metal concentrations suggesting its potential in tolerating and extracting heavy metal contaminants in sediments. Laterally growing herbs such as *C pubescens* and *P. phaseoloides* cover the soil surface preventing direct contact with wind and rainfall thereby reducing rate of erosion, evaporation of soil water and heating of soil (Wang et al., 2018). The metal tolerant and fast growing nature of these plants eliminates other competitors thus

Table 7. Correlation between physicochemical parameters, abundance, species richness (S) and Shannon index (H').

Correlation	pH	Conductivity	TDS	Nitrate	Phosphate	Sulphate	Abundance	Species richness (S)	Shannon index (H')
pH	1								
Conductivity	0.658	1							
TDS	0.656	1.00**	1						
Nitrate	0.041	0.560	0.561	1					
Phosphate	-0.819	-0.334	-0.335	0.483	1				
Sulphate	-0.019	0.292	0.301	0.746	0.293	1			
Abundance	0.073	-0.452	-0.443	-0.284	-0.267	0.346	1		
Species richness (S)	-0.333	-0.132	-0.118	0.122	0.146	0.700	0.569	1	
Shannon index (H')	-0.736	-0.437	-0.429	0.338	0.729	0.655	0.368	0.748	1

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).
Source: Author

Table 8. Correlation between heavy metal concentration and abundance of four plant families.

Correlation	Fe	Cu	Zn	Cd	As	Mn	Asteraceae	Fabaceae	Phyllanthaceae	Poaceae
Fe	1									
Cu	-0.829	1								
Zn	0.365	-0.527	1							
Cd	0.290	-0.322	0.615	1						
As	0.040	-0.505	0.168	-0.364	1					
Mn	0.424	-0.567	0.763	-0.012	0.523	1				
Asteraceae	-0.187	0.077	-0.493	-0.954*	0.619	0.150	1			
Fabaceae	0.252	-0.331	-0.295	-0.787	0.687	0.351	0.900*	1		
Phyllanthaceae	-0.420	0.131	0.689	0.323	0.161	0.454	-0.285	-0.434	1	
Poaceae	0.489	-0.147	0.609	0.543	0.580	0.366	-0.651	-0.465	0.209	1

*Correlation is significant at the 0.05 level (2-tailed).
Source: Author

occurrence corroborates with other studies which associated the ability of grasses to tolerate heavy metals to their high abundance at mined sites (Zhang et al., 2014; Anoliefo, 2008; Prasad and Freitas, 2003; Gibson and Polard, 1988). The occurrence of plants such as *P. purpureum* and *Pteris vittata* at all sampling sites confirms the ability of these plants to tolerate and accumulate different heavy metals in mine tailings (Hassan et al., 2020; Zhang et al., 2014).

Most sites recorded pH values typical of gold mine tailings (6.0 - 7.5), however acidity associated with mine tailings increases heavy metal bioavailability which favours metal uptake by tolerant plants (Sheoran et al., 2010). Hassan et al. (2020) suggested that alkaline soils support the growth of plants in heavy metal contaminated media thus the acidic condition of mine tailings could limit plant growth. Moreover, Kabas et al. (2017) indicated that under acidic conditions bioavailability of metals increases therefore accentuating their effect in plants. Comparatively, the pH and nutrient levels in soil are lower than other abandoned mine sites in China, Portugal, Poland and Nigeria (Guo et al., 2019; Amadi et al., 2017; Kasowska et al., 2018; Pratas et al., 2005). The low nutrient level at study area is known to impair optimal growth and development of plants (Mensah, 2015). Therefore, low levels of soil nutrients coupled with acidity could partly account for the comparatively low abundance and diversity of plants at the Marlu gold mine tailings dam (Kasowska et al., 2018; Huang et al., 2012).

The levels of iron (Fe) in soil were comparative higher than reports of other gold mine tailings in Ghana (Bansah and Addo, 2016; Bempah et al., 2013) and this could be due to high levels of Fe associated with gold ore (pyrite) in Ghana which is not transformed during mineral extraction. The report of Amadi et al. (2017) indicated higher levels of Fe in abandoned mine tailings compared to Marlu, however the levels at Marlu tailings dam could impair root development. Adverse effects of copper (Cu) have been observed in plants when soil levels exceed 50 mg/kg, however the study area had levels greater of Cu

Table 9. Correlation between physicochemical parameters and abundance of dominant plant families.

Correlation	pH	Conductivity	TDS	Nitrate	Phosphate	Sulphate	Asteraceae	Fabaceae	Phyllanthaceae	Poaceae
pH	1.000									
Conductivity	0.616	1.000								
TDS	0.616	1.000**	1.000							
Nitrate	-0.410	0.200	0.200	1.000						
Phosphate	-0.711	-0.154	-0.154	0.872	1.000					
Sulphate	0.103	0.200	0.200	0.700	0.359	1.000				
Asteraceae	0.205	-0.200	-0.200	0.200	-0.051	0.800	1.000			
Fabaceae	0.237	0.154	0.154	0.564	0.237	0.975**	0.872	1.000		
Phyllanthaceae	0.181	-0.354	-0.354	-0.707	-0.363	-0.707	-0.354	-.0544	1.000	
Poaceae	0.410	0.000	0.000	-0.700	-0.872	-0.200	0.200	-0.154	0.000	1.000

*Correlation is significant at the 0.05 level (2-tailed), **Correlation is significant at the 0.01 level (2-tailed).
Source: Author

but plants did not show any signs of toxicity (Mir et al., 2021). This could be viewed as Cu tolerance and hyperaccumulation potential by plants at the Marlu tailings dam. Mossa et al. (2020) indicated levels of zinc (Zn) less than 100 mg/kg in soil facilitate growth and development of plants, implying that the observed soil levels could favour plant growth, and by extrapolation their abundance at the Marlu tailings dam. Compared to other gold mine tailings dams in Ghana, the levels of Zn and Cd in soil at Marlu tailings are low (Petelka et al., 2019). Despite the toxicity of cadmium of very low concentrations in soil (<2 mg/kg), it is worth mentioning the observed range (2.6 - 3.0 mg/kg) could limit plant growth and therefore reduce plant community abundance and diversity at the Marlu tailings dam (Kushwaha et al., 2015). Earlier reports of gold mine tailings dams in Ghana recorded higher levels of As in soils compared to this study (Mensah et al., 2020; Antwi-Agyei et al., 2009). The levels of As observed in soils at Marlu tailings dam is known to impede vital metabolic reactions, and plant species growing in arsenic polluted environments exclude its sequestration to the cell wall components of roots in order to survive its presence (Tripathi et al., 2007).

