https://doi.org/10.1590/1678-4499.20220098

SOIL AND PLANT NUTRITION
Article

Morphometric indices in the Curuá-Una River sub-basin as potential indicators for forest restoration in hydrographic mesoregions in the Central Amazon

Denison Lima Correa[1], Lucieta Guerreiro Martorano[2,*], José Reinaldo da Silva Cabral de Moraes[3], Leila Sheila Silva Lisboa[4]

1. Universidade Estadual do Pará – Departamento de Tecnologia de Madeira – Castanhal (PA), Brazil.
2. Embrapa Amazônia Oriental – Núcleos de Apoio à Transferência de Tecnologia Médio Amazonas – Santarém (PA), Brazil.
3. Universidade Estadual Paulista "Júlio de Mesquita Filho" – Faculdade de Ciências Agrárias e Veterinárias – Jaboticabal (SP), Brazil.
4. Secretaria Municipal de Belém – Departamento de Matemática – Belém (PA), Brazil.

Received: May 15, 2022 | **Accepted:** Oct. 6, 2022

Section Editor: Gabriel Constantino Blain

***Corresponding author:** lucieta.martorano@embrapa.br

How to cite: Correa, D. L., Martorano, L. G., Moraes, J. R. S. C. and Lisboa, L. S. S. (2022). Morphometric indices in the Curuá-Una River sub-basin as potential indicators for forest restoration in hydrographic mesoregions in the Central Amazon. Bragantia, 81, e4422. https://doi.org/10.1590/1678-4499.20220098

ABSTRACT: Watersheds are planning units because they are delimited by topographic divisions formed by a main river and its tributaries, in which water drainage is channeled into a course of greater water volume, such as the Amazon basin, which flows into the Atlantic Ocean. The objective of this work was to analyze the morphometry of the hydrographic sub-basin of the Curuá-Una River (SBHRM), that integrates the Curuá-Una hydrographic micro-region in western Pará, Brazil, and its surroundings. Data from abiotic variables integrated in a geographic information system were used to identify the areas that most need restauration using production systems such as agroforestry as part of a forest restoration process, necessary to land degradation in the sub-basin and its surroundings. It was found that the sub-basin of the Curuá-Una River has a more elongated shape, confirmed by the circularity index, compactness coefficient, and shape factor. It is a fifth order sub-basin with a densely branched drainage network with a low probability of flooding due to the predominance of undulating relief. The morphometric characteristics present conditions that can be used in anthropic areas integrated into production systems such as agroforestry. The existence of tree species such as *andiroba*, *copaíba*, and the Brazil nut tree in the Tapajós basin, as inventoried by the Project RADAMBRAZIL, must be included in agroforestry arrangements in the recovery of degraded areas in western Pará.

Key words: fragility, erosion, forest restoration.

INTRODUCTION

Water has multiple uses, such as for human consumption, irrigation of crops and gardens, livestock raising, industrial production, and energy generation, besides ecosystem maintenance functions. The projected increase in the worldwide population will put greater pressure on the need for potable water and will decrease the stability of water availability to the global population (UCN and WRI 2014). Water is an essential element for the life on planet Earth. For humans, water resources have social, economic, and environmental relevance, being a raw and fundamental material for industrial processes, energy generation, as well as regulating the plant production cycle (Carvalho et al. 2012). In Amazon, water represents an important transport route, mainly for riverside communities.

Certain abiotic factors modulate geomorphological patterns on the earth's surface (Keith et al., 2022). The dynamic processes associated with the type of parent rock, intensity of weathering factors because of physical resistance to endogenous (tectonic) and exogenous (erosion) mechanical and chemical forces that express morphogenesis and their effects as a result

of human actions in watersheds (Almajmaie et al. 2017, Fu et al. 2017). Morphometric analyses of watersheds allow for estimations of the relationships between basin physiography and the dynamics of its hydrology (Singh et al. 2019).

Considering that a watershed is the ideal spatial unit for the planning and integrated management of natural resources (Bertoni and Lombardi Neto 2008), the National Water Resources Policy, established by Law No. 9,433 (Brasil 1997), set up principles and norms capable of guaranteeing the management of a natural rainwater catchment area, where the flows converge to a single exit point, called the outflow point, the lowest part of the main water course (Carvalho 2014). Evaluating the biophysical variables in hydrographic basins, with the use of geographic information system tools, can aid management and granting of priority water use rights, irrigation, hydroelectric potential analysis, as well as flood control and quality water supply in production centers such as the western region of the state of Pará, Brazil.

Satellite data make it possible to carry out analyses such as identifying areas that present vulnerabilities in hydrographic basins, especially regarding the erosive process of rainfall. Analyses of the dynamics of sediment transport, as well as information on the main routes of water contamination and potential recreational use of water, are important applications that can be used (Santos et al. 2016). The management of microbasins consists of elaborating and applying physical-conservationist, socioeconomic, environmental, water, edaphic, botanical, and fauna diagnoses to point out problems and propose solutions, according to the specificities of the watershed.

According to Valente and Gomes (2005), a hydrographic basin is delimited by a geographic space that is defined as a watershed, represented by the line that joins points of higher elevations, causing the rainwater, when it reaches the soil surface, to have the flow directed towards another stream or river.

