

Benefits associated with topoclimatic zoning for native species of the Brazilian Amazon: methodological innovation

Lucieta Guerreiro Martorano (✉ lucieta.martorano@embrapa.br)

Embrapa Eastern Amazon, NAPT Middle Amazon

Silvio Brienza Júnior

Embrapa Eastern Amazon, NT MAFORT

Leila Sheila Silva Lisboa

Municipal Secretary of Belém SEMEC

José Reinaldo da Silva Cabral de Moraes

São Paulo State University (Unesp)

Article

Keywords: ZoNative, Silviculture, Reforestation, Forest management

Posted Date: November 2nd, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-2136756/v1>

License:  This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Additional Declarations: No competing interests reported.

Abstract

In 2006 the soybean moratorium provided the impulse for the installation of a large grain exporting port in western Pará, and the states of Mato Grosso and Pará became references at a national level for grain production. Topoclimatological zoning for species is a methodological innovation that accounts for phenological phases based on herbarium registries, and occurrence as described by RADAMBRAZIL forest inventories. This process also includes climatic data including range of annual precipitation, quarterly maximum and minimum rainfall, months with total rainfall below 60 mm, ranges of water stress with soil water holding capacity based on 300 mm, maximum, minimum, and average thermal regimes, air humidity and vapor pressure deficit, and altitude ranges. The zoning process is finalized by a panel of specialists who assign importance values to each variable and conduct statistical analyses to define the variables that best explain the productive potential for each species. This study presents the results of topoclimatological zoning for the species paricá (*Schizolobium amazonicum*) and tachi-branco (*Tachigali vulgaris* L.F.). Through this method, it is possible to identify areas with high, medium, and low topo climatic potential for any native species in the Amazon.

Introduction

The Amazon Forest has accumulated approximately 119 ± 28 Pg of carbon (C), equivalent to about 1.5 decades of current global C emissions resulting from human activities, and therefore it has an important role at a large scale in the global climate system^{1,2}. The scenarios elaborated in projected that by 2050 of the 12 principal Amazonian watersheds, 8 would lose about half of their forest cover³. These authors showed that in all the scenarios, deforestation pressure in the eastern Amazon would be intense principally due to paving of main highways.

However, harvesting and processing of timber from native forests in the Amazon has made Brazil one of the most important wood exporters in the world⁴. The number species harvested annually reached 1,300, and between 2007 and 2009 25 species accounted for 50% of the total commercialized volume⁵. With respect to forest plantations, in 2019, 7.8 million hectares were mapped, which were primarily composed of Eucalyptus and Pinus species, besides species such as Acacia, Araucaria, Parica, and Teak⁶.

As demonstrated by Eucalyptus plantation forests, Brazil has great potential to be an important player in the global market for wood from planted forests of native species in each biome. With respect to the Amazon biome, policies and actions that promote silviculture of native species represent a strategy to mitigate pressure on native forests from deforestation and the illegal timber market, thus increasing the provision of environmental goods and services offered by cultivated native species.

In 2018, a literature review including 3,303 articles published on native Brazilian trees was conducted as part of the Brazil Coalition for Climate, Agriculture, and Forests⁷. After analysis based on tacit knowledge by a panel of 50 specialists from a wide range of institutions, 15 native Amazonian species and 15 from the Atlantic Forest biome were selected as special focus species based on timber potential, results from

research studies, and edaphoclimatic conditions, among other variables. However, in order to advance the development of silviculture of native trees it is necessary to increase technical-scientific knowledge based on use of existing information available in freely available databases. Among the gaps in knowledge of the silviculture of native trees are the following thematic areas: i) seeds and seedlings, ii) genetic improvement, including vegetative propagation, iii) plantation management, iv) wood technology, v) topoclimatic zoning, vi) forest products market, and vii) forestry policies and legislation⁷.

It is known that the planting of native trees depends not only on public policy, but above all else on research results that are able to answer questions about where to plant a specific species. Climatic zoning, as proposed by for planting of Eucalyptus in Brazil, marked the beginning a new phase of the planning process for the indication of appropriate areas for planting forest species⁸. The variables used in this initial study were altitude, climate type, vegetation, air temperature and average annual rainfall, as well as the rainfall distribution, and potential for water stress and thermal conditions for freezing events.

Considering deforestation pressure in the Amazon and the need for information to aid in the success of forest restoration projects, advancements in knowledge of native forest species will promote productive silvicultural practices for species in the region. Methodological initiatives that have as objective the expansion of successful silvicultural operations in the Amazon region, such as use of agroforests, were elaborated on by (2005), whose study introduced the concept of bioclimatic zoning⁹.

According to¹⁰, bioclimatic zones, similar to those in the study by, were presented for 15 forest species, which encompassed the territory denominated the "Green Arc", an area of about 17 million hectares in the state of Pará. It was shown in this study that not all of the 15 recommended species native to the Amazon were apt for use in the Green Arc region¹⁰.

To identify areas that have potential for forest plantations using native tree species, it is necessary to develop and improve methods that are able to reduce implementation time and financial costs through integration of biophysical variables to establish areas that have high, medium, and low potential for a specific species. Zoning for forest species in Brazil has been applied to Eucalyptus in the south of Brazil¹¹, edaphic zoning for Amazonian species and bioclimatic zoning for indication species to be used in agroforest systems¹².

Data published by the Brazilian Forest Service in the National System of Forest Information (SNIF) in the 2019¹³ elaborated on thematic areas such as forests and forest resources, forest production, forestry markets and economy, and forestry teaching and research during the period 2017 and 2018.

