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Article

Biodiversity in the Brazilian Amazon: Scientific Analysis and Technological Prospecting

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RESUMO

A Amazônia Brasileira figura como uma das maiores áreas ecológicas do mundo, cuja riqueza de biodiversidade animal e vegetal oportuniza significativos contributos no âmbito dos serviços ecossistêmicos. Contudo, historicamente a região vem sendo ameaçada por desmatamento acelerado e demais atividades antrópicas. Nesse sentido, emerge a pertinência de estudos de prospecção científica e tecnológica a fim de proporcionar direcionamento de esforços e investimentos orientados à sua preservação. Ante ao exposto, a pesquisa realizada teve como objetivo caracterizar as publicações científicas e as patentes de invenção que versam sobre biodiversidade e Amazônia Brasileira, de maneira conjunta. Para tanto, realizou-se uma investigação quantitativa e descritiva operacionalizada por meio de uma análise bibliométrica na base de dados *Web of Science* e de um estudo de prospecção tecnológica na base *PatentScope*. O portfólio obtido totalizou 683 artigos científicos ao passo que o conjunto de patentes de invenção foi composto por 166 registros. Os resultados demonstraram que as pesquisas sob o referido escopo podem ser divididas em três *clusters,* quais sejam: (i) mecanismos de proteção ambiental; (ii) biodiversidade de flora, e; (iii) biodiversidade de fauna. Por sua vez, o mapeamento tecnológico enfatizou a contemporaneidade do tema e as potencialidades de avanços tecnológicos sustentáveis na Amazônia os quais são fortemente legitimados pelas causalidades ambientais. Dessa forma, as contribuições da pesquisa respaldam-se na exploração dos avanços sobre biodiversidade na Amazônia Brasileira sob a perspectiva de desenvolvimento científico e tecnológico, contemplando dois indicadores centrais de progresso de determinada área. Logo, os achados obtidos podem orientar o desenvolvimento e a implementação de estratégias, bem como a consolidação de políticas públicas orientadas à cenários futuros.
Palavras-chave: conhecimento científico; desenvolvimento sustentável; inovação.

ABSTRACT

The Brazilian Amazon is one of the largest ecological areas in the world, with a wealth of animal and plant biodiversity that provides significant contributions to ecosystem services. However, the region has historically been threatened by accelerated deforestation and other human activities. In this sense, scientific and technological prospecting studies are needed to direct efforts and investments aimed at its preservation. In view of the above, the research conducted aimed to characterize scientific publications and invention patents that deal with biodiversity and the Brazilian Amazon, together. To this end, a quantitative and descriptive

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investigation was carried out using a bibliometric analysis in the Web of Science database and a technological prospecting study in the PatentScope database. The portfolio obtained totaled 683 scientific articles, while the set of invention patents was composed of 166 records. The results demonstrated that research under this scope can be divided into three clusters, namely: (i) environmental protection mechanisms; (ii) biodiversity of flora, and (iii) biodiversity of fauna. In turn, the technological mapping emphasized the contemporaneity of the theme and the potential for sustainable technological advances in the Amazon, which are strongly legitimized by environmental causalities. Thus, the contributions of the research are based on the exploration of advances in biodiversity in the Brazilian Amazon from the perspective of scientific and technological development, considering two central indicators of progress in a given area. Therefore, the findings obtained can guide the development and implementation of strategies, as well as the consolidation of public policies oriented towards future scenarios.
Keywords: scientific knowledge; sustainable development; innovation.

Introduction

The Amazon represents one of the largest ecological areas in the world, characterized by its rich biodiversity and significant contributions in terms of ecosystem services (Bhattacharya 2019). This biome has tropical rainforest as its predominant vegetation, located in South America and distributed over approximately seven million square kilometers, extending across nine countries (Fearnside 1996; Ellwanger et al. 2020).However, 60% of the Amazon is in Brazilian territory, making the Brazilian Amazon or "Legal Amazon Region" - a term also used to refer to the forest - comprise the states of the Northern Region, such as Acre, Amapá, Amazonas, Pará, Roraima, Rondônia and Tocantins, as well as part of the Midwest represented by Mato Grosso and a portion of the Northeast, with inference to Maranhão (Browder 1988; Santos et al. 2023).

Brazil is therefore of global importance in terms of conserving the biodiversity of this region (Vieira et al. 2008; Ometto, Aguiar & Martinelli 2011; Da Ponte et al. 2015), which has been constantly threatened by anthropogenic activities (Lapola et al. 2023). As a consequence, other externalities become latent since the Amazon rainforest accounts for half of the carbon stored in tropical forests worldwide (Pan et al. 2011).

Thus, concerns about the fate of Amazonian biodiversity are imminent, since the biome's paleoclimatic stability is threatened by anthropogenic disturbance (Peres et al. 2010). Thus, the deregulation of the local and regional climate also emerges as a direct reflection of progressive deforestation (Backer & Spracklen 2019), which corresponds to the main degradation observed in the biome (Guerra et al. 2020).

In other words, this issue is considered inseparable from slowing down global climate change (Silva et al. 2023), the complexity of which intensifies in relation to tropical forests (Rödig et al. 2018). As a consequence, heat waves, floods, droughts and storms are devastating terrestrial and aquatic life (Nepstad et al. 2008; Battisti & Naylor, 2009), causing the disappearance of species of fauna and flora (Mu & Jones 2022; Nunes et al. 2022) and making the future dubious for the next generations (França et al. 2020).

