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Bioeconomic markets based on the use of native species (NS) in Brazil

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ABSTRACT

Biodiversity markets offer considerable promise but are accompanied by controversies. Here, we map the utilization of native species (NS) from Brazil's biodiversity across eleven industrial sectors: foodstuffs, beverages, textiles, clothing, leather, wood, pulp and paper, biofuels, pharmochemicals, rubber and furniture. We show that there exists a diverse range of NS use in industrial products (48%) and activities (73%). These economic activities represent potential annual exports of approximately USD $50 billion. However, we found that only 1% of the potential business, USD $500 million of annual exports, is consolidated and can be traced to such products. We show that biodiversity markets and larger annual revenues locate in municipalities away from places in which biodiversity products originate. Therefore, the biodiversity business in Brazil remains largely untapped. This prompts a critical examination of the role of biodiversity within the Brazilian industry and its alignment with the Brazilian Biodiversity Law and the Nagoya Protocol. Our study is a pioneering effort that provides strategic recommendations. We suggest that the responsibility for sustainable NS utilization predominantly falls on sectors dominated by major corporations, most notably pharmochemicals and biofuels. These industry sectors possess the potential to lead the transition towards responsible and sustainable biodiversity practices within Brazil.

1. Introduction

The concept of bioeconomy holds a prominent position on the policy agenda, yet the actual implementation of a bioeconomy rooted in the utilization of native species (NS) presents an exceptionally challenging task, even in megabiodiverse nations such as Brazil. The utilization and trade of NS can either contribute to biodiversity conservation or exacerbate its decline (Barron et al., 2022; Marsh et al., 2020; McRae et al., 2020; Tierney et al., 2014). Therefore, biodiversity markets offer considerable promise but are accompanied by controversies (Barron et al., 2022; Gardner et al., 2019; OECD, 2003; van der Hoff and Zwieten, 2022; Young and Castro, 2021). Brazil, as a megabiodiverse country, holds a repository of over 60,000 registered native flora species (REFLORA, 2021), and this number continues to grow as a portion of the nation's biodiversity remains undiscovered by science. Native species from Brazil's biodiversity are associated to the traditional knowledge, multifunctional livelihoods, culture and religion of indigenous and traditional communities (Carvalho Ribeiro et al., 2018; Ellis et al., 2021; Levis et al., 2017).

Considerable efforts have been made to critically evaluate both the complexity of concepts (Farnsworth et al., 2015; Meinard and Grill, 2011) and applications of economic and monetary valuation of biodiversity (Dasgupta, 2021; Hahn et al., 2023; Nunes and van den Bergh, 2001; Strand et al., 2018). A substantial body of research on the economic valuation of biodiversity has focused on capturing the immaterial, insurance and indirect use values of biodiversity (Bateman et al., 2011; Blicharska et al., 2019; Brown, 2005; Hahn et al., 2023; Quaas et al., 2019; Schaafsma et al., 2014). However, there is a lack of systematic approaches for deriving economic estimates for tangible and direct use values (e.g., annual revenues) associated with the use of NS in Brazil. This is paradoxical, as economic estimates for natural goods that are exchanged in markets are usually easier to obtain, especially in countries developing bioeconomy markets based on NS use, such as Brazil.

Indeed, there is a scarcity of available estimates for the utilization of biodiversity products in Brazil, both in their raw and processed forms. In

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2021, the Amazonia 2030 initiative estimated an annual average of US$ 298 million (for the years 2017 to 2019) in trade involving 64 unprocessed products, encompassing Non-Timber Forest Products, fish, and agroforestry (Coslovsky, 2021). This study reveals that these exports account for only 0.17% of the global biotrade market, which reaches a staggering USD 176.6 billion annually (Coslovsky, 2021). In 2023, the New Economy for the Brazilian Amazon initiative projected market values of USD $2.5 billion in 2020 (BRL $12 billion) and USD $8.1 billion in 2050 (BRL $38.5 billion) across various production chains, spanning primary, secondary and tertiary sectors (Nobre, 2023). This estimation concerns 13 products, including açai (fruit and palm hearts), cocoa, Brazil nut, babaçu (coconut and oil), cupuaçu, honey, rubber, buriti, urucum, copaiba, and andiroba (Nobre, 2023). Despite the marked discrepancy in estimates for the trade of unprocessed products, primarily due to methodological differences, none of these studies assess the role of the processing industry within the bioeconomic markets in Brazil.

While the literature generally promotes the idea that regions like the Amazon have high potential and prospective or option value, it has been reported that native species (NS) in Brazil have been currently predominantly marketed as unprocessed raw materials with low added value (Carvalho Ribeiro and Soares Filho, 2022; Carvalho Ribeiro et al., 2018, 2020; Jaramillo-Giraldo et al., 2017; Lopes et al., 2019; Strand et al., 2018). As of 2019, most NS products were traded for less than USD 0.5 per ton (IBGE, 2019), providing annual land rents of up to only USD 50 per hectare (Strand et al., 2018). In an effort to enhance the value of its vast biodiversity, Brazil has emphasized the role of biodiversity and bioeconomy as a development asset over the last few decades (CNI, 2014, 2016; MMA, 2009; Nobre et al., 2016; Nobre and Nobre, 2019). There is, however, a general absence of market intelligence and industrial policy dedicated to this concern at the level of the federal government, though now some states (e.g., Pará). have begun to materialize interest in this segment and to develop sectoral plans. Despite attempts to promote the sustainable use of native species (NS) through technological and social innovations as a key strategy for adding economic value to biodiversity markets (Nobre and Nobre, 2019) a comprehensive methodological framework is still lacking for estimating the number of products, the economic sectors and the quantity and types of companies engaged in the consolidated processing and trade of NS in Brazil. This knowledge gap impedes realistic assessments of biodiversity as a national asset for sustainable development. Consequently, the use of both consolidated and potential NS, as well as the biodiversity markets for industrially processed NS products in Brazil, remains largely uncharted.