The report showed that Brazil is considered to be a leader in forest resources with 498 million hectares of forests composed of 98% native and 2% planted species, wherein 55% of the forests are located on public lands and 45% in private areas. The forestry economy in 2018 was responsible for generating a total of R\$20.5 billion, and in 2017 processed wood generated R\$109.5 billion. Exported wood and non-wood forestry products generated R\$14.2 billion in 2018, and formal employment in the forestry sector was

responsible for 1.25% of the total of jobs created in the country. There were 74 undergraduate forestry courses at universities in Brazil with a total of 1,695 students graduating in 2018, and in the 11 graduate forestry programs a total of 558 new forestry professionals graduated, which demonstrates the large potential these programs have to provide professionals to the productive sector¹⁴.

Furthermore, scientific advances have been applied to questions such as whether there was suppression of a certain percentage of native commercial species inventoried in anthropogenically modified areas in the RADAMBRAZIL project¹⁴. Other questions are: Which species has topoclimatic potential for use in forest restoration in the Legal Amazon based on analysis of agroclimatic variables? How has the evolution of scientific knowledge aided the expansion of silviculture of native species in the region? What is the evidence for success in meeting the demands of the forest production sector? Therefore, the objective of this study is to present the methods of topoclimatic zoning for native forest species (ZoNative) and the benefits associated with conservationist processes in anthropogenic areas in the Legal Amazon.

Results

The Köppen climate classification system is one of the most used to aid in planning, principally with respect to activities associated with agriculture, cattle ranching, and silviculture¹⁵ modified aspects of this system such as annual average temperature, rainfall of the months with the lowest precipitation, and total annual rainfall, dividing the values into groups of 500 mm¹⁶ identified 10 climatic subtypes (Fig. 1), with the most represented groups being Am₃ and Af₃, indicating that the totals for monthly rainfall present transitional conditions in terms of the months with rainfall below (Am₃) and above 60 mm (Af₃), although for both groups total annual rainfall varied between 1,500 and 2,000 mm. When observing the typical vegetation pattern of savannas in the Amazon, the climate pattern clearly falls within the groups Aw₃, Aw₄ and Aw₅. Less than 12% of the Amazon has monthly rainfall averages above 60 mm and annual rainfall above 2,500 mm (classifications Af₁ and Af₂), thus demonstrating the importance of topoclimatic analyses in planning for native species plantations¹⁷.

Figure 2 shows the occurrences of species inventoried by the RADAMBRAZIL project¹⁴, and those that were impacted by anthropogenic processes, indicating that there was omission of 47% of the species that had commercial timber potential. These data corroborate the scenarios established by³, wherein greater pressure for deforestation exists in the eastern Amazon. The forest loses genetic material, thus requiring conservationist strategies to fill gaps in knowledge of tropical silviculture^{18,19}.

In the context of the study area being within the scope of the Unification of Ecological and Economic Zoning project for the Legal Amazon (UZEE), topoclimatic zoning for tachi-branco (*Tachigali vulgaris*) was done²¹ verified that 57% of anthropogenic areas have high potential for inclusion of this native species for energy generation based on biomass, and only 7% of these areas have low potential, with the remaining 36% having medium potential. Figure 3 identifies the high, medium, and low potential areas

with respect to inclusion of tachi-branco in forest restoration actions in areas already altered by anthropogenic actions in the Legal Amazon.

Innovation potential and associated benefits

Based on the results for topoclimatic zoning for paricá^{22,23} which showed areas of high, medium, and low potential for this species in the state of Pará the first large scale integrated cultivation system was installed in the municipality of Ulianópolis. In the first year the rural producer planted soybeans with paricá, and in the second year the rotation was paricá-corn²⁴.

The definition of potential areas for plantations of native forest species of commercial value aims to support decision making with respect to cultivation of timber and non-timber species in the region. Furthermore, the inclusion of species in areas of high potential, besides supporting compliance with environmental regulations on rural properties, also provides an opportunity for research to contribute to mitigation of greenhouse gases (GHG), and to indicate areas that can be certified in programs for carbon credit and ecosystem services.

The zoning methodology (ZoNative) could be applied to the²⁴ forest species identified by⁷ for the Amazon and Atlantic Forest biomes, with the short-term goal of identifying potential areas for investments in silviculture of native species with a higher percentage of success in terms of environmental adaptation and production of specific species. With respect to the establishment of a forest plantation, the indication of a species is just one step in the process, because plantations depend on the availability of quality seed to meet the demand of silviculture's.

Discussion

Research on genetic improvement and research on planted native species in long-term experiments, such as the 40-year-old research plots in Belterra, Pará, are fundamental to the implantation process of native species plantations. Nevertheless, as a result of reductions in research funds, these plots are threatened by encroaching anthropogenic pressure due to lack of resources for site and fence maintenance and safeguarding of the integrity of the borders of the research area. This represents a loss of an opportunity to conduct research on native species plantations in the Amazon.

It is thought that the inclusion of Amazonian native species in integrated production systems will amplify the participation of rural producers in the world market for tropical woods. Silviculture using native species²⁵ has the potential to meet the growing demand for tropical sawn woods and to generate other benefits, principally related to a reduction in deforestation and forest degradation. Plantation forests have high potential to aggregate value for rural producers in programs that pay for ecosystem services such as biodiversity conservation, thermal regulation, removal of millions of tons of carbon from the atmosphere, beside creating thousands of 'green' jobs and increasing the income of rural communities, with the support of public and private financing.

Removing native tropical forests as the primary source of wood, which is almost entirely illegally extracted or harvested without technical criteria and substituting them for sustainably managed native forests of plantation forests of native species in the near future will require public policies and investments to combat illegality and promote research, development, and innovation (RD&I) using native species for reforestation. A program for strengthening integrated production systems will support research incorporating ZoNative for more species with high potential to contribute to the GDP of Brazil, while adhering to the sustainable development objectives (SDO).