Vegetation plays an important role in controlling soil erosion (Michaelides et al. 2009), favoring hydraulic roughness, since the presence of vegetation represents almost 80% of total resistance and it is the dominant roughness element on slopes (Zhao et al. 2016). The objective of this work was to analyze the morphometry of the hydrographic sub-basin of the Curuá-Una River (SBHRM) that integrates the Curuá-Una hydrographic micro-region in western Pará and its surroundings.

METHODS

This study used the Multi-scale Ottocoded Hydrographic Base (ANA 2017), which has hydrographic details at larger scales for specific areas in the national territory, in addition to the review of the basins previously prepared up to 2017. A cutout was made using four hydrographic mesoregions located in the Central Amazon based on the National Hydrographic Division (DHN250), on a scale of 1:250,000 (IBGE 2019). A cutout was made using four hydrographic macro-regions located in the Central Amazon.

These mesoregions include information generated by the National Water Resources Council (CNRH), where the Orthorectified Hydrographic Base (ANA 2017) includes two more hierarchical levels, including spatial limits, names, and codes. The hydrographic mesoregion approach was adopted because on this basis it is possible to assess the process of use and occupation, fragilities, and water availability aimed at water planning and management in different sectors.

An analysis of natural regeneration can be used to aid in diagnosing the state of conservation of a population and its response to natural or human disturbance since individuals can be recruited to compose posterior successional stages (Silva et al. 2008). Small fragments associated with productive use of soil slowly degrade when native vegetation is removed in areas used for mechanized agriculture. This occurs because of the reduction in ecosystem services that native areas provide such as microclimate regulation, and control of hydrological flux and biogeochemical cycles. Therefore, the relationship between vegetation cover and hydrological cycles can be used as an aid in planning for soil use and occupation.

The Project RADAMBRAZIL was a pioneering effort in the survey of information on Brazilian natural resources, including the Amazon biome, through aerial surveys conducted in the 1970's and 80's. Recently, the Brazilian Institute of Geography and Statistics (IBGE) released an online database called the "Environmental Information Database" (BDiA), including the data from RADAMBRAZIL on forest inventories (IBGE 2019).

Therefore, considering the potential of this database to generate new information, an integrated analysis of databases was carried out plotting the native Amazonian species inventoried by the Project RADAMBRAZIL to stratify those species

that were impacted by the anthropogenic processes, focusing only the Central Amazon, delimited by four hydrographic mesoregions. Climatic typology databases were used for the Legal Amazon, using the methodology adapted by Martorano et al. (1993), which was applied to the entire Amazon region by Martorano et al. (2017), evaluating the total species in every typological range with the goal of identifying the most impacted species.

The soils are, in general, well drained, porous, deep, of variable texture, and with low or average fertility. The only exceptions are the soils of basic origin, calcareous soils and the so-called *terra preta do índio*, with above average natural fertility. Latosols, usually resulting from Tertiary sedimentation processes, have good agricultural potential when rationally used (Falesi 1974, Guimarães et al. 2013).

Also, the fragilities database was used regarding the erosive potential of rains in the Amazon to analyze the occurrences of species inventoried in RADAMBRAZIL that would be in the classes of very high and high fragility, as an indicator of use of these species in restoration actions (Engel and Parotta 2001, Brienza Júnior et al. 2008) in the hydrographic mesoregion. A Landsat 8 satellite image from 2020 was also used, with a spatial resolution of 30 × 30 m of the Curuá-Una River sub-basin.

Considering that there is a need to implement demonstrative units in restoration actions, in accordance with Federal Law No. 12,651 (Brasil 2012), which provides protection of native vegetation, a morphometric analysis of the hydrographic sub-basin was carried out in SBHRM belonging to the Curuá-Una River basin, located in the surroundings of the Tapajós National Forest (FNT), in the west of the state of Pará, in the municipality of Mojuí dos Campos. Thus, the study area is located in the Santarém microregion, delimited between the parallels 03º 00' 56.23" and 03º 11' 48.96" of south latitude and the meridians of 54º 35' 26.31" and 54º 30' 59.05" west longitude.

In the area of the municipality of Mojuí dos Campos, there is a total of 4,988.236 km2 (02º 10' 17" south latitude and 56º 44' 42" west longitude), and there are surrounding municipalities of Santarém, Prainha, Alenquer, Belterra, and Uruará. The basins of the Moju and Mojuí rivers are tributaries of the Curuá-Una River basin and together they form the entire existing water network in the so-called Planalto Region. The numerous small streams and rivers converge towards the central one, which is the Curuá-Una. Together, they make up the total of 9,986 km2, or 37.65% of the entire municipality, occupying the eastern portion of the region. In Fig. 1 it is possible to identify the area that can be used for restoration actions.