The concentration of copper (Cu) correlated negatively with plant abundance, diversity and species richness. This perceived reduction in plant abundance, species richness and diversity corroborates with the findings of Yoon et al. (2006) who indicated detrimental impacts of increased Cu concentrations on diversity indices. The low concentrations of arsenic (As) and cadmium (Cd) did not affect abundance of grasses (family Poaceae) indicating the adaptability of the grasses to these heavy metals (Hernandez and Pastore, 2008). This observation is reflected in the notable high relative abundance of *P. purpureum* which is known to possess tolerance to heavy metals (Dhar et al., 2018). Fabaceae includes plants capable of fixing nitrogen in soil and was moderately correlated with nitrogen levels indicating their established contribution towards soil fertility and plant diversity (Sheoran et al., 2010). Pandey et al. (2014) indicated the high abundance of leguminous plants (Fabaceae) growing on mine tailings could be attributed to their rich rhizospheric microbial communities which are responsible for transforming crude metal residues in mine tailings, thus making them thrive in harsh chemical constraints of mine tailings.

Soil acidity correlated negatively with the low plant species richness and diversity indicating adverse impact of acidity on vegetation establishment on gold mine tailings which are usually acidic in nature (Huang et al., 2012). Plants are known to thrive in slightly acidic or neutral-alkaline soil pH which reduces heavy metal bioavailability and toxicity (Huang et al., 2012). Consequently, the impact of soil acidity partly accounts for the reduced abundance and diversity of plants at most mine tailings dams especially those left without adequate plant cover (Petelka et al., 2019; Ginocchio et al., 2017). Nutrient (phosphate and sulphate) concentrations were in tandem with increase in species richness and Shannon index, and this pattern has also been reported in earlier studies (Maiti and Ghose, 2005; Hernandez and Pastore, 2008). However, nitrate levels were negatively correlated with abundance and diversity of plants which could be attributed to the relatively low soil nitrate levels. The importance of improving levels of major nutrients (nitrogen, sulphur and phosphorus) towards the establishment of plant communities has led to the introduction of leguminous plants during phytoremediation attempts on mine tailings dams nevertheless their survival is still challenged by the toxicity of heavy metals (Gagnon et al., 2020).

Conclusion

The findings of this research indicate negative impacts of high concentrations of heavy metals, low nutrient levels and soil acidity on plant diversity (Shannon and species richness) at the Marlu tailings dam. Plant families most affected by concentrations of cadmium in mine tailings were Asteraceae and Fabaceae, however *P. purpureum* (Schumach.) (Poaceae) dominated the study area in terms of species abundance due to its multiple heavy metal tolerance and phytoaccumulation properties. Furthermore, levels of toxic heavy metals such as arsenic and cadmium were associated with the low abundance of plants except *P. purpureum* which confirms its role in phytoremediation of heavy metal contaminated mine tailings. Consequently, the Marlu tailings dam requires regimented remedial efforts for which *P. purpureum*, *P. phaseoloides* and *Leucaena leucocephala* could be employed.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Assessment of carbon sequestration by mangrove plantations in Casamance (Oussouye, Ziguinchor, Senegal)

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The mangrove ecosystem abounds in fish and wood resources exploited by local populations for cooking and house construction. This has resulted in a strong loss of mangrove surfaces whose causes are explained by the combined action of natural and anthropic factors. To minimize the regression of the mangrove in Casamance, the Oceanium Association has organized since 2006 reforestation campaigns of mangrove trees. To date, the effectiveness of carbon sequestration by mangrove plantations has never been evaluated in southern Senegal. The present study aims to estimate the produced phytomass (biomass) and the aerial carbon stock of mangrove plantations to promote mangrove restoration actions. Three study sites were selected, namely the communes of Oukout, Mlomp and Diémbéring, in the Ziguinchor region (Senegal). They polarize 24 plantations distributed in 8 villages of the study area. The characterization of the mangrove plantations was performed from May to July 2020 using 2.5 m x 2.5 m plots, arranged alternately on each transect set up by plantation. The overall amount of carbon sequestered in the plantations in 2020 was estimated at 0.155 tC/ha for stems, 0.389 tC/ha for leaves and 0.501 tC/ha for roots. These results correlated with plant height allowed the development of a regression model to assess the total carbon stock in mangrove plantations. This model explained 81% of the total carbon stock in 7–10-year-old plantations. Results from this study suggest that mangroves can be dynamic and promising areas for climate change mitigation.

Key words: Mangrove, restoration, biomass, carbon sequestration, plantation.

INTRODUCTION

In Senegal, the largest mangrove formations are found in the Saloum Delta and in Casamance, mainly along the coastal lagoons (WWF, 2012). The mangroves in the department of Oussouye are one of the most beautiful formations in Lower Casamance and are also the seat of the main rural activities carried out in the department (rice growing, fishing, oyster and shellfish harvesting, beekeeping as well as ecotourism-related products and activities (Bassene, 2017). These mangrove formations constitute a particular ecosystem because of their functions, importance, and location. In addition to their recognized carbon sequestration potential, mangrove formations are home to many wildlife and floristic resources on which the riparian populations directly depend. Indeed, their ecological importance in terms of multiple trophic levels and coastal protection against marine erosion has been demonstrated by various authors (Aubé, 1999; Field, 1995; Jatobá et al., 2016; Ndour et al., 2014b; Pavithra et al., 2019).

The mangrove area which was estimated at 150,000 ha in Casamance in the early 1980s covered only 83,000 ha in 2006 (Bos et al., 2006). Like in Casamance region, there is an overall decline in quality and quantity of mangrove formations in the department of Oussouye. Diéye et al. (2022) studied dynamics of the mangrove formation in the department of Oussouye by remote sensing and reported a 47.1 and 90% decline for the dense and less dense mangrove facies, respectively, between 1972 and 1986. This strong loss of mangrove surfaces has been attributed to the combined influence of natural and anthropic factors (Sippo et al., 2018). The natural factors are mainly due to the rainfall deficit of 1970s and 1980s which resulted in land salinization and acidification and low natural regeneration (Diatta et al., 2021). This is mainly due to excessive wood cutting for fuel and construction and also hydro-agricultural developments such as the Affiniam dam (Tendeng et al., 2016). This latter has led to the modification of the hydrological regime of the river and the longer submersion of mangroves. In addition, the prolonged dewatering of the initial mangrove soils induced physicochemical and morphopedological modifications marked by a strong salinization and an acidification of the soils.