The entire world questions deforestation in the Amazon, and this is one of the largest preoccupations of researchers whose work is focused on the use of conservationist techniques in anthropogenic areas, as well as the preservation of areas that require great care in terms of management such as springs, hilltops, and areas that are considered ecological sanctuaries. Data available from the MapBiomass project show that it is possible to identify the evolution of forcing processes of environmental change between 1985 and 2019. This project also identified effects associated with the new Brazilian Forest Code²⁶, using 2008 as the baseline to evaluate deforestation and the approval of the Code in 2012 as another baseline, with analysis through 2019. Among the analyses done by this project is the National Inventory of Emissions between 1994 and 2002, 2000 and 2010, and 2010 to 2019.

The analyses in this study will aid in the indication of areas that need forest restoration and the native species that can be used. The development of technologies that can mechanize the entire process of plantation establishment will require collaboration between teaching, research, and extension activities and the rural producer. The identification of new wood and non-wood bioproducts represents a opportunity to conserve the biodiversity that is typical of tropical environments with multiple uses. Brazil, and specifically the Amazon, need development of actions rooted in technical-scientific partnerships that aggregate private enterprise and research institutions. Forest plantations using native species will tend to gain in terms of scale through the indication of areas that are deemed adequate for their installation.

Methods

Using as a base the data from the RADAMBRAZIL¹⁴, a spatial diagnosis was done of the occurrence of native species inventoried in the Government Amazon Integration Program²⁶. Surveys were conducted in herbariums in order to obtain information related to collection periods and the expression of flowers and fruits of species during their collection. Analysis using ZoNative of agroclimatic variables, topographic conditions, hydrological networks, delimitation of anthropogenic areas using a baseline of the year 2008, statistical analyses, and the use of a panel of specialists to define the criteria used in the weighting matrix for topoclimatic zoning of native species. This method was then presented at national and international scientific events^{16,27,28}. Subsequently, new research was conducted to amplify and validate previous field findings^{23,28,29}. Principal component analysis was applied to identify variables used in the construction of maps considering the limiting conditions for high, medium, and low topoclimatic potential for each species analyzed in the zoning. Computational advances and the availability of

geospatial tools made important contributions to this analysis and allowed for more complex and robust analyses²⁴.

In this way, this methodology presents innovations that can aid in planning for establishment of plantations of a specific native species, taking into account a range of variables including natural occurrence, period of expression of phenological phases, climatic data including range of annual precipitation, quarterly maximum and minimum rainfall, average annual temperature, temperature extremes (maximum and minimum), months with total rainfall in months with under 100 mm, total rainfall in quarters with under 60 mm, total annual rainfall divided into groups of 500 mm, thermal amplitudes during the period of expression of phenological phases, annual air humidity and vapor pressure deficit. The objective of this analysis is to describe the response of species to the conditions prevalent in their original environment, which considers processes of exchange, transfer, and conversion of matter and energy²⁸.

It is important to emphasize that there is little information on phenological responses of species that can be used to conduct topoclimatic analyses, and therefore this process is similar to mining for information, since in herbariums and in the older bibliographic references, collection points were not georeferenced. The collection points referenced in these materials are therefore all that is available to insert in the geographic information system (GIS) tools to subsequently generate the topoclimatic zoning. Studies related to climatic gradients can be applied in diverse manners, especially to explain species distribution³⁰ climatic prediction³¹, as well as to optimize silvicultural treatments of native species²³, by including species from areas with high potential in production arrangements³².

Using this method, commercial species were selected from the state of Pará that could be used to expand areas of forest plantations, such as paricá (*Schizolobium amazonicum*). Areas with high, medium, and low potential were identified in Pará that have high potential and topoclimatic conditions that can minimize the risks associated with species adaptation²⁴. These areas would promote a reduction in the time needed for the species to express its full development²⁴, thus reducing the need to implement long-term silvicultural experiments which incur large costs associated with installation, monitoring, field work, and data collection. Species selection was based on its ecological and economic importance for the region. It is therefore important to emphasize that due to limitations posed by data availability for each species, registries in herbariums aided in the identification of the period of flowering and fruiting based on the month and year of field collections, analyzed as a function of climate time series data. The panel of specialists aided in the definition of the weighting matrix for elaboration of the zoning. To validate the topoclimatic zones, the points of occurrence for each species, as registered in the RADAMBRAZIL project¹⁴, were subsequently evaluated to establish the number of occurrences in zones of high, medium, and low topoclimatic potential

It is important to emphasize that, in general, investments in forest areas are made based on demand with the goal of aggregating value to rural properties, principally in areas undergoing degradation in the region. The process of forest restoration depends on the availability of seeds, seedling production,

silvicultural treatments, inputs, forest products generated (wood and non-wood), and market opportunities. In contrast, topoclimatic zoning aims to subsidize decision making processes that seek to establish forest plantations of native Amazonian species. Information from herbariums aided in the evaluations of phenological responses of species associated with climate conditions in the collection areas. In this way, the catalog registries deposited in the herbariums acquire a greater importance to the generation of information used in this research. Considering that there are gaps in the meteorological monitoring network in the Legal Amazon and that the scientific and technological advances that provide spatial information in the form of interoperable databases, it has been possible to amplify the scalability of climatic information. The use of time series data as well as data from climate normals^{33,34}, has aided in the use of interpolated data such as those of the World clim model³⁵, discussed by^{17,20}. Figure 4 shows a schematic design of the geodatabase used in the elaboration of methodological Innovation (ZoNative).

Declarations

Data availability

All data generated or analyzed during this study is included in this article. The datasets generated and analyzed during the current study are publicly available because they are easily generated from the bases cited in the methodology. 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). The data obtained from herbarium records are not easily available, but depending on the scientific interest, it is possible to explain how information is extracted, such as flowering season, occurrence locations, among others, described in the methodology. The datasets used and/or analyzed during the current study available from the corresponding author on reasonable request.

Acknowledgements

The authors express their gratitude to all the researchers who worked at RADAMBRAZIL, in the surveys of data on native species of the Amazon that are part of the information base in the herbaria and made available for the realization of ZoNative. weather and climate conditions in the region.

References

1. Lopez-Gonzalez G, Mitchard ETA, Feldpausch TR et al. Amazon forest biomass measured in inventory plots Plot Data from “Markedly divergent estimates of Amazon forest carbon density from ground plots and satellites”. ForestPlotsNET (2014). Doi: 105521/FORESTPLOTSNET/2014_1
2. Phillips, O.L., Brien, R.J.W. & the RAINFOR collaboration. Carbon uptake by mature Amazon forests has mitigated Amazon nations’ carbon emissions. *Carbon Balance Manage* **12**, 1 (2017). Doi : <https://doi.org/10.1186/s13021-016-0069-2>.

3. Soares-Filho, B., Nepstad, D., Curran, L. et al. Modelando a conservação na bacia amazônica. *Nature* **440**, 520-523 (2006). [Vol 440|23 March 2006|doi:10.1038/nature04389](#)
4. IBAMA – Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Relatório de qualidade do meio ambiente. [recurso eletrônico]: RQMA Brasil 2020 / Hanry Alves Coelho, Andrea Alimandro Corrêa (coordenação). Brasília, DF: IBAMA, (2022).
5. IBAMA. Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis. Relatório de Qualidade do Meio Ambiente – RQMA: Brasil 2013 / Diretoria de Qualidade Ambiental. – Brasília: Ibama. 268 p. (2013).
6. IBÁ- Indústria Brasileira de Árvores. Anual Report IBÁ. 177 p (2021).
7. Rolim, S.G., Pina-Rodrigues, F.C.M., Piotto, D.; Batista, A.; Freitas, M.L.M.; Brienza Junior, S.; Zakia, M.J.B.; Calmon, M. Research Gaps and Priorities in Silviculture of Native Species in Brazil. *Working paper*, WRI, Brasil, São Paulo, 44p. (2019). Doi: <https://wribrasil.org.br/pt/publicacoes>.
8. Golfari, L.; Caser, R.L.; Mooura, V.P.G. Zoneamento ecológico esquemático para reflorestamento no Brasil. Belo Horizonte: Centro de Pesquisa Florestal da região do Cerrado. *PNUD/FAO/IBDF/BRA-45. Série Técnica* **11** (1978).
9. Silva, P. T. E., Brienza Junior, S., Yared, J. A. G., Barros, P. L. C. & Maciel, M. N. M. Identificação e caracterização de zonas bioclimáticas das áreas de inserção de sistemas agroflorestais praticados na Amazônia brasileira. *Revista de Ciências Agrárias (Belém)* **49**, 87-100, (2008). Doi: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/30411/1/REVISTA49-artigo08.pdf>.
10. Andrade, D.B.M. Indicação de áreas preferenciais para uso de espécies florestais potenciais em sistemas agroflorestais no arco verde paraense. Dissertação (Mestrado em Ciências Ambientais) – Programa de Pós-Graduação em Ciências Ambientais, Instituto de Geociências, Universidade Federal do Pará, Museu Paraense Emílio Goeldi e EMBRAPA, Belém 70p. (2012).
11. Pozo, P. & Säumel, I. How to Bloom the Green Desert: *Eucalyptus* Plantations and Native Forests in Uruguay beyond Black and White Perspectives. *Forests* **9**, 614, (2018). Doi: <https://doi.org/10.3390/f9100614>.
12. Damasco, G. et al. Certification of açaí agroforestry increases the conservation potential of the Amazonian tree flora. *Agroforest Systems* **96**: 407-416, (2022). Doi: <https://doi.org/10.1007/s10457-021-00727-2>
13. Serviço Florestal Brasileiro – Boletim SNIF, 2019. 36 p.- Brasília/DF
14. RADAMBRAZIL. Folha SA. 22 Belém; geologia, geomorfologia, solos, vegetação, uso potencial da terra, v. 5, Rio de Janeiro, (1974).
15. Martorano, L.G., Nechet, D. & Pereira, L.C. Tipologia climática do Estado do Pará: Adaptação do método de Köppen. *Bol. De Geogr. Teorética* **23**, 45–46 (1993). Doi: <https://periodicos.ufpe.br/revistas/rbgf>.
16. Martorano, L.G., Brienza Junior, S., Monteiro, D.C. A., Lisboa, L.S., Cândia, O.N., Martorano, P.G. & Espírito Santo, J.M. Condições topobioclimáticas associadas à ocorrência de Taxi-branco (*Sclerolobium panuculatum* Vogel) e Paricá (*Schizolobium parahyba* var. *amazonicum* (Huber ex