Full and transparent traceability of biodiversity markets in Brazil is crucial for several reasons. It serves to reduce illegal trade and benefits the communities where biodiversity knowledge originated (Blicharska et al., 2019; Lenzen et al., 2012; Wiedmann and Lenzen, 2018). Traceability also plays a pivotal role in clarifying the roles and responsibilities of companies and businesses under international targets, such as the Convention on Biological Diversity's strategic goals (CEBDS, 2014; Smith et al., 2020). Furthermore, understanding which industry sectors are currently using and trading NS products can aid in directing appropriate biodiversity financing instruments to strategic sectors (OECD, 2020; van der Hoff and Zwieten, 2022).

Traceability of native species (NS) within the processing industry is also crucial for incorporating annual revenue estimates to support public policy and decision-making. The Brazilian Biodiversity Law (13.123/2015), in conjunction with the country's ratification of the Nagoya Protocol (NP) in 2021, plays a pivotal role in adding value to the utilization of NS and the traditional knowledge associated with their use. However, it's important to note that both the NP and the Brazilian biodiversity law do not have a legal scope limited to "native species." Each country that ratifies the NP can independently determine its material scope. The NP references "genetic resources," while the Brazilian law uses the concept of "genetic heritage," which could encompass both NS and non-native species that have been locally adapted and bred (Nogueira et al., 2010). The NP and the Brazilian Biodiversity Law also distinguish between "access" and "use," i.e., between access for research and development (R&D) and the use of raw materials or genetic resources. For more details on access and patenting literature in Brazil, please refer to Nogueira et al. (2010).

According to the Brazilian Biodiversity Law, companies that economically use the country's NS (excluding exotic species) are obligated to share the resulting benefits with the communities where the traditional knowledge originated. If these benefits are monetary, they take the form of a federal tax amounting to 1% of the company's net annual revenue, with exceptions for micro and small-sized companies, micro-entrepreneurs, individuals, traditional small landholders, and their cooperatives, whose annual revenue equals or is less than USD $75,000 (BRL $360,000). These resources must be invested in actions promoting the conservation and sustainable use of biodiversity through the National Benefit Sharing Fund – Fundo Nacional de Repartição de Benefícios in Portuguese (Brasil, 2015). As a result, the NP has the potential to bolster the international biotrade market for Brazil, a market in which other South American countries such as Peru, Bolivia, and Colombia already participate (Carvalho Ribeiro and Soares Filho, 2022). Additionally, the NP is instrumental in promoting equity across conservation objectives and beneficiaries (Friedman et al., 2018).

To contribute to the advancement of knowledge regarding Brazil's bioeconomy markets, this study seeks to estimate the number of products, industry sectors and annual revenues of companies that processed and traded NS within the processing industry in Brazil between 2000 and 2020. In doing so, our research sheds light on ways to strengthen and develop the biodiversity markets of NS in Brazil, ultimately contributing to a roadmap for a more equitable distribution of benefits derived from the use of NS to the providers of biodiversity knowledge.

2. Methods

Open-source and official datasets were used as inputs for a data mining engine based on PostgreSQL (https://www.postgresql.org/), with queries executed simultaneously through the Dinamica EGO (https://csr.ufmg.br/dinamica/) parallel processing framework (Soares-Filho et al., 2013). Consequently, our search engine is able of efficiently examining the utilization of plant and animal native species (NS) in more than 40 million companies within the Brazilian processing industry. These companies span various sectors, including foodstuff, beverages, textiles, clothing, leather, wood, pulp and paper, biofuels, pharmochemicals, rubber, and furniture. These eleven sectors were selected due to their significant use of NS products while avoiding double counting. The chemical sector was not included due to overlaps with the pharmochemical sector. The workflow can be summarized as follows: 1) documenting evidence of the use of NS in commercial products and economic activities, 2) distinguishing between types of use, including a) consolidated (traceable through trade codes or certification bodies) and b) potential use (evidence of use exists, but a direct link to companies cannot be established using available datasets), and 3) validating results through systematic sampling (see Fig. 1).

