



ARTÍCULO DE INVESTIGACIÓN / RESEARCH ARTICLE

# ECOLOGICAL FUNCTIONALITY OF FOREST AND STREAM CORRIDORS IN AN AREA OF THE PLAINS PIEDMONT IN CASANARE

## Funcionalidad ecológica de los corredores forestales y fluviales en una zona del piedemonte llanero del Casanare

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### ABSTRACT

Between 2010 and 2020 a study was conducted on the functionality of the ecological corridors within the San José de Matadepantano farm, a property of 811 ha located in plains piedmont, which alternates poorly drained savannas, swamps, and forests, with land uses for agriculture, livestock, and the infrastructure of a rural university campus.

To evaluate the functionality of the forest corridors, length, amplitude, coverage area, and continuity metrics within the landscape were estimated using multiannual LANDSAT images; additionally, field visits were made to record possible forest gaps that could affect the flow of fauna through the corridors. In order to determine the functionality of the stream corridors, four sampling points were chosen along caños Tiestal and Güio, where physiographic and bathymetric profiles were modeled using the SURFER 15 software, in addition, spatial heterogeneity was calculated using the Shannon-Wiener index, physiognomy and floristic composition of the streamside vegetation was represented in scale graphic profiles, the percent distribution of aquatic habitats was determined and species diversity of fish communities was calculated. Findings obtained during the last decade allow us to conclude that the ecological corridors maintain their functionality with an active biotic flow in both forest and stream corridors. However, critical points were detected where the forests could lose their connectivity, which would affect the sustainability and transit of regional biodiversity.

**Keywords:** caños, connectivity, diversity, ecological corridors, spatial heterogeneity.

### RESUMEN

Entre los años 2010 y 2020 se realizó un estudio de la funcionalidad de los corredores ecológicos en la finca San José de Matadepantano, un predio de 811 hectáreas localizado en el piedemonte llanero, que alterna sabanas mal drenadas, pantanos y bosques, con usos del suelo destinados a agricultura, ganadería y la infraestructura de un campus universitario rural. Para evaluar la funcionalidad de los corredores boscosos, se estimaron las métricas longitud, amplitud, área de cobertura y continuidad dentro del paisaje, por medio de imágenes multianuales LANDSAT, adicionalmente se hicieron visitas de campo para registrar brechas que afectaran el flujo de fauna a través de los corredores. Para determinar la funcionalidad de los corredores acuáticos, se escogieron cuatro puntos de muestreo a lo largo de los caños Tiestal y Güio, en los que se levantaron perfiles fisiográficos y batimétricos por medio del programa SURFER 15, se calculó la heterogeneidad espacial por medio del índice de Shannon-Wiener, se representó la fisonomía y la composición florística de la vegetación ribereña con perfiles gráficos a escala, se determinó la distribución porcentual de los hábitats acuáticos y se calculó la diversidad de especies de las comunidades ícticas. Los hallazgos obtenidos durante la última década permiten concluir que los

corredores ecológicos conservan su funcionalidad, con un flujo biótico activo tanto en los forestales como en los acuáticos. No obstante, se detectaron puntos críticos en donde los bosques pueden llegar a perder su conectividad lo que afectaría el sostenimiento y tránsito de la biodiversidad regional.

**Palabras Clave:** caños, conectividad, corredores ecológicos, diversidad, heterogeneidad espacial.

## INTRODUCTION

The Colombian plains Piedmont are the geographic strip that borders the Cordillera Oriental in transition to the Orinoquía plains commonly known as the “Llanos Orientales”. Llanos are characterized by extensive grassland savannas that experience varying degrees of seasonality depending on the predominant climate in each subregion and are home to integrated zonal mosaics of herbaceous, forest, and aquatic ecosystems of great biodiversity. Despite their apparent homogeneity, the ecological conditions of the Llanos Orientales differ geographically according to location since towards the Orinoco River the soils are ancient due to the geological influence of the Guiana Shield, while in the Piedmont successive orogenic uplifts have given rise to soils of much more recent sedimentary formation. Because of this spatial distribution, the farther away from the Cordillera Oriental the soils are considered unproductive for human use because of their acidity, low cation exchange capacity, sometimes toxic aluminum content, and outcrops of compacted laterites rich in iron; In contrast, towards the piedmont, the soils have better fertility conditions due to the influence of terraces and alluvial fans formed by the sedimentary contribution of the white Andean rivers that flow down from the mountain range with a significant load of nutrients.

As the most fertile region of the Orinoquía, the plains of Piedmont have historically been subjected to a sustained and growing dynamic of intensive land use, which not only imposes an increase in anthropic pressures on water and soils but also puts the sustainability of regional biodiversity at risk. The regime of disturbances and transformations imposed on Piedmont ecosystems is primarily caused by agricultural and livestock expansion, which has generated a high degree of fragmentation; in this perspective, maintaining connectivity between natural landscape coverages through the consolidation and conservation of strategic ecosystem corridors becomes a priority. The main purpose of this study was to examine the functionality of gallery forests and two “caños” as ecological corridors in an area located in the plains piedmont of Casanare, where, in addition to agricultural and livestock activities, the infrastructure of a rural university campus has been expanding in the last decade.

## MATERIALS AND METHODS

### STUDY AREA

The study area corresponds to a piedmont zone located 10 km east of the municipality of Yopal, department of

Casanare, at an altitude of 230 m above sea level, where the warm and humid climate is characterized by a temperature close to 27 °C and an average rainfall that fluctuates between 2500 and 3500 mm per year; the rainiest season extends from April to July, while the driest months are December, January, and February. The drainage network that makes up the surface runoff is made up of streams commonly named “caños” that originate in Piedmont and flow into the Cravo Sur River basin. Relief, mostly flat, sometimes presents undulations with smooth transitions and no abrupt features, except for some ravines on the edge of the dissections where the “caños” run. Soils, mostly clayey and slightly acidic medium fertility that allows them to be used for planting various crops, although their poor drainage capacity produces waterlogging that can prevail even after the dry season, so the predominant natural grasslands correspond to hyper-seasonal flooded savannas (Sarmiento, 1996).

The study was conducted in San José de Matadepantano, a farm of 811 ha occupied by a mosaic of ecosystems, including poorly drained savannas, swamps, patches of relict forests, and gallery forest corridors around two streams: caños Tiestal and Güio. (Fig. 1). Caño Tiestal begins near the town of Yopal, after 5 km it enters the farm and crosses it from west to east in a stretch of 7.5 km and then follows its course for about 40 km until it flows into the Cravo Sur river; on the other hand, caño Güio rises within the study area, runs parallel to the caño Tiestal for about 5.7 km and then joins it after leaving the farm.