Because of the ecological, environmental and socioeconomic importance of mangrove formations for the local communities, local initiatives have been multiplied with the support of NGOs and programs such as IUCN, JICA, PADERCA, WFP and OCEANIUM (Cormier-Salem et al., 2017a) to promote the protection, rehabilitation and restoration of the mangrove formations. In this context, the "*Plant your tree*" program, initiated by a partnership between a Senegalese NGO, Oceanium, and a group of donors, the GEF, Carbon Livelihoods Venture Fund and private companies (Fondation Voyageur, Danone, Yves Rocher), was launched in 2006 in the Casamance estuary. The reforestation of mangroves was carried out due to the multiple products provided by these formations and used in human and livestock nutrition, pharmacopoeia, service, and energy wood. Today, the proven capacity of mangroves to sequester more carbon than other ecosystems has contributed to the recent interest in promoting mangrove formations for combating the negative impacts of climate change (Jadot, 2007). This potential for climate change mitigation is due to the capture of atmospheric CO_2 that is stored in the leaves, stems, and stilt roots of plantations (Diatta et al., 2017).

Moreover, mangroves trap an average of 1.4 gigatons of carbon per square kilometer per year (Laffoley and Grimsditch, 2009). In the Saloum delta, 1,936 tons of carbon were sequestered by a 2-year-old mangrove plantation in Djirnda (CCLME, 2014; Ndour et al., 2012a).

Despite the potential of mangrove formations to sequester carbon and mitigate the greenhouse effect, their carbon sequestration potential has never been evaluated in Casamance. After several years of mangrove reforestation in Casamance, it is important to assess the potential of high carbon sequestration by *Rhizophora* spp. plantations to better evaluate restoration and conservation programs in mangrove areas in Senegal. Thus, the general objective of this study is to improve the knowledge of *Rhizophora* spp. plantations in terms of produced biomass and carbon sequestration potential. Specifically, the aim is to evaluate the carbon sequestered by mangrove plantations and to develop a regression model to evaluate the carbon stock by plantations.

MATERIAL AND METHODS

Site description

The Department of Oussouye (Figure 1) is located between northern latitudes: 12°20' and 12°30' and western longitudes: 16°30' and 16°40'. It belongs to the southern eco-geographic zone whose forest resources are among the richest in the country in terms of both quantity and quality, and thus constitutes one of the most important ecosystems in Senegal. Oussouye is located in the extreme southwest of the Ziguinchor region and covers 891 km² or 12.14% of the area of the Ziguinchor region (ARDZ, 2016). It is bordered by the Casamance River to the north, the Republic of Guinea Bissau to the south, the Nyassia District to the east and the Atlantic Ocean to the west.

The department of Oussouye is characterized by a low relief and a small coastal portion consisting of lowlands of less than one meter (1 m) above sea level. This situation has favored marine intrusion in Casamance and the presence of mangrove forests (Marius et al., 1986). The climate of the department benefits from a low to very low monsoon circulation on the one hand and a low to medium circulation on the other hand over a period of five to six

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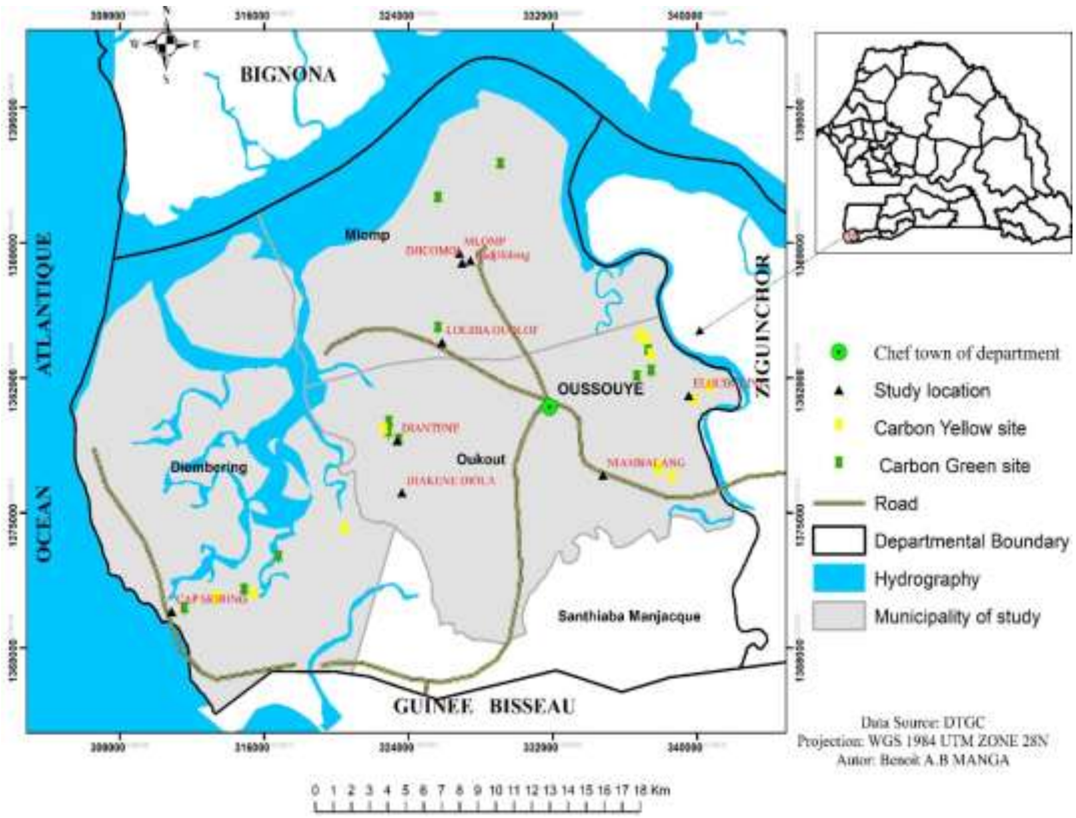

Figure 1. Location map of the Department of Oussouye (Ziguinchor, Senegal).
Source: Authors

Table 1. Summary of strata selection.

Sites	Stratum type		Strata sampling proportion
Oukout	Green	5	
	Yellow	10	
Diémbéring	Green	1	41%
	Yellow	1	
Mlomp	Green	6	
	Yellow	1	

Source: Authors

months (Sagna, 2005).

