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LEAF LITTER DECOMPOSITION FROM THREE SPECIES PRESENT IN A TROPICAL DRY FOREST STREAM OVER A RIPARIAN QUALITY GRADIENT.

Descomposición de la hojarasca de tres especies presentes en un arroyo de bosque seco tropical a lo largo de un gradiente de calidad riparia

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ABSTRACT

In endangered regions, such as the water bodies from tropical dry forests, ecological processes such as riparian litter decomposition is an important topic when considering restoration projects for these ecosystems. Nevertheless, most studies on litter decomposition have focused on other ecosystems such as tropical rainforests or forests from northern hemisphere, so there are few studies that relate riparian plants to litter decomposition in dry forest. To help understanding this process, we propose two hypotheses: Species with a higher cellulose concentration and secondary compounds in the leaves will have a lower decomposition rate, but with a greater variation according to the sampling site and season, due to the water physicochemical differences. And leaf litter decomposition rates will reflect differences in riparian quality, due to increases in physicochemistry such as conductivity and pH. We select leaves from three common species (*Guadua angustifolia, Guazuma ulmifolia,* and *Zygia longifolia*) to record the decomposition rate, with the environmental characterization (climatic physicochemical and QBR index data). We observe differences in decomposition rates according to litter plant species, due to leaves chemical composition. In contrast, there were no significant relations between decomposition rates and environmental data according to sampling zones and seasons. This helps to understand how the variables are related to the processes of litter decomposition in the aquatic systems of dry forests, in order to support the theoretical basis for future restoration projects of dry forests, to focus on establishing an adequate litter input to sustain trophic networks.

Keywords: Colombia, riparian buffers, water pollution.

RESUMEN

En regiones amenazadas, como los cuerpos de agua de los bosques secos tropicales, los procesos ecológicos como la descomposición de la hojarasca riparia son un tema importante cuando se plantean proyectos de restauración de estos ecosistemas. Sin embargo, la mayoría de los estudios sobre la descomposición de la hojarasca se han centrado en otros ecosistemas, como los bosques húmedos tropicales o los bosques del hemisferio norte, por lo que existen pocos estudios que relacionen las plantas riparias con la descomposición de la hojarasca en el bosque seco. Para ayudar a entender este proceso, proponemos dos hipótesis: Las especies con mayor concentración de celulosa y compuestos secundarios en las hojas tendrán una menor tasa de descomposición, pero con una mayor variación según el sitio de muestreo y la estación, debido a las diferencias fisicoquímicas del agua. Y las tasas de descomposición de la hojarasca reflejarán diferencias en la calidad ribereña, debido a aumentos en la fisicoquímica del agua como la conductividad y el pH. Seleccionamos hojas de tres especies comunes (*Guadua angustifolia, Guazuma ulmifolia* y *Zygia longifolia*) para registrar la tasa de descomposición, junto con la caracterización ambiental (datos fisicoquímicos climáticos y del índice QBR). Observamos diferencias en las tasas de descomposición según la especie vegetal de la hojarasca, debido a la composición química de las hojas. Por el contrario, no se observaron relaciones significativas entre las tasas de descomposición y los datos ambientales según las zonas y estaciones de muestreo. Esto ayuda a entender cómo se relacionan las variables con los procesos de descomposición de la hojarasca en los sistemas acuáticos de los bosques secos, con el fin de apoyar la base teórica para futuros proyectos de restauración de los bosques secos, para centrarse en el establecimiento de un aporte de hojarasca adecuado para sostener sus redes tróficas.

Palabras Clave: Barreras riparias, Colombia, Contaminación del agua.