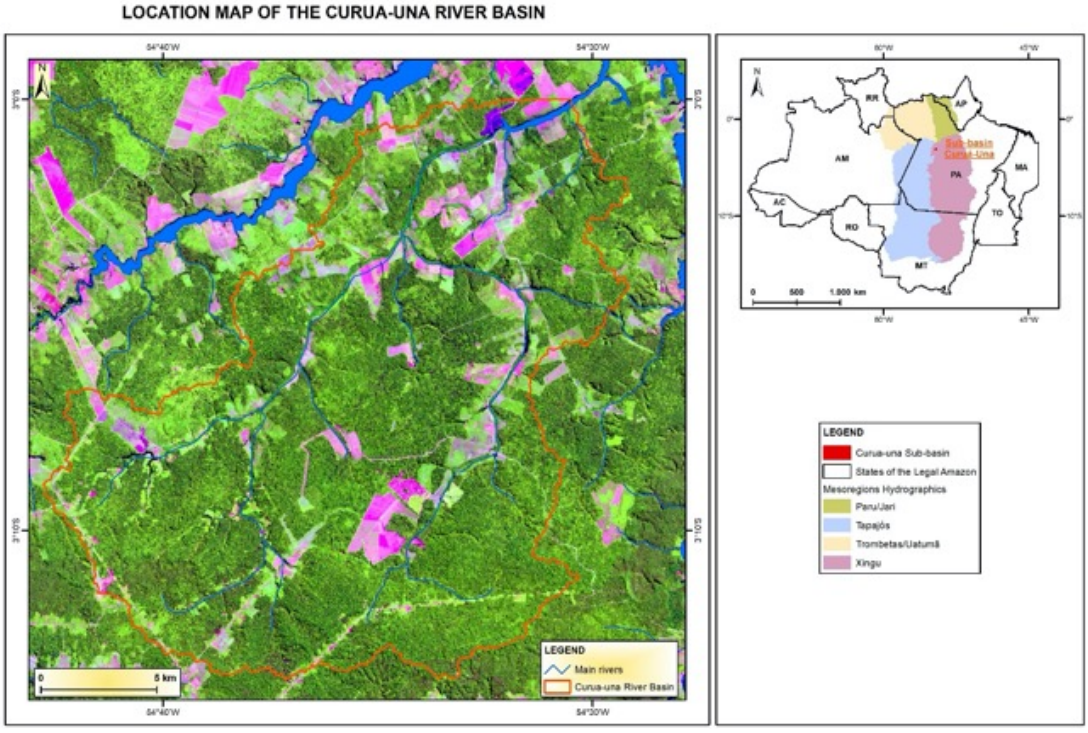

Figure 1. Location of the study area in the west of the state of Pará, Brazil.

Source: elaborated by the authors

For this study, a georeferenced database was built, with information plans, on a scale of 1:100,000. In this step, the geographic information system (GIS) ArcGIS 10.6 was used. In the second stage, an image of the SRTM S04W055 project was downloaded, which comprises the study area, made available free of charge by the North American government through the United States Geological Survey (USGS), with a spatial resolution of 30 m. In the third stage, using the MDE, the sub-basin was extracted, as well as its drainage network. The extension "Hydrology" was used, according to the diagram shown in Fig. 2.

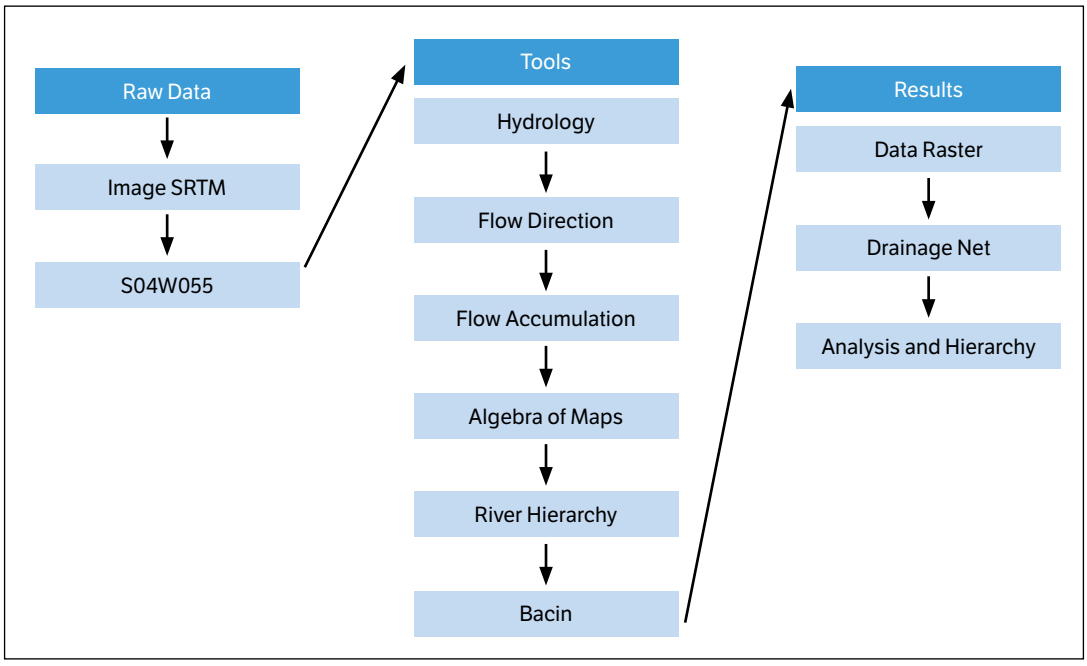

Figure 2. Methodological diagram.