In addition to the natural ecosystems, some portions of the land on the farm are used for pasture, livestock, and crops (Briceño-Vanegas, 2014); however, the main anthropic intervention is the infrastructure of the Utopia University Campus, which covers some 20 ha of land on which administrative buildings, classrooms, laboratories, paths, housing and equipment modules have been built over the last 11 years housing a student population made up of young victims of rural violence from the most remote regions of the country.

## FUNCTIONALITY OF ECOSYSTEM CORRIDORS IN THE LANDSCAPE

To evaluate the functionality of the ecosystem corridors formed by the gallery forests and the caños Tiestal and Güio, the following variables were estimated 1. coverage, length, width, and continuity of the forest corridors, 2. physiography, marginal vegetation, spatial heterogeneity, habitat availability and fish diversity of aquatic corridors.

Table 1. Landscape descriptors of the ecological corridors inside San José de Matadepantano farm. a. aquatic habitat types. b. decadal comparison of landscape metrics and attributes

<b>a</b>				
<b>Variable</b>	<b>habitats</b>			
	<b>pools (P)</b>	<b>main channel (Ch)</b>	<b>riffles (R)</b>	<b>macrophytes (M)</b>
depth (cm)	120-200	10-120	0-10	0-30
current speed	very low	moderate	high	variable
substrate granulometry	rock-stone	stone	pebble	silt-sand
direct solar incidence	low	variable-high	high	high
accumulation of organic matter	high	variable	low	high
flow type	laminar flow	laminar flow	troubled flow	variable
annual persistence	persistent	persistent	persistent	variable
temporal variability	low	moderate	high	moderate
spatial variability	low	low-moderate	high	low-moderate

<b>b</b>				
<b>Variable</b>	<b>corridors</b>			
	<b>caño Tiestal forest corridor</b>		<b>caño Güio forest corridor</b>	
year	<b>2010</b>	<b>2020</b>	<b>2010</b>	<b>2020</b>
percent of occupied area	9.07	8.9	8.76	9.61
coverage area (ha)	73.56	72.63	71.1	78
length (km)	7.34	7.34	5.69	5.69
minimum width (m)	32	27.8	21.4	30.8
maximum width (m)	248	248	264	264
average width	125	123	135	138
number of gaps	5	5	4	3
ecological integrity	ecological connectivity intact		ecological connectivity intact	
ecological functionality	biotic flow persist		biotic flow persist	

	<b>stream corridor</b>		<b>stream corridor</b>	
	<b>2010</b>	<b>2020</b>	<b>2010</b>	<b>2020</b>
year				
physiography/spatial arrangement	patch dynamics		patch dynamics	
spatial heterogeneity average ( <i>H</i> )	1.87	1.74	2.13	2.11
habitat availability	high	high	high	high
fish diversity average ( <i>H</i> )	2.15	2.21	2.23	2.29
ecological integrity	ecological connectivity intact		ecological connectivity intact	
ecological functionality	biotic flow persist		biotic flow persist	

### COVERAGE, LENGTH, WIDTH, AND CONTINUITY OF FOREST CORRIDORS

To determine whether gallery forests' functionality as landscape corridors has been affected by anthropogenic interventions in the last decade, periodic field visits were made from 2011 to 2019 in which walking tours were conducted to detect interruptions or fragmentations in forest continuity. Additionally, LANDSAT images from

2010 and 2020 were compared to quantify possible losses of the functionality of forest corridors using the following metrics calculated in both years: corridor coverage, length, minimum, maximum, and average width, the annual average number of gaps, and percentage of occupation of forest corridors in the landscape matrix with the expression proposed by McGarigal et al. (2005):

$$\% P = \frac{\sum_{j=1}^n a_{ij}}{A} (100)$$

where  $a_{ij}$  corresponds to the area of coverage of each gallery forest corridor and  $A$  is the total area of the landscape in the San José de Matadepantano farm.

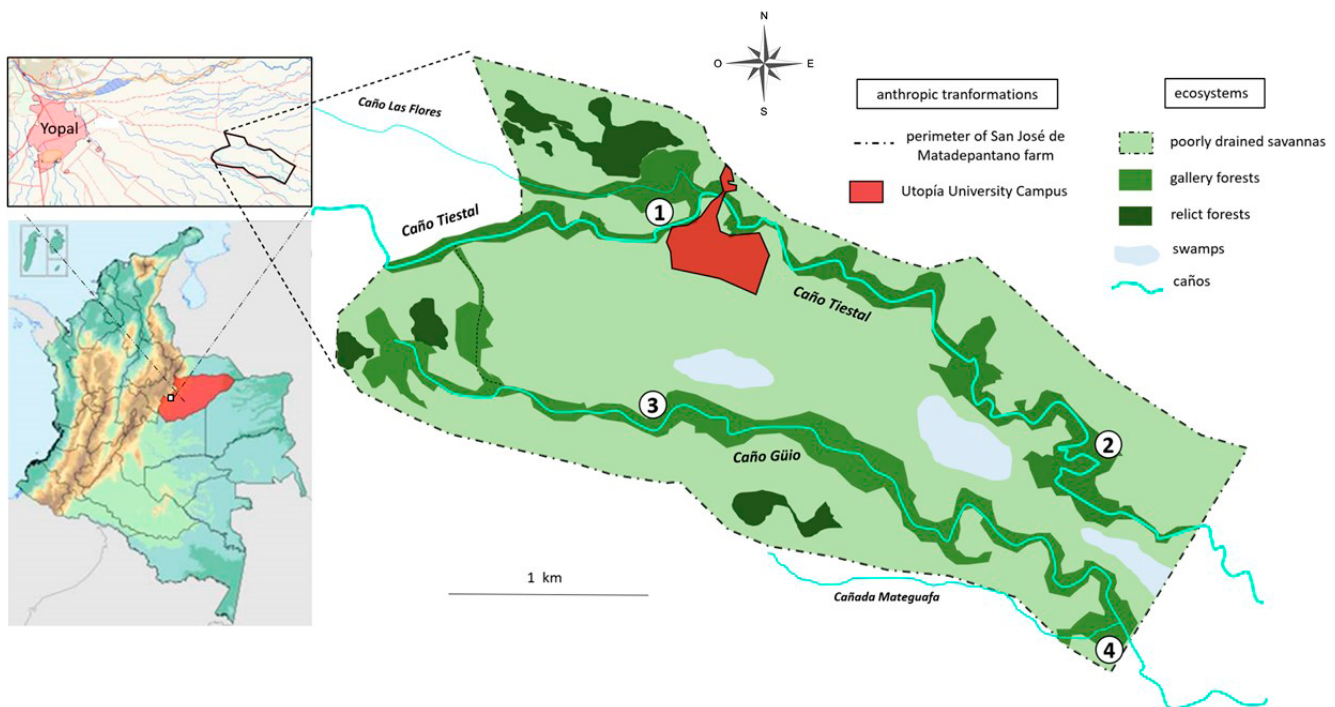
### PHYSIOGRAPHY, SPATIAL HETEROGENEITY, MARGINAL VEGETATION, HABITAT AVAILABILITY, AND FISH DIVERSITY OF STREAM CORRIDORS