INTRODUCTION

Tropical Dry Forests (TDF) are environments located in altitudes lower than 1200 m a.s.l., with an annual rainfall lower than 2500 mm, and soils that promote an extensive tree cover (Halffter, 1992; DRYFLOR, 2016). Also, TDF have low resilience to disturbances that, added to their longer dry seasons, cause their change into xerophytic areas due to the cumulative effects of these disturbances and original flora replacement by more drought-resistant species (Pennington et al., 2000). Currently, according to the Alexander von Humboldt Institute, more than 90% of the Colombian TDF tree cover areas have been modified. Additionally, the Colombian system of protected areas records that less than 5% of the dry forest is located in some type of protected area, being the most threatened environment in Colombia (Linares and Fandiño, 2009; Pizano et al., 2016). Specifically, within the tropical dry forest environments, we find the riparian and aquatic systems, where these ecosystems have deteriorated due to demographic and agricultural growth in recent years (Melo-Cruz et al., 2017; Romero-Duque et al., 2019). Due to the above, the environmental protection projects for the TDF have focused on the conservation of the hydric and riparian ecosystem to promote dry forest restoration (Pizano et al., 2016; Romero-Duque et al., 2019; Andrade et al., 2022). For this reason, recent studies have highlighted the quality of the riparian habitat as a key element in ecosystems conservation (Galeano Rendón et al., 2017; Rincón et al., 2017).

Riparian habitats are defined as the habitats near a stream whose soils and vegetation are affected by the humidity and flooding and are thus different from the surrounding soils (Granados-Sanchez et al., 2006). The riparian vegetation has multiple functions, including its value as a buffer that stabilizes the hydrological and physicochemical characteristics of the stream, against external conditions such as deforestation and other anthropic influences (Gregory et al., 1991; Lowrance et al., 1997). The riparian vegetation also serves as a shield that limits the solar radiation influence on the stream, since the riparian vegetation is mostly composed of trees (Suárez et al., 2002; Granados-Sanchez et al., 2006; Kibichii et al., 2007; Cory et al., 2014). The riparian forest is important for many ecological dynamics within the ecosystem, but in this case, we focus on its function as a source of energy and nutrients that it provides to the aquatic ecosystem, as this directly influences changes in the dynamics of trophic networks and the assembly of organisms in the system. (Fajardo et al., 2000; Munné et al., 2003; Segura et al., 2003; Moulton and Wantzen, 2006).

In low-order streams, the riparian vegetation presence generates shading over the stream bed limiting autochthonous primary productivity, making allochthonous primary production the main source of energy in these ecosystems (Mantel et al., 2004; Moulton, 2006; Neres-Lima et al., 2017). For that reason, the riparian system in these streams provides energy and nutrients to streams in the form of plant litter (Graça et al., 2015; Rincón et al., 2017). Litterfall inputs depend on two variables: (1) the riparian vegetation density, which is related to the riparian quality and seasonality that affected litter amount inputs according to the climatic patterns (Christopher, 2014), and (2) the riparian tree species composition that is delimited by tree's phenology and is related to the litter fall quality input in the stream (Schimpf and Danz, 1999; Leite-Rossi et al., 2016; Biasi et al., 2019; Ramos et al., 2021).

Consequently, this incoming leaf litter undergoes multiple shredding and decomposition processes that are mediated by agents such as water flow and the action of shredders macroinvertebrates that reduce standing stock of litterfall and facilitate its degradation in the ecosystem (Carvalho and Uieda, 2010; Follstad Shah et al., 2017; von Schiller et al., 2017). In detail, increases in flow are related to the physical abrasion of the leaves (Ramos et al., 2021). Meanwhile, water temperature, pH and dissolved oxygen are variables that facilitate or hinder the chemical decomposition of the leaves and their colonization by shredders macroinvertebrates as Trichoptera and Diptera individuals (Ferreira et al., 2012; Ramos et al., 2021). Additionally, changes in the stream physicochemical and hydrology as a consequence of alterations in riparian quality and/or human actions, also play a relevant role in litter decomposition (Ferreira et al., 2012). However, the decomposition litter process may be slowed down by vegetal characteristics as the leaves chemical and physical composition which are leaf species variables that extend the time in which flow abrasion (e.g.: lignin and cellulose concentrations, and leaf toughness) or colonization by macroinvertebrates (e.g.: secondary compounds, nitrogen and phosphorus) needs to assimilate the leaf litter into the ecosystem (Ostrofsky, 1997; Ferreira et al., 2012; Boyero et al., 2016; Ramos et al., 2021).

