

Delimitation of the round river with ecosystemic criteria of the Mijitayo river, Pasto municipality-Nariño

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Abstract: This study was conducted along the Mijitayo River, located in the Municipality of Pasto, southwestern Colombia. The research aimed to implement an ecosystem protection-based methodology to determine the width of the riparian buffer zone and identify the most suitable native species for ecological restoration, with the classification of life zones in the study area as the core analytical component. Relevant phytosociological characteristics were assessed, including vegetation height, coverage, density, and relative frequency. These indicators were used to calculate the Importance Value Index (IVI)—a key metric. Combined with drainage density and watershed catchment area data, this index supported the ecosystem-based delimitation of the riparian buffer zone.

Four life zones were identified within the study area: Lower Montane Dry Forest (bs-MB), Montane Humid Forest (bh-M), Very Humid Montane Forest (bmh-M), and Sub-Andean Páramo. The corresponding recommended riparian buffer widths for these zones were 15 m, 25 m, 29 m, and 23 m respectively. Lastly, priority native species were selected for targeted restoration:

Lower Montane Dry Forest: *Verbesina arbórea*, followed by *Fuchsia dependens* and *Bocconia frutescens*

Montane Humid Forest: *Tibouchina mollis* and *Verbesina arbórea*

Very Humid Montane Forest: *Baccharis latifolia*, followed by *Maytenus prunifolia* and *Cavendishia bracteata*

Sub-Andean Páramo: *Phyllanthus salviifolius*, followed by *Munnozia* sp.

Key words: water round; basin; importance value index

1 Introduction

A watershed is considered a geographical area where a system of surface and underground water currents flows and converge at a single point. In this area, the interaction of natural processes and human activities is fostered. (Formica, et al., 2015).

Riparian zones are an integral part of water bodies, and their vegetation is characterized by its location in transitional areas between terrestrial and aquatic habitats at different strata (Romero, et al., 2014). Key functions of riparian areas include flood mitigation and the transport of nutrients and/or pollutants, as well as the protection of aquatic and riparian ecosystems.

Biotic and abiotic characteristics are affected in these areas, primarily by human intervention, generating a strong impact on water quality and causing serious reductions in biodiversity (Galeano et al., 2017). Considering the problems outlined, this article presents the application of a methodology based on the preservation of riparian ecosystems, under the

premise that these areas serve as corridors for the establishment and transit of numerous migratory or transient species, where their habitat requirements are maintained (García, 2007). Additionally, they serve as flow regulators and help maintain local microclimatic conditions (Magdaleno, 2013a).

The methodology of this study was carried out taking as a reference the regulations that propose the maintenance of rivers and the ecosystems surrounding them; Decree 2245 of 2017 incorporates the *Technical Guide for the Delineation of Hydrological Buffer Zones* in Colombia, adopted by resolution of the Ministry of Environment and Sustainable Development. This document establishes the methodology for defining preservation and restoration areas known as riparian buffer zones, and stipulates that the minimum protection width shall not be less than 30 meters on each side of the river channel (Minambiente, 2018).

The study consisted of determining the width of the Mijitayo River riparian zone by averaging the height of the dominant trees (H). This was done based on information obtained from sampling and calculations of the micro-watershed's drainage area and density. Finally, suitable native species for this riparian zone were proposed based on phytosociological characteristics such as cover, density, and relative frequency. These characteristics were used to determine the Importance Value Index (IVI) for each species identified in each life zone.

2 Materials and methods

Study area. This research was conducted on the Mijitayo River, west of the city of Pasto, Nariño Department, Colombia, on the foothills of the Galeras volcano at 1° 13' North Latitude and 77° 17' West Longitude of the Greenwich Meridian (Jiménez et al., 1989 cited by Madroño, 2006). The upper basin is covered by forests, as well as herbaceous and shrubby vegetation. The predominant ecosystems in this sector are páramo and subpáramo (CORPONARIÑO, 2009). The middle stretch features dense and fragmented forests, with a canyon landscape whose slopes are covered by eucalyptus and secondary vegetation. The lower section of the river constitutes a transition zone between rural and urban land uses (Jiménez, 1989; Madroño, 2006).