- Ducke) Barneby) preferenciais para implantação de plantios florestais no Estado do Pará. In: REUNIÃO BRASILEIRA DE MANEJO E CONSERVAÇÃO DO SOLO E DA ÁGUA, 18, Terezina. Anais... Terezina, 4p, (2010).
17. Martorano, L.G., Vitorino, M.I., Caxias da Silva, B.P., Cabral de Moraes, J.R., Lisboa, L.S., Sotta, E.D., Reichardt, K. Climate conditions in the eastern amazon: Rainfall variability in Belem and indicative of soil water deficit. *Afr. J. Agric. Res.* **12**, 1801–1810 (2017). Doi: <https://doi.org/10.5897/AJAR2016.11801>.
 18. Lohbeck, M.L., Poorter, L., Lebrija-Trejos, E., Martínez-Ramos, M. et al. Successional changes in functional composition contrast for dry and wet tropical forest. *Ecology* **94**, 1211–6 (2013). Doi: <https://doi.org/10.1890/12-1850.1>.
 19. Piotto, D., Craven, D., Montagnini, F., Ashton, M., Oliver, C., Thomas, W.W. (2019) Successional, spatial, and seasonal changes in seed rain in the Atlantic forest of southern Bahia, Brazil. *PLoS ONE* **14**: e0226474. <https://doi.org/10.1371/journal.pone.0226474>
 20. Martorano, L.G., Lisboa, L., Muniz, R., Sotta, E. & Beltrão, N. Evidence of Ecological Resilience Clusters to climate typology in the Amazon Rainforest: A methodological proposal. In Proceedings of the International Scientific Conference “Our Common Future Under Climate Change”, Paris, France, 7–10 July 2015; Abstract book. [S.l.: s.n.]. 2015; p. 264. Available online: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/129298/1/p264.pdf> (accessed on 27 June 2021).
 21. Martorano, L.G., Tourne, D.C.M., Lisboa, L.S., Sousa, V.G., Santos, L.S.; Brienza Júnior, S. Zoneamento topoclimático do taxi-branco (*Tachigali vulgaris* L.F) na Amazônia Legal: estratégias de planejamento com metas de desenvolvimento sustentável. Belém: Embrapa Amazônia Oriental 70p. (Documentos, Embrapa Amazônia Oriental, 435) (2018). Doi: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/170212/1/DOCUMENTOS-435-OnLine.pdf>.
 22. Martorano, L. G., Monteiro, D. C. A., Brienza Junior, S., Lisboa, L. S. S., Espírito Santo, J. M., & Almeida, R. F. Top-bioclimate conditions associated with the natural occurrence of two Amazonian tree species for sustainable reforestation in the State of Para. Ecosystems and Sustainable Development VIII. Spain: Universidad de Alicant, 144, 111-122. (2011).
 23. Tourne, D.C.M., Martorano, L.G., Brienza Junior, S. et al. Potential topoclimatic zones as support for forest plantation in the Amazon: Advances and challenges to growing paricá (*Schizolobium amazonicum*). *Environmental Development* **18**, 26-35, (2016). Doi : <http://dx.doi.org/10.1016/j.envdev.2015.11.002>.
 24. Martorano, L.G., Siviero, M.A., Tourne, D.C.M. et al. Agriculture and forest: A sustainable strategy in the Brazilian Amazon. Australian Journal of crop Science. *AJCS* **10**, 1136-1143 (2016).
 25. Nunes, S., Gastauer, M., Cavalcante, R.B.L. et al. Challenges and opportunities for large-scale reforestation in the Eastern Amazon using native species. *Forest Ecology and Management* **466**, 118-120 (2020). Doi: <https://doi.org/10.1016/j.foreco.2020.118120>.

26. BRASIL. Decreto Nº 67.113, de 26 de agosto de 1970. Regulamenta o Decreto-lei nº 1.106, de 16 de junho de 1970, que instituiu o Programa de Integração Nacional. Brasília: Câmara dos Deputados DOSSIÊ AMAZÔNIA 149. 1970. Preprint at <https://www2.camara.leg.br/legin/fed/decret/1970-1979/decreto-67113-26-agosto-1970-408679-publicacaooriginal-1-pe.html>
27. Brienza Junior, S., Monteiro, D.C.A., Martorano, L.G., Lisboa, L.S., Maestri, M. P. & Schuler, A. Energetic potential of the *Sclerolobium paniculatum* Vogel (taxi-branco) and its preferential top climatic condition in Eastern Amazonia, Brazil. In: *Conference on International Research on Food Security, Natural, Resource Management and Rural Development*. Hamburg: Alemanha (2009). Doi: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/108759/1/5555.pdf>.
28. Martorano, L.G., Monteiro, D.C.A., Brienza Junior, S., Lisboa, L.S., Espírito Santo, J. M. & Almeida, R. F. Top-bioclimate conditions associated to natural occurrence of two Amazonian native tree species for sustainable reforestation in the State of Pará, Brazil. In *Ecosystems and Sustainable Development* (Eds. Ashurst Lodge: Wittpress) (2011). Doi:<https://doi.org/10.2495/ECO110101>.
29. Monteiro, D.C.A., Martorano, L.G., Brienza Junior, S., Lisboa, L.S., Ferreira, M. do S. G. & Martorano, P.G. Condições Topobioclimáticas preferenciais para plantios energéticos de taxi-branco (*Sclerolobium paniculatum* Vogel) na Amazônia Oriental Brasileira In *Reunião Anual da Sociedade Brasileira para o Progresso da Ciência* 62 (2010). Doi: <https://ainfo.cnptia.embrapa.br/digital/bitstream/item/30000/1/3343.pdf>.
30. Gavin, D. G., Fitzpatrick, M. C., Gugger, P. F., Heath, K. D., Rodríguez-Sánchez, F., Dobrowski, S. Z., ... & Williams, J. W. Climate refugia: joint inference from fossil records, species distribution models and phylogeography. *New Phytologist* **204**, 37-54 (2014). Doi: <https://doi.org/10.1111/nph.12929>.
31. Dubuis, A., Giovanettina, S., Pellissier, L., Pottier, J., Vittoz, P., & Guisan, A. Improving the prediction of plant species distribution and community composition by adding edaphic to topo-climatic variables. *Journal of Vegetation Science* **24**, 593-606, (2013). Doi: <https://doi.org/10.1111/jvs.12002>.
32. Martorano, L.G., Martins-da-Silva, R.C.V., Brienza Junior, S., Lisboa, L.S., Monteiro, D.C. & Beltrão, N.E.S. Topoclimatic conditions and natural occurrence of copaifera spp. to support the inclusion of species in forest arrangements in the State of Para, Brazil. In *Tropentag 2014: Conference on international research on food security, natural resource management and rural development*, Prague, 2014. Proceedings. Prague: Czech University of Life Sciences, 2014. <https://www.alice.cnptia.embrapa.br/alice/handle/doc/1003994>. access in July 2021
33. INSTITUTO NACIONAL DE METEOROLOGIA (INMET). Normais Climatológicas do Brasil, 1961-1990, 2009, Brasília, DF. disponível em: <http://www.inmet.gov.br/portal/index.php?r=clima/normaisclimatologicas>. Access in July 2021
34. INMET. Normais Climatológicas do Brasil: Período de 1961 -1990 and 1981-2010. (2018). <<http://www.inmet.gov.br/portal/index.php?r=clima/normaisClimatologicas>>. access in July 2021.
35. Hijmans, R.J., Cameron, S.E., Parra, J.L., Jones, P.G. & Jarvis, A. Very high-resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**, 1965-1978 (2005). Doi: <https://doi.org/10.1002/joc.1276>.