As a result of the background, many studies aim quantify the entry of allochthonous litter fall into streams and an even greater number of studies try to evaluate the process of leaf litter decomposition according to riparian quality

(Graça, 2001; Graça et al., 2015). However, such studies in environments such as the TDF are not as numerous as might be expected, so we set the research aim to calculate the litter decomposition rate of three common species in a stream within a tropical dry forest ecosystem, and asked the following question: What is the relationship between the conservation status of the riparian forest and the decomposition of litter entering the stream? We propose two hypotheses: (1) Species with a higher concentration of cellulose and secondary compounds in the leaves will have a lower decomposition rate, but with a greater variation according to the sampling site and season, due to the physicochemical differences of the water. And (2) leaf litter decomposition rates will reflect differences in riparian quality, due to increases in physicochemical variables such as conductivity and pH, such as the middle zone of the stream, or as a consequence of ecosystem seasonality.

MATERIALS AND METHODS

Study area

The study area is located in the municipality of Paicol of the department of Huila, Colombia, within a remnant of TDF in the hydrographic basin of the Upper Magdalena River Valley. This region registers an average rainfall of 1500 mm per year, temperatures between 19 and 25 °C, and a monomodal regime with a rainy season that goes from November to March, an intermediate season between April to July, and a dry season from August to October (IDEAM, 2013). In this TDF region, riparian forests usually present a species composition dominated by Fabaceae plants, which are leafy species under water stress conditions that invest greater resources in the construction of cavitation resistant tissues in order to resist the loss of leaves during the dry season (Cuellar-Cardozo et al., 2022). Therefore, the riparian forest has a constant closed canopy throughout the year, with no periods of concentrated litterfall.

The study was carried out in “La Avería” stream, which is a third-order fluvial environment belonging to the Páez River mesobasin in the Huila western area. This stream arises at an altitude of 922 m a.s.l., over a rock-type substrate, within a conserved remnant of the riparian forest, and extends a length of approximately 4.5 km through areas where the forest has been disturbed by urban dumping, rice crops, and cattle ranching, with sand and leaf litter substrates to finally flow into the Páez River at an altitude of 805 m a.s.l.

We defined three sampling zones along the stream according to changes in riparian vegetation: 1) The upper zone (2° 26’ 22.3” N; 75° 46’ 31.4” W, 922 m a.s.l.) corresponds to the area where the native forest is still preserved, dominated by *Zygia longifolia* (Willd.) Britton and Rose. 2) The middle zone (2° 26’ 31.8” N; 75° 46’ 5.9” W, 813 m a.s.l.) is located in a sector where the riparian cover disappears as a consequence of the presence of crops, and the water flow is contaminated by wastewater discharges from the nearby urban center. 3) The lower zone (2° 26’ 57.2” N; 75° 45’ 24.6” W, 805 m a.s.l.) is a riparian forest dominated by *Guazuma ulmifolia* Lam. with the presence of livestock in the fluvial system surroundings. We established an approximate distance of 1.5 km between each sampling zone. At the same time and taking into account the rain regime, we establish three sampling seasons: the dry season (July to September 2020), the intermediate season (November 2020 to January 2021), and the rainy season (March to May 2021).

Environmental characterization

The climatic data for the study area—rainfall (mm) and temperature (°C)—were taken from the average records from the two meteorological stations belonging to the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), located in the Paicol urban area and the Páez river respectively. Stream physicochemical characteristics were recorded in triplicate with a HANNA HI98194® multiparameter probe: conductivity (µS cm-1), dissolved oxygen (mg l-1), total suspended solids (mg l-1), pH, and water temperature (°C). We also measured the flow of the stream (m3 s-1) according to the method proposed by Elosegi and Sabater (2009), which multiplies depth (m), width (m), and water velocity (m s-1), measured using a flowmeter JDC Electronics 94356 FS.

We determined the vegetation cover in each station by quantifying the state of conservation of the riparian forest with the QBR (*qualitat del bosc de ribera*) index adapted for Colombia, at each station, we made ten transects of 30 m each (five on each side of the stream) to average the values and interpret our data with theoretical levels (Suárez et al., 2002; Munné et al., 2003; Posada and Arroyave, 2015; Galeano Rendón et al., 2017).

Additionally, in the same transects used for the QBR index, we recorded the input of solar radiation (W m-2) with a LI-COR LI-210R® lux meter. We also calculated the density of the forest cover using a spherical densitometer according to the methodology in Lemmon (1956).