2.1. Use of native species by the processing industry

We searched governmental databases related to economic activities, specifically the Classification of National Economic Activities (CNAE – Classificação Nacional de Atividades Econômicas in Portuguese) within the Processing Industry section. Our focus was on eleven sectors where the market for native species (NS) is relevant (SM1). Within these sectors, we conducted searches across Industry's List of Products (PRODLIST) and utilized trade codes from the Mercosur Common Nomenclature (MCN). In addition, we made use of databases from regulatory bodies, including the Federal Income Tax agency and health certification data from ANVISA (National Sanitary Agency). Detailed descriptions of the datasets used, along with information on the data

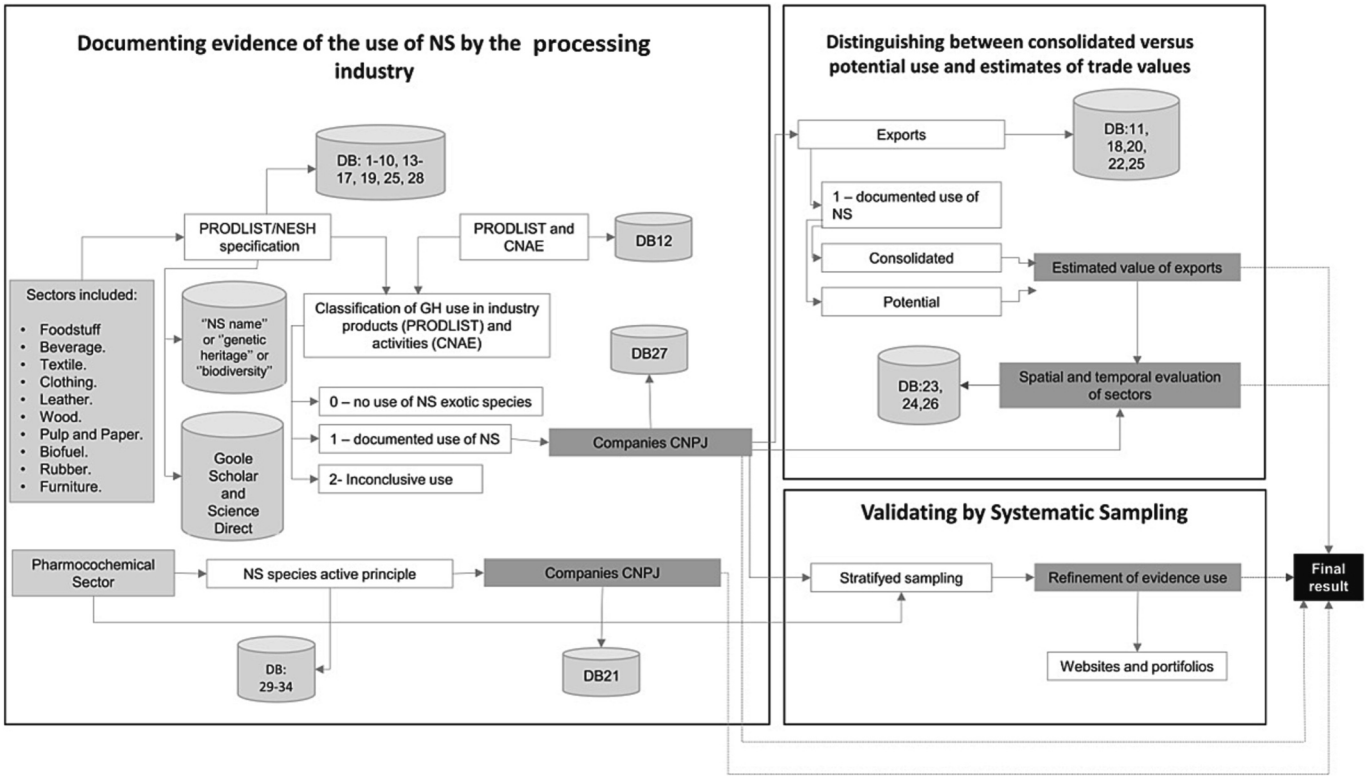

Fig. 1. Flowchart and data mining process.

mining algorithms, can be found in the Supplementary Material (SM1).

It is important to note that for the pharmochemical sector, the PRODLIST does not allow for a direct association between NS and products, as products in this sector can be prepared from a variety of natural active principles or synthetic components. For this sector, we solely relied on ANVISA data. Although a significant portion of the pharmochemical industry may be using NS, to our knowledge, there is no freely available data that allows us to identify which components are related to NS and which companies are involved in their processing.

2.2. Consolidated versus potential use and estimates of trade values

In cases where the use of at least one native species (NS) was documented in the PRODLIST, CNAE, MCN, further evidence was collected to determine the type of use, whether it was consolidated or potential. This differentiation is crucial as it provides more specific insights into how the use of NS varies across sectors and products. In the consolidated category, we included cases where the use is well-established, with a trade code or the company's registration with a certification body, allowing for a direct link to the company's tax registry numbers (CNPJ). This procedure ensured a higher degree of certainty in our estimates. In the potential use category, we included cases where NS use had been documented in the industry, but a direct link to a company's tax registry or trade codes was not found. For both consolidated and potential use, we calculated estimates for the number of commercial products, annual exports, and identified company profiles (e.g., small vs. large companies). To estimate annual export revenue, we categorized companies based on their number of employees using the Annual Report on Social Information (RAIS - Relação Anual de Informações Sociais in Portuguese) database. To make the association of NS use compatible with the official classification of economic activities in Brazil's CNAE and RAIS, we used an official key matrix (available at the link in SM1). This key matrix allowed us to classify export products in line with the CNAE classification. The use of MCN had the advantage of providing both the commercial value and volume of exported products. We associated the companies' CNPJ and MCN codes with the Harmonized System (HS) to assess annual exports over the past decade. We also linked the companies' headquarters' locations to the Human Development Index of the municipalities to explore whether biodiversity markets are associated with human development. Links to the databases, tables, and a detailed description of these procedures can be found in SM1 and SM2.