However, while recognizing the scientific and political efforts made to conserve the Brazilian Amazon, it is also clear that public funding for research is still incipient in this biome (Stegmann et al. 2024). In line with this, there is an intensification of community concern in all its dimensions - including scientific and technological - about directing efforts towards the preservation of biodiversity and related environmental services (Rosa et al. 2021).

In this sense, bibliometric studies are relevant, as they provide an opportunity to verify multiple characteristics of bibliographic production on various topics (Salinas-Ríos & García López 2022). Thus, since the 1990s, such research has become prominent, especially in view of its potential to contribute to decision-making processes on budgets and the allocation of resources and efforts by the scientific community (Bornmann & Leydesdorff 2014).

Thus, technological innovation promoted in Amazonian territories also tends to provide opportunities for the commercial exploitation of products from biodiversity (Coutinho 2004), as these have natural compounds that can be used in the development of cosmetics, medicines, etc. (Teixeira et al. 2019; Feldmann 2021). Thus,

technological innovations that involve the search to commercialize products from the Amazon's biodiversity (Visentin 2011) can help to keep the forest standing by generating sustainable value (Pimentel et al. 2015).

Another relevant aspect is the development of technological innovations aimed at preserving the biodiversity of this biome. However, it is recognized that there is a conflicting relationship between economic growth and biodiversity conservation, and technological progress is seen as a way of mitigating this situation (Czech 2008). That said, technological efforts can bring benefits to the field of environmental economics (Popp et al. 2010).

In view of the above, scientific and technological mapping makes it possible to broadly investigate the efforts made to promote an area (Amparo, Ribeiro & Guarieiro 2012), reflecting the current stage of Research & Development (R&D) in the field of Amazonian biodiversity - which has a positive impact on economic and social development (Nascimento et al. 2021). Therefore, the aim of this research was to quantify and characterize the scientific publications and invention patents that deal with the themes of biodiversity and the Brazilian Amazon.

In this way, the study falls within the scope of scientific and technological foresight research, which hegemonically relies on the analysis of scientific articles and patents as basic indicators of progress in R&D (OECD 2005). In other words, this type of research makes it possible to ascertain the stage of development of a given sector (Vincent et al. 2017; Linhares et al. 2018) and to provide information about the frontier of knowledge to different spheres of society (Tseng et al. 2007).

Therefore, studies using this approach are particularly important for guiding decisions oriented towards future scenarios, as the neo-Schumpeterian trilogy of innovation (invention - innovation - diffusion) advocates that invention corresponds to the stage that precedes the commercial exploitation of a technology (innovation) and its consequent adoption and dissemination (diffusion) (Schumpeter 1936). Thus, the research explores advances in biodiversity in the Brazilian Amazon from the perspective of scientific and technological development, taking into account two central indicators of progress in a given area (Shelton & Leydesdorff 2012).

Methodological Procedures

The research carried out is characterized as quantitative and descriptive, operationalized through two sequential and complementary stages, namely: (i) bibliometric analysis, and; (ii) technology foresight study. Therefore, this section presents the methodological procedures used for data collection and analysis in each of the stages, highlighting their systematization.

Bibliometric analysis

According to Borgman and Furner (2002), bibliometrics is an investigative procedure that aims to identify patterns and trends in scientific literature. The use of this method has been intensified in recent years due to the maximization of the volume of scientific data, making it possible to verify the evolutionary nuances of a field of study in line with the identification of emerging areas of research (Donthu et al. 2021). To this end, bibliometrics uses the scientific article as its analytical unit (Salinas-Ríos & García López 2022).

Furthermore, bibliometric analysis is based on three main classical laws, namely: Lotka's Law, Bradford's Law, Zipf's Law (Lawani 1981; Machado Júnior et al. 2016). The first of these concerns the contributions of each author to the development of a scientific field, weighing up their absolute distribution (Kushairi & Ahmi 2021). It can also be called the Inverse Square Law and proposes that a small number of researchers are responsible for a high number of publications, while a few authors contribute too few studies (Lotka 1926).

In turn, Bradford's Law deals with the existence of a set of journals specialized in a particular subject or scientific field (Machado Júnior et al. 2016), and is also known as the Law of Dispersion (Rousseau & Rousseau 2000). In other words, Bradford (1934) postulates that this law is based on the hypothesis that there is a specialized subset of scientific journals on a specific subject, with other journals with a broader scope permeating its margin. Therefore, the application of this law provides mechanisms for selecting journals with greater relevance to a given area of knowledge (Alvarado 2016).

Notwithstanding, Zipf's Law, also known as the Law of Minimum Effort, is based on checking the incidence or recurrence of words in passages of text (Machado Júnior et al. 2016). Thus, it creates a *ranking* of the occurrence of terms considered to be the main ones in a given text (Fairthorne 1969). In this way, it contributes to the identification of descriptives that pulverize scientific documents and provide an opportunity for their lexical interpretation (Lobo & Barwaldt 2023).

The database selected for the search was *Thomson Scientific*'s *Web of Science*, which is an important resource for providing scientific literature in different areas of knowledge (López-Illescas et al. 2008). It was the first worldwide bibliographic database and has been the only source of information of this nature for over forty years (Bass et al. 2020; Pranckuté 2021), which justifies its relevance for bibliometric analysis (Li et al. 2018).