Litter decomposition rate

We determined the decomposition rate of litter in the stream according to the methods in Elosegi and Sabater (2009). The litter was collected from three tree species: *Guadua angustifolia* (Kunth), *Guazuma ulmifolia* Lam. and *Zygia longifolia* (Willd.) Britton & Rose, which previous studies have shown as abundant species along the stream in the study area (Fig. 1) (Cuéllar-Cardozo et al., 2022). Regarding the chemical composition of its leaves, *G. angustifolia* has a 44.94% cellulose, 22.92% lignin, 42.47% carbon, and 2.92% ash in addition to five flavonoids, a phenol, vitamin E and K, and Tetraethyl silicate (Morales Noreña and Sanchez Vallejo, 2008; Sánchez-Echeverri et al., 2014). On the other hand, *G. ulmifolia* leaves are the most palatable specie, due to its lower cellulose and lignin content changed by volatile constituents as tannins, flavonoids, phenolic acids, and caffeine (Arriaga et al., 1997; Ortega et al., 1998). Finally, *Z. longifolia* was the species with the least amount of information about the chemical composition of its leaves. Nevertheless, in multiple studies on litter decomposition rates, *Z. longifolia* is defined as the species with the most recalcitrant leaves due to its high concentrations of phosphorus and carbon (Ardón et al., 2006; Ardón and Pringle, 2007, 2008).

The leaves were collected directly from multiple trees located in the study area during the rainy season (June 2020), only leaves with a healthy and homogeneous appearance were collected. This material was taken to the laboratory to be dried in an oven at 40 °C for 48 h, weighed (4.5 ~ 5.0 g), and enclosed into mesh bags (25 x 10 cm) with a 5 mm mesh opening. In total, 135 litter bags were placed throughout the experiment; in each sampling period (2020-2021) (rainy, intermediate, and dry), 45 litter bags were used (three species * three stream sites * five sampling dates). The organization of the litter bags within the stream was carried out randomly, covering the greatest possible heterogeneity in the environment and maintaining a minimum distance of 5 m between each one of them.

Subsequently, three leaf litter bags were removed on days seven, 14, 28, 56, and 63 after the experiment had elapsed in each of the stations. On the same day (day zero), three extra litter bags were prepared for each litter treatment and taken to the field, and returned to the laboratory to be used to calculate the ash-free dry mass (AFDM) conversion factor, considering mass loss from handling. The degraded litter was taken to the laboratory where it was placed in an oven at 80 °C for 72 h and was weighed on an analytical balance with a precision of 0.01 g, to later be calcined in a muffle at 480 °C for four hours to obtain the AFDM. The litter decomposition rate was obtained utilizing a negative exponential regression model proposed by several authors among which Elosegi and Sabater, (2009) and Boyero et al. (2011):

$$M_t = M_0 e^{-kt}$$

Where *Mt* is the mass in grams of litter (as AFDM) on the different days of extraction of the litter bags, *M0* is the initial mass in grams of the litter, *k* is the litter decomposition rate and *t* is the time elapsed in the experiment expressed in days.

Figure 1. Plate with the procedure used during the experiment. a. The conserved canopy status at one of the sampling points. b. Leaves collected from the different species used in the experiment. c. Leaves arranged in the desiccator oven for their preparation in the litter packages. d. Leaf litter packages placed inside the stream. GU: *Guazuma ulmifolia*. ZL: *Zygia longifolia*. GA: *Guadua angustifolia*.

Data analysis

We tested the normal distribution using the Kolmogorov-Smirnov test in the whole environmental variables and we used multiple Kruskal-Wallis analyses to find significant differences according to the sampling area and season. For hypothesis one, we did an analysis of covariance (ANCOVA) to compare litter decomposition between zone, season, and plant species (time as covariate; zone, season, and litter as factors; and litter decomposition rate (*k*) and ln-transformed litter remaining fraction as the dependent variables). We used a Tukey test as *a posteriori* comparison test to identify where these differences occur. On the other hand, to test hypothesis two, we carried out a linear regression model to evaluate effects (i.e. variations) in the decomposition rates caused by environmental variables and seasonality. Whole data analysis was performed using SPSS v26.