For the delimitation of the study area, maps of the Pasto River Sub-basin obtained from the Pasto Territorial Planning Plan, 2009, were used; where the hydrological sectorization of the Mijitayo River was observed, with a total of 11.67 Km². Likewise, it presents four life zones that correspond to Lower montane dry forest (bs-MB), Montane humid forest (Bh-M), Montane very humid forest (bmh-M) and Sub-Andean Páramo (p-SA) (CORPONARIÑO; 2009).

Floristic inventory. Sampling was carried out in a total area of 0.1 ha to ensure representativeness. Nine 2x50 m transects were established (Mostacedo and Fredericksen, 2000), distributed across the four life zones. Each transect point was georeferenced, and native tree species (Minambiente, 2018) taller than 3 m and with a diameter at breast height (DBH) greater than 2.5 cm (Mateucci and Colma, 1982) were considered in each transect. Based on this, an average height was calculated for all inventoried individuals to determine the height of the dominant trees (H) in each life zone.

Once tree height (H) and the width of the ecosystem component were calculated, the relationship between drainage density and catchment area was determined. From this relationship, the N value was obtained (Table 1), which was used to define the land strip corresponding to the ecosystem component, namely the width of the riparian zone (Minambiente, 2018).

To determine the drainage density (Dd) of the Mijitayo micro-basin (Equation 1), the *Technical Guide of Criteria for the Demarcation of Watercourse Zones* in Colombia (2018) was taken into account. The AutoCAD 2015 and Excel 2013 programs were used, where the data obtained in the field were entered, relating to the length of all watercourses in kilometers (km) located within the Mijitayo micro-basin and the area of the basin in square kilometers (km²).

To accomplish the above, the following equation was applied:

$$D_d = \frac{L}{A} \text{ [Equation 1]}$$

Where:

D_d = Drainage density (km/km²)

L = Total length of watercourses (km)

A = Total basin area (km²)

Table 1. N value according to basin area and drainage density

Contributing Catchment Area (km ²)	Value of N		
	Drainage Density		
	Low	Medium	High
	< 0.5 km/km ²	0.5–1.0 km/km ²	> 1.0 km/km ²
0 < A ≤ 1	2.0	1.5	1.0
1 < A ≤ 10	2.5	2.0	1.5
10 < A ≤ 100	3.0	2.5	2.0
100 < A ≤ 1000	3.5	3.0	2.5
1,000 < A ≤ 10,000	4.0	3.5	3.0
10,000 < A ≤ 100,000	—	4.0	—

MADS y UNAL; 2012

Selection of native tree species for the riparian zone. Initially, the phytosociological characteristics of the individuals found after sampling in the study area were determined (Mateucci and Colma; 1982). (Equations 2, 3, 4, 5).

$$CR = \left(\frac{I_t}{I_e} \right) \times 100 \text{ [Equation 2]}$$

Where:

CR = Relative coverage

I_e = Sum of interception of each species

I_t = Total interception of all species

Relative density

$$DR = \left(\frac{N}{A} \right) \times 100 \text{ [Equation 3]}$$

Where:

DR = Relative density

N = Number of individuals

A = Area in which individuals were found

Absolute frequency

$$FA = \left(\frac{a_i}{UM} \right) \text{ [Equation 4]}$$

Where:

FA = Absolute frequency

a_i = Number of occurrences of a given species

UM = Sampling units established per life zone

Relative frequency

$$FR = \left(\frac{FA}{A} \right) \times 100 \text{ [Equation 5]}$$

Where:

FR = Relative frequency

FA = Absolute frequency

A = Total number of occurrences of all species

The Importance Value Index (Equation 6) was calculated based on the sum of the phytosociological variables from Equations 3, 4 and 5, including relative coverage, relative density and relative frequency (Mostacedo & Fredericksen, 2000).

Importance value index

$$IVI = CR + DR + FR \text{ [Equation 6]}$$

Where:

CR = Relative coverage

DR = Relative density

FR = Relative frequency

3 Results and discussion

Floristic inventory. From the sampling carried out in the life zones, 1,018 individuals were identified (See ANNEX 1), distributed in 20 families, among the most abundant being Asteraceae and Melastomataceae, among the most representative species 26 species, among which are *Baccharis Latifolia* (Chilca), *Verbesina arborea* (Velo), *Tibouchinamollis* (Flor de Mayo), *Otholobium mexicanum* (Tarta), *Cavendishia bracteata*, *Fuchsia dependens* (Zarcillejo), etc (Table 2).

Table 2. Individuals recorded for each life zone

Life zone	No. of native individuals	No. of transects
Lower montane dry forest (bs-MB). 2,750–2,927 m a.s.l.	122 (6 species and 5 families)	2
Montane humid forest (Bh-M) 2,961–3,099 m a.s.l.	362 (17 species and 14 families)	2
Montane very humid forest (bmh-M) 3,450–3,575 m a.s.l.	388 (24 species and 18 families)	4
Sub-Andean páramo (p-SA) 3725 m a.s.l.	146 (2 species and 10 families)	1

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In the lower montane dry forest, it was evident that the diversity of native tree vegetation is lower compared to the other study areas, a finding corroborated by observations made after floristic inventories were conducted in the area (Jiménez and Andrade, 2015). Furthermore, in addition to other factors such as floodplains along the watercourse, the situation described may primarily be attributed to anthropogenic intervention processes, mainly agricultural and livestock activities, that have taken place in these ecosystems (Solarte et al., 2007).

The most abundant family was Asteraceae, with two species: *Verbesina arborea* (Velo) and *Baccharis latifolia* (chilca). Using the floristic inventory of the Buga Alto sector of the Paquiestancia forest, Cayambe, Ecuador, as a reference, the presence of *Baccharis latifolia* was found in the same life zone. The area where this inventory was conducted is located at an altitude of 2,830 meters above sea level (Gutiérrez, 2010). This case is similar to the present study, so it can be stated that the aforementioned environmental conditions favor the development of this species.

Regarding the montane rainforest, unlike the first life zone, a greater diversity of native tree species was found because, due to its considerable altitude, access is more limited and therefore human activity tends to decrease. The most abundant family was Melastomataceae, with the species *Tibouchina mollis* (May Flower) having a significant number of

individuals compared to the other species found.

The above is verified with the results of the floristic inventory carried out by the University of Nariño, whose objective was to determine the adaptation and growth capacity of different types of native species in the Botana farm located 7 km from the city of Pasto at an altitude of 2,970 m.a.s.l., yielding as a final result *Tibouchina mollis* as the most suitable individual to be implemented in a reforestation, thanks to its rapid growth (Luteyn; 2007).

Subsequently, in the very humid montane forest, the diversity of native tree species was greater. It was found that as altitude increased, tree height decreased compared to the two preceding life zones. This may be due to climatic conditions such as the low temperature in this area.

It was also identified that the most abundant family was Asteraceae, with species such as *Baccharis latifolia* (Chilca) and *Verbesina arborea* (Velo). This information was corroborated by a biodiversity study of tree species in the (bmh-M) carried out in the upper basins of the Pasto and Guamués rivers within the municipality of Pasto, in which *Baccharis latifolia* was one of the most abundant species (Ordoñez et al. 2004).

Finally, in the sub-Andean Páramo, climatic elements such as humidity changed compared to the previous zones. This is due to an inversely proportional relationship: at higher altitudes, pressure decreases, directly influencing humidity. Conversely, in areas with low pressure, humidity increases (Faasafety, 2008). This explains the change in general characteristics in the last life zone, as adaptations were observed in the ecosystem, such as hairs on the leaves and stems of plants. The soil was more humid, with mosses, ferns, and abundant leaf litter. Epiphytic plants were also found growing on the trees. Regarding height, the native tree species were shorter than those found in the first sampled areas; however, the height of the sampled individuals ranged from 9 to 22 meters.

The most abundant family was the Asteraceae, with three species: *Munnozia* sp., *Verbesina arborea*, and *Baccharis odorata*. In relation to this finding, a floristic inventory was conducted for the Galeras Flora and Fauna Sanctuary Management Plan. This inventory enabled the characterization of various native tree species, among which *Munnozia* sp.—a component of the páramo ecosystem—was predominant (López et al., 2005).

Establishment of Riparian Zone Width. Regarding riparian zone width values, the lower montane dry forest (bs-MB) was set at 15 m, the montane humid forest (bh-M) at 25 m, the very humid montane forest (bmh-M) at 29 m, and the sub-Andean páramo (p-SA) at 23 m. These widths were calculated based on the average height of the dominant tree species surveyed, recorded as 10 m, 17 m, 20 m and 15 m respectively for the aforementioned life zones (Figure 1). Among the geomorphological parameters calculated for the Mijitayo micro-basin, the basin area measures 9.87 km², and the drainage density (Dd) is 2.7 km/km². This value falls within the standard reference range, which spans from 0.5 km/km² for poorly drained basins to 3.5 km/km² for exceptionally well-drained basins (Monsalve, 1999).