2.3. Validating by systematic sampling

To validate our estimates of native species (NS) use across various economic sectors and products, we conducted a stratified sampling. This involved randomly selecting 30% of company registration numbers (CNPJs) for specific economic activity codes (CNAE) (SM3). For these companies, we assessed whether they used NS by examining references to NS use within the companies' website portfolios. We analyzed the product portfolios of companies that were well-known for their utilization of NS. Due to limited information regarding the ingredients of each product, our analysis was restricted to the front label, which described the composition of each product. In addition to this, we presented and discussed our approach with experts from the Ministry of the Environment and the United Nations Development Programme (UNEP) in Brazil in 2020.

3. Results

3.1. The use of NS in the processing industry in Brazil

We conducted a comprehensive mapping of the use of native species (NS) across 11 economic sectors within Brazil's processing industry. Our findings reveal that 73% of economic activities (72 out of 98) incorporate NS (SM1). Within the processing industry's list of products (PRODLIST), we identified NS use in 48% of the products (528 out of 1152) (see Table SM1). Given this presence of NS, one would naturally expect that NS products could contribute significantly to Brazil's export volume. These economic activities collectively represent annual exports

of approximately USD $50 billion. However, upon conducting a thorough search to securely identify final products utilizing NS, we found that only 1%, USD $500 million of annual exports, can be definitively attributed to such products. In essence, while NS theoretically possess the potential to play a substantial role in Brazilian exports, the reality does not reflect this scenario.

Of the 72 economic activity sectors with documented NS use, only 10 were classified as consolidated use, allowing for direct linkage between trade codes and companies' tax registry numbers (CNPJ) (see Fig. 2). Consolidated use typically pertains to industrial activities requiring permits or registrations by regulatory or certification bodies. It also involves cases in which Mercosur Common Nomenclature (MCN) trade codes feature specific NS names (e.g., processed Brazil nuts). Out of the 40 million companies listed in the database of the Brazilian Ministry of Economy, there are 20 million active, unique company tax codes (CNPJ) encompassing the 11 economic sectors analyzed here. We reveal that approximately 779,000 companies registered their tributary code (CNPJ) in economic sectors (CNAEs) where NS use is documented. However, a direct link between NS use, MCN, and CNPJ can only be established for 25% of these cases (approximately 192,000 companies). For the remaining 75%, even though NS use is documented, it was not feasible to establish a direct association between the use of NS and MCN or CNPJ.

Fig. 2, in the left column, displays the annual exports for industrial activity sectors with consolidated use of NS. These sectors include plywood, wood splitting, food products and ready meals, cocoa and chocolate, vegetable starch and oil, juices, and fruit preserves. Overall, our estimations suggest that over 750 MCN trade codes are specifically associated with NS (see SM2). However, for the majority of economic sectors and products, even if NS use is documented, there is no direct link between NS use, company registry (CNPJ), or trade codes (MCN) (right column in Fig. 2, representing potential use of NS). Consequently, for the vast majority of businesses that involve the country's biodiversity, there remains a need for the further development of traceability