The morphometric study was divided into two categories (Christofoletti 1981), including linear aspects (river hierarchy identification, bifurcation relationship, relationship between the average length of the channels by hierarchy), and areal aspects (shape and determination of drainage density, hydrographic density, maintenance coefficient, relief, and declivity ratio), similar to the work developed by Kanhaiya et al. (2019), using different morphometric parameters.

Subsequently, the data were compared with those from the Project RADAMBRASIL to determine the species that could be used to recuperate areas that are considered as being highly fragile in terms of erosivity as a function of topography and based on regional climatic data.

RESULTS AND DISCUSSION

For the morphometric characteristics, it was found that the sub-basin of the Curuá-Una River has an area of 382.48 km^2, with perimeter of 117 km, and therefore it is classified as a microbasin. According to Christofoletti (1981), 233 first order channels were identified, corresponding to 50.34% of the channels. As for second order channels, 113 were accounted for, representing 24.4% of the drainage network, followed by 52 third order channels (11.23%), 44 fourth order channels (9.5%) and 21 fifth order channels (4.53%), identified automatically by the hydrology tool, resulting in the total of 463 channels for the drainage system.

Therefore, the number of channels in the Curuá-Una River micro basin decreases as the order increases, corresponding to an inverse relationship between the numbers and the orders of the channels. The first order channels had the total length of 192.40 km, the second order 97.104 km, the third order 38.81 km, the fourth order 36.07 km and the fifth order 17.68 km.

According to the channel hierarchy, it was identified that the sub-basin hydrography of the Curuá-Una River (SBHCUR) is of fifth order, evidencing its high ramification, since the lower the order (< 5, for example), the less branched channels

are the sub-basins (Ferreira et al. 2012, Campos et al. 2015, Oliveira and Antônio 2015). The values of the main axis length (Lp) and total length of the drainage network (Lt) presented values of 32 and 382.06 km, respectively. Table 1 presents other morphometric characteristics of the sub-basin.

Table 1. Morphometric characteristics of the Curuá-Una sub-basin.

Aspects	Morphometric characteristics	Unit	Value
Linear aspects	Perimeter of the basin	km	117
	Maintenance coefficient (Cm)	m^2	1,000
	Length of the main basin axis (L)	km	32
	Maximum length of channels (maximum L)	km	192.4
	Minimum length of channels (minimum L)	m^2	17.68
	Total length of channels	km	382.06
	Circularity index	-	0.35
	Number of channels	m	464
	Order or basin	-	5
Areal aspects	Basin area	km^2	382.48
	Compactness coefficient (Kc)	-	1.68
	Density of drainage	km^2	1
	Fat form factor (kf)	-	0.37

For the four hydrographic mesoregions Trombetas/Uatumã, Paru/Jari, Xingu, and Tapajós, 48.1% of the inventoried individuals concentrated in the climate typology Am3, followed by 27.8% in the Aw3 typology, and 16% in the Af3 for the species inventoried by the Project RADAMBRAZIL, indicating that these species occur in areas with total annual rainfall ranging from 2,500 to 2,000 mm. The Curuá-Una sub-basin has typical climate characteristics of the Am3. The monthly rainfall events, in this climatic typology, present values lower than 60 mm in the least rainy month. In the typologies Am2, Am4 and Aw4 (Fig. 2), the percentage of occurrence of native species was 1.3, 2.4, and 4.4%, respectively (Fig. 3).