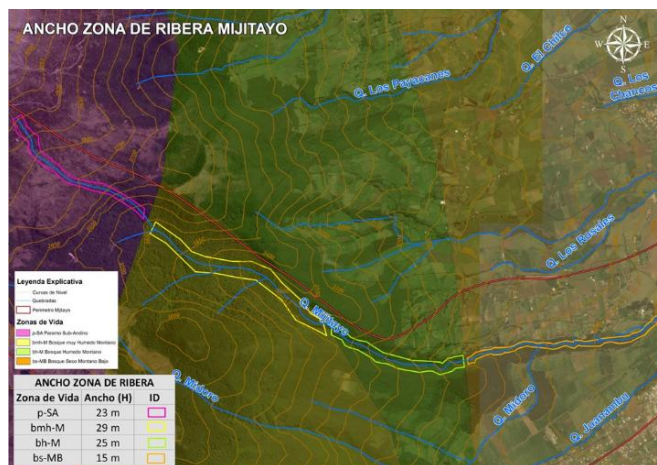


Figure 1. Riparian zone width for each life zone. (Authors)

From the above analysis, the value of N was determined to be 1.5, a dimensionless coefficient (Table 1). This value was applied together with the average tree height H for each life zone, yielding the riparian zone widths mentioned at the beginning of this section.

As observed, the values were influenced by human intervention processes, such as deforestation and the expansion of agricultural and livestock frontiers, which have contributed to a reduction in vegetation cover in the riparian zone and, consequently, lower average heights. It is important to note that the methodology states that the higher the average height (H), the greater the width of the riparian zone for each life zone (Minambiente; 2018).

After data collection and the calculation of riparian zone width for each sampled life zone, it was found that none of the width values reached 30 meters measured from the average maximum water level, as required by Colombian regulations. This raises a discussion over whether such dimensions are sufficient to guarantee the conservation of water resources. The Ministry of Environment of Colombia (Minambiente, 2018) stresses that, in addition to ecological factors, hydrological and geomorphological factors must also be taken into account, since these factors remain relatively stable over short time periods. Studies carried out by Fundaguiza (2013) along sections of the Pasto and Miraflores Rivers show that riparian zone boundaries are defined as wider when geomorphological and hydrological analyses are applied.

However, depending on the objective set, the width of the riverbank zone will be completely different, since it depends on the composition and density of the vegetation present, the length and type of the watercourse, as well as the slope of the land (Fischer and Fischenich; 2000).

Likewise, the appropriate determination of the widths of channel protection strips must respond to the function that is expected to be satisfied, the focus of this research being the protection from a perspective of conservation of riparian vegetation, without ignoring that it is also necessary to provide the rivers with the space to develop other processes, such as: the preservation of aquatic ecosystems, the development of erosion processes, among others (Gayoso and Gayoso; 2003).

The management of the riparian zone will vary from very narrow to wide depending on the fluvial geomorphology in the area, such as floodplains, valleys, among others, and also on the type of adjacent land use, for example, a national park, agriculture, forestry, urban housing, among others (Price and Lovett; 2002).

Proposal of native species for ecological restoration. Finally, based on the results obtained from the phytosociological study, the species with the highest Importance Value Index (IVI) were selected and proposed. These species are considered the most suitable for implementation across the four identified life zones. For the lower montane dry forest, the proposed species are *Verbesina arborea* and *Fuchsia dependens*. For the montane humid forest, the selected species are *Tibouchina mollis* and *Verbesina arborea*. In the case of the montane very humid forest, *Baccharis latifolia* and *Maytenus prunifolia* were chosen. Lastly, for the sub-Andean páramo (p-SA), the selected species are *Phyllanthus salviifolius*, followed by *Munnozia* sp (Table 3).

Table 3. Species potentially suitable for ecological restoration in the riparian zone.