As a search guideline, the following terms and Boolean operators were defined, which should be contained in the "*topic*" field: "*biodiversity*" *AND* "*Brazilian Amazon*". The inclusion of terms in the English language is justified by its hegemony in the scientific context, being considered "the lingua franca of science" (Álvares 2016). Therefore, it is understood that using this language to select documents enhances the scope of the investigation, as it is used by scientists all over the world to communicate their scientific discoveries (Drubin & Kellogg 2012).

The selected document typology was articles, and the publication period included all years up to March 12, 2024. This resulted in a portfolio of 683 documents. Data analysis considered the three classic laws of bibliometrics, as well as the time distribution of publications, country and affiliation of authors and co-occurrence of terms.

In order to assist in data organization and analysis, electronic spreadsheets from Microsoft Excel software were used. Additionally, the VOSviewer software was employed, which enables the creation and exploration of graphical representations in Euclidean spaces based on data networks (Arruda et al. 2022). In other words, it is based on the clustering of publications and the proposition of resulting clusters (Van Eck & Waltman 2017).

Technological Prospecting Study

As far as technological prospecting research is concerned, the technical procedure used was patent analysis, which corresponds to the standard procedure for operationalizing this type of study. The database used for the search was PatentScope. PatentScope is a free technology intelligence tool developed by the Intellectual Property Organization in collaboration with national and regional patent offices, whose worldwide reach includes more than 115 million patent documents and provides access to international Patent Cooperation Treaty (PCT) applications, demonstrating its relevance (OVTT 2024; WIPO 2024a).

The search field considered the title, abstract and claims of the patent documents. The following terms and Boolean operators were used: "Amazon" AND "Biodiversity". It should also be noted that the search was carried out in English due to its hegemony in the scientific and technological environment - so much so that there are tools that enable patent documents to be translated into and from English (List 2012).

Thus, the publication period corresponded to all the years up to March 20, 2024, which resulted in a portfolio made up of 166 documents from patent families. As an analytical procedure, the following variables

were considered: year of patent publication, priority country (where the technology was commercially protected), signatories, area of classification of the invention and essence of the proposed technology.

Microsoft Excel spreadsheets were used to help organize the data and carry out the analyses. The results were presented using graphical representations and illustrative diagrams. Lastly, the findings were compared with those from other scientific studies in order to elucidate the panorama of technological development in biodiversity and the Amazon.

Results and Discussion

Based on the search criteria and guidelines used in the bibliometric analysis, a scientific portfolio comprising 683 articles was obtained, the first of which was published in 1994. In contrast, the prospecting study showed that the first patent document that made up the technological portfolio investigated was published in 1998, with the last five years (2019-2024) accounting for around 45.18% of the patents verified. Figure 1 shows the time distribution of both portfolios of documents obtained.

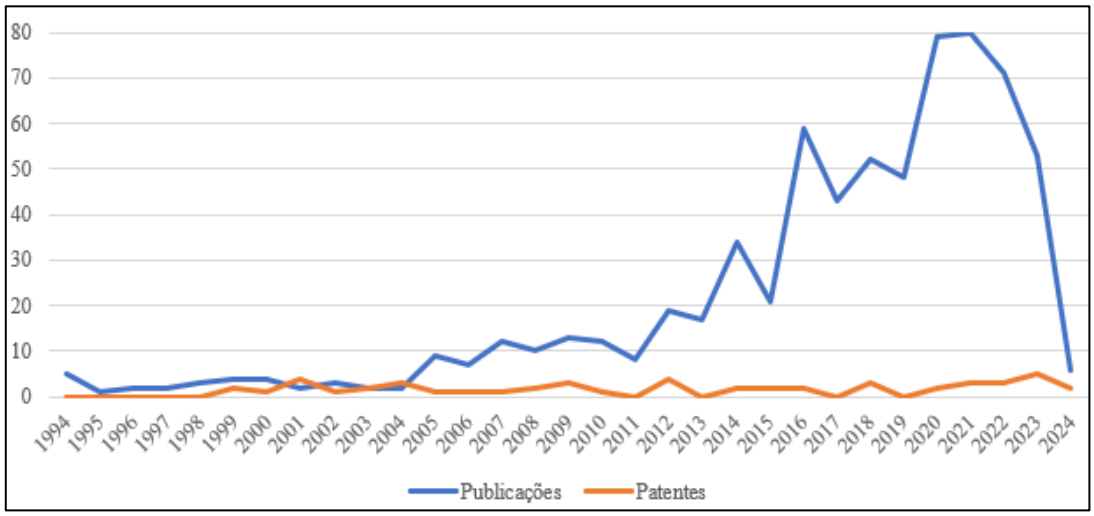

Figure 1. Time distribution of the scientific and technological documents analyzed. Source: research results (2024).

The results show that "biodiversity" and the "Brazilian Amazon" when treated together are an emerging topic of study, with the last five years (2019-2024) accounting for almost half (49.34%) of the total number of articles analyzed. Similarly, over time, especially since 2020, there has also been a significant increase in interest in enabling technologies related to the Amazon and biodiversity. This finding can be explained by the maximization of environmental concerns around the world, as well as the exploitation of the commercial potential of products from Amazonian flora.

Accordingly, Bradford's Law was also found in the scientific studies investigated. In this sense, the articles are distributed across 281 different journals, with 60.14% accounting for just one publication. On the other hand, 2.14% of the journals account for 17.0% of the publications, which is the set of specialized journals in the area. Table 1 shows the most prominent journals on biodiversity and the Brazilian Amazon.