Figures

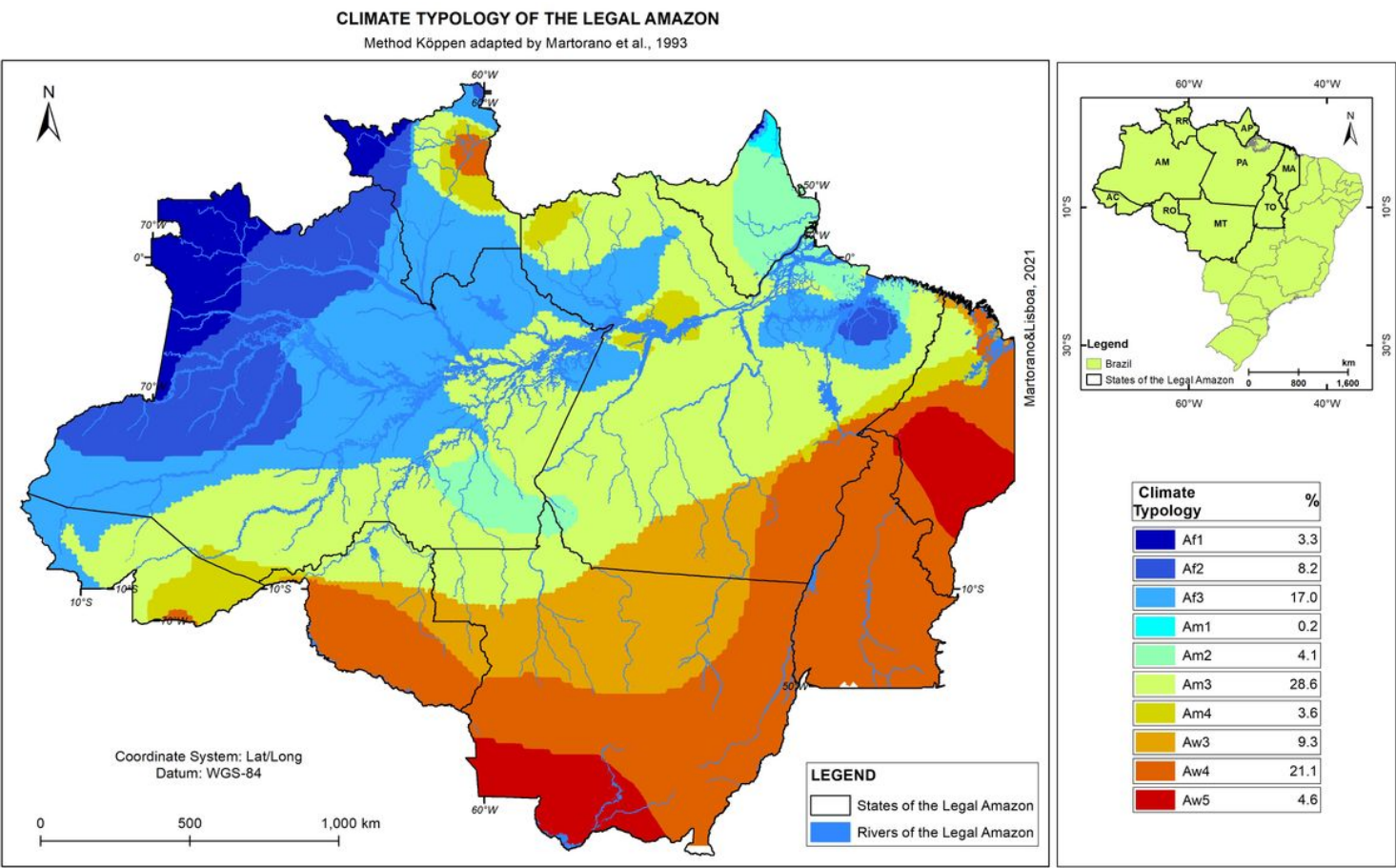


Figure 1

Climate typology of the Legal Amazon, modified from the Köppen classification system and proposed by^{15,17,20}.