To evaluate the functionality of the aquatic corridors, four sampling points were selected along the caños Tiestal and Güio (Fig. 1). Point 1, located at coordinates 5°19' 28" N and 72°17'37" W was called *campus* since it is located in the portion of caño Tiestal adjacent to the major focus of anthropogenic activity; point 2, was called *bosque* and was located at coordinates 5°18' 42" N and 72°16'20" W in the middle of a portion of caño Tiestal surrounded by dense forest; point 3, which was designated with the name *pista*, was located at coordinates 5°18' 53" N and 72°17'40" W in the upper course of the caño Güio 1.5 km from its source; and point 4, called *confluencia*, was located at coordinates 5°18' 13" N and 72°16'19" W in a section of the same caño where the Mateguafa stream confluences. Point 1 was established a few meters from the

Utopia Campus, while points 2, 3, and 4 were in natural areas with very few anthropogenic incidences to compare the integrity of the aquatic corridors in places with different degrees of intervention.

At each sampling point, the flow was measured and bathymetric profiles in 100 m sections were made following a modification of the methodology of Lisenby et al. (2014); then, the most constant bathymetry data during the sampling years and seasons were chosen and transformed in 3D graphical models using SURFER 15 software to represent the physiographic features of the aquatic body. The riparian vegetation was represented in graphic profiles with the physiognomic-structural aspects and the floristic composition of the gallery forest according to the transect methodology proposed by Gentry (1988). The spatial heterogeneity of the aquatic body was calculated using the Shannon-Wiener diversity index and the percentage distribution of the habitats present was calculated according to the characteristics summarized in Table 1a.

To estimate the diversity of fish communities, detailed photographic records were taken at each sampling point of the ichthyofauna captured temporarily by artisanal means to avoid the sacrifice and collection of specimens. Although in most cases taxonomic identification was achieved *in situ*, those specimens that were difficult to determine were subsequently identified with the help of the taxonomic keys of Eigenmann (1911, 1922), Schultz (1944), Sterba



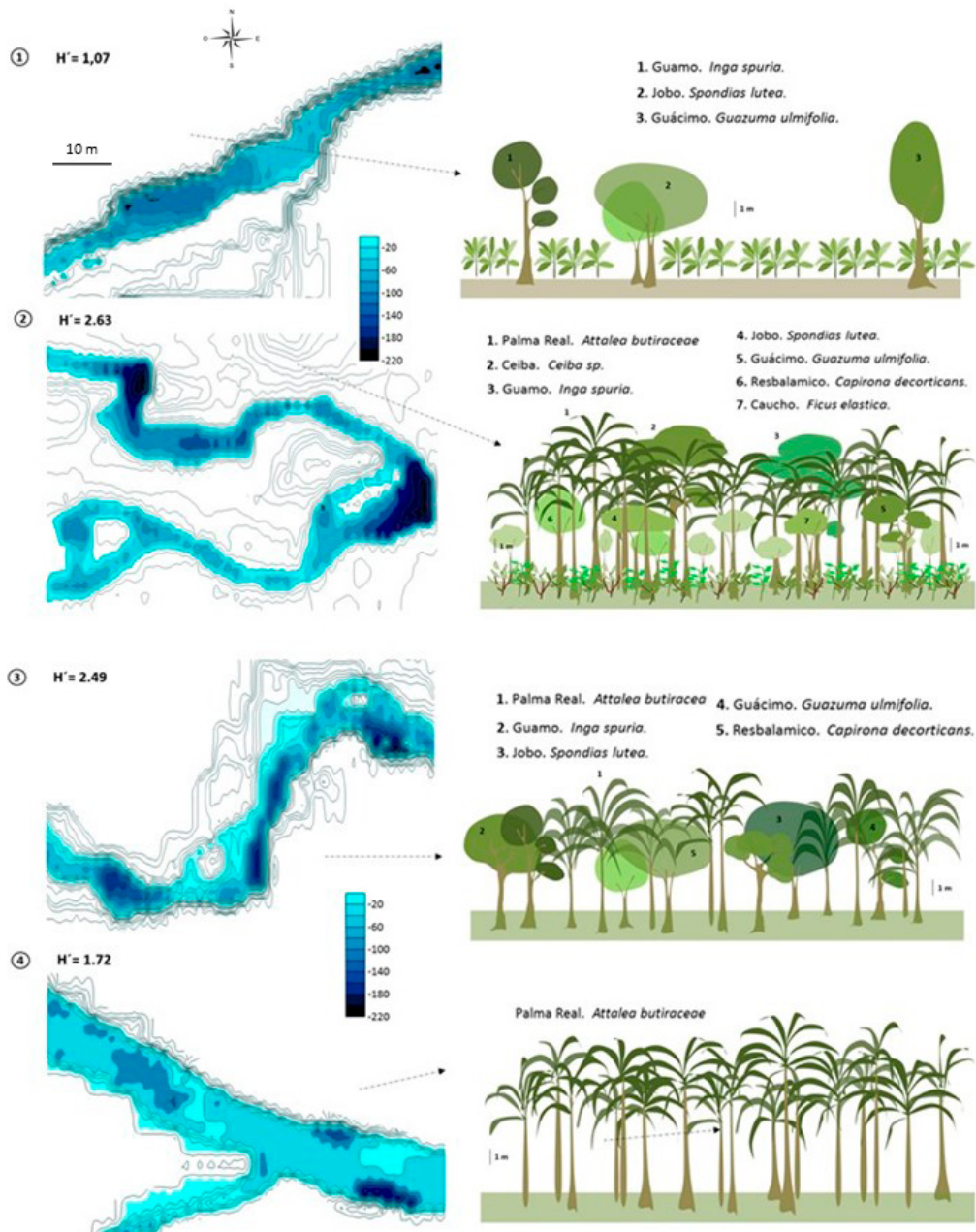
**Fig. 1.** Study area. San José de Matadepantano farm is located in the plains piedmont of Department Casanare. The numbered circles correspond to the sampling points where some ecological variables including in the study.