Table 1. Main journals on biodiversity and the Brazilian Amazon

Journal	No. of publications	JCR*	Publisher
Plos One	25	3,7	*Public Library Science*
Biodiversity and Conservation	22	3,4	*Springer*
Biological Conservation	21	5,9	*Elsevier*
Forest Ecology and Management	21	3,7	*Elsevier*
Land Use Policy	14	7,1	*Elsevier*
Ecological Indicators	13	6,9	*Elsevier*

Journal Citation Report.

It was found that the publisher with the most scientific journals whose scope is centered on the subject under investigation is Elsevier. It is also responsible for the journals analyzed with the highest impact factor, known as JCR. This is an index used by the Web of Science since the 1950s which assesses the importance of a journal based on the number of citations (Garfield 2006; Leydesdorff 2006).

Furthermore, 200 authors were responsible for developing the total number of articles that made up the portfolio analyzed. Of these, three deserve to be highlighted due to the amount of scientific research on biodiversity in the Brazilian Amazon to which they contributed: Jos Barlow (33 publications), Júlio Louzada (20 publications) and Carlos Peres (20 publications).

The author who has contributed most to research on the subject is affiliated to *Lancaster University* in the UK, where he teaches in the area of Conservation Sciences. His research addresses the impacts of anthropogenic activities on the biodiversity of tropical forests and the provision of ecosystem services, and he has been studying the Brazilian Amazon since 1998. The researcher has published a total of 244 scientific documents on the *Web of Science*, cited more than 17,000 times, giving him an H Index of 65, which indicates the quality and relevance of his studies. Therefore, based on the results obtained, it is possible to infer that this is the author who contributes most to the advancement of the subject under investigation, in line with Lotka's Law.

Júlio Louzada, affiliated with the Federal University of Lavras, in Brazil, and has 101 scientific documents available on the Web of Science database, totaling more than four thousand citations and giving him an H Index of 35. His research interests focus on ecology and conservation, and between 2012 and 2017 he was an associate professor at Lancaster University. Thus, much of his research was carried out in partnership with the aforementioned author, which demonstrates the importance of research collaboration and inter-institutional cooperation for the promotion of science.

Nonetheless, the author Carlos Peres is also Brazilian and currently works as a visiting professor at the Federal University of Paraíba in Brazil and a professor at the University of East Anglia in the UK. His publications comprise 426 documents included in the Web of Science, which total more than thirty thousand citations and give him the highest H Index among the three researchers shown, corresponding to 94. He was one of the founders of the world's leading research groups in tropical forest ecology and conservation, of which the two researchers mentioned above are also members.

Regarding to the countries of origin of the authors responsible for the portfolio of studies analyzed, the findings show that they come from 62 different countries. Of this total, Figure 2 shows those regions with the highest recurrence and which have at least five corresponding documents.

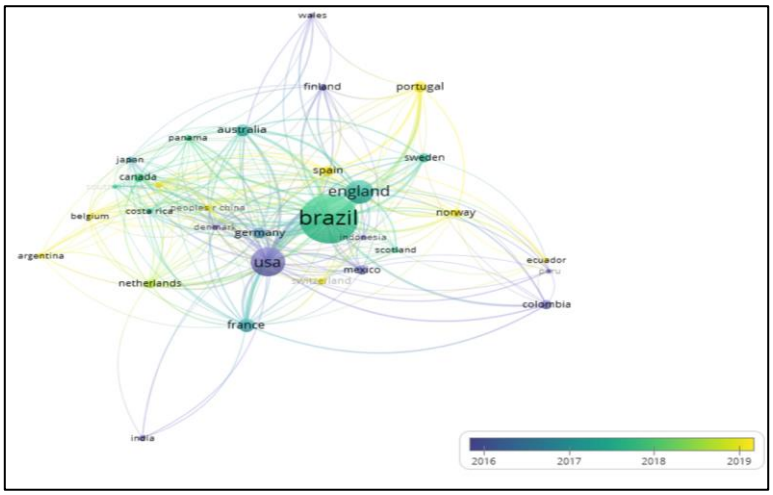

Figure 2: Authors' main countries of origin. Source: prepared using *VOSviewer software* (2024).

Brazilian authors are predominant, accounting for 78.04% of the articles analyzed. This finding can be justified by the fact that the subject involves the Brazilian Amazon, since Brazilian researchers are geographically close to the region, which makes it feasible and easy to collect primary data, for example. This was followed by 27.4% of studies involving authors from the United States and 19.3% involving scientists from England.

It is also clear that in this type of graphic representation in network format, in addition to the vertices or terms whose size expresses their incidence, there is an association between them. In other words, it is possible to see the dynamics of collaboration between organizations from different countries in the development of research into biodiversity and the Brazilian Amazon.

Given this panorama, we then proceeded to check the organizations with which the researchers are affiliated. Thus, the portfolio of articles derives from the collaboration of 963 different teaching and research organizations, 92 of which contribute at least five articles. Figure 3 shows the density network which allows us to visualize the predominant organizations, with the lighter the color, the greater the incidence of the organization.