RESULTS

We observed significant changes in the stream environmental variables, according to the Kruskal-Wallis analysis ($k = 27$; $F\text{-value} = 11.27$, $df = 36$, $p\text{-value} < 0.05$). According to the sampling area, there were differences in solar radiation, conductivity, dissolved oxygen, total suspended solids, pH, water flow, and water temperature explained spatially by the three sampling points along the stream. On the other hand, solar radiation, rainfall, environmental temperature, conductivity, total suspended solids, pH, and water flow presented significant differences temporally (Table 1). About the QBR index, the stream upper area as the natural conditions of the riparian forest registered a score of 95. In contrast, the lower zone had a medium value of 68 due to the livestock impact. Finally, the middle zone scored a low value of 45 as a result of the near-disappearance of the vegetation cover.

The exponential regression models calculated the average decomposition rate (*k*) at each leaf species according to sampling area and season (Fig. 2). Regarding the changes in the decomposition rate according to the sampling zones, for *G. angustifolia* similar values are observed, decreasing in each sampling zone along the stream. On the other hand,

Table 1. Mean ± standard error of the environmental data present in each sampling zone and season in the La Avería stream. * = Significant variables (*p-value < 0.05*).

Parameter	Upper Zone	Middle Zone	Lower Zone	Dry	Intermediate	Rainy
Solar Radiation (W m-2)	0.34 ± 0.08	0.69 ± 0.16*	0.20 ± 0.09	0.49 ± 0.15	0.20 ± 0.05*	0.53 ± 0.14
Environmental temperature (°C)	24.46 ± 0.12	24.46 ± 0.12	24.46 ± 0.12	24.20 ± 0.13*	24.47 ± 0.08*	24.71 ± 0.12*
Rainfall (mm)	80.16 ± 10.98	80.16 ± 10.98	80.16 ± 10.98	36.87 ± 4.30*	80.50 ± 6.00*	123.10 ± 9.40*
Water temperature (°C)	23.34 ± 0.24	23.49 ± 0.26	21.67 ± 0.27*	22.51 ± 0.35	22.63 ± 0.22	23.36 ± 0.35
Dissolved oxygen (mg l-1)	8.32 ± 0.30	7.93 ± 0.42	13.82 ± 0.64*	10.56 ± 0.67	10.23 ± 0.75	9.21 ± 0.93
Total Suspended Solids (mg l-1)	62.96 ± 2.38	62.17 ± 2.51	49.18 ± 3.23*	65.31 ± 2.24*	56.67 ± 3.76	52.33 ± 2.26
Conductivity (µS cm -1)	125.96 ± 4.78	142.81 ± 4.96	96.13 ± 6.47*	129.96 ± 4.49*	112.46 ± 7.85	104.48 ± 4.56
pH	7.854 ± 0.047	7.364 ± 0.066*	7.847 ± 0.042	7.621 ± 0.082	7.842 ± 0.058*	7.601 ± 0.074
Water flow (m3 s-1)	1.65 ± 0.56	1.18 ± 0.28	0.81 ± 0.13*	0.76 ± 0.15*	1.43 ± 0.20	1.45 ± 0.59

G. ulmifolia presents low value, observed in the middle zone. Meanwhile, *Z. longifolia* presents a minimum value in the lower zone of the stream. Regarding the litter decomposition rate according to seasonality, *G. angustifolia* presents the highest value during the rainy season. The opposite is the case with *Z. longifolia*, which has the lowest k value during the rainy season. Finally, no relevant changes were observed in the decomposition rate of *G. ulmifolia* according to the sampling season.

About the first hypothesis and according to the ANCOVA, we observed significant differences in litter remaining according to the plant species, where *Z. longifolia* showed a lower *k* in contrast with the other species (F-value = 3.64, df = 9, R2 = 0.18, Mean = 4.72 ± 0.09, Tukey test *p-value* < 0.01) (Table 2). At the same time, we did not observe differences in the litter remaining between *G. angustifolia* and *G. ulmifolia*. On the other hand, litter remaining does not exhibit significant differences by sampling zone (F-value = 3.64, df = 9, R^2 = 0.18, Mean = 0.73 ± 0.15) and season (F-value = 3.64, df = 9, R2 = 0.18, Mean = 0.8 ± 0.16). However, it is observed that the highest value in the decomposition rate occurs in the upper zone, and the lowest value in the middle zone of the stream. According to seasonality, the highest *K* values occur during the intermediate season, and the lowest value during the rainy season.