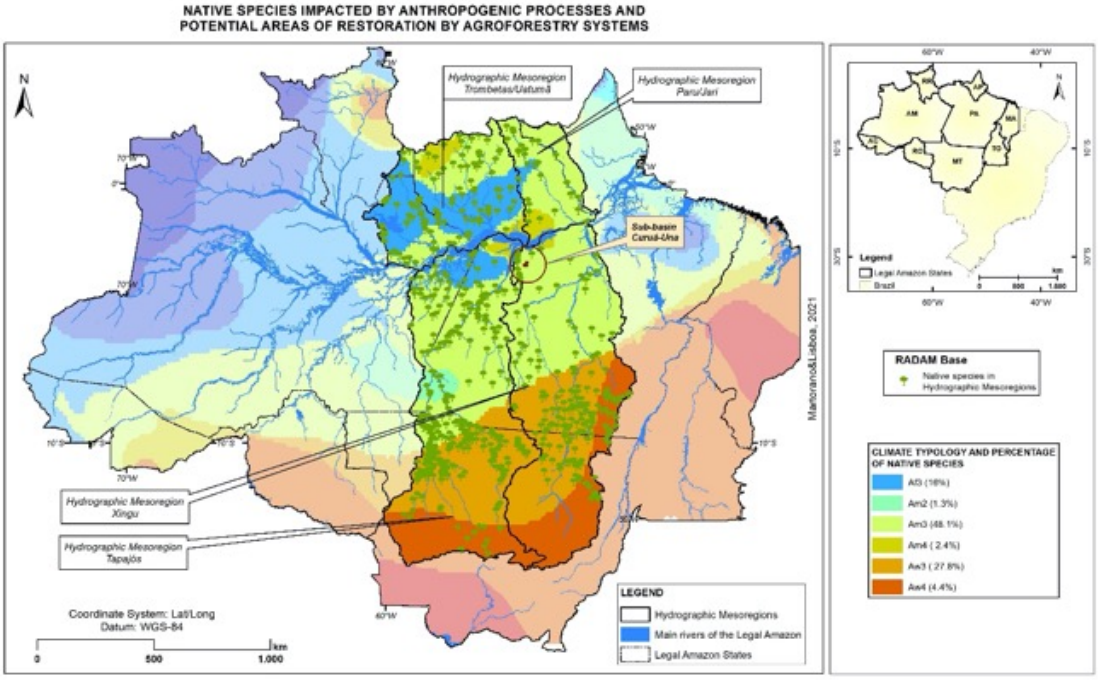

Figure 3. Climatic typology with emphasis on the occurrence of native forest species in four hydrographic mesoregions in the Central Amazon.
Source: elaborated by the authors

When analyzing the degree of suppression by anthropogenic processes on the vegetation inventoried by Project RADAMBRAZIL, it is noticed that, in the classes of very high fragility, 22.3% of the mapped species were suppressed, and, under conditions of high fragility, the values totaled 18% of loss of species by anthropogenic processes (Fig. 4). It is noteworthy to observe that the Curuá-Una sub-basin is located in a very high fragility area, reinforcing the need for strategic restoration actions.

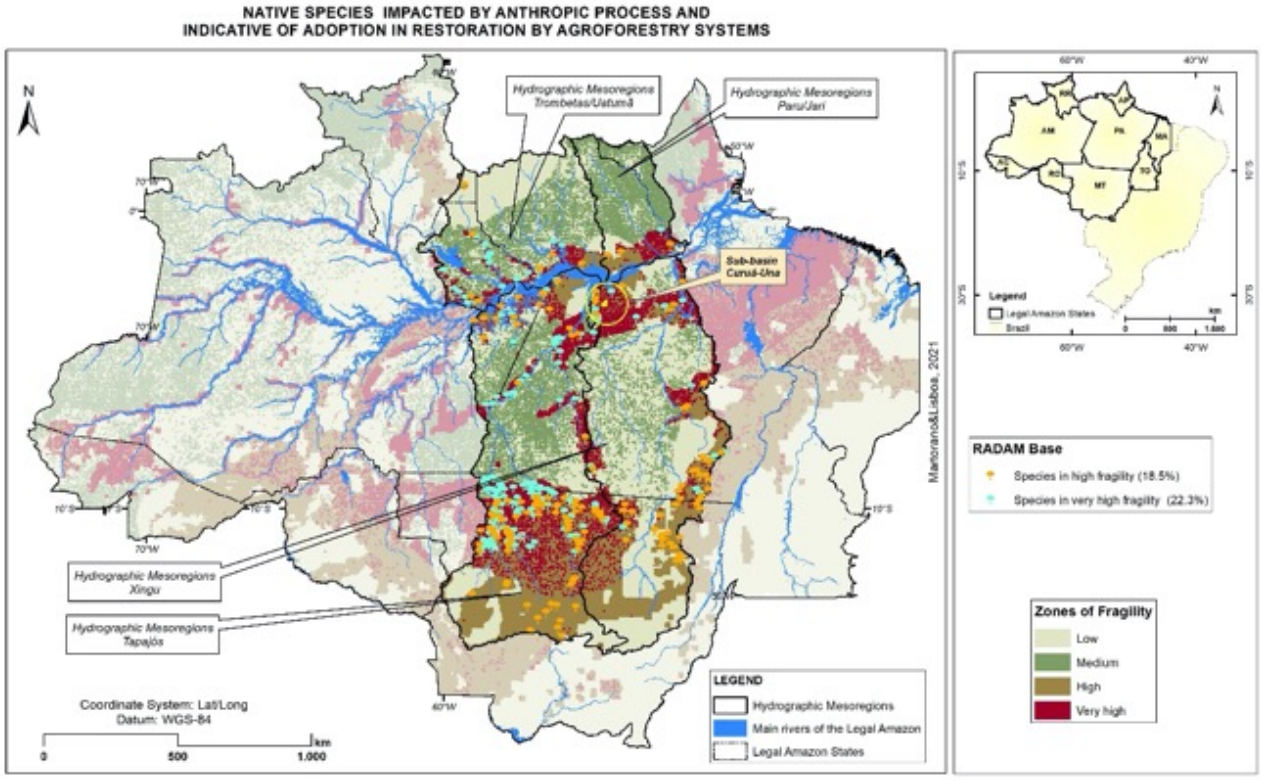

Figure 4. Percentage of losses of individuals inventoried by RADAMBRAZIL Project in areas of very high and high fragility as a restoration strategy using integrated production systems such as agroforestry in the Central Amazon.

Source: elaborated by the authors

Figure 5 shows points with occurrence of native species such as Brazil nut (*Bertholletia excelsa*), *copaíba* (*Copaifera* sp.) and *andiroba* (*Carapa guianensis Aubl.*), demonstrating the potential for inclusion of these species in agroforestry systems in the process of forest restoration in degraded areas in the hydrographic basin and the sub-basin of the Curuá-Una River.