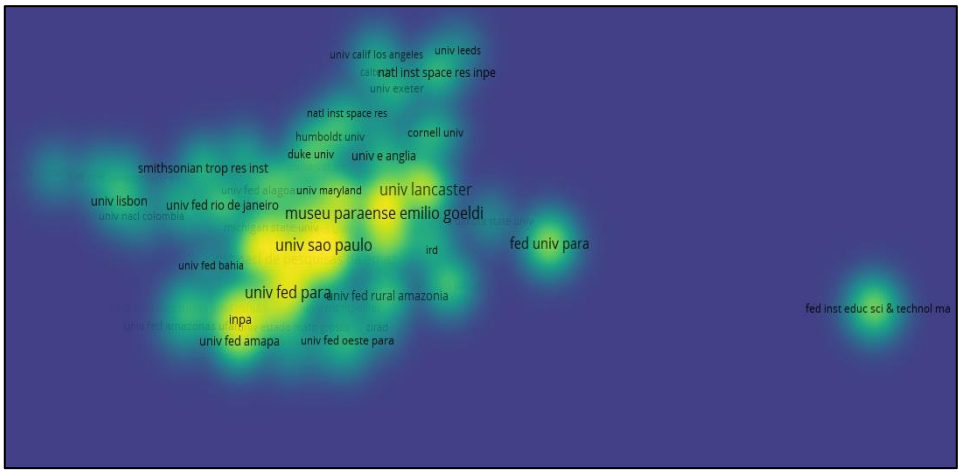

Figure 3 - Visualization of the density of the authors' affiliation organizations. Source: prepared using *VOSviewer software* (2024).

It is observed that the University of São Paulo is one of the world's leading organizations directing research efforts towards this subject. In addition, Zipf's Law was used to analyze the predominant terms in the titles of

the articles analyzed. According to Serra and Ferreira (2014), this field of the scientific document presents elements that make the connection with what is being studied, giving the reader or reviewer an idea of what they might find. It therefore summarizes the essence of the research carried out (Figueiredo 2001).

Hence, Figure 4 illustrates a word cloud generated from the terms contained in the titles of the analyzed articles. It should be noted that the size of each term is proportional to its incidence, with the most prominent referring to those with prominence.

Figure 4 - Word cloud of the predominant terms in the titles of the articles analyzed. Source: prepared using *WordArt software* (2024).

It is evident that the terms used as search guidelines were more recurrent. Similarly, "*forest*", "*species*", "*deforested*" and "*land*" also stood out, which can be explained by the scope of the research carried out. In line with this, it is also understood that keywords are the main descriptors used to index scientific articles and guide searches (Figueiredo 2001). The importance of such terms is intensified in the area of ecology, evolution, biology, conservation and related fields since there are no standardized descriptors (Grames et al. 2019).

Nevertheless, the portfolio analyzed showed 3,497 distinct keywords, 239 of which recur at least five times. This resulted in a descriptor co-occurrence network made up of 6,409 associations, as shown in Figure 5.

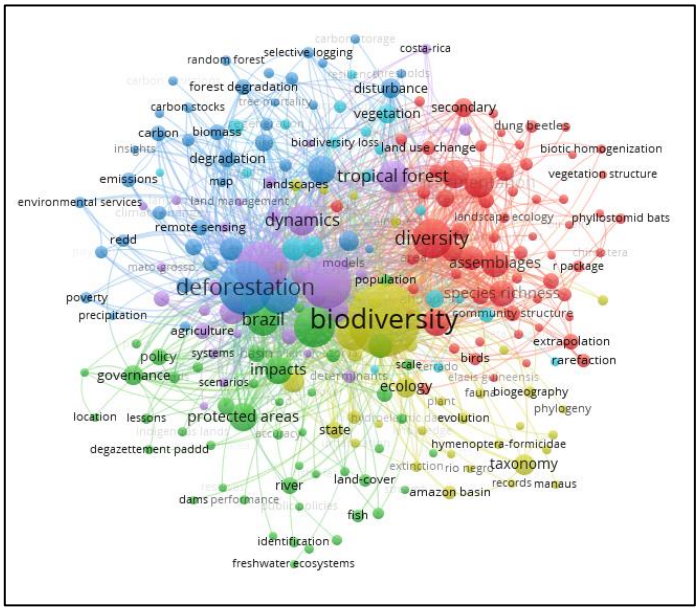

Figure 5 - Co-occurrence network of predominant keywords. Source: prepared using *VOSviewer software* (2024).

Keywords are particularly important since, together with the title, they express the central approaches of the studies analyzed. We then proceeded to analyze the co-occurrence of terms in the title and abstract of the

scientific documents. In order to do so, we used the binary counting method and considered the incidence of each term to be at least ten times. This resulted in 427 terms, of which the 60% with the greatest relevance are shown in Figure 6.