About the second hypothesis, we did not find any significant relationship between the decomposition litter rate and environmental variables in the stream according to the regression models (Table 3). Nevertheless, in detail, we observed that the water temperature presents some correlation with the decomposition rate of *G. angustifolia*. While, in the case of *G. ulmifolia*, the decomposition rate correlates to a minimum grade with the environmental temperature. Finally, *Z. longifolia*'s decomposition rate correlated most strongly with pH and flow rate.

DISCUSSION

Our first hypothesis was supported because there were significant changes in litter decomposition rate according to plant species. Although it is not possible to establish a reason why these differences occur, the literature makes it clear

Table 2. Mean ± standard error of the decomposition rate (*k*) according to the exponential regression models for each sampling zone, season, and leaf litter species in the La Avería stream. *=Significant values (*p-value < 0.05*).

Sampling zone	Upper zone	0.020 ± 0.004
	Middle zone	0.016 ± 0.005
	Lower zone	0.018 ± 0.003
Sampling season	Dry	0.018 ± 0.003
	Intermediate	0.020 ± 0.004
	Rainy	0.014 ± 0.003
Leaf litter species	*G. angustifolia*	0.026 ± 0.005
	G. ulmifolia	0.021 ± 0.004
	Z. longifolia	0.011 ± 0.001*