Forest cover in hydrographic basins is very important to the fishing sector in Amazon. Arantes et al. (2018) related that in areas with greater forest cover there was greater total fish biomass, mainly of species that are important commercially speaking. Areas that are exposed without vegetation due to human activities lead to soil erosion (Araújo et al. 2020). These erosive processes are intensified as a larger area loses vegetation cover (Santos et al. 2018, Bramorski and Crestana 2020).

Among the tree species that are most used in agroforestry is the Brazil nut tree (*Bertholletia excelsa* H. B. K.), due to the high commercial value of its fruits, which are sold nationally and internationally (Silva et al. 2008). This species was found in 26 of a total of 108 agroforestry systems researched in this study, which demonstrates its economic and silvicultural importance to forest restoration. The species *Carapa guianensis Aubl.* (*andiroba*) and *Copaifera sp.* (*copaíba*) are Amazonian species with high aggregated value, principally in the cosmetic and pharmaceutical industries (Amorim et al. 2020).

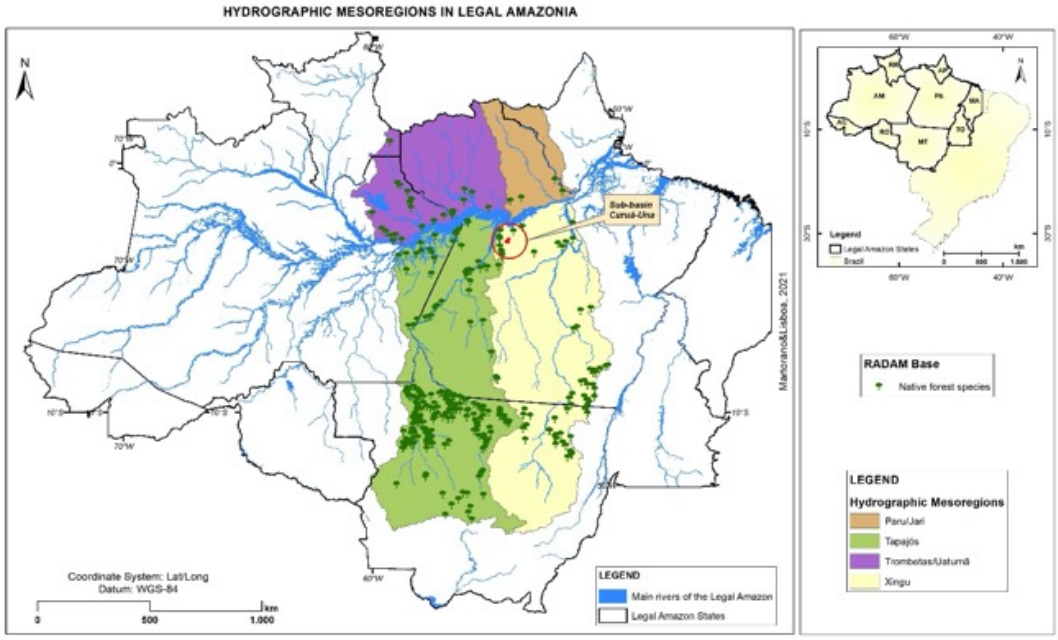

Figure 5. Map indicating native Amazonian species inventoried by RADAMBRAZIL Project that can be used in agroforestry arrangements for forest restoration in the sub-basin of the Curuá-Una River, western Pará.

Source: elaborated by the authors

CONCLUSION

The sub-basin of the Curuá-Una River is a basin with an elongated shape, according to circularity indices, the compactness coefficient, and shape factor. The sub-basin falls into the fifth order category with a densely branched drainage network with a low probability of flooding, due to the predominance of undulating relief.

The methodology allows for evaluation of the morphometric characteristics of the basin, as a strategy to support planning based on land use and occupation, as well as of hydrogeological and topoclimatic studies, to point out the most recommended sites for restoration actions. The inclusion of species such as *copaíba*, Brazil nut and *andiroba*, which have been highly impacted by anthropogenic processes, may be key species for the restoration of Tapajós basin areas.

AUTHORS' CONTRIBUTION

Conceptualization: Correa, D. L. C. and Martorano, L.G.; **Methodology:** Correa, D. L. C., Martorano, L. G. and Lisboa, L. S. S.; **Investigation:** Correa, D. L. C. and Martorano, L. G.; **Writing – Original Draft:** Correa, D. L. C. and Martorano, L. G; **Writing – Review and Editing:** Correa, D. L. C., Martorano, L.G. and Moraes, J. R. S. C.; **Supervision:** Martorano, L. G.

DATA AVAILABILITY STATEMENT

The datasets generated and analyzed during the current study are not publicly available because they are easily generated from the bases cited in the methodology. Recently, IBGE released an online database called BDiA, including the data from RADAMBRAZIL Project on forest inventories (IBGE 2019). The datasets used and/or analyzed during the current study will be available upon request.

FUNDING

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
https://doi.org/10.13039/501100002322
Finance Code 001

ACKNOWLEDGMENTS

The authors express their thanks to all the teaching and research institutions that provided data and information that were fundamental for carrying out this study.