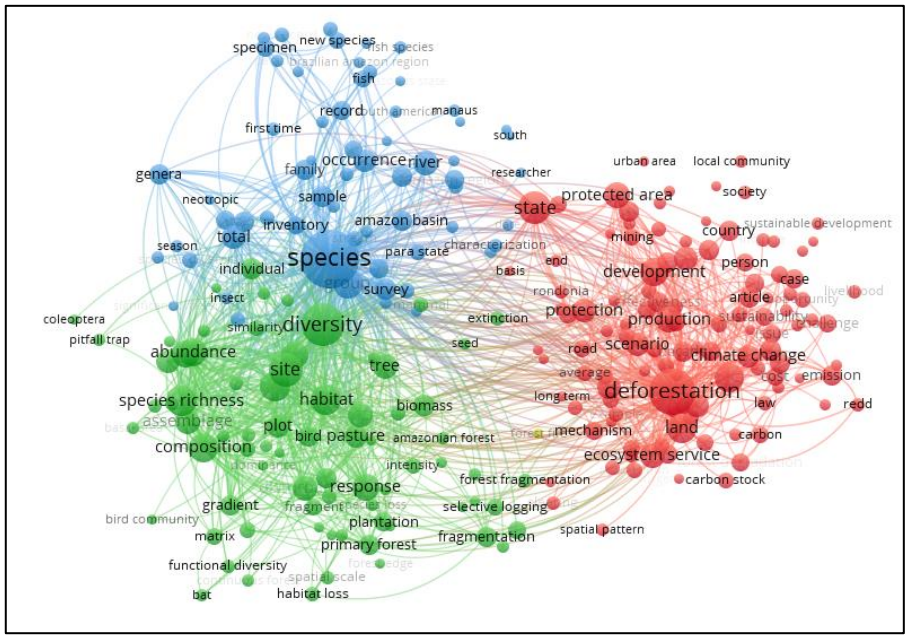

Figure 6 - Co-occurrence network of predominant terms. Source: prepared using *VOSviewer software* (2024).

We can see a network made up of 256 vertices or terms and 17,197 associations distributed in three clusters separated by color. It should be noted that the size of the vertices and their respective labels is proportional to the strength of the association, making some markers invisible to avoid overlap (Van Eck & Waltman 2017; Korom 2019). The predominant association in each cluster is as follows: (i) red cluster, made up of 115 vertices; (ii) green cluster made up of 77 vertices, and; (iii) blue cluster made up of 63 vertices.

The red cluster can be called "Environmental protection mechanisms", as it includes research on deforestation, land use, ecosystem services, carbon sequestration, among other related sub-themes. Studies under these scopes have expanded worldwide in recent years, providing subsidies for decision-making in the political and environmental management spheres (Milheiras & Mace 2019). Although investigating tropical rainforests — such as the Amazon Forest — is important due to the massive flows of carbon and nutrients in accordance with changes in land use and agricultural expansion (Boener, Mendoza & Vosti 2007).

In turn, it is possible to call the green *cluster* "Flora biodiversity of the Brazilian Amazon", as it brings together research into tree diversity, pastures and biomass, for example. According to Stropp et al (2020), the plant biodiversity of the Brazilian Amazon is strongly threatened by deforestation, and poor documentation in this regard contributes to the loss of knowledge about unique species that once inhabited the area. Therefore, studies under this aegis are essential to encourage environmental preservation and the maintenance of the standing forest.

The blue *cluster*, on the other hand, is made up of the smallest portion of the studies analyzed, whose name corresponds to "Biodiversity of fauna in the Brazilian Amazon", since it addresses issues related to animal species, insect populations and even human insertion in this context. Azevedo-Ramos and Galatti (2002) highlight the wealth of animal diversity in the region, showing evidence of more than 160 species of amphibians, some of which are exclusive to the Brazilian Amazon. The relevance of such themes also includes the medicinal use of local fauna based on procedures carried out by traditional communities, which denotes the appreciation and proximity of native peoples to biodiversity (Barros et al. 2012).

In line with this, Gentry (1992) points out that the Brazilian Amazon has one of the most diverse and rich biodiversities in the world, both in terms of flora and fauna. Furthermore, it is recognized that for centuries, the Amazon rainforest has permeated the popular and scientific imagination of the Western population as being a dense forest, minimally inhabited by small traditional communities and practically untouched (Heckenberger et al. 2007), which today is perceived as a utopian vision.

Therefore, studies that analyze this region are fundamental for drawing up guidelines for sustainable development, both in terms of management strategies and in mitigating externalities arising from anthropogenic activities (Ritter et al. 2017). In addition, consideration of the social impacts on the way of life of the traditional peoples who inhabit the region also requires attention (Codeço et al. 2021).

With regard to the portfolio of technological documents, consideration was given to the codes under which the patents analyzed are classified. To do this, we looked at the *International Patent Classification* (IPC), created in 1971 through the Strasbourg Agreement. In essence, this classifies technological areas into classes ranging from A to H. These, in turn, are divided into subclasses through a hierarchical system made up of more than 70,000 groups (Brasil 2015).

In other words, patents are classified according to their technology and not in terms of products (Jaffe 1986). In an analogy with scientific production, it can be said that while publications are organized in journals, patents are structured in classification systems, including the IPC (Leydesdorff et al. 2014). However, it should be noted that each patent can be classified under more than one IPC code, denoting its scope and adherence to other technological domains. As a result, there were ten predominant patent classifications in the portfolio analyzed, as shown in Table 2.

It should be noted that the classifications belonging to subgroups C12 (in this case, C12N, C12P and C12Q) deal with biochemistry, microbiology, enzymology, genetic engineering and other related elements. In turn, the patents in class G06 (in this case, G06Q, G06F and G06N) deal with computing, calculation or counting. However, technologies under the A61 classification (in this case, A61K and A61P) include artifacts in the context of hygiene, medical and veterinary sciences. Class C07 covers organic chemistry, while A01 covers technologies within the scope of agriculture, livestock, hunting and fishing (WIPO 2024b).