(1959), Gery (1964), Lowe-McConnell (1987), and with the comparison of the ichthyological collections of the Museo de La Salle in Bogota. Subsequently, species diversity was calculated using the Shannon-Wiener index and finally, a grouping analysis with the Bray-Curtis index was used to determine if there were differences between sampling points.

## RESULTS

### Coverage, length, width, and continuity of forest corridors

In general, the gallery forest corridors associated with the main caños of the San José de Matadepantano farm



**Fig. 2.** Physiography, bathymetry, spatial heterogeneity ( $H'$ ), structure, and floristic composition of ecological corridors along sampling points in caños Tiestal and Güio.

did not experience significant dimensional changes between 2010 and 2020 (Table 1b); some metrics such as length and maximum width remained unchanged, the forest corridor of caño Tiestal maintained a length of 7.34 km and a maximum width of 248 m, while caño Güio forest registered 5.69 km in length and a width of 264 m in its widest stretch. It is important to emphasize that both corridors presented total longitudinal continuity in terms of forest cover, with no bare stretches of trees (Fig. 1); however, in the forest corridor of caño Tiestal the minimum width was reduced from 32 m in 2010 to 27.8 m in 2020, which caused a decrease in the average width and if this trend persists poses a future risk of opening gaps that could compromise the functionality of the corridor. On the other hand, the forest corridor of caño Güio followed an opposite trend, as the minimum width increased from 21.4 to 30.8 m, raising the average width from 135 to 138 m.

Regarding the coverage variation, both corridors showed opposite trends: the forest around the caño Tiestal reduced its coverage from 73.56 to 72.63 ha, so its percentage of occupation in the landscape went from 9.07 % to 8.9 %. Meanwhile, caño Güio forest increased its coverage from 71.1 to 78 ha, which means an increase from 8.76 % to 9.71 % of the occupation in farm the landscape; this is very significant because the forest corridor of caño Güio reaches greater coverage than the caño Tiestal, being almost 2 km shorter.

Although the integrity of both forest corridors persisted throughout the decade of comparison, in the field visits carried out over several years within the farm, small gaps were detected to enable passages for human transit or cattle crossing either for watering or for rotational grazing. In 2010, the corridors showed five gaps in the caño Tiestal forest and four in the caño Güio forest; ten years later, the gaps remained in the caño Tiestal forest, while one of the gaps in the Güio forest corridor closed by natural vegetal regeneration. Despite the risk that this practice poses to the functionality of the forest corridors, currently, there have been no interruptions in connectivity that threaten the transit of fauna, since the clearings have been opened at ground level, but have not interrupted the continuity of the canopy.

### PHYSIOGRAPHY, SPATIAL HETEROGENEITY, MARGINAL VEGETATION, HABITAT AVAILABILITY, AND FISH DIVERSITY OF STREAM CORRIDORS

“Caños” correspond to small rivers in which meandering sections are combined with other straighter, branched, rugged, or staggered sections, which makes it impossible to present width and depth values that are representative of the entire channel. For this reason, the physiographical pattern, spatial heterogeneity, and riparian vegetation characteristics were represented in sampling points (Fig. 2); the results are described below.

**Campus:** This sampling point was located adjacent to the zone where anthropogenic activity and infrastructure construction are most intensive and where the greatest number of soil transformations for agricultural and livestock uses are concentrated. There, caño Tiestal flows linearly with a width of between 1.6 and 4.2 m and a depth of between 0.5 and 1.1 m; the bathymetric range change abruptly and the banks of the river are flanked by ravines up to 2 m high; the average spatial heterogeneity in this section of the river was 1.07. Regarding marginal vegetation, the forest on the left bank has been replaced by crops, despite a few spaced trees of guamo (*Inga spuria* Humb. & Bonpl. ex Willd. 1806), guácimo (*Guazuma ulmifolia* Lam, 1980) and jobo (*Spondias lutea* L, 1762) prevail.

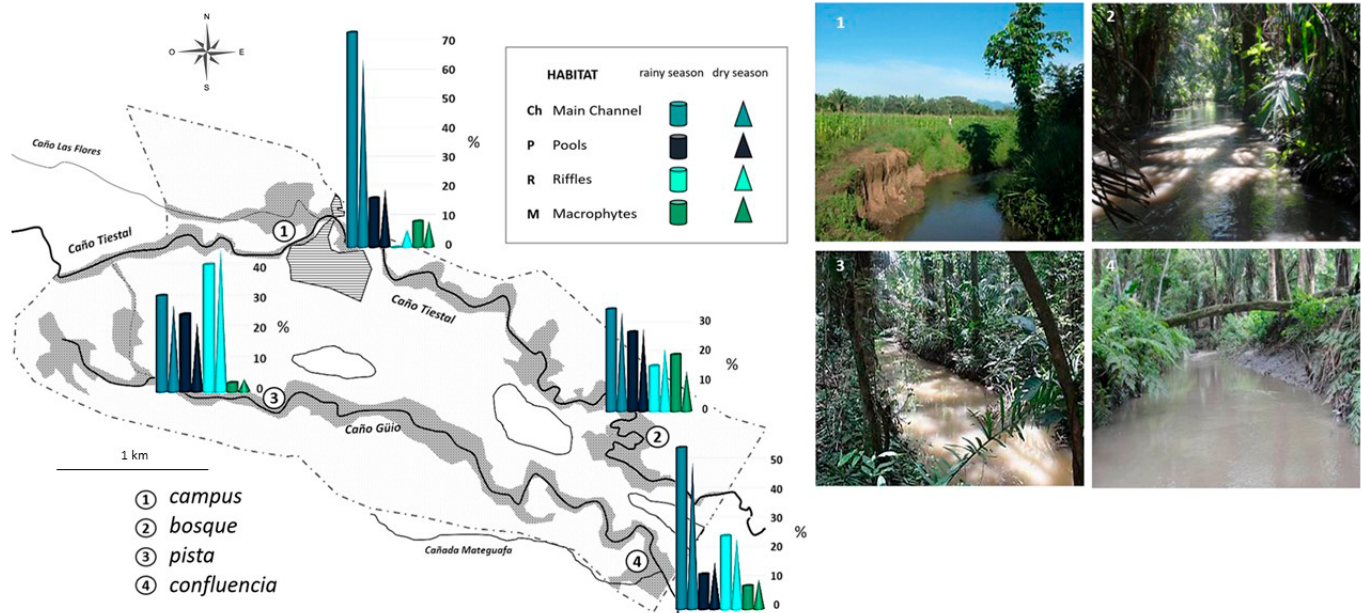
**Bosque:** In this section, caño Tiestal meanders through the densest part of the forest corridor far from anthropogenic influence. Caño reaches 9 m wide where it runs unified, but sometimes branches into small branches of different dimensions; the depth ranges between 0.1 and 2.2 m and the spatial heterogeneity reaches a value of 2.63, the highest of all the sampled points. Gallery forest surrounding the water body is the most diverse of the entire forest corridor and alternate palm groves of *Attalea butyracea* Mutis ex L.f. with trees strata occupied by species guamo (*Inga spuria*), resbalamico (*Capironea decorticans* Spruce), jobo (*Spondias lutea*), caucho (*Ficus elastica* Roxb. ex Hornem.), guácimo (*Guazuma ulmifolia*) and ceiba (*Ceiba sp.*).