Site selection

The choice of the study area is based on the International Union for Conservation of Nature (IUCN) classification made in 2010 following an assessment of mangrove plantations. In the department of Oussouye, the communes of Oukout, Mlomp and Diémbéring are identified as sample units. The choice of these communes is motivated by the quality of the sites (green or yellow), and by their eligibility under the Clean Development Mechanism (Borner and Guissé, 2010).

Based on these two types of strata, the stratified random inventory was adopted in mangrove plantations. The green strata are favorable for the growth of *Rhizophora* spp*.* seedlings because their soils are muddy and have a moderate level of salinity. These strata are submerged by high tides during the dry season and are dominated by natural *Rhizophora* spp*.* (Cormier-Salem et al., 2017b). Yellow strata are moderately favorable for mangrove reforestation. Their soils are clayey-sandy, compact and submerged at high tide during the dry season (Cormier-Salem et al., 2017a). These strata are characterized by the presence of small mangroves (2 m), poor plant growth and limited natural regeneration.

The random sampling consisted in randomly selecting all eligible strata reforested between 2006 and 2012 and whose areas are between 3 and 5 ha. From these eligible strata, 58 plantations were pre-selected in all the communes and the selection of the number of plantations according to strata was determined by simple random sampling. Thus, 24 plantations out of 58 were pre-selected covering 8 villages, corresponding to a sampling proportion of 41% of the strata (Table 1).

In the selected strata, *Rhizophora* spp. is the only species recorded in the inventory plots. However, *Avicennia germinans* and *Laguncularia racemosa* were noted at the periphery of the strata and sometimes, exceptionally, in the center of the plantations. *Rhizophora* spp. belongs to the *Rhizophoraceae* family. The study of phenology allowed us to note that 100% of mangroves with propagules are of the species *R. mangle*.

Data collection

During the inventory of mangrove plantations, the sampling unit was a square plot of 2.5 m x 2.5 m (6.25 m^2), placed along a transect following the largest diagonal of each plantation (Figure 2) in accordance with the method developed by (Ndour, 2005;

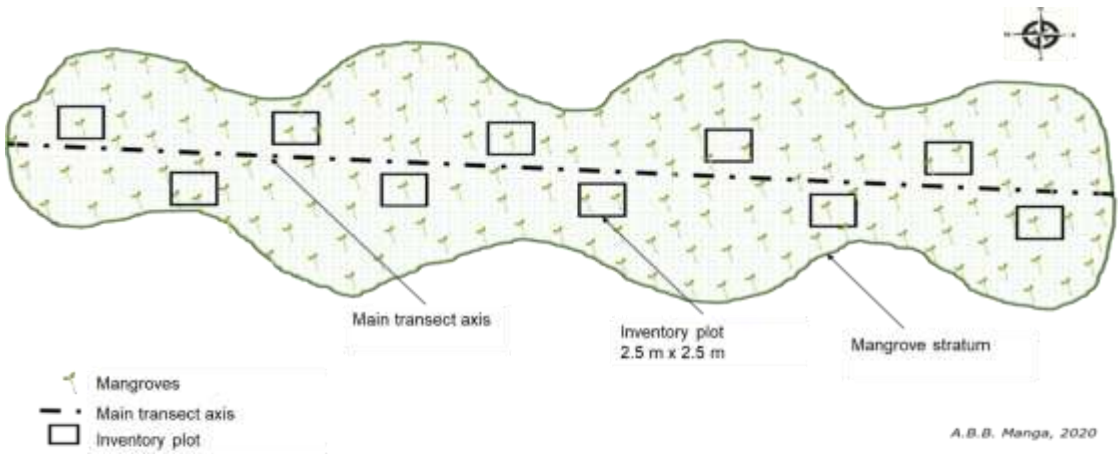

Figure 2. Layout of the sampling units.
Source: Authors

Figure 3. Delineation of the inventory plots.
Source: Authors

Deugué-Namboma, 2008). The transects were set during the rainy season of 2020. In each plantation, one (1) transect of 250 m length was set up, resulting in an average of 10 plots of 2.5 m x 2.5 m (Figure 2) following a series of distances between 5 and 25 m. The maximum distance of 25 m was chosen based on the smallest diagonal and the minimum distance of 5 m was chosen to avoid the edge effect of the bolongs which are defined as a saltwater channel, characteristic of the coastal areas of Senegal or Gambia, near estuaries (Ndour et al., 2014b). This method resulted in a sample size of 240 plots for all communes for a total area of plantations estimated at 110 ha of mangrove plantations. The GPS coordinates of the plantations were used to locate the sampling units. The surveyed area of the sampling units is estimated at 0.125 ha and represents 0.11% of the area of the reforested plantations. Figure 3 shows the delineation of the inventory plots.

Vegetation surveys

Within each plot, data were collected on floristic composition and dendrometric parameters (height, stem diameter and cross crown of each tree). The height of a plant, which corresponds to its height taken at the terminal meristem, is measured with a graduated yardstick for the larger sizes or with a metric tape for the smaller ones (Figure 4). The diameter at the base of the plants above the insertion point of the stilt roots is measured with a caliper**.** The floristic composition and the dendrometric data were collected from May to July 2020 in the department of Oussouye (Ziguinchor, Senegal).

The cross-sectional diameters of the crowns in meters of the trees are measured with a measuring tape. This measurement was used to estimate the crown area of mangrove plantations by projecting their crowns on the ground in reference to the area of the vegetation survey. The percentage of ground cover was calculated using the following formula.

$$Ground\ cover\ percentage\ (\%) = \frac{\Sigma\ ground\ cover\ of\ individuals\ in\ the\ sampled\ area\ (m^2)}{Sampled\ area\ (m^2)}\ x\ 100$$

Data collection on the dynamics of mangrove plantations

All trees in the plots were counted (replanted, regrown, dead) during the duration of the study (from May to July 2020) and data collection from 2010 helped determine the density, mortality, and evolutionary trend of the plantations. The data collected on the dynamics of mangrove plantations were performed at the same

Figure 4. Height measurement of Rhizophora spp. Plants.
Source: Authors

Figure 5. Clear cutting of Rhizophora spp.
Source: Authors

Figure 6. Weighing of the harvested biomass.
Source: Authors

sites for 2010 and 2020.

The total number of plants includes both young plants and adult plants. Thus, the mangrove plants in a state of fruiting are considered as seedlings and those without stilt roots in a "vegetative" state as regenerated (regrowth). The observed density is obtained by the ratio of the total number of individuals in the sample divided by the sampled area.

$$D = \frac{N}{S}$$

With N= total number of individuals in the considered sample and S = surface of the sample in ha.