With regard to the signatories of the patents - that is, organizations or people who hold the intellectual property rights - ten organizations account for more than a third (36.75%) of the total number of patents on the Amazon and biodiversity available on *PatentScope*. Among them is the *Washington State University Research Foundation*, which accounts for 17 documents, all of which relate to technologies for recombinant enzymes and proteins, as well as their methods of use.

Furthermore, among the predominant signatory organizations there is only one Brazilian: the Brazilian Agricultural Research Corporation (EMBRAPA). The institution contributes with four patent registrations on the development of proteins from the web of three typical spider species from the Brazilian Amazon (*Nephilingis cruentata*, *Nephilingis cruentata* and *Avicularia juruensia*). In essence, the inventions include the development of nucleic acid molecules that encode spider web proteins, as well as the transformation of cells containing a chimeric gene. They also describe biofilms and compositions that can be obtained from these microbiological and biochemical processes.

As for the territories in which the technologies were commercially protected, 21.08% of the patents analyzed had *Patent Cooperation* Treaty (PCT) applications. By filing an international patent application under the PCT, it is possible to obtain simultaneous protection for a technology in 157 countries, including Brazil (WIPO 2024c). It should be noted that over the last few years PCT applications have intensified, with a high grant rate and superior quality in terms of technological artifacts (Zhao 2022).

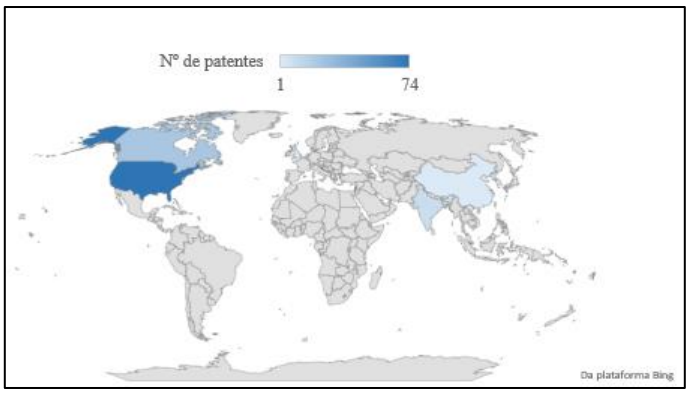

Figure 7. Geographical distribution of individualized protection of the patents analyzed Source: research results (2024).

Moreover, it is possible to apply for patents on an individual basis in each country where the technology is believed to have commercial exploitation potential. However, it should be noted that the institutional environment related to intellectual property management and the drafting of technological development policies are not uniform throughout the world, which implies significant differences between countries (Papageorgiadis & Sofka 2020). In this sense, Figure 7 shows the geographical distribution of individualized patent protection in the Amazon and biodiversity on a scale of intensity of incidence.

Table 2 - Predominant classification of the patents analyzed

IPC code	Description	No. of patents
C12N	Microorganisms or enzymes; their composition; propagation, preservation or maintenance of microorganisms; mutation or genetic engineering; culture media	45
G06Q	Information and Communication Technologies [ICT] specially adapted for administrative, commercial, financial, management or supervisory purposes; systems or methods specially adapted for administrative, commercial, financial, management or supervisory purposes, not otherwise provided for	37
A61K	Preparations for medical, dental or personal hygiene purposes	31
C07K	Peptides	23
C12P	Fermentation processes or the use of enzymes to synthesize a desired compound or chemical composition or to separate optical isomers from a racemic mixture	20
C12Q	Measuring or testing processes involving enzymes, nucleic acids or microorganisms; compositions or test papers for the same; processes for preparing such compositions; condition-responsive control in microbiological or enzymological processes	18
G06F	Electrical-digital data processing	17
G06N	Computing arrangements based on specific computing models	10
A01N	Preservation of human or animal bodies or plants or parts thereof; biocides, e.g. as disinfectants, pesticides or herbicides; pest repellents or attractants; plant growth regulators	9
A61P	Specific therapeutic activity of chemical compounds or medicinal preparations	8

Source: survey results (2024).

There is a predominance of patents protected in the United States, corresponding to 44.58% of the portfolio analyzed. In addition to the territories indicated in the figure above, the European Patent Office (EPO) has eight registered documents. In a nutshell, this organization provides protection for technologies in around 40 European countries simultaneously, as it is the executive arm of the European Patent Organization (MCTI 2024).

It should be noted that although EMBRAPA is responsible for invention patents on biodiversity and the Amazon, Brazil is not among the countries in which individual technology protection has been sought. In other words, all the artifacts that have PCT applications have been protected in multiple territories, including Brazil, but there has been no record of specific protection in the country. In this sense, Oliveira and Marques (2014) show that EMBRAPA has a collection of 129 patent applications in Brazil and 89 abroad, denoting the importance of the organization for the country's technological and, consequently, economic development.

In addition, EMBRAPA articulates and makes feasible technologies aimed at the sustainable development of agribusiness based on bioeconomic aspects, becoming a benchmark for induced and successful institutional innovation (Bueno et al. 2021), both nationally and internationally. It is therefore no surprise that it is on the list of signatories of patents that include biodiversity and the Amazon in their scope, ensuring representativeness for national research, science and technology.

In line with this, Santos et al. (2023) found that most of the patents involving the flora of the Atlantic Forest biome were also developed and filed outside Brazil. This finding corroborates the idea that biodiversity has become an important focus of interest for technological development, which can contribute to its preservation. This is important since technological innovation, as a rule, drives further innovation, consolidating a virtuous circle of development, which tends to encourage the conservation of natural ecosystems (Simmonds et al. 2020).