**Pista:** This section of caño Güio is characterized by a winding riverbed with small islands or promontories that protrude into the main channel. The maximum width exceeds 7 m, and the depth fluctuates between 0.1 and 1.8 m, which is why this segment reaches a spatial heterogeneity of 2.49. The banks have gentle slopes and are sometimes so flat that they can be submerged by occasional floods when the caño overflows; these slopes are covered with *Attalea butyracea* palm groves alternating with riparian forests with a floristic composition like that of the caño Tiestal.

**Confluencia:** In this place, located on the southeastern boundary of the farm, caño Güio receives the waters of the Mateguafa stream, there the maximum width of caño reaches 6 m, and the depth ranges between 0.2 and 1.1 m. Although this section is far from anthropic disturbances, the confluence generates a high sediment load that, when deposited in the bed of the stream, reduces its spatial heterogeneity to a value of 1.72. As for riparian vegetation, the banks are occupied almost exclusively by *Attalea butyracea* palm groves, suggesting a high level of anthropic intervention in the gallery forest in the past.

In terms of habitat availability, caños Tiestal and Güio showed the presence of Pools (P), Main Channel (Ch), Riffles (R), and Macrophytes (M), whose characteristics are summarized in (Table 1a). Macrophytes habitat integrates different types of aquatic or marginal plants that include erect forms of *Montrichardia arborescens* (L.) Schott, 1854,





**Fig. 3.** Percent distribution of habitats along caños Tiestal and Güio in both hydrological periods. Photos on the right side show landscape aspects of each sampling point.

riparian coverages of *Paspalum repens* P. J Bergius, emerged plants of *Ludwigia helminthorrhiza* (Mart.) Hara, and floating islands composed of *Pistia stratiotes* L. and *Eichhornia crassipes* (Mart.) Solms 1883. Although all four habitat types were present in both caños, the percentage distribution of these varied among sites (Fig. 3). On *campus* and *confluencia* sampling points, there is a clear dominance of the main channel habitat (Ch) over the other three habitat types; this result corroborates low heterogeneity of these sections. On the other hand, *bosque* and *pista* sampling points maintained a more equitable balance in the percentage distribution of all habitats as a response to their greater spatial heterogeneity. The comparative data between dry and rainy seasons did not show significant differences that could imply drastic changes in habitat availability because of the hydrological regime.

As for the fish communities, 63 fish species were identified during the years of field recording, most of them present in both caños. The species composition was distributed among the orders Characiformes (58.3 %), Siluriformes (28.9 %), Gymnotiformes (7.1 %), and Perciformes (5.7 %). Fish community diversity calculated with the Shannon-Wiener index for global multi-year sampling was 2.1786 and had little variation between caños and between sampling points; *pista* was the most diverse sampling point (2.2325), followed by *confluencia* (2.1921), *bosque* (2.1725), and *campus* (2.1173). In contrast, comparing fish diversity among

habitats of all sampling points revealed a discriminant pattern that placed Pools at *bosque* sampling point (P *bosque*) as the most diverse habitat (2.5), while Main Channel at *campus* sampling point (Ch *campus*) and Pools at *confluencia* sampling point (P *confluencia*) had the lowest diversity scores of 1.66 and 1.83, respectively (Fig. 4a). The similarity analysis with the Bray-Curtis index showed that the structure of the fish community responds more to the specific habitat occupation than a difference in relative abundance between the two caños (Fig. 4b). Thus, the discriminating variable that governs fish diversity in both aquatic ecosystems is habitat availability and diversity, which in turn depends on spatial heterogeneity; this ensures that species can make use of their preferred habitat in any stretch of the caños, highlighting their suitability as river corridors.

## DISCUSSION

### FOREST CORRIDORS

Approximately 70.3 % of the landscape of San José de Matadepantano farm is occupied by open plains that alternate poorly drained savannas with areas for crops and livestock pastures; 2.6 % is occupied by the buildings of the Utopía University campus, while the remaining 27.1 % corresponds to forest cover distributed between forest

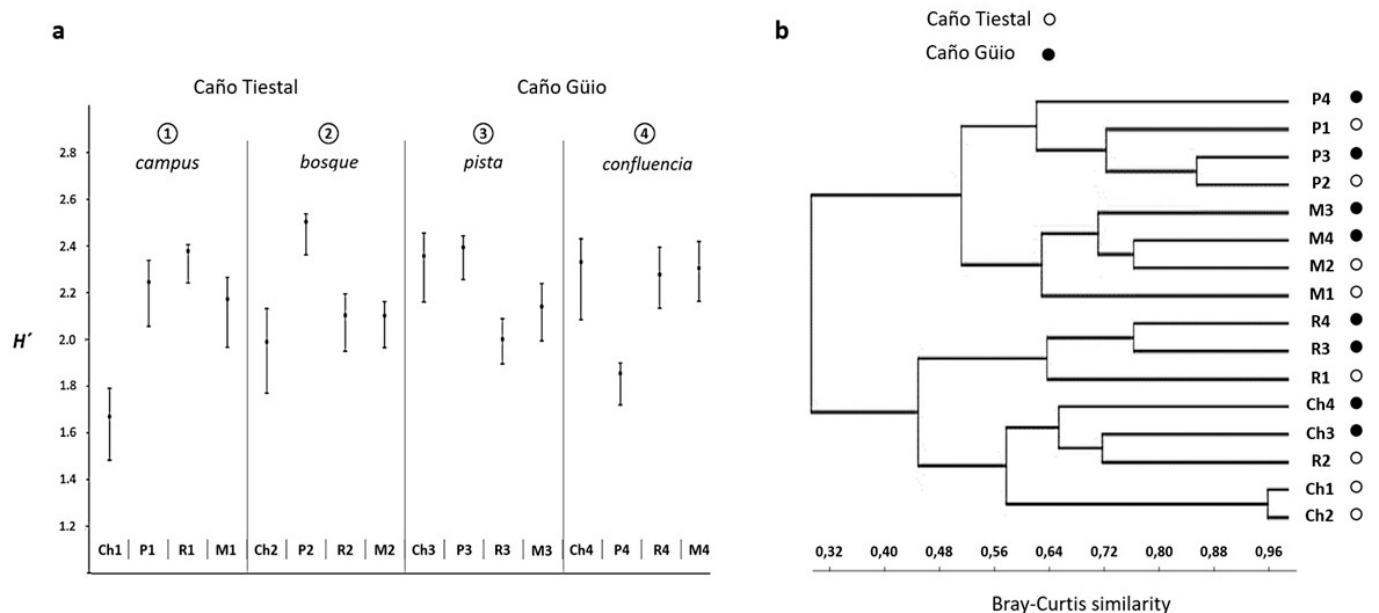
relict patches (8.5 %) and gallery forests (18.6 %). The only access to San José de Matadepantano consists of a road that connects the property to the city of Yopal and borders the perimeter of the farm on the north side; vehicular traffic on this road is very low, so there is no considerable anthropogenic disturbance that affects the internal ecosystems from the outside. However, the neighboring farms have extensive use for agriculture or cattle ranching, which conduced to considerable fragmentation of their forests, leaving the San José de Matadepantano farm as one of the few areas where the natural ecosystems are still highly conserved.