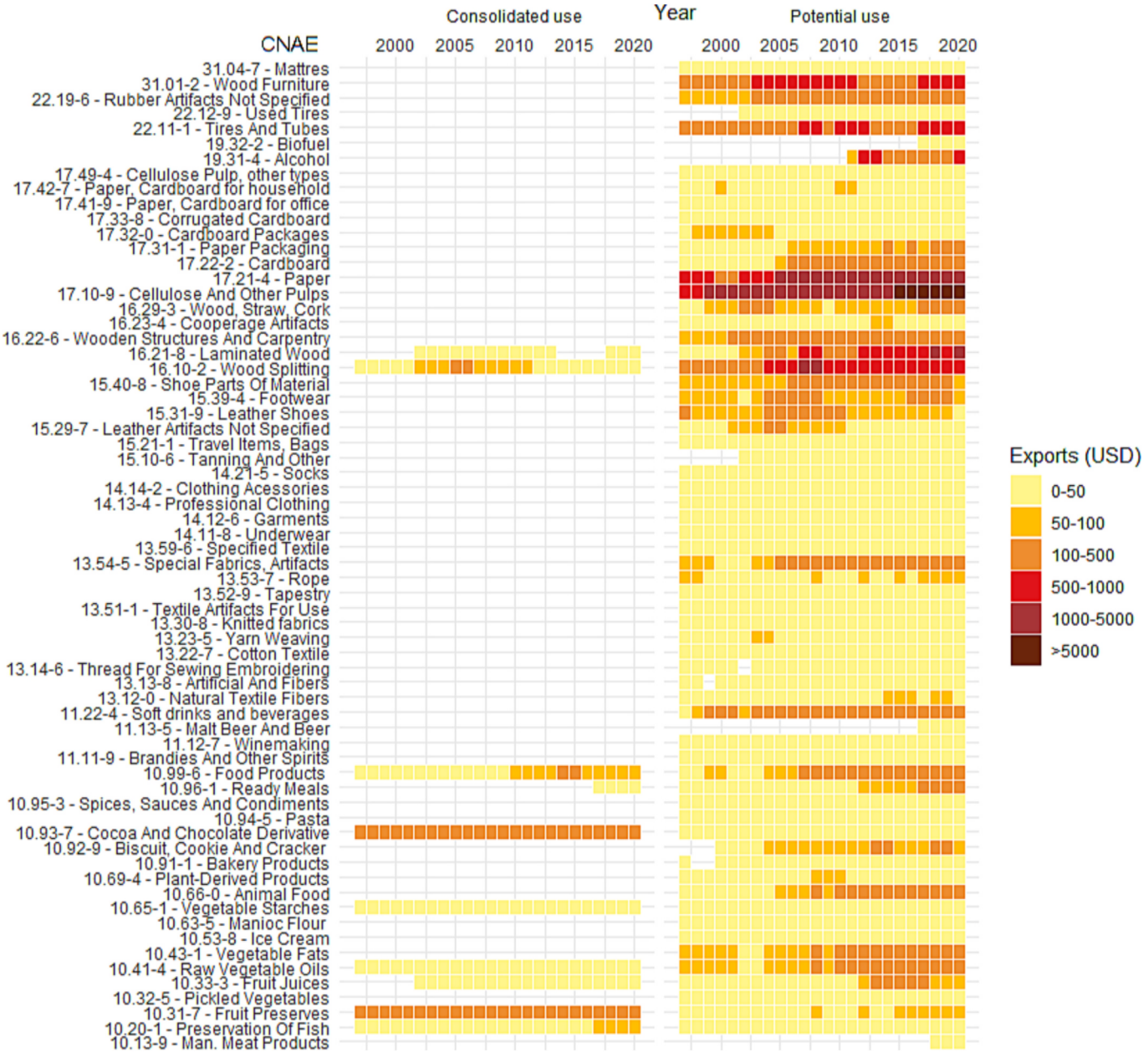

Fig. 2. Annual exports of industrial sectors in which there is use of NS. Left column there exists a direct link. Right Column shows all CNAEs in which the use of NS is documented, but there is no link to companies CNPJ/MCN.

methods and open databases to identify the companies required to contribute to the National Benefit Sharing Fund, as outlined in both the Brazilian biodiversity law and the Nagoya Protocol.

In the industrial sectors where the use of native species (NS) is documented, micro and small entrepreneurs make up the majority, ranging from 25% to 90%. The food and clothing sectors include the majority of small to medium-sized companies. Big companies, constituting 30% of the total, are prevalent in the pharmochemical, cellulose & paper, rubber & plastic, and biofuel sectors, which play a significant role in advancing the bioeconomy in Brazil.

3.2. Biodiversity markets across time and space

From the 1980s to 2020, exports of products derived from native species (NS), including both potential (in blue) and consolidated use (in light green), accounted for approximately 25% of the total Brazilian exports (see Fig. 3a). In total, exports could have reached up to USD 50 billion. However, only a small portion of this trade can be directly linked to NS through companies' registry numbers (CNPJ) and trade codes (MCN). This direct association corresponds to an average annual export of USD 500 million (see Fig. 3b).

The export profile of products derived from native species (NS) has evolved over time (see SM 2.1). Until 2005, the majority of exports originated from the forestry sector, primarily consisting of timber, as well as vegetables, fruits, and other plant parts. Starting from 2010, the food sector gained prominence and currently accounts for the majority of exports. In 2020, in addition to food, vegetables/fruits, and products from the forestry sector, the meat and fish/crustacean industries have also witnessed substantial growth.

Our validation procedure reveals that the majority of companies utilizing NS are small to medium-sized and frequently lack websites. In sectors with large companies, such as the pharmochemical sector, the use of NS in products cannot be accurately traced. This underscores the challenges in estimating the contribution of NS to the country's processing industry.

By correlating annual exports with the Human Development Index (HDI) of Brazilian municipalities (see Fig. 4), we demonstrate that biodiversity markets generate most of their annual revenues in municipalities that already have high to very high HDI levels. This highlights that revenue from NS processing and exports predominantly occurs in regions far from Northern Brazil, which has lower HDI but is renowned for its high biodiversity.

4. Discussion/conclusion

We have developed an innovative data mining engine that utilizes relational databases to establish associations between the use both flora and fauna native species (NS) and industries' products (PRODLIST), economic activities (CNAEs), trade codes (MCN) and companies' tax records (CNPJ). Our methodological approach addresses the challenges associated with estimating annual revenues attributed to the tangible and direct utilitarian values of biodiversity in large countries like Brazil. Our findings reveal that although the use of NS in industry is documented, it remains an invisible component of resource valuation. We show that there exists a diverse range of NS use in industrial products (48%) and activities (73%). It was therefore expected that NS products could contribute significantly to exports. These economic activities collectively represent potential annual exports of approximately USD $50 billion. However, a thorough search to securely identify products utilizing NS, shows that only 1% of the potential business, USD $500 million of annual exports, are consolidated and can be attributed to such products. Our study shows that there are a total of 779,000 registered companies in Brazil engaged in activities (CNAE) that involve the documented use of NS, which can be linked to approximately 25% of the country's exports (Fig. 3a) and 750 MNC trade codes encompassing both fauna and flora.