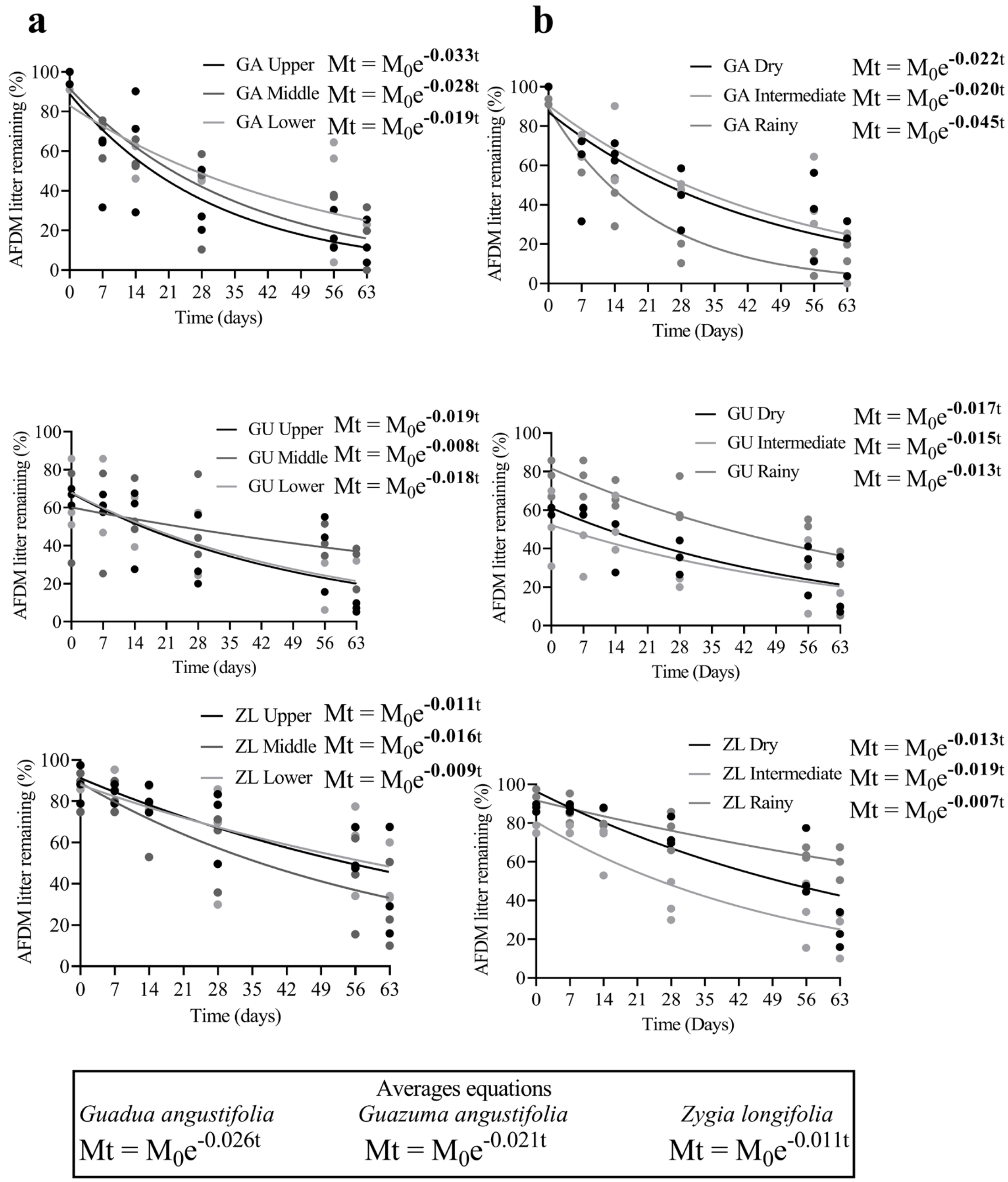

Figure 2. Exponential regression models for litter decomposition per leaf specie according to (a) sampling zone and (b) sampling season. The distribution of the data and the fit curve are shown.

that the chemical composition of the plant species leaves is a factor when considering changes in the rate of decomposition according to the plant species (Ostrofsky, 1997; Hui and Jackson, 2009; Zhang et al., 2019; Ramos et al., 2021). In detail, *Z. longifolia* registered the lowest decomposition rate and therefore took longer to degrade—a phenomenon related to chemical composition and hardness. This tree species is recognized for having a higher concentration of phenolic, lignin, and cellulose concentrations (Ardón and Pringle, 2007, 2008; Ardón et al., 2009). On the other hand, *G. angustifolia* and *G. ulmifolia* were species with other types of leaf compositions, showing higher concentrations of carbon and phosphorus that allow a higher decomposition rate (Londoño et al., 2002; Kumar and Gurunani, 2019; Rafi et al., 2020; Inga Santillán and Chavez Quintana, 2020).

We rejected the second hypothesis because there were no significant relations between litter decomposition rate and environmental characteristics (climatic, physicochemical, and riparian system quality data). This confirmed the idea that the change among the study reaches did not affect

Table 3. Lineal regression models of decomposition rate for each litter species and environmental variables in the La Avería stream.

Litter species		Solar Radiation (W m^{-2})	Environ-mental tempera-ture (°C)	Rainfall (mm)	Water tempera-ture (°C)	Dissolved oxygen (mg l^{-1})	Total Sus-pended Solids (mg l^{-1})	Conducti-vity (µS cm^{-1})	pH	Water flow (m^3 s^{-1})
G. angustifolia	Slope (m)	-0.01 ± 0.01	0.03 ± 0.2	0.03 ± 0.01	-0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
	Intersect (b)	0.04 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.14 ± 0.01	0.02 ± 0.01	0.04 ± 0.02	0.04 ± 0.02	-0.02 ± 0.10	0.03 ± 0.05
	R2	0.01 ± 0.03	0.01 ± 0.03	0.02 ± 0.03	0.41 ± 0.02	0.01 ± 0.03	0.01 ± 0.03	0.01 ± 0.03	0.01 ± 0.03	0.05 ± 0.03
	p-value	0.37	0.97	0.35	0.14	0.38	0.70	0.67	0.56	0.11
G. ulmifolia	Slope (m)	-0.01 ± 0.01	-0.01 ± 0.01	0.01 ± 0.01	-0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
	Intersect (b)	0.04 ± 0.01	0.41 ± 0.22	0.04 ± 0.01	0.16 ± 0.08	0.02 ± 0.01	0.01 ± 0.02	0.01 ± 0.02	-0.07 ± 0.11	0.03 ± 0.01
	R2	0.05 ± 0.03	0.05 ± 0.03	0.03 ± 0.01	0.05 ± 0.03	0.02 ± 0.03	0.04 ± 0.04	0.04 ± 0.03	0.02 ± 0.03	0.01 ± 0.03
	p-value	0.11	0.09	0.21	0.11	0.36	0.14	0.16	0.35	0.89
Z. longifolia	Slope (m)	-0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	-0.01 ± 0.01	0.01 ± 0.01	-0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01
	Intersect (b)	0.02 ± 0.01	-0.02 ± 0.08	0.02 ± 0.01	0.04 ± 0.03	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	-0.05 ± 0.04	0.01 ± 0.01
	R2	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.01 ± 0.01	0.05 ± 0.01	0.05 ± 0.01
	p-value	0.32	0.69	0.77	0.37	0.96	0.98	0.83	0.11	0.11