However, it is estimated that approximately 90% of the world's genetic resources are found in developing countries, while 90% of R&D activities take place in developed countries (Visser 2006). Thus, despite the complexity and political dissonance between patents as a mechanism to stimulate environmental preservation and their imperative without reference to conservation objectives (Lawson 2010), the articulation of efforts and resources to promote technologies based on biodiversity, providing global gains, becomes prominent.

With regard to the essence of each patent analyzed, it can be seen that they permeate different areas of knowledge, ranging from aspects inherent in computer engineering to biochemical elements, for example. Figure 8 shows a word cloud based on a lexical analysis of the terms contained in the titles of the patent documents, with the size of each word being proportional to its incidence.

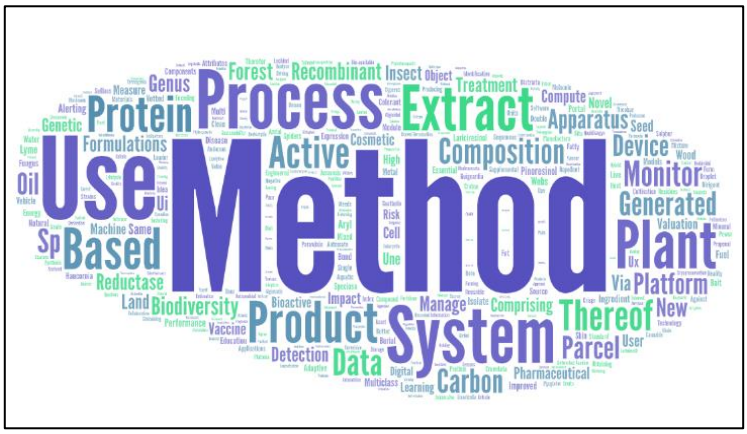

Figure 8. Word cloud from lexical analysis of the title of the patents analyzed. Source: research results (2024).

It can be seen that the majority of patent documents deal with technologies related to production and use methods and processes. Among the products featured are those relating to plant and fungal extracts, essential oils, active formulations and recombinant proteins, as well as technologies used for environmental monitoring, carbon sequestration, energy use, tropical forest specificities and other environmental implications.

Nevertheless, in general, the cosmetic and pharmacological potential of components from Amazonian biodiversity is a basic element of the technological artifacts investigated, which denotes the richness of the flora and fauna of natural biomes. Similarly, R&D efforts have been made to enable technologies aimed at environmental monitoring and the optimization of natural resources, which explains the significant number of patents under this scope.

However, it is recognized that the patentometric study is a complex analysis. Its challenges derive mainly from the language and terminology used in patent documents in order to purposely hinder understanding and make the technology described less clear and comprehensible (Verbene et al. 2010). In addition to aspects concerning novelty, patent information can also be used for strategic purposes related to competitive advantage, which explains the imposition of intrinsic limits in patent documents (Cesaroni & Baglieri 2012).

Despite these difficulties with text mining and extracting data from documents, the contributions made by patent studies are undeniable, as they derive from information stored in consolidated knowledge bases (Abbas et al. 2014). Therefore, there are insights that can foster environmental preservation in the Amazon by recognizing the innovative and commercial potential of products from its biodiversity.

Final considerations

The results obtained showed that research into biodiversity and the Brazilian Amazon is heterogeneous and multifaceted. It was also found that scientists' interest in the subject is relatively recent, with an emphasis on the last few years. This may reflect the maximization of environmental concerns arising from climate change, as well as the intensification of the complexity of discussions on these aspects.

Thus, the study's contributions are based on elucidating the panorama that characterizes international scientific publications, providing *insights* for new research. It also identifies the journals with the greatest relevance to the area, as well as the most influential authors. In addition, we consider the teaching and research organizations that are exploring the subject, highlighting the importance of collaboration and inter-institutional and international cooperation for the promotion of science.

Similarly, from the basic analysis of patents on biodiversity and the Amazon, it can be seen that environmental pressures have intensified sustainable technological prospecting in this biome, which explains the increase in intellectual property registrations over the last five years. Among the innovative opportunities, it can be seen that the technologies emerge in different areas of knowledge, making for a multidisciplinary connotation in line with biology, computing, medical and agricultural sciences, for example.

However, although the Amazon is the largest territory in Brazil, it can be seen that international institutions play a greater role in patent registration, since only EMBRAPA appears in *PatentScope*. In addition, the United States stands out as the territory with the largest number of patents protected. This finding indicates a fertile field to be explored by Brazilian organizations and is the *insight of* this study.

Notwithstanding, the limitations of the research regarding the lack of in-depth analysis of the content of the reviewed articles are acknowledged. Furthermore, for future studies, it is recommended to include additional search filters to identify articles with greater representativeness in order to conduct a systematic literature review. In addition, an analysis of the national literature landscape concerning all Brazilian biomes is also suggested, aiming to identify similarities and differences among the investigations.

Finally, it is highlighted that patent records face limitations in presenting innovations due to their confidential nature. Therefore, it was not possible to further explore and exemplify the potential products that may enter the market in the next decade. Furthermore, it is suggested that future studies on this topic consider the integrated use of other patent databases, such as Questel Orbit, recognized as one of the main global access platforms with unique analytical tools available.

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