Our assessment of the consolidated usage at USD $500 million per year surpasses the estimation of USD $298 million per year made by the Brazilian Platform Amazonia 2030 (Coslovsky, 2021). Given our identification of processed products in various industries, our findings can serve as a complementary dataset to the study for 64 products by the Amazonia 2030 initiative (Coslovsky, 2021). In contrast, our estimates fall considerably below the USD $2.5 billion in the "New Economy of Amazon" report (Nobre, 2023). While it's possible that our approach leads to an underestimation of the annual NS trade, we believe that the aforementioned report might be overestimating figures, possibly

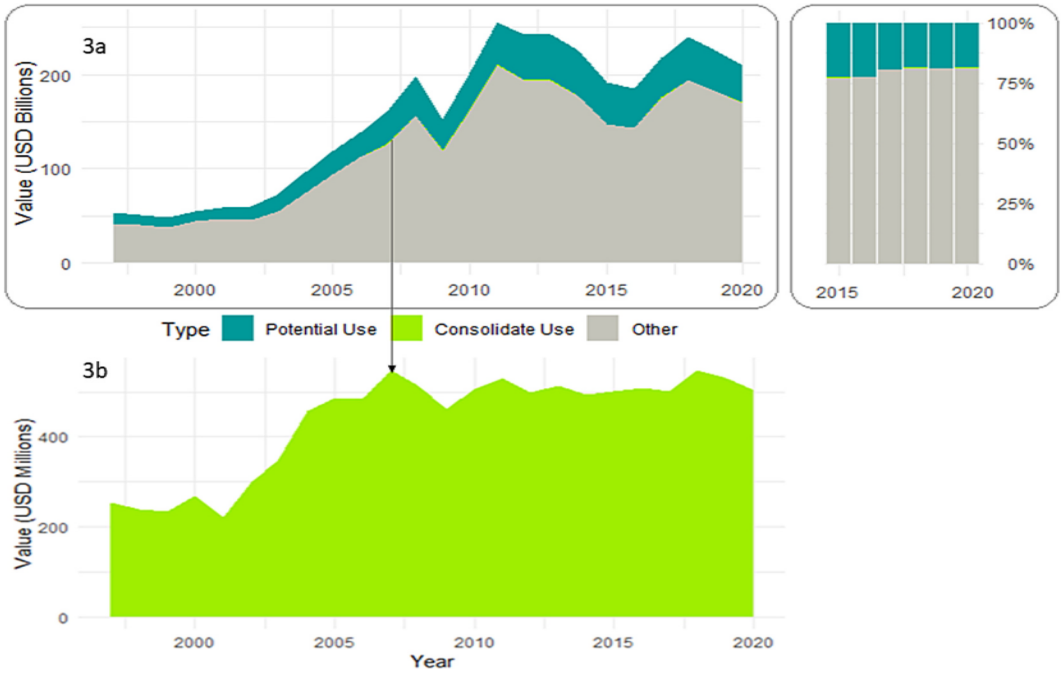

Fig. 3. a) Share of NS in exports. Total value of exports (grey), NS potential use (blue) NS consolidated use (light green) 3 b) annual exports of consolidated use of NS. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