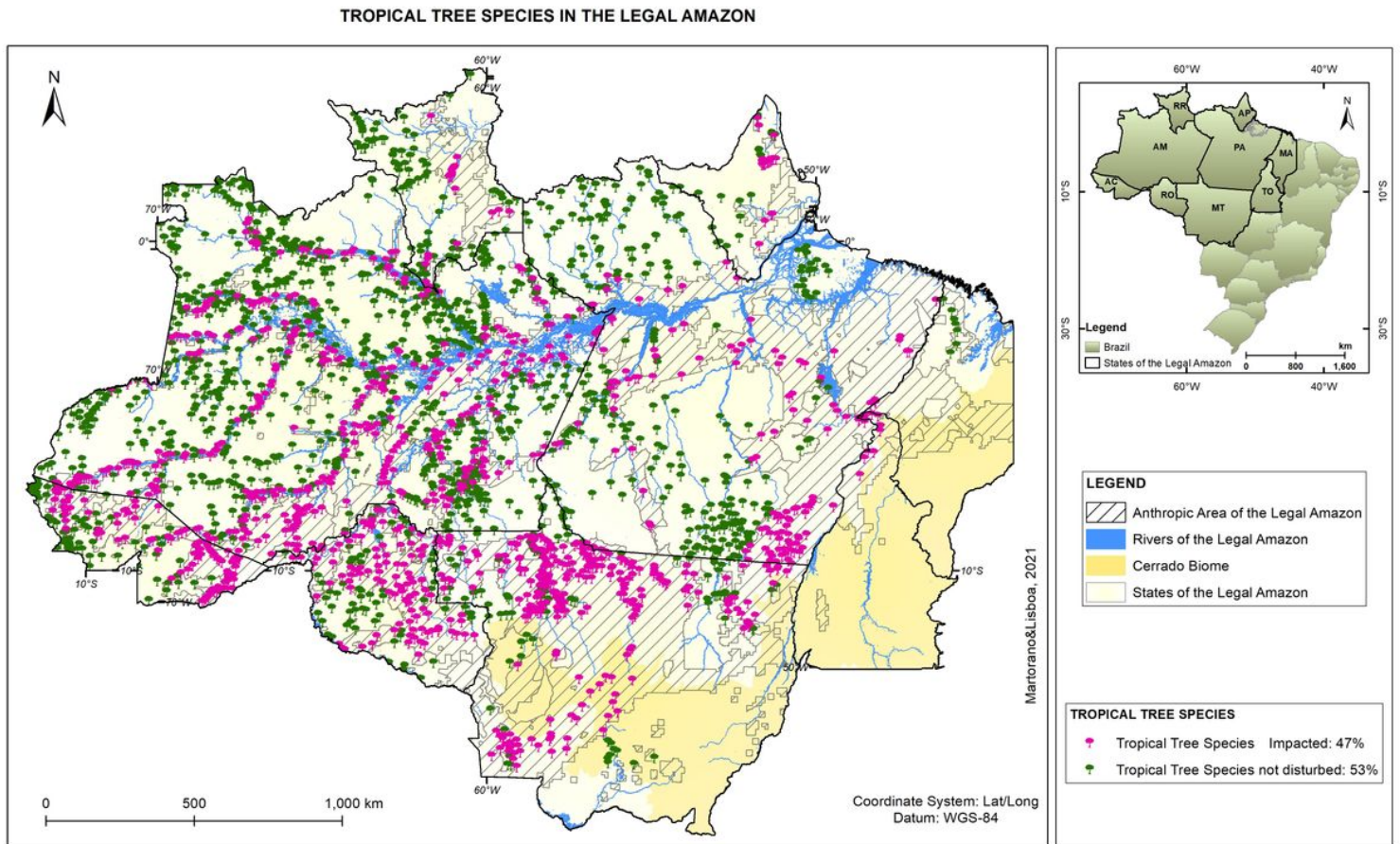


Figure 2

Areas with occurrence of native species with their respective percentages of suppression through anthropogenic processes in the Legal Amazon.