Quantification and estimation of biomass

In each plot, the height of all the plants was measured to determine the average plant height of the plot. Based on the average plant height, two plants close to the average height were randomly selected for the evaluation of the above-ground biomass that is a total of 20 plants per site, that is, 480 plants for the entire study area. A clear cut (Figure 5) was made following the identification of the two average height plants in the plot. The different compartments made up of leaves, stems and roots were weighed in their entirety (Figure 6), then a sample was taken from each compartment. The samples cut into leaves, stems and roots are weighed on the same day using a CH-50K100 electronic balance with a precision of 1 g and a capacity of 50 kg. In the laboratory, these samples are dried in an oven (Figure 7) at 105°C for 72 h and between 96 and 120 hours depending on the compartments collected.

For all sample categories, a minimum of 5 randomly selected samples were weighed daily until weight stabilization. Stabilization took three days for leaves and one week for stems and roots depending on sample size. From the selected samples, the moisture content (MC) is calculated;

Figure 7. Oven drying of samples.
Source: Authors

$$MC\ (\%) = \frac{Wet\ sample - Dry\ sample}{Dry\ sample}\ x\ 100$$

Drying these samples allowed us to determine the fresh-to-dry biomass conversion factor for each compartment. This conversion factor is the average ratio (Ra) obtained from weighting the dry mass of the sample by their fresh mass:

$$R_a = \frac{Dry\ sample}{Wet\ sample}$$

According to (Picard et al., 2012; Rondeux, 1999)
Thus, the quantity of dry biomass produced by the plantations is estimated by multiplying the fresh biomass of each compartment by this average ratio (Ra), that is:

$$Q_{ms} = BTF\ x\ Ra$$

With $\mathbf{Q_{ms}}$ = amount of dry matter; **BTF** = total fresh biomass of an entity of the species. The total biomass is calculated by summing the biomass of all compartments.

Assessment of carbon sequestration

The amount of carbon sequestered is estimated from the dry biomass obtained. This biomass is converted using the conversion factor of the carbon fraction of dry matter into living biomass 0.47 according to (GIEC, 2006) based on the following formula:

$$Amount\ of\ carbon = Dry\ biomass\ x\ 0.47$$

Regression analyses relationship between growth parameters and carbon sequestration

The dendrometric measurements are used to develop a regression equation between growth parameters and the amount of carbon sequestered based on the following relationships:

$Y_1 = a + bH$ and $Y_2 = a + bC^2H$

With **Y=** amount of carbon sequestered, **H**= total height and **C** the circumference. These models allow relating to the sequestered carbon (Y) and the explanatory dendrometric parameters **H** and $\mathbf{C^2}$H. These linear models led to regressions of the type: Y_1= a + bH and Y_2 = a + bC^2H, where a is the intercept of the line and b its slope. These partial regression coefficients were determined using SAS JMP Pro version 15.0.0 statistical software (SAS Institute Inc., Carey, NC) (Proust, 2016).

Data processing and analysis

The Excel spreadsheet was used to determine the observed density, biomass conversion factor, amount of dry biomass and carbon sequestered in the plantations. The data were analyzed using SAS JMP Pro version 15.0.0 statistical software (SAS Institute Inc.). This statistical analysis tool was then used to perform analyses of variance (ANOVA) for plant and carbon sequestration parameters and to establish a regression relationship between carbon and dendrometric parameters (C and H). When assumptions of normal distribution of data and homoscedasticity were not met, data were transformed using Box–Cox power transformation. Treatment means were separated using Fisher's protected LSD test at α **=** .05 level of probability when values were significant. Correlation analyses were performed to ascertain the relationships between the amount of carbon sequestered and plant height as well as the square circumference * height.

RESULTS

Floristic composition of mangrove plantations

The analysis of Figure 8 revealed that Oukout had a significantly higher ground cover (16%) than Mlomp and Diembering sites in 2020. The crown area of mangrove plantations in Mlomp and Diembering were, respectively, 37 and 39% lower than the percent ground cover in Oukout. The cross-sectional diameters of the mangrove plantation crowns revealed significant differences ($p<0.05$) between sites.

Estimation of the produced biomass

The amount of fresh biomass at the sites is estimated to be 0.597 t/ha for stems, 1.711 tons per hectare for leaves and 2.292 tons per hectare for roots in 2020. The conversion factors for this fresh biomass are 0.55 for stems, 0.48 for leaves and 0.46 for roots, respectively. Evaluation of dry matter from conversion factors yielded 0.331 t/ha for stems, 0.828 t/ha for leaves and 1.066 t/ha for roots for the studied mangrove plantations.

The analysis of variance for the amount of dry matter per plant between sites reveals a significant difference (P-value =5,25 $^{e-05}$). The analysis of the Figure 9 revealed that 0.23592 t of total dry biomass was recorded in Oukout, 0.01894 t in Mlomp, and 0.00618 t in Diembering. Consistently, Oukout site recorded the

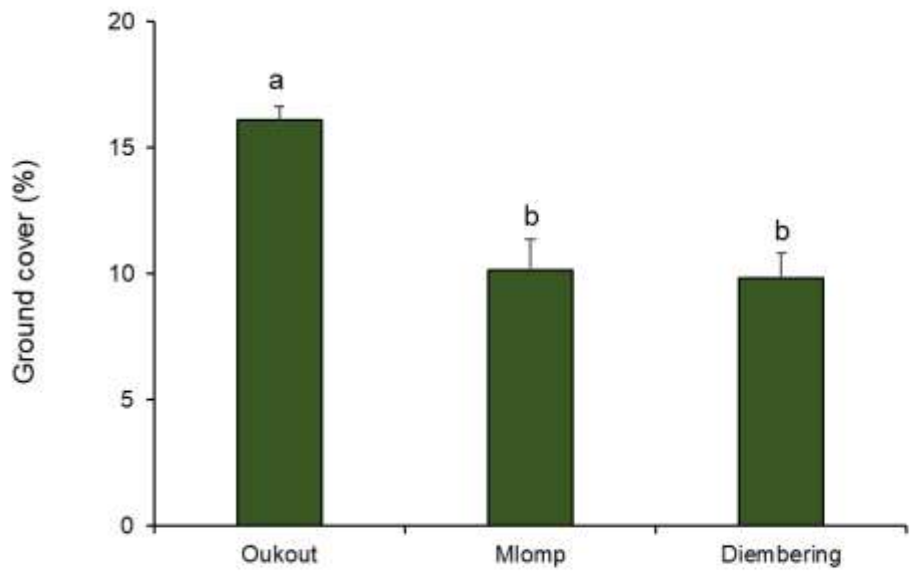

Figure 8. Mean percentage of ground cover of mangrove plantations in Oukout, Mlomp and Diembering. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD and error bars represent standard error of the mean.
Source: Authors

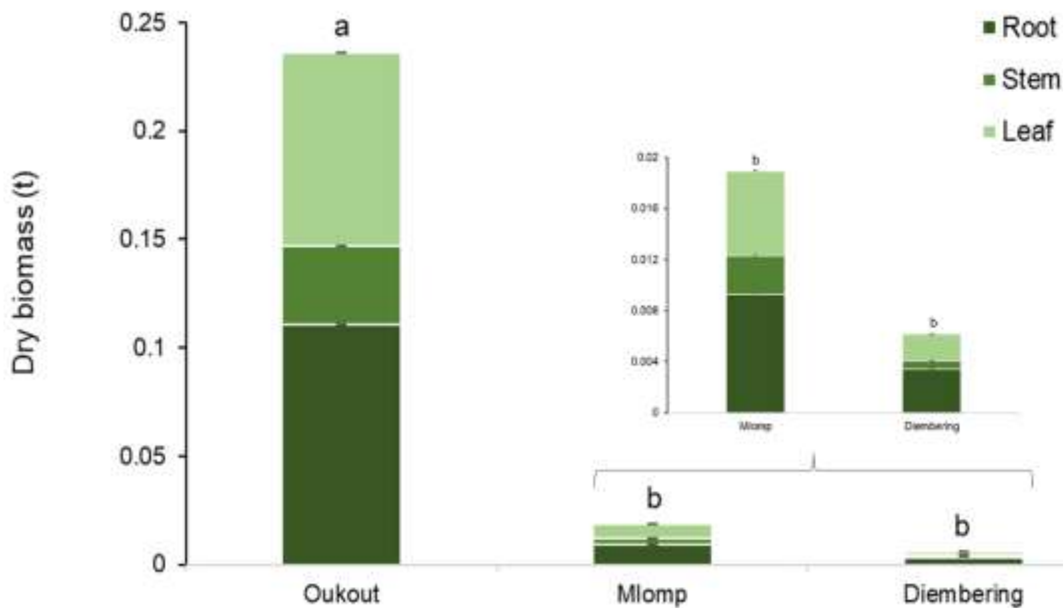

Figure 9. Dry biomass of mangrove formations in Oukout, Mlomp and Diembering. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD and error bars represent standard error of the mean.
Source: Authors

highest dry biomass per organs compared to Mlomp and Diembering. Specifically, the root, stem, and leaf dry biomass were respectively 0.11051, 0.03643 and 0.08898 t. The dry biomass of the mangrove organs was significantly lower in Mlomp and Diembering and was 0.00928 t and 0.00341 t for roots, 0.00303 t and 0.00065 t for stem, and 0.00663 t and 0.00212 t for leaf biomass, respectively.

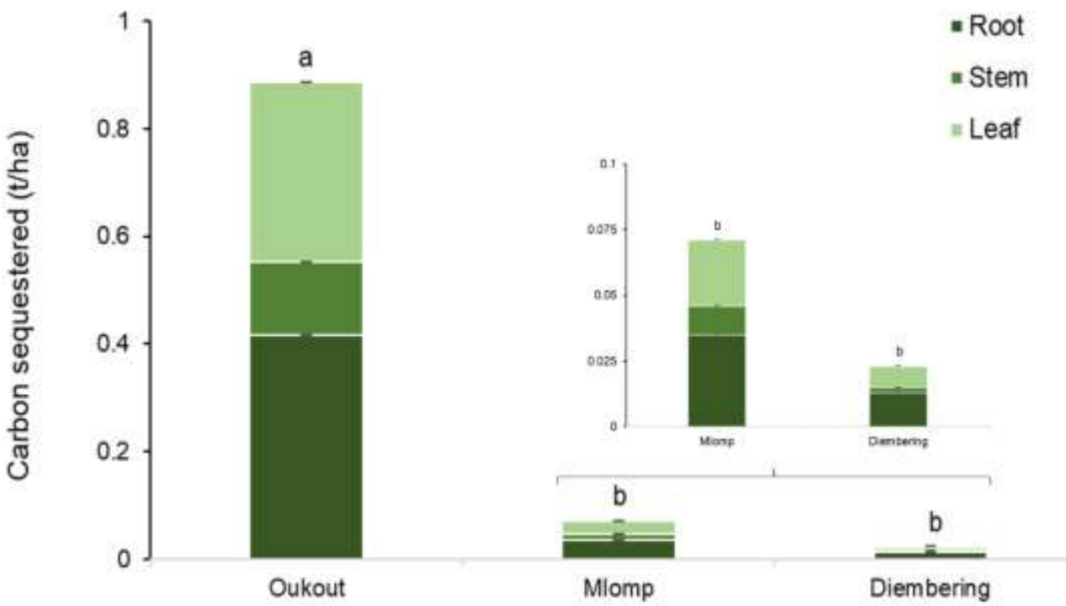

Figure 10. Carbon sequestered by mangrove formations in Oukout, Mlomp and Diembering. Treatments connected by dissimilar letters are significantly different at α = 0.05 according to Fisher's protected LSD and error bars represent standard error of the mean.
Source: Authors

The amount of dry biomass per individual obtained by stratum in the plantations of the sites differed significantly for all sites in Oukout (P-value =2.16 $^{e-07}$), Diémbéring (P-value =1.75 $^{e-07}$) et Mlomp. This also shows a variation in mean biomass per plant for Oukout (0.00103±0.00134t), Diémbéring (0.00012±0.00043t) and Mlomp (0.00036±0.00080t).

Carbon sequestered in mangrove plantations

The overall amount of carbon sequestered in the sites is estimated to be 1.046 tonnes of carbon per hectare (tC/ha). With reference to the compartments, stems provided 0.1554tC/ha leaves 0.3891 tC/ha and roots 0.5010 tC/ha. The analysis of variance of the overall amount of carbon sequestered reveals a significant difference (P-value <.0001*) between sites. The Figure 10 revealed that Oukout sequestered 0.921 tC/ha while Mlomp and Diembering only recorded 0.086 and 0.038 tC/ha, respectively. Similar to the dry biomass per organs of mangrove plantations, the plants organs of Oukout had higher carbon sequestration values than Mlomp and Diembering. The root, stem, and leaf organs, respectively, sequestered 0.422, 0.16, and 0.339 tC/ha. These values correspond to 1000% more carbon sequestered for each organ at either Mlomp Diembering. The average amount of carbon sequestered per individual in *Rhizophora* spp. plantations is 0.000379± 0.00067t at these sites. Figure 4 show the carbon sequestered by mangrove formations in Oukout, Mlomp and Diembering.

Regression relationship between height and sequestered carbon

The analysis of the graph (Figure 11) shows a good relationship between the amount of carbon sequestered from *Rhizophora* spp*.* and the height of the plants. This graph shows that plant height has a positive relationship with the amount of carbon sequestered (p-value < 0.0001*). The coefficient values are characterized by a constant at the origin of -0.001702, a positive slope of +0.0025368 and a coefficient of determination R^2 = 0.81 (Prob. F<.0001*).

Regression relationship between C²H and sequestered carbon

The regression relationship between C²H and sequestered carbon is presented on the Figure 12. The analysis of this graphs shows a significant relationship (p-value < 0.0001*) between the amount of carbon sequestered from *Rhizophora spp.* and the parameter C²H. Therefore, the combination of diameter and height is positively related to carbon sequestration. The model obtained is characterized by a constant at the origin of -0.000188, a positive slope of +0.6897366 and a coefficient of determination R^2 = 0.77.

The analysis of simple regression analyses shows a

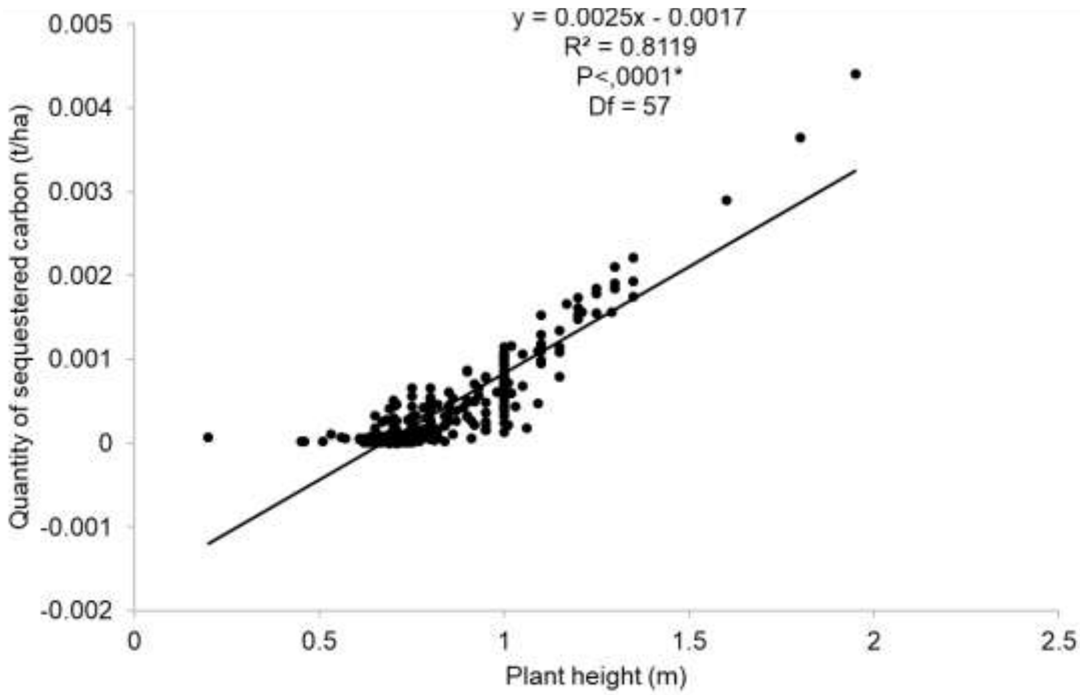

Figure 11. Regression of carbon sequestration with plant height.
Source: Authors

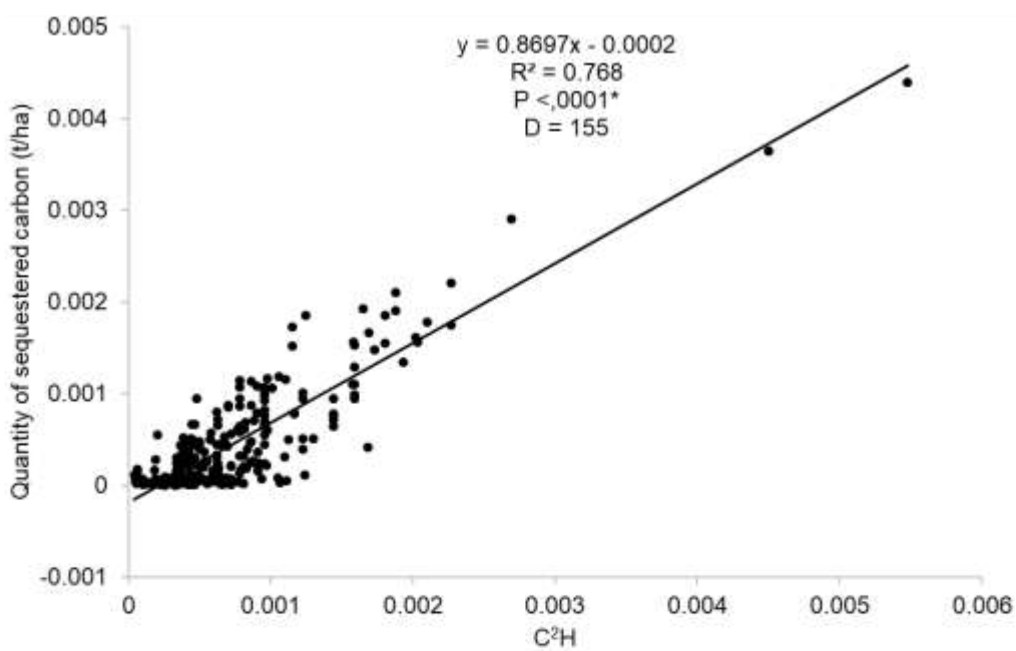

Figure 12. Regression of the amount of carbon sequestered as a function of the square circumference * height of the plants.
Source: Authors

good fit between sequestered carbon and height (R^2 = 0.81). On the other hand, the combination of the two parameters (C^2H) determines a regression relation of less precision with (R^2 = 0.77). It appears from these two types of analysis that these two models can be validly used to evaluate the carbon sequestered by mangrove plantations in Casamance.

DISCUSSION

Floristic composition and structure of mangrove plantations

The study showed a mono genus presence of *Rhizophora* compared to the species *Avicennia germinans*. This result confirms those of various authors who have reported that mangrove plantations are often mono-specific in some regions (Diedhiou et al., 2015; Ndour et al., 2018; Cormier-Salem et al., 2017b). The monitoring of phenology showed a dominance of *R. mangle* in the plantations although five (05) other species are present in the study area. These are *Rhizophora racemosa*, *Rhizophora harisonnii*, *Avicennia germinans*, *Conocarpus erectus* and *Laguncularia racemosa*. These monospecific plantations can be explained by the use of a single species during mangrove restoration campaigns. However, this tendency is far from deliberate, as *R. mangle* is the mangrove that produces more propagules from the Saloum Delta to Casamance according to (Ndour et al., 2014c).

Analysis of the amount of biomass produced by the plantations

Predicting biomass using regression equations is key to estimating the contribution of various forest ecosystems to the carbon cycle (Picard et al., 2012). Comparison of biomass conversion factors shows significant variation in moisture between compartments of the aerial pool. As a result, the factor of each compartment was retained for the conversion of fresh biomass to dry biomass following the approach of Ndour et al. (2014a) in the Saloum Delta.

Dry biomass by compartment suggests that root biomass is more important than stem and leaf biomass. This may be due to the degree of lignification of rhizophores and their importance in stabilizing mangroves on mudflats. This result corroborates those of Ndour et al. (2014c) who showed that low compactness can explain the development of a stronger root structure and scope for mangrove tree anchoring and stability in the environment.

A comparison of dry biomass between sites shows that the Oukout plantations have a greater quantity of dry biomass. These results can be explained by the difference in soil quality (muddy) and the proximity of the bolongs, unlike Diémbéring and Mlomp plantations. This difference in biomass according to soil characteristics is confirmed by GAYE, (1984) who maintains that the development of a plant depends on the conditions of the environment and its photosynthetic capacity.

Assessment of the amount of carbon sequestered

The estimation of aboveground biomass produced by mangrove plantations showed a strong relationship between growth parameters (height and diameter) and sequestered carbon. The result obtained confirms those of Deugué-Namboma (2008) and Ndour et al. (2012a) which indicate 1.9 tons of carbon sequestered by a 2 year old mangrove plantation in the Saloum Delta. Estimating the amount of carbon sequestered in relation to height gave the best regression correlation compared to that of the square of circumference time’s height (C^2H). This result could be due to the variation of stem branching order with size and roots with age.

Analysis of carbon sequestered by compartments shows that roots sequester more carbon than leaves and stems. This result confirms the findings of Ndour et al. (2014c) that showed that root biomass is always slightly greater than that of other parts of the plant. Furthermore, there is a difference in carbon stock between the Oukout plantations and those in Diémbéring and Mlomp. This result is in agreement with those of Murray et al. (2011) who also reported that apart from the inorganic carbon in the soil, the rest (organic carbon) is found in the living biomass. Indeed, sites where the amount of dry matter is highly significant, give equally highly significant carbon sequestration as demonstrated by the GIEC, (2006).

The mangroves of Casamance thus play the role of carbon sink, contributing to lessen the causes of global warming. It is undeniable that mangroves have a strong capacity to sequester carbon, superior to other ecosystems. The evaluation of carbon sequestration in mangrove plantations in the Saloum Delta (Senegal) has shown that they can sequester 1.936 tons of carbon in two years (Deugué-Namboma, 2008). In Senegal, over the 30-year period, an amount of 81.132.86 tCO2-e is expected due to the reforestation carried out in Casamance and in the Saloum delta (Cormier-Salem et al., 2016). Global terrestrial vegetation has been projected to sequester 112–169 PgC (1PgC = 1015g carbon) each year, which plays a vital role in global carbon recycling (Sha et al., 2022). The findings suggest that optimizing land management can sequester higher, if not the highest, potential carbon from the managed vegetation, representing a promising way to mitigate climate changes.

Regression analyses for sequestered carbon assessment

In this study, it was essential to understand the different parts where mangroves fix and store carbon and the role of mangroves in the carbon cycle. Like other woody plants, mangroves consist of above-ground and below-ground biomass of carbon fixation and storage assimilated by mangroves and returned to the atmosphere via above- and below-ground respiration.

This study shows a difference in the accuracy of the regression models obtained depending on the growth parameters tested. According to the partial coefficients of regression (intercept, slope) and the coefficient of determination, a significant difference was noted between the regression models. The coefficient of determination (R^2) is higher for the model that estimates sequestered carbon as a function of height than the model that estimates it as a function of the square of the circumference and height, that is, C^2H. These results indicate that height influences plant biomass as well as the C^2H parameter to a lesser extent.

The models obtained with $Y_1 = a + bH$ gives a higher accuracy with a coefficient of determination $R^2 = 0.81$. This regression model remains lower than the cubing rate model ($R^2= 0.968$) developed in the Saloum Delta by NDOUR et al., (2014). However, the models obtained are more accurate than those developed in the Republic of Guinea ($R^2 = 0.63$) by Arsenault (1993). The two equations (Y_1 and Y_2) from this study are substantially similar to those found by Clough and Scott, (1989) in Queensland with more significant regression relationships ($R^2 = 0.746$ et $R^2 = 0.847$) found in the Mangoky Delta. However, besides longitudinal and latitudinal factors our regressions are less accurate than those obtained by Suzuki and Tagawa (1983) as well as (Rakotomavo, 2018) in southern Japan with regression relationships of $R^2 = 0.973$ et de $R^2 = 0.959$.

Conclusion

The study on the assessment of carbon sequestration by mangrove plantations in Casamance revealed that the plantations have a significant amount of dry matter. This quantity of dry biomass shows a good carbon sequestration in Casamance. These results sufficiently demonstrate the importance of restoring mangrove ecosystems through the mangrove planting technique. In addition, this study revealed that young mangrove plantations in full growth could be potential carbon sinks.

Despite observing promising results, further research in the quantification of the aboveground biomass in all eligible plantations in Casamance and the study of edaphic factors to establish a relationship between the species and the type of soil adapted to its reforestation will be required for the development and prosperity of the carbon market in mangrove ecosystems in Senegal.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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