Considering the above, the two gallery forest corridors that cross the farm have become a bastion of biodiversity, not only as refuge habitats but also as transit routes for regional fauna. Thanks to the multi-annual analysis of LANDSAT images, it has been possible to verify that the forests surrounding caños Tiestal and Güio have total continuity within the Matadepantano farm, but when they leave it begin to present intermittent stretches devoid of forest in which they are exposed to the advance of grasslands until their banks. In the face of this fragmentation process, the impacts on the streams are not long in coming, since the transverse abiotic flows between the water and the deforested banks are magnified and out of control, while the longitudinal flow of fauna is slowed or interrupted, altering the ecosystem balance.

Within the farm, forest corridors have not lost their connectivity, but the opening of crossings for human or cattle ranch traffic represents a potential risk of widening the gaps in the future to the point of affecting their functionality if

measures are not taken to prevent it. The same happens with the amplitude reduction of the corridors, especially in the caño Tiestal forest where there are stretches whose width has been reduced to a critical minimum (Spackman and Hughes, 1995) and this may generate a “bottleneck” effect, which usually allows the passage of fauna at the individual level, but restricts it at the population level (Noss, 1993). If this were to happen, either by physical disappearance of habitat or by a reduction in its quality, the loss of functionality of forest corridors would lead to a reduction in the home range of generalist species, impede the dispersal of migrant species, and weaken the gene pool of arboreal species whose populations stayed confined to isolated forest patches (MacArthur and Wilson, 1967; Hanski and Gilpin, 1997; Burel and Baudry, 2002).

Despite the existence of gaps and the reduction of the forest width, the transit of terrestrial macrofauna along the gallery forests of the Tiestal and Güio streams is a good indicator that they still have functionality as ecological corridors. In several field visits it was possible to observe the passage of armadillos (*Priodontes maximus* Kerr, 1792), anteaters (osos hormigueros, *Myrmecophaga tridactyla* Linnaeus, 1758), cusumbos (*Nasua nasua* Linnaeus, 1766) and chigüiros (*Hydrochoerus hydrochaeris* Linnaeus, 1766), as well as populations of squirrel monkeys (monos ardilla, *Saimiri sciureus* Linnaeus, 1758), corn monkeys (*Sapajus apella* Linnaeus, 1758) and howler monkeys (monos aulladores, *Alouatta seniculus* Linnaeus, 1766) that move through the canopy. Specimens of herpetofauna were also sighted using the interface between the forest and the bodies of water; such is the case of species like lagarto lobo (*Tupinambis*



**Fig. 4.** a. Compartmented fish species diversity per caño, sampling point, and habitat. b. Grouping dendrogram shows that fish communities are packed per habitat, according to a patch dynamic model.



*teguixin* Linnaeus, 1758), babilla (*Caiman crocodrilus* Linnaeus, 1758), güio (*Eunectes murinus* Linnaeus, 1758) and morrocoy (*Geochelone carbonaria* Spix, 1824).

The fact that during the ten years of sampling, macrofauna have passed through the forest corridors of caños Tiestal and Güio demonstrates their structural and functional integrity, but this is not an unequivocal guarantee that they will not experience future fragmentation due to the expansion of anthropogenic activities. For this reason, to plan land uses near forests, it is necessary, first of all, to differentiate between fragmentation gaps and cutting gaps, since the former can generate clearings within the forest without necessarily generating a dysfunction of the biotic flow, while the latter cause loss of connectivity that interrupts the transit of fauna both between longitudinal sections of the same corridor and between the corridor and the forest relicts located outside it. Secondly, it is necessary to encourage native revegetation to widen the “bottlenecks” and convert the biological corridors into ecological connectors (Forman, 1995), since the wider the corridor, the greater the flow of populations, promoting gene flow, especially of those species that would not venture out into the open field due to the risk of predation.

## STREAM CORRIDORS

Caños Tiestal and Güio are highly heterogeneous lotic ecosystems because they have a discrete spatial arrangement, with a structure that resembles a mosaic of pieces with very changing characteristics in terms of physiography, width, type of flow, current velocity, or depth. So, their ecological ordering pattern does not correspond to those rivers that are governed by the continuum model (Vannote et al., 1980), but rather to those streams that function under the patch dynamics model (Pickett and White, 1985).

Although the spatial heterogeneity of both caños is evident, caño Güio showed values within the range of 2.11 to 2.13, while caño Tiestal experienced a decrease from 1.87 to 1.74 between 2010 and 2020 (Table 1b). In the path of caño Tiestal through *campus* sample point, spatial heterogeneity was the lowest of all those recorded in the study because anthropogenic activities are concentrated there due to the proximity of the university campus and, in addition, gallery forest has been cleared on the left bank to make way for crops, which increases soil erosion and the sedimentation that homogenizes the bed bottom (see photo 1 in Fig. 3). A very contrasting situation occurs at *bosque* station, located about 5 km downstream, where the physiographic and bathymetric conditions of the caño reflect the highest degree of heterogeneity because of its remoteness from anthropogenic influence and of being surrounded by the best-preserved stretch of gallery forest in the entire farm (see photo 2 in Fig. 3). As for caño Güio, at *pista* sample point aquatic body reaches its greatest heterogeneity, not only due to the physiographic and bathymetric contrasts that produce high variability in the underwater space, but also to the

shelter provided by the surrounding dense forests to protect the channel from lateral runoff that cause sedimentation (see photo 3 in Fig. 3). For most of its course, caño Güio retains these same characteristics of heterogeneity; however, at the *confluencia* sample point, where it receives the waters of the Mateguafa stream, sediments accumulate at the bottom, reducing the bathymetric contrasts and producing homogenization; In addition, the surrounding forest is composed exclusively of *Attalea butyracea* palm groves whose scattered and thinned woody elements do not provide an adequate filter to contain the edaphic runoff into the stream during downpours (see photo 4 in Fig. 3).