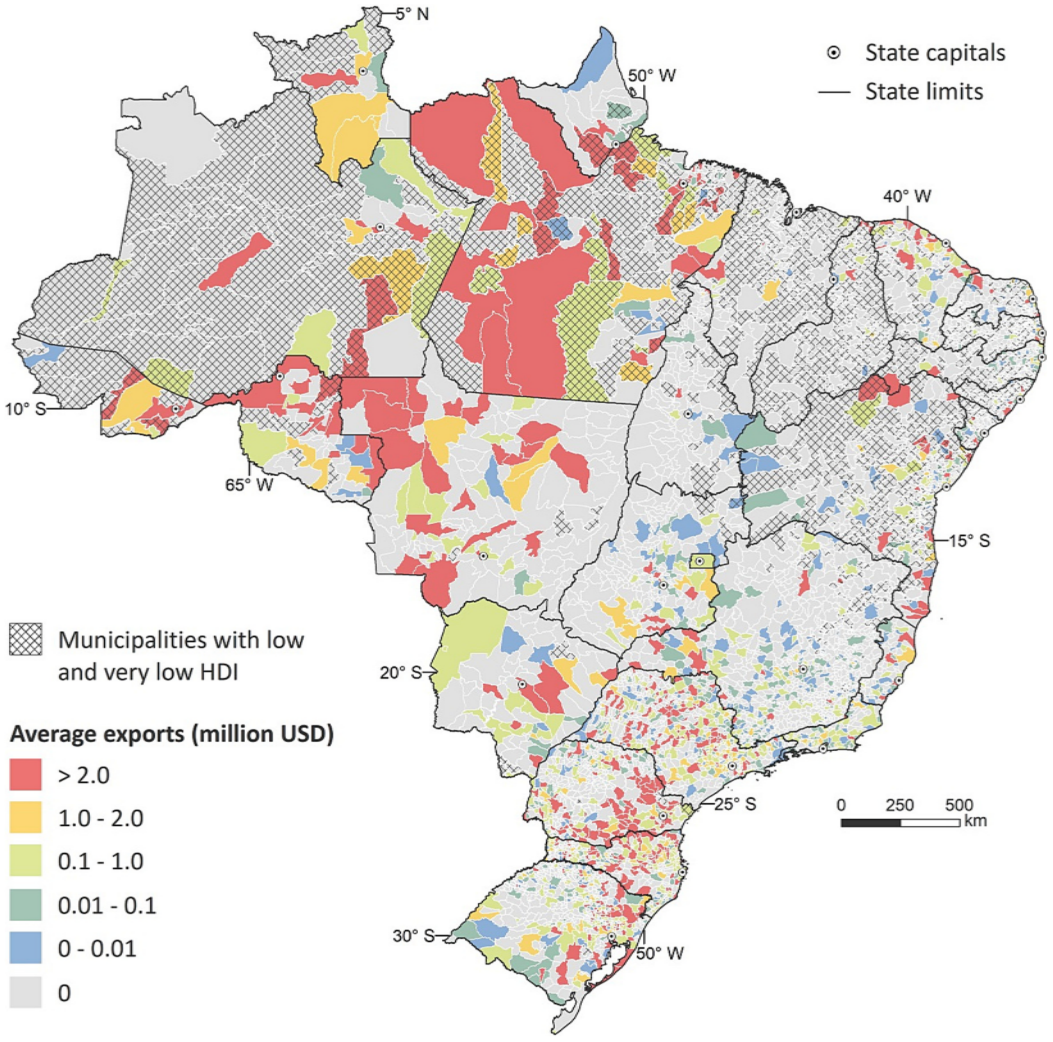

Fig. 4. Average Annual Exports of NS over the period 2015–2020 and the municipalities with low and very low development index (HDI).

through the aggregation of potential and consolidated uses.

While there exists a diverse range of NS use in industrial products and activities (see Table SM1), the economic benefits derived from such resource utilization in direct industrial processing might also underestimate the overall use and indirect values associated with them (refer to Fig. 3). Although it is possible that NS-based products are far more significant economically than what we found, the available official data and the traceability approach we develop does not capture this.

It has been reported that NS are traded mostly as raw materials and that there is lack of processing of such products by the Brazilian process industry itself. Our estimates provide valuable insights for effectively directing funding towards strategic bioeconomic markets. While the pursuit of new technologies holds promise, it also entails considerable risks. Instead of concentrating on exploring new markets or products (Nobre and Nobre, 2019), our findings suggest an immense opportunity for Brazil to expand its international market presence within a multi-billion dollar industry, in which Brazilian companies are already actively participating. Although major companies, particularly in the pharmochemical and biofuel sectors, tend to invest predominantly in a limited range of NS, there exists a need to develop appropriate mechanisms that incentivize diversification. Furthermore, in coordination with government regulations, companies operating in sectors such as pharmochemicals and biofuels could potentially play a pivotal role in bridging the financial gap in biodiversity financing (OECD, 2003, 2020). In contrast to larger corporations, small and medium-sized enterprises rely heavily on the utilization of a diverse array of NS. Hence, the diversity of financing instruments and mechanisms should be tailored to cater to the specificities of individual companies (van der Hoff and Zwieten, 2022).

This study made it possible to know the sectors, products, and companies where the NS market holds significant relevance, a follow-up targeted approach might comprise engaging with larger companies operating within these sectors to delve deeper into the development of traceability issues. This might lead to more adequate attention to the importance of NS in the national bioeconomy, as well as finding ways to generate resources for traditional communities which have retained the knowledge and protected the resource base associated with these species. Therefore, it is likely that benefit-sharing mechanisms from the NP and the Brazilian Biodiversity law will only apply to a small share of the overall business that benefits from the direct use of the country's biodiversity. This brings the need to further develop and mainstream social equity across biodiversity markets (Friedman et al., 2018). This also highlights the need to explore ways to make the biodiversity market in Brazil a good business for both traditional livelihoods (providers) and companies (users) alike, especially in highly biodiverse regions of the Amazon, Atlantic Forest, and Cerrado (Carvalho Ribeiro and Soares Filho, 2022; Oliveira et al., 2019). Governmental bodies in charge of implementing the biodiversity fund (Fundo Nacional de Repartição de Benefícios) can now build on this method for fully implementing traceability of NS in the industry.

This study can be the basis for improving and implementing a comprehensive national system of environmental economic accounting by tracking the production, processing and export of native and other natural based products. Our method can be used to guide IBGE's work (with support of the UN Statistical Division and UNEP) on the development of accounts of ecosystem services as part of a strategy for improving the tracing and tracking of such products in the national economy.

By using the "official" datasets available for the industry markets, we show the sectors that have a comparative advantage since they are already operational. Many successful economic development policies across the world use export as a criterion to decide which sectors and companies should receive public support. Exports connect local companies with foreign companies and markets and, as such, facilitate financial investments and technology development. International trade also demands productive excellence and continuous improvement (Lenzen et al., 2012). In turn, bioeconomy policies, in addition to supporting the development of new compounds, molecules, or materials from Brazilian biodiversity, can also promote science and technology to support processing industry sectors and companies already using NS.

Considering that there has been so far a scarce investment in biodiversity across the processing industry, our estimates are encouraging for many reasons. Until now, policies have solely supported vegetal extractivism on the basis of securing a floor price and the development of specific product market chains with little processing and low added value. If biodiversity industry markets already in place are indeed nurtured, and traceability is fully implemented, annual revenues will likely gain much more relevance in fostering the role of corporate social responsibility in Brazil (Stehr et al., 2019).