REFERENCES

Almajmaie, A., Hardie, M., Doyle, R., Birch, C. and Acuna, T. (2017). Influence of soil properties on the aggregate stability of cultivated sandy clay loams. Journal of Soils and Sediments, 17, 800-809. https://doi.org/10.1007/s11368-016-1568-1

Amorim, S. L., Silva, L. B., Barata, J. S., Pereira, M. A. F. M., Oliveira, A. C. P. and Athayde, A. C. R. (2020). Prospecção fitoquímica da *Carapa guianensis* (Meliaceae) e *Uncaria guianenesis* (Rubiaceae) com vista á atividade anti-helmíntica sobre nematódeos gastrintestinais de pequenos ruminantes. Scientia Naturalis, 2, 133-142. Available at: http://revistas.ufac.br/revista/index.php/SciNat. Accessed on: Jul. 11 2022.

[ANA] Agência Nacional de Águas e Saneamento. (2017). Catálogo de Metadados da ANA. Bases Hidrográficas Ottocodificadas Multiescalas. Available at: https://metadados.snirh.gov.br/geonetwork/srv/api/records/b228d007-6d68-46e5-b30d-a1e191b2b21f. Accessed on: Jul. 11, 2022.

Arantes, C. C., Winemiller, K. O., Petrere, M., Castello, L., Hess, L. L. and Freitas, C. E. C. (2018). Relationships between forest cover and fish diversity in the Amazon River floodplain. Journal of Applied Ecology, 55, 386-395. https://doi.org/10.1111/1365-2664.12967

Araújo, K. V., Andrade, A. M. and Dobbss, L. B. (2020). Análise da fragilidade potencial e emergente do município de Canaã dos Carajás, sudeste do Estado do Pará. Geografia Ensino & Pesquisa, 24, e28. https://doi.org/10.5902/2236499444092

Bertoni, J. and Lombardi Neto, F. (2008). Conservação do solo. 6. ed. São Paulo: Ícone.

Bramorski, J. and Crestana, S. (2020). Erosão hídrica em um Latossolo Vermelho-Amarelo sob diferentes sistemas de manejo e chuva simulada. Revista Sítio Novo, 4, 73-80. https://doi.org/10.47236/2594-7036.2020.v4.i2.73-80p

[Brasil]. (1997). Lei nº 9.433, de 8 de janeiro de 1997. Diário Oficial da União.

[Brasil]. (2012). Lei nº 12.651, de 25 de maio de 2012. Available at: http://www.planalto.gov.br/ccivil_03/_ato2011-2014/2012/lei/l12651.htm. Accessed on: Jul. 11, 2022.

Brienza Júnior, S., Pereira, J. F., Yared, J. A. Z., Morão Júnior, M., Gonçalves, D. A. and Galeão, R. R. (2008). Recuperação de áreas degradadas com base em sistema de produção florestal energético madeireiro: indicadores de custos, produtividade e renda. Amazônia: Ciência & Desenvolvimento, 4, 197-219. Available at: http://www.alice.cnptia.embrapa.br/alice/handle/doc/659006. Accessed on: Jul. 11, 2022.

Campos, S., Uzó, M., Campos, M., Pissara, T. C. T. and Rodrigues, B. T. (2015). Caracterização morfométrica da microbacia do rio Bauru/SP obtida por técnicas de geoprocessamento. Inter Espaço: Revista Brasileira de Geografia e Interdisciplinaridade, 1, 222-234. https://doi.org/10.18766/2446-6549/interespaco.v1n3p222-234

Carvalho, A. P. V., Brumatti, D. V. and Dias, H. C. T. (2012). Importância do manejo da bacia hidrográfica e da determinação de processos hidrológicos. Revista Brasileira de Agropecuária Sustentável, 2, 148-156. https://doi.org/10.21206/rbas.v2i2.177

Carvalho, R. G. (2014). As bacias hidrográficas enquanto unidades de planejamento e zoneamento ambiental no Brasil. Caderno Prudentino de Geografia, v. spe., 26-43.

Christofoletti, A. (1981). A variabilidade espacial e temporal da densidade de drenagem. Notícias Geomorfológicas, 21, 3-22.

Engel, V. L. and Parrota, J. A. (2001). Uma avaliação da semeadura direta para restauração de terras degradadas na região central de São Paulo. Ecologia e Manejo Florestal, 152, 169-181. https://doi.org/10.1016/S0378-1127(00)00600-9

Falesi, I. (1974). Soils of the Brazilian Amazon. In C. Wagley (Ed.). Man in the Amazon (p. 201-229). Gainesville: University Press of Florida.

Ferreira, R. G., Moura, M. C. O. and Castro, F. S. (2012). Caracterização morfométrica da sub-bacia do Ribeirão Panquinhas, ES. Revista Enciclopédia Biosfera, 8, 2250-2256.