Regarding hydrological variations, the multiannual average flow varied according to dry and rainy periods from 0.45 to 0.57 m<sup>3</sup>/s in caño Tiestal and from 0.38 to 0.45 m<sup>3</sup>/s in caño Güio. During the rainy seasons, caños overflowed, but only in those stretches where the banks were sufficiently flat to allow water to enter the riparian forests. Some unusual flood events occurred in the rainy months of 2012 and 2017 when the water overtopped the slopes of the caños in several stretches and entered the open savannas; then, when the waters receded, the spatial distribution of some habitats had been reconfigured, especially those more unstable habitats (see Table 1a); For example, the macrophyte habitat (M) gave way in several places due to the drag of the alluvium, while at the same time logs and woody debris fell into the water, which shows that the hydrological effect of the floods acts as a disturbance on the arrangement of the microhabitats (Pickett and White, 1985). Despite the above, spatial heterogeneity and percentage distribution of habitats persisted in both caños during the decade of sampling.

The comparison of spatial heterogeneity along each caño reflects the supply of habitats since in rivers arranged in patches, greater variability in the physiographic and bathymetric sequences implies greater beta diversity, which, in turn, is directly proportional to the diversity of aquatic species, mainly at the level of the fish communities (Winemiller et al., 2010). During the sampling decade, beta diversity conditions reflected differences among the four sampling points expressed in the percentage distribution of the habitats Ch, P, R, and M. At campus sampling point, the predominant habitat was Ch with a percentage of 70 %, since the anthropogenic disturbances mentioned in previous paragraphs caused a disproportionate reduction of the P, R and M habitats (Fig. 3). As expected, at *bosque* and *pista* points, where caños and their surrounding forests are highly conserved, the percentage distribution of habitats were more evenly represented. It could be argued that the bathymetric surveys carried out on the *campus*, *bosque*, *pista*, and *confluencia* sampling stations are not sufficient to elaborate a profile of comparative heterogeneity and habitat availability, since these results could be enriched with a greater number of surveys; however, it should be clarified that in the field visits caños were traveled in their entirety and no change

in the structural pattern was observed that would suggest that their general conditions were not represented at the sampling points chosen in the study.

About fish communities, species richness and composition recorded in caños Tiestal and Güio were representative of the typical ichthyofauna of plain piedmont caños (Briceño et al., 1998; Briceño-Vanegas, 2015). Comparative analysis of diversity did not show substantial differences between caños but did reveal a discriminant pattern between habitats. *Campus* sampling point showed the lowest fish diversity throughout the study; this result was due to the restriction of the habitats P, R, and M, which led to the dominance of some characid species such as *Astyanax bimaculatus* Cuvier, 1819 or *Hemibrycon jabonero* Schultz, 1944, which are very abundant in Ch habitat. Another environment that showed low fish diversity was P habitat at *confluencia* sampling point, where there was a disproportionate increase in the abundance of *Toracocharax stellatus* Kner, 1858 concerning the rest of the species; its unusual dominance may be due to the fact that macrophyte formations were found at the edge of the pools, mainly arracachales (*Montrichardia arborescens*) where swarms of insects that fall into the water proliferate and constitute almost 100 % of their diet (Netto-Ferreira et al. 2007).

Habitat use is a variable determined by spatial heterogeneity as there are species that are closely linked to a particular habitat; Such as the case of loricariid species such as *Hypostomus plecostomus*, *Cochliodon plecostomoides* or *Chaetostoma brevis* that frequent the bottom of the main channel, cichlids such as *Aequidens metae* that prefer macrophyte habitat to feed and reproduce safe from predation, or most effective predators such as *Hoplias malabaricus*, *Charax gibbosus* or *Acestrorhynchus falcatus* that prefer the pools to stalk their prey. Undoubtedly, there are also many generalist species with the use of underwater space, either due to their size or their omnivorous character; however, the grouping analysis presented in Figure 4b showed that in caños Tiestal and Güio, the spatial distribution of the species obeys more to their specific affinity for some type of habitat than to the influence of other environmental factors. Based on this result, it is possible to argue that the fish communities are assembled in both caños in a deterministic manner thanks to the spatial and temporal stability of their habitats; precisely for this reason, it is necessary to prevent anthropic impacts, since a river arranged in patches is much more vulnerable to stochastic events than one arranged in the continuum (Briceño et al., 1998).

Neither of the two caños did the fish community composition show a longitudinal substitution gradient as usually occurs in rivers that follow a continuum pattern; on the opposite, species maintained a certain habitat specificity even in parts of the channel far apart. Patch dynamics demonstrates the affinity of the species for types of resources but does not imply that they are confined to

a particular stretch of the channel (López-Delgado et al. 2020). No dams or fragmentations were found that would interrupt biotic flow, in which case caños would not behave according to the patch dynamics model but according to a serial discontinuity model (Ward and Stanford, 1983). Beta diversity expressed by spatial heterogeneity and biotic flow evident in both caños confirms its functionality like high biodiversity ecological corridors.

## CONCLUSIONS

With its 811 ha, San José de Matadepantano farm is home to a mosaic of ecosystems dominated by poorly drained savannas, swamps, and forests, interconnected through forest and river corridors that, at the time of this study, have not suffered considerable deterioration nor by anthropogenic activities neither by the land uses regime. Field observations made during the last decade and multi-annual satellite analyses have corroborated that there have been no significant changes in terms of loss of natural cover areas within the farm landscape.

Gallery forests are the main ecological corridors that serve as a bridge for the settlement and transit of terrestrial macrofauna within the farm. Despite their length, width, and continuity have remained almost unchanged in the last decade, some critical points have been detected where connectivity is potentially at risk of being lost in the future. The most critical is located in the area adjacent to the Utopía University campus, where part of the forest on one of the banks of caño Tiestal has been replaced by extensions of crops; other points at risk are the cutting gaps that are distributed along the two forest corridors and that so far have not expanded to the point of affecting their connectivity; however, the excessive narrowing of the forests at some points may produce a bottleneck effect that could end up affecting the flow of fauna.