These estimates for the direct use values of NS in industry need to be carefully examined and placed in the context of other biological and social estimates, as well as in the controversies and limitations of biodiversity financing (Nunes and van den Bergh, 2001; van der Hoff and Zwieten, 2022). A natural follow-up question stemming from this study is how the current situation could be enhanced. We emphasize three primary pathways for advancement, each to be led by different entities: academia, governments, and the private sector. Academia has the potential to concentrate on strategies that bridge the gap between the literature addressing the intangible insurance and symbolic advantages derived from biodiversity and the often-unnoticed biodiversity markets associated with NS in the industry (Bachi and Carvalho-Ribeiro, 2023; Barron et al., 2022; Nunes and van den Bergh, 2001). Brazilian sociobiodiversity represents the fusion of socio-cultural and biological diversity linked with the collection and pre-processing of NS through the utilization of traditional communities' skills and knowledge. These traditional livelihoods are multifunctional; consequently, addressing either their tangible or intangible aspects falls short of valuing the entire socio-ecological system (Bachi and Carvalho-Ribeiro, 2023; Carvalho Ribeiro and Soares Filho, 2022; Carvalho Ribeiro et al., 2018).

Governments can contribute to enhancing the current situation by fully implementing traceability measures within the NS industry markets. Enhancing traceability for products from native species (NS) is a multifaceted process that requires the cooperation of various stakeholders. Different government levels, including the federal, state, and municipal authorities in Brazil, can coordinate regulatory framework and enforcement. To achieve this, a system for the identification and documentation of native species and their uses and products can be developed.

The use of technology, such as the "Selo Verde," (https://www.semas.pa.gov.br/seloverde/) can help track products from extractivist communities to markets. An essential step in this process is data collection and reporting. Developing a database that includes information about the species, location, type of production system (extractivist vs managed) and stakeholders involved in the sociobiodiversity chain is crucial. SisGen (https://sisgen.gov.br/)is already in place and can contribute to fulfilling these needs.

This comprehensive implementation of traceability holds the potential to overcome the challenges encountered in this study and to tackle the constraints inherent in our methodology. One noteworthy limitation lies in the fact that the CNAES, PRODLISTS and MCN trade codes frequently do not explicitly refer to NS, often grouping them under vague categories like "other." Another notable constraint is the incomplete tracking of NS usage across both the chemical and pharmochemical sectors (CNAEs 20 and 21, respectively). Given the considerable overlaps between these sectors, we concentrated solely on the pharmochemical sector to prevent double counting, even though evidence suggests that a substantial portion of exports might fall under the chemical sector. Consequently, our estimates adopted a precautionary stance, potentially leading to an underestimation of the biodiversity business.

Another limitation relates to our exclusive focus on the value of exports, causing our estimates to overlook a significant portion of the "informal" NS trade within national markets. Despite these acknowledged limitations, our study conveys crucial messages. We unveil the industry sectors, products, and companies that have engaged in NS processing over the past decades. As far as we are aware, these are innovative estimations of annual revenues that highlight the substantial disparity between the consolidated and potential markets for NS utilization within Brazil's processing industry. Consequently, an additional viable pathway for advancement involves the collaboration of both the private sector and Non-Governmental Organizations (NGOs) that have harnessed NS to foster sustainable development programs, thereby bolstering the sustainable use of NS and the related traditional livelihoods as valuable business assets.

A national survey conducted by the Brazilian National Federation of Industry has indicated the significance of NS for businesses, irrespective of their size (CNI, 2016). Approximately 78% of companies have reported their investments in the sustainable utilization of NS, either as primary components or excipients for commercial products. Nonetheless, as of December 2020, among the four prominent companies in Brazil renowned for employing NS within the pharmochemical sector, only one has featured a list of regional sustainable development programs supported by the company on its website.

Economic sectors that generate revenue in municipalities with very low and low human development index are associated with activities such as logging and timber processing and food/beverage industries (fruit preserves and juices) (SM2). This indicates that, in addition to being away from the places where the exports of NS products are larger, the areas that provide NS and hold the traditional knowledge associated with the use of biodiversity are yet to be duly mapped (Godar et al., 2015; OECD, 2003). The available databases (SM1) lack systematic reports on the knowledge and practices associated with the use of NS by traditional livelihoods (in Portuguese Conhecimento Tradicional Associado CTA).

As science and technology continue to develop novel modes for using biodiversity resources, it is also necessary to monitor those developments to make sure the benefits are returned and reinvested to improve the well-being of the traditional communities where the biodiversity knowledge originated. To achieve this goal, well-designed and implemented national biodiversity conservation policies, combined with sustainable development strategies, will be central to guarantee that the future generations benefits from the country's immense biodiversity.

CRediT authorship contribution statement

Sónia Carvalho Ribeiro: Conceptualization, Data curation, Formal analysis, Funding acquisition, Methodology, Project administration, Supervision, Validation, Writing – original draft, Writing – review & editing. **Britaldo Soares Filho:** Investigation, Software, Writing – original draft, Writing – review & editing, Methodology. **Tiago Cesalpino:** Data curation, Formal analysis. **Alessandra Araújo:** Data

curation, Formal analysis, Methodology, Writing – original draft. **Marina Teixeira:** Data curation, Formal analysis, Methodology. **Jussara Cardoso:** Formal analysis, Methodology. **Danilo Figueiras:** Formal analysis. **Felipe Nunes:** Data curation, Formal analysis, Funding acquisition. **Raoni Rajão:** Methodology.

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Declaration of competing interest

No competing interests.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecolecon.2024.108124.

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