decomposition rates—these factors had no appreciable influence on the *k* value. We assume that the lack of environmental effects on the *k* value is a consequence of how the different stressors affected litterfall decomposition in opposite ways. For example, decreases in water temperature and solar radiation reduced decomposition rates, while increases in flow rate and pH promoted effects on the *k* value, resulting in no net changes in *k* values (Pan et al., 2015; Mori et al., 2020; Zhao et al., 2022).

Nevertheless, literature clarifies that in neotropical dry forest areas, changes in riparian forests do affect litter inputs, which directly affects overall decomposition, even though it may not affect the decomposition rate of a particular leaf species (Follstad Shah et al., 2017; Lidman et al., 2017; Rialli Santos Brandão et al., 2022). Also, alterations in the stream physicochemical have a direct impact on the litter colonization by macroinvertebrates and biofilm, since in degraded environments there is a lower rate of litter decomposition due to a lack of these organisms (Ardón and Pringle, 2007; Hui and Jackson, 2009; Ramos et al., 2021).

As additional information, results on the QBR index showed that the stream upper area registered a score of 95 defined as a sector with little anthropic disturbance, dense native vegetation, and the minimum entry of solar radiation into the water body (Posada y Arroyave, 2015; Cuéllar-Cardozo et al., 2022). Thus, we deduced that the natural state of the stream corresponds to a watercourse surrounded by a riparian cover composed largely of native vegetation such as *Z. longifolia*, which gives rise to a thick forest that limits the entry of solar radiation (Vargas, 2015; Cuéllar-Cardozo et al., 2022). In contrast, the middle zone exhibits the lowest value in the QBR index. This is typical of highly disturbed environments where the riparian vegetation cover has been almost eliminated, increasing the incoming solar radiation to the system (Acosta et al., 2009). Combined with the presence of structures such as viaducts and dumping areas, the natural flow of the stream can be modified, as it happens in the study area, where in the middle zone there are discharges that modify the flow of the stream (Suárez et al., 2002; Olascuaga-Vargas et al., 2016). Finally, the values of the QBR index within the medium-high range (68) fell within the lower zone, where these values are typical of environments with low levels of disturbance due to the presence of low-scale livestock. This causes a discontinuity of the tree patches in the riparian environment and a resultant coverage that allows a moderate entry of solar radiation to the flow of water (Chará et al., 2007). The middle zone scored a low value of 45 as a result of the near-disappearance of the vegetation cover increasing the entry of sunlight, in addition to the existence of rigid structures that modify the water flow (Munné et al., 2003; Olascuaga-Vargas et al., 2016; Cuéllar-Cardozo et al., 2022).

CONCLUSIONS

In conclusion, we reinforce the idea that in neotropical dry forest aquatic environments, litter decomposition is a process influenced mainly by the leaf type coming from plant species in the riparian zone. The results help to understand how the plant diversity in the riparian forest influences the stream. For this reason, this paper is the first of its kind in the TDF ecosystems and supports the idea that restoration projects should set goals focused on increasing the diversity of riparian plants by reforesting key species with different leaf litter decomposition values in order to maintain a constant litter decomposition process and thus a secure energy input to the trophic networks from the aquatic ecosystem.

Although this manuscript did not find a significant effect of the water physicochemical characteristics and riparian quality of the stream stretches on leaf decomposition, many other studies observed effects of these factors both on the leaf decomposition rates, as the structure, composition, and functional aspects of aquatic communities. Thus, for further studies, we recommend considering variables associated with riparian plant species (such as the chemical and nutritional composition of the leaves of each plant) to foster a better understanding of how leaf litter decomposition affects aquatic environmental dynamics.

AUTHOR'S PARTICIPATION

Both authors contributed equally to the production of the article. José A. Cuéllar-Cardozo: participation in the methodological phase and in the final drafting of the paper. Hakan Bozdoğan: interpretation of the results, discussion and in the final drafting of the paper.

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CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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