Caños Tiestal and Güio, as the main lotic systems on the farm, are the fluvial corridors through which the aquatic fauna moves; both present a patch arrangement pattern, high spatial heterogeneity, wide availability of aquatic habitats and a high fish diversity. However, both caños present stretches where the values of these variables have been ostensibly reduced: in caño Tiestal, the stretch near the university campus was identified as the point with the least heterogeneity and therefore with a significant reduction in fish diversity; in caño Güio, the point where a similar phenomenon occurs is the portion of its final route in the farm due to the low diversity of the riparian forest that has been reduced to vestiges of *Attalea butyracea* palm groves due to anthropic interventions in the past.

Thanks to the movement of terrestrial and arboreal macrofauna through the forests, as well as the presence of a high richness of fish species in the underwater environments, it can be concluded that, under current conditions, both forest and river corridors present favorable conditions in

terms of their ecological functionality within the farm; however, it is recommended that the administration of the property takes preventive and conservation measures in the critical points detected in this work. At the scientific level, another publication is being prepared with the results of the detailed characterization of the fish communities, which due to its length could not be included in this article. In addition, a systematic sampling of the fauna in the forests, a complete characterization of the aquatic fauna groups represented in the macroinvertebrates, and a second monitoring of the evolution of the ecological corridors of the farm in the next decade is proposed.

## AUTHOR'S PARTICIPATION

Both authors of this paper were responsible for the research design, literature review, fieldwork, analysis of primary information, and preparation of the scientific article.

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## CONFLICT OF INTEREST

The authors declare that this work is original, unpublished, and does not represent any conflict of interest with other authors or third parties.

## REFERENCES

Briceño-Vanegas, G. (2014). Caracterización ecológica general de unidades de paisaje de la finca San José de Matadepantano (Yopal, Casanare). *Épsilon*, (22), 189-206.

Briceño-Vanegas, G. A. (2015). Evolución de la integridad estructural de ecosistemas lóticos del piedemonte llanero frente a la intervención antrópica. *Acta. biol. Colomb*, 20(2):133-144. <http://dx.doi.org/10.15446/abc.v20n2.42307>

Briceño, G., Galvis, G. y Guillot, G. (1998). Dinámica ecológica de las comunidades ícticas de tres sistemas lóticos del piedemonte llanero. *Diógenes*, 5(1):17-41.

Burel F. y Baudry J. (2002). *Ecología del Paisaje: conceptos, métodos y aplicaciones*. Ediciones Mundiprensa.

Eigenmann, C. H. (1911). *The freshwater fishes of British Guyana*. Linnaeus press.

Eigenmann, C. H. (1922). *The fishes of western South America*. Linnaeus press.

Forman, R. T. T. (1995). *Land Mosaics. The ecology of landscapes and regions*. Cambridge University Press. <https://doi.org/10.1017/9781107050327>

Gentry, A. H. (1988). Changes in Plant Community Diversity and Floristic Composition on Environmental and Geographical Gradients. *Ann. Missouri Bot. Gard* 75:1-52. <https://doi.org/10.2307/2399464>

Gery, J. (1964). *Characoids of the world*. Neptuno, N. J: TFH Public. 672 p.

Hanski, L. and Gilpin, M. E. (1997). *Metapopulation biology, ecology, genetic and evolution*. Academic Press.

Lisenby, P. E., Slaterry, M. C. and Wasklewicz, T. A. (2014). Morphological organization of a steep, tropical headwater stream: The aspect of channel bifurcation. *Geomorphology*, 214, 245-260. <https://doi.org/10.1016/j.geomorph.2014.02.009>

López-Delgado, E. O., Winemiller, K. O. and Villa-Navarro, F. A. (2020). Local environmental factors influence beta-diversity patterns of tropical fish assemblages more than spatial factors. *Ecology*, 101(2). <https://doi.org/10.1002/ecy.2940>

Lowe-McConnell, R. H. (1987). *Ecological studies in tropical fish communities*. Cambridge University press. <https://doi.org/10.1017/CBO9780511721892>

MacArthur, R. H. and Wilson, E. O. (1967). *The theory of Island Biogeography*. Princeton University Press.

McGarigal, K., Cushman, S. and Regan, C. (2005). *Quantifying terrestrial habitat loss and fragmentation: a protocol*.

Noss, R. (1993). "Wildlife corridors" in: Smith, D. S. and Hellmund, P. C. (eds) (1993). *Ecology of Greenways: Design and Function of Linear Conservation Areas*. University of Minnesota Press.

Netto-Ferreira, A. L., Albrecht, M. P., Nessimian, J. L., and Caramaschi, É. P. (2007). Feeding habits of *Thoracocharax stellatus* (Characiformes: Gasteropelecidae) in the upper rio Tocantins, Brazil. *Neotrop Ichthyol*, 5(1), 69-74. <https://doi.org/10.1590/S1679-62252007000100009>

Pickett, S. T. A. and White, G. S. (1985). *The ecology of natural disturbance and patch dynamic*. Academic Press.

Sarmiento, G. (1996). "Ecología de pastizales y sabanas en América Latina", en: Sarmiento G. y Cabido M. (eds). *Biodiversidad y Funcionamiento de Pastizales y Sabanas en América Latina*. CYTED-CIELAT.

Schultz, L. P. (1944). "The catfishes of Venezuela with descriptions of thirty-eight new-forms". *Proceedings of the United States National Museum*. 94(3172), 173-338, <https://doi.org/10.5479/si.00963801.94-3172.173>

Spackman, S. C., and Hughes, J. W. (1995). Assessment of minimum stream corridor width for biological conservation: species richness and distribution along mid-order streams in Vermont, USA. *Biol conserv*. 71(3), 325-332. [https://doi.org/10.1016/0006-3207\(94\)00055-U](https://doi.org/10.1016/0006-3207(94)00055-U)

- 
- Sterba, G. (1959). *Freshwater fishes of the world*. Prensa Vikinga.
- Vannote, R. L., Minshall, G.W., Cummins, K.W., Sedell, J. R. and Cushing, C. E. (1980). The River Continuum Concept. *Fish Aquat Sci*, 37(1):130–137. <https://doi.org/10.1139/f80-017>
- Winemiller, K. O., Flecker, A. S., and Hoeinghaus, D. J. (2010). Patch dynamics and environmental heterogeneity in lotic ecosystems. *Journal of the North American Benthological Society*, 29(1), 84-99. <https://doi.org/10.1899/08-048.1>
- Ward, J. V. and Stanford, J. A. (1983). “The serial discontinuity concept of lotic ecosystems”. In: Fontaine; S. M., and Bartell (eds). *Dynamics of Lotic Ecosystems*. (pp. 29-42) Ann Arbor Science.