Life Zone	Species	Highest Importance Value Index (IVI)
Lower montane dry forest (bs-MB), 2,750–2,927 m a.s.l.	<i>Verbesina arborea</i>	78.4
	<i>Fuchsia dependens</i>	55.7
Montane humid forest (Bh-M), 2,961–3,099 m a.s.l.	<i>Tibouchina mollis</i>	76.4
	<i>Verbesina arborea</i>	66.5
Montane very humid forest (bmh-M), 3,450–3,575 m a.s.l.	<i>Baccharis latifolia</i>	43
	<i>Maytenus prunifolia</i>	40.2

Life Zone	Species	Highest Importance Value Index (IVI)
Sub-Andean páramo (p-SA), 3725 m a.s.l.	<i>Phyllanthus salviifolius</i>	45
	<i>Munnozia</i> sp.	40.3

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This proposal aims to achieve, in the future, the implementation of a useful tool for carrying out ecological restoration processes in the riverbank area of the Mijitayo River; because after the execution of the study it was determined that in none of the sections is the required width of the water zone respected, which is fundamental for the conservation of the characteristics and the optimal state of the water sources.

According to Table 3, the use of *Verbesina arborea* is recommended; studies affirm the importance of implementing this species in living fences, with the aim of providing habitats and resources that increase landscape connectivity, which is closely related to the preservation of ecosystems adjacent to water resources (Navia et al. 2017).

During the surveys conducted for this study, the degradation and deterioration of the ecosystems present in the Lower Montane Dry Forest (bs-MB) was identified; mainly due to the greater anthropogenic intervention in these areas; therefore, it is appropriate to propose restoration with species that guarantee and improve the conditions of the ecosystems surrounding the Mijitayo River; thus maintaining and improving its quality.

Another recommended species is *Fuchsia dependens* (Zarcillejo), thanks to its ability to regulate runoff, control erosion, and protect watersheds (Castro and Martínez, 2008). Additionally, this species adapts easily to humid sites and can generally be planted near streams or other bodies of water. It is a native plant that readily adapts to the environment and is characterized by its rapid growth (Caranqui, 2011). These characteristics make this species suitable for the restoration of the Mijitayo River's riparian zone; since, in addition to its rapid growth, it would help prevent the runoff of agrochemicals and other pollutants that negatively impact the river's water quality.

For its part, one of the recommended species for the montane rainforest is *Tibouchina mollis* (seven-bark tree), which influences revegetation processes and comprehensive ecological restoration. It is used as a tool to replace the environmental values, goods, and services that local communities have lost (Cabrera et al. 2014). This is the case in the life zone designated for this study, since fragmentation of the native forest was evident during fieldwork due to the planting of timber species such as pines and eucalyptus. Therefore, implementing this species would not only achieve ecosystem recovery but also the maintenance and regeneration of the surrounding natural systems.

Finally, *Munnozia* sp. was selected for the study due to its watershed protection function, which ensures the restoration of ecosystem functionality (Mora, 2012). As one of the recommended species for implementation in the Sub-Andean Páramo, the described functions are of utmost importance. This ecosystem is currently a strategic priority for protection and conservation, as it supports abundant vegetation and constitutes one of the main birthplaces of water sources.

4 Conclusions

The values obtained for the riparian buffer zone of the Mijitayo River, based on the ecosystem component, are as follows: 15 m for the lower montane dry forest (bs-MB), 25 m for the montane humid forest (bh-M), 29 m for the montane very humid forest (bm-M), and 23 m for the sub-Andean páramo (p-SA). However, Decree 2245 of 2017 stipulates that the strip parallel to the high-water line or the permanent channel line of rivers and lakes must have a minimum width of 30 m. Therefore, the value established by this regulation must be adopted. In addition, the corresponding protection and conservation area associated with the geomorphological and ecosystem components must also be included.

According to the analysis of the highest Importance Value Index (IVI) values, as well as the morphological and functional characteristics of the sampled individuals, the native species suitable for the ecological restoration of the riparian zone of the Mijitayo River are: *Verbesina arborea*, *Fuchsia dependens*, *Bocconia frutescens*, *Tibouchina mollis*, *Baccharis latifolia*, *Cavendishia bracteata*, *Phyllanthus salviifolius*, and *Munnozia* sp.

Native tree cover within the life zones located at an altitude of 3,450 to 3,755 m.a.s.l. is in the best conservation status. This is because the topographic conditions make the area difficult to access, greatly reducing the degree of anthropogenic intervention.

To date, there is no sufficiently robust legal framework to limit human intervention in riparian areas. Coupled with the difficulty of restoring the riparian buffer in already intervened zones, this creates the need to develop mechanisms that not only define the width of the riparian strip but also enable its effective implementation.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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Additional information

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