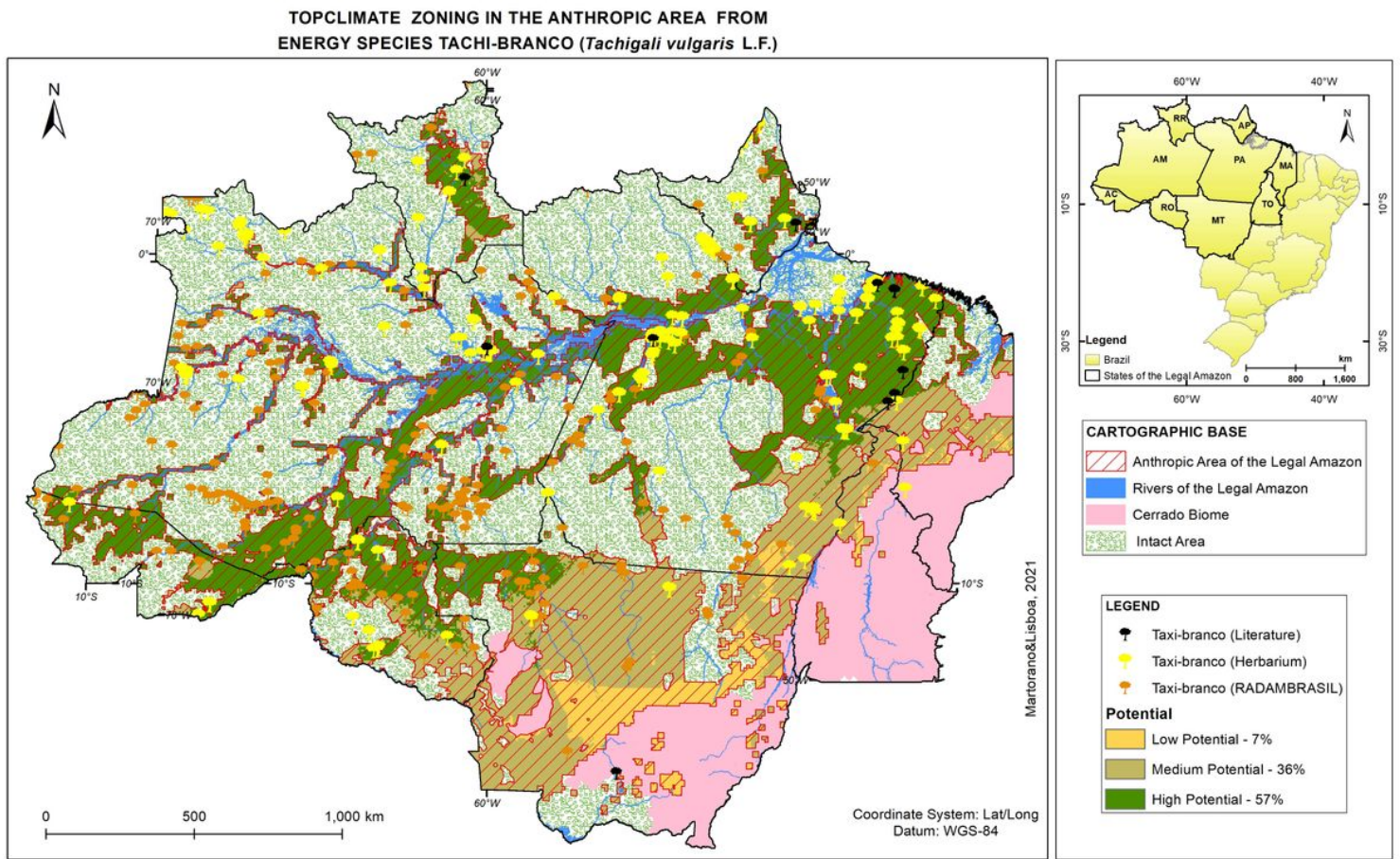


Figure 3

Topoclimatic zoning in anthropogenic areas for the biomass energy species tachi-branco (*Tachigali vulgaris*), indicating areas with high, medium, and low potential in the Legal Amazon.

GEODATABASE

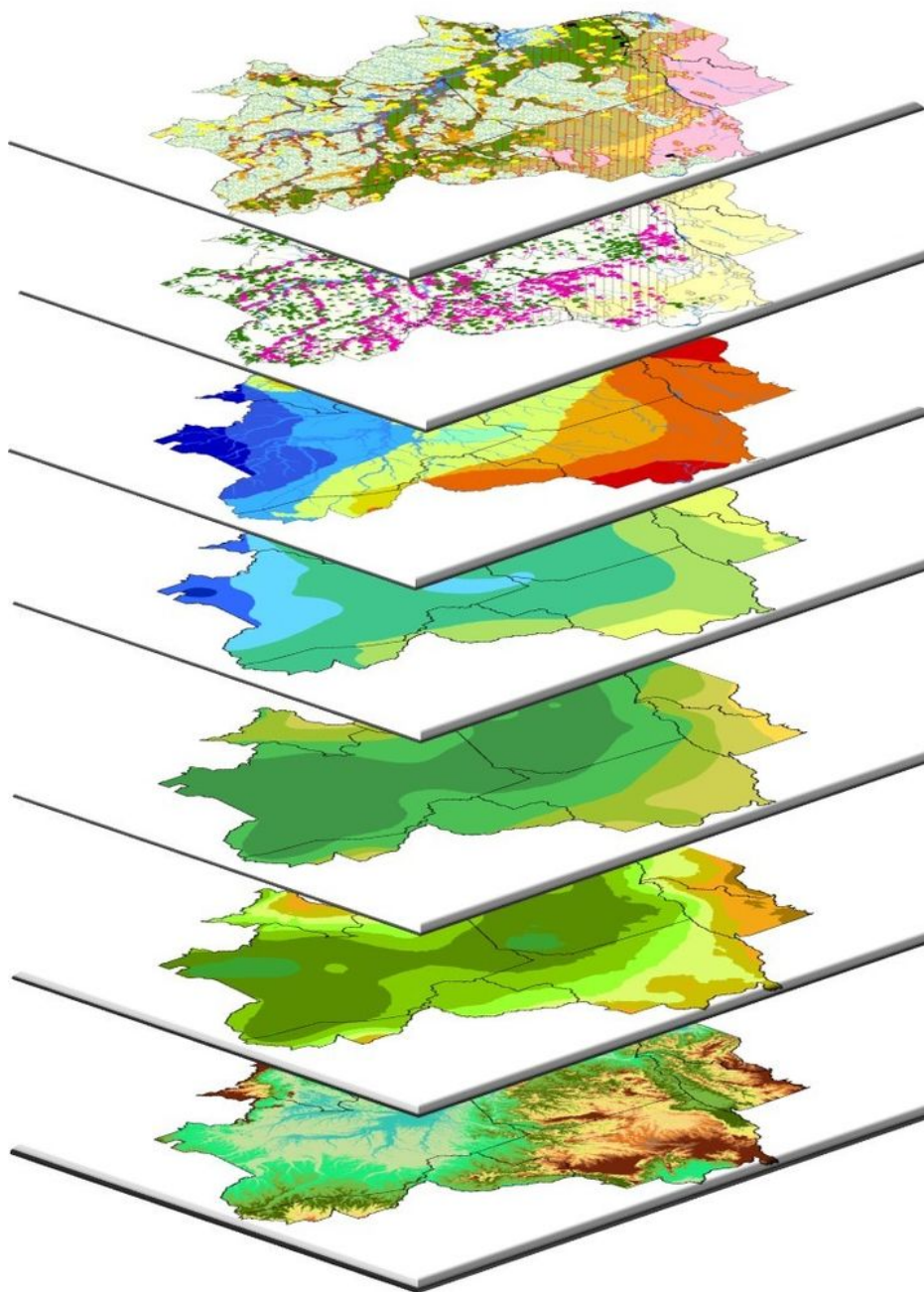


Figure 4

Schematic design of the database and information used (Hydrographic basins, Native species of silvicultural interest, data from the literature; climate database, anthropic areas, data from field experiments, Herbarium data, RADAMBRASIL data and hypsometric data) in ZoNative for species from the Brazilian Amazon.