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BIOMASS AND CARBON DIOXIDE CAPTURE: RESEARCH FOR *Araucaria angustifolia* (Bertol.) Kuntz

CAPTURA DE BIOMASSA E DIÓXIDO DE CARBONO: PESQUISA PARA Araucária angustifolia (Bertol.) Kuntz

José Augusto Spiazzi Favarin[1], Emmanoella Guaraná Araújo[2], Matheus Pinheiro Ferreira[3], Eben North Broadbent[4], Ana Paula Dalla Corte[5]

[1]Postgraduate Program in Forest Sciences, