

Full Length Research Paper

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

Ouattara Dongui Séniva*, Tapé Logboh David and Edia Oi Edia

Laboratoire d'Environnement et de Biologie Aquatique (LEBA), UFR-Sciences et Gestion de l'Environnement (SGE), UNIVERSITE NANGUI ABROGOUA (UNA), 02 BP 801, Abidjan 02, Côte d'Ivoire.

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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

*Corresponding author. E-mail: ouattaradonguiseniva@yahoo.fr. Tel: 0101036907.

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, stream 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 where 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, Euphorbiaceae (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 (Dougoudou, Tributary Dougoudou 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 μ m 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 (40x 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:

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

where M_t is final mass of leaf litter (g), M_0 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*.

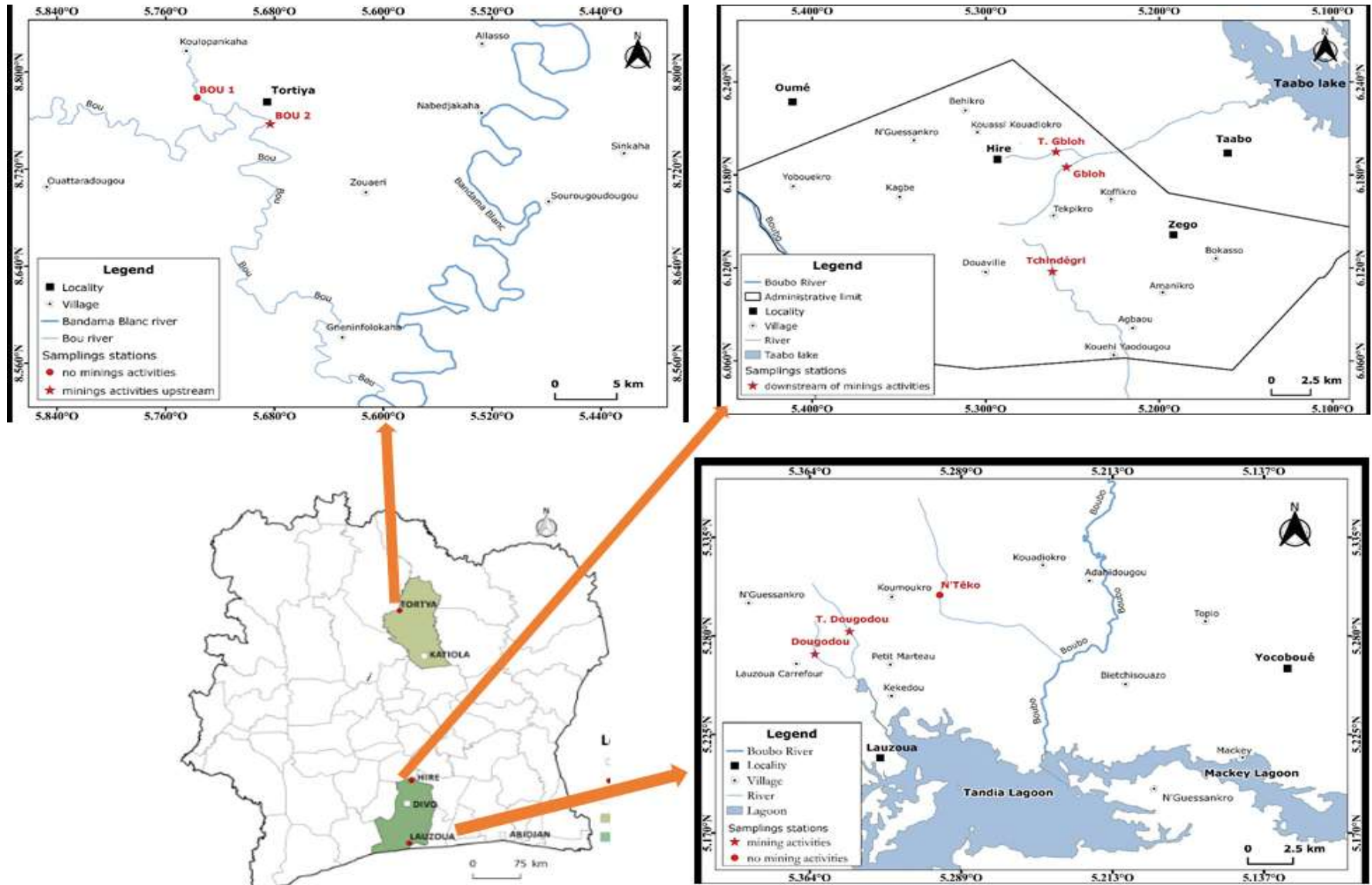


Figure 1. Geographic location of sampling stations in streams studied in three mining areas.

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>"

CNTIG - Cartes & Atlas

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 contribution 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

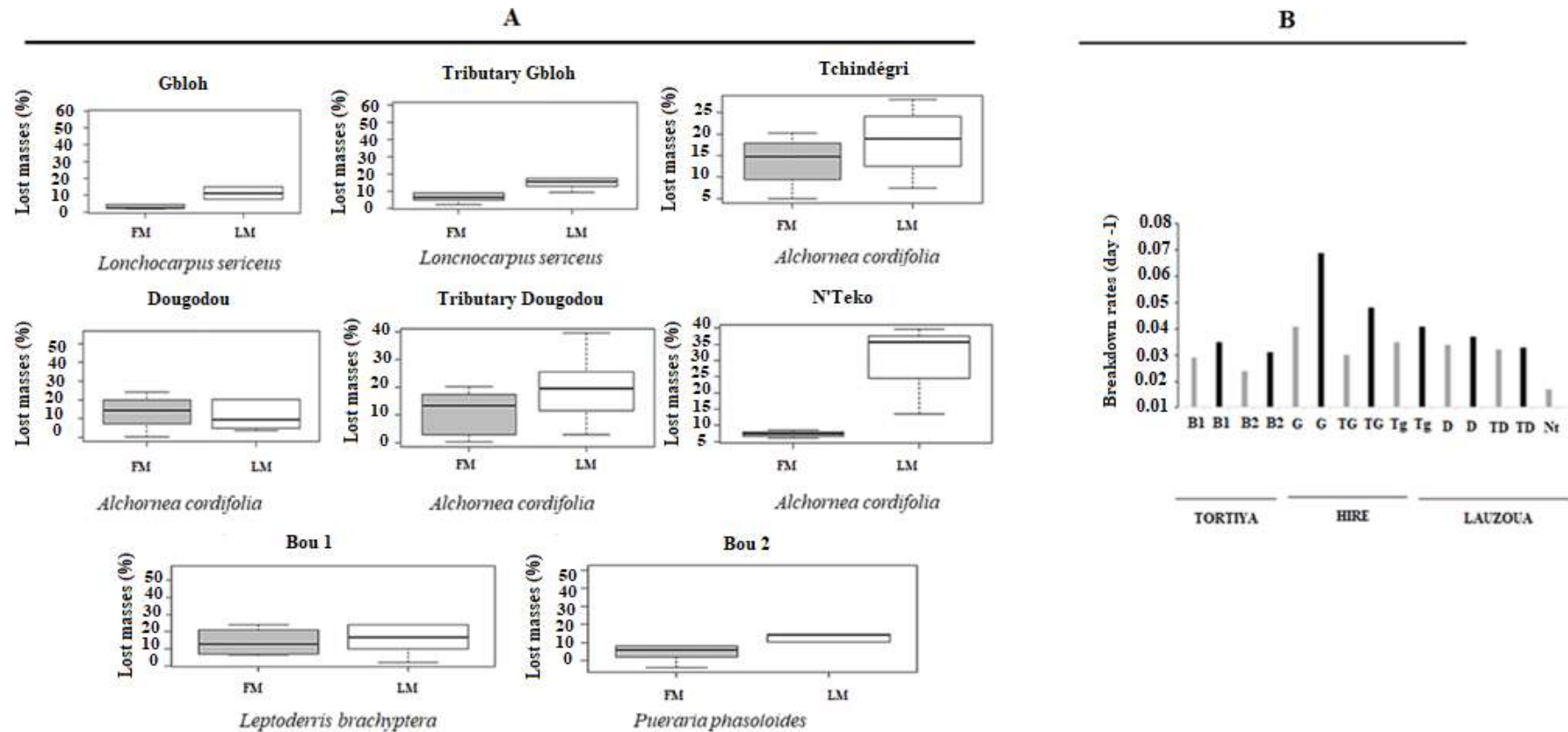


Figure 2. A: Lost masses in leaf litter nets (FM: fine mesh net, LM: large mesh net) at all stations; B: Leaf litter breakdown rates at all stations (grays bars: fine mesh, blacks bars: large mesh).

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 macroinvertebrates of the streams studied.

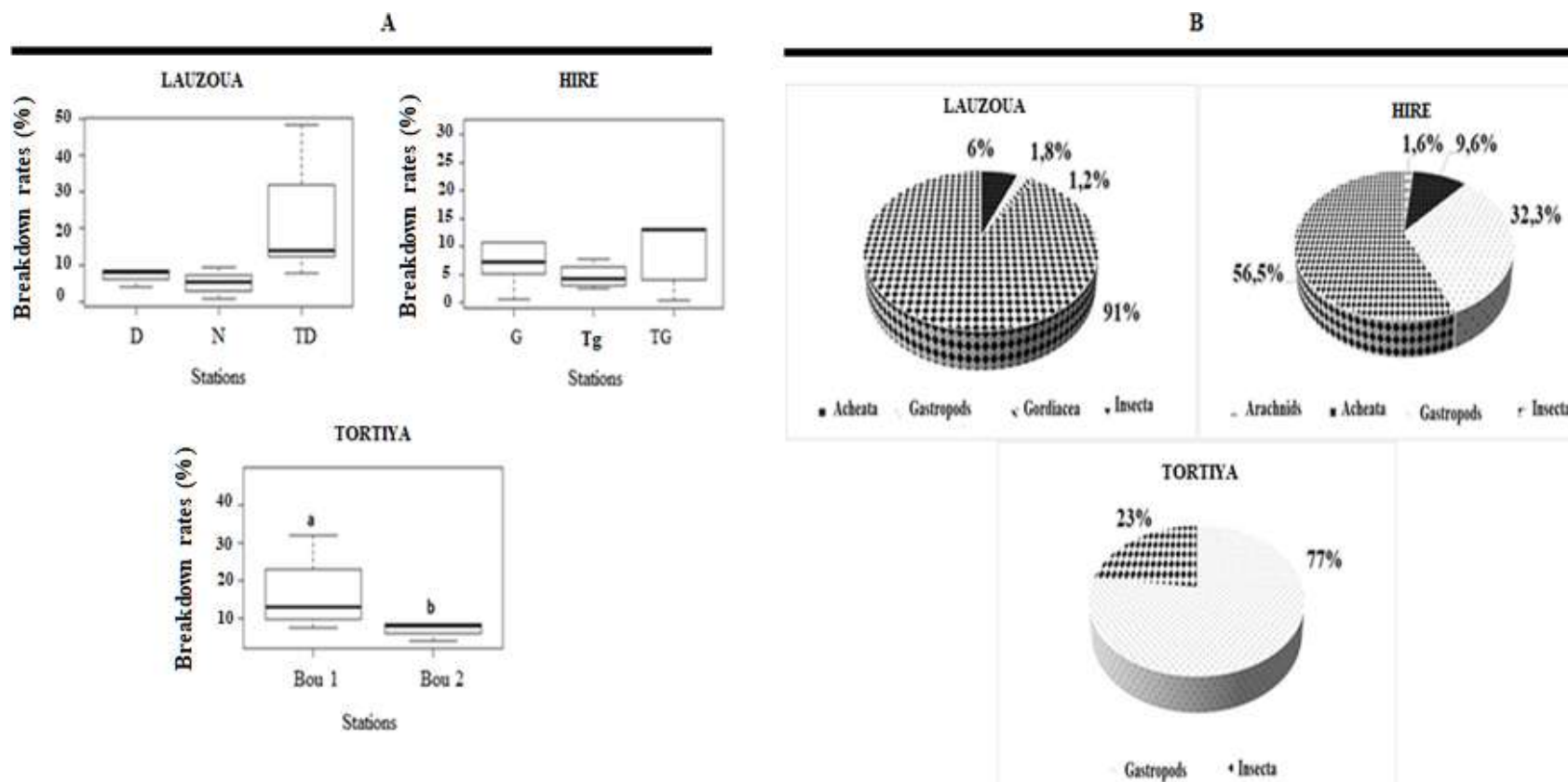


Figure 3. A. macro invertebrates' contribution in leaf litter breakdown rates. B= Percentage of macroinvertebrates classes involved in leaf litter breakdown process. Source: Author

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
Acheata	Rhynchobdelliformes	Glossiphoniidae	<i>Glossiphonia</i> sp.	Parasites				*			
			<i>Helobdella</i> sp.	Parasites			*				
Arachnids	Trombidiformes	Hydrachnidae	<i>Hydrachnella</i> sp.	Predator	*	*				*	*
Bivalves	Unionoida	Corbuliidae	<i>Corbula gibba</i>	Filter						*	

Table 2. Cont.

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