Fu, Y, Li, G. L., Zheng, T. H., Li, B. Q. and Zhang, T. (2017). Splash detachment and transport of loess aggregate fragments by raindrop action. Catena, 150, 154-160. https://doi.org/10.1016/j.catena.2016.11.021

Guimarães, J. T. F., Cohen, M. C. L., França, M. C., Alves, I. C. C., Smith, C. B., Pessenda, L. C. R. and Behling, H. (2013). An integrated approach to relate Holocene climatic, hydrological, morphological and vegetation changes in the southeastern Amazon region. Vegetation History and Archaeobotany, 22, 185-198. https://doi.org/10.1007/s00334-012-0374-y

[IBGE] Instituto Brasileiro de Geografia e Estatística. (2019). Banco de Dados de Informações Ambientais. Available at: https://bdiaweb.ibge.gov.br/#/home. Accessed on: Jul. 11, 2022.

Kanhaiya, S., Singh, S., Singh, C. K., Srivastava, V. K. and Patra, A. (2019). Geomorphic evolution of the Dongar River Basin, Son Valley, Central India. Geology, Ecology, and Landscapes, 3, 269-281. https://doi.org/10.1080/24749508.2018.1558019

Keith, D. A., Ferrer-Paris, J. R., Nicholson, E., Bishop, M. J., Polidoro, B. A., Ramirez-Llodra, E., Tozer, M. G., Nel, J. L., Nally, R. M., Gregr, E. J., Watermeyer, K. E., Essl, F., Faber-Langendoen, D., Franklin, J., Lehmann, C. E., Etter, A., Roux, D. J., Stark, J. S., Rowland, J. A., Brummitt, N. A., Fernandez-Arcaya, U. C., Suthers, I. M., Wiser, S. K., Donohue, I., Jackson, L. J., Pennington, R. T., Iliffe, T. M., Gerovasileiou, V., Giller, P., Robson, B. J., Pettorelli, N., Andrade, A., Lindgaard, A., Tahvanainen, T., Terauds, A., Chadwick, M. A., Murray, N. J., Moat, J., Pliscoff, P., Zager, I. and Kingsford, R. T. (2022). A function-based typology for Earth's ecosystems. Nature, 610, 513-518. https://doi.org/10.1038/s41586-022-05318-4

Martorano, L. G., Nechet, D. and Pereira, L. C. (1993). Tipologia climática do Estado do Pará: adaptação do método de Köppen. Boletim de Geografia Teorética, 23, 45-46.

Martorano, L. G., Vitorino, M. I., Caxias, S. B. P., Moraes, J. R. C., Lisboa, L. S., Doff, S. E. and Reichard, T. K. (2017). Condições climáticas na Amazônia Oriental: Variabilidade de precipitação em Belém e indicativo do déficit hídrico do solo. African Journal Agriculture Research, 12, 1801-1810. https://doi.org/10.5897/AJAR2016.11801

Michaelides, K., Lister, D., Wainwright, J., Parsons, A. J. (2009). Controles de vegetação em pequena escala e dinâmica de erosão em um ambiente degradante de terra seca. Processos Hidrológicos, 23, 1617-1630. https://doi.org/10.1002/hyp.7293

Oliveira, B. R. and Antônio, G. B. (2015). Caracterização da bacia do Maxixe com o auxílio de Sistemas de Informações Geográficas. Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental, 19, 761-782. https://doi.org/10.5902/2236117018933

Santos, L. S., Barbosa, A. M. S., Martorano, L. G., Moraes, J. R. S. C. and Aparecido, L. E. O. (2018). Distribuição da precipitação e da erosividade mensal e anual na Flona Tapajós e seu entorno. Revista Ibero Americana de Ciências Ambientais, 9, 124-133. http://doi.org/10.6008/CBPC2179-6858.2018.007.0012

Santos, L. S., Gutierrez, C. B., Pontes, A. N., Silva Junior, O. M., Souza, A. A. and Martorano, L. G. (2016). Geotecnologia aplicada na análise de bacias hidrográficas e rede de drenagem: Estudo das bacias hidrográficas do Murucutu e Aurá. Revista SODEBRAS, 11, 131-135. Available at: http://www.alice.cnptia.embrapa.br/alice/handle/doc/1047887. Accessed on: Jul. 11, 2022.

Silva, P. T. E., Brienza Junior, S., Yared, J. A. G., Barros, P. L. C. and Maciel, M. N. M. (2008). Principais espécies florestais utilizadas em sistemas agroflorestais na Amazônia. Revista de Ciências Agrárias, 49, 127-144.

Singh, S., Prakash, K. and Shukla, U. K. (2019). Decadal scale geomorphic changes and tributary confluences within the Ganga River valley in Varanasi region, Ganga Plain, India. Quaternary International, 507, 124-133. https://doi.org/10.1016/j.quaint.2018.05.022

[UCN and WRI] International Union for Conservation of Nature and World Resources Institute. (2014). A guide to the Restoration Opportunities Assessment Methodology (ROAM): Assessing Forest landscape restoration opportunities at the national or sub-national level. Working Paper (Road-test edition). IUCN, Gland.

Valente, O. F. and Gomes, M. A. (2005). Conservação de nascentes: hidrologia e manejo de bacias hidrográficas de cabeceiras. Viçosa: Aprenda Fácil.

Zhao, C., Gao, J., Huang, Y., Wang, G. and Zhang, M. (2016). Effects of vegetation stems on hydraulics of overland flow under varying water discharges. Land Degradation, 27, 748-757. http://doi.org/10.1002/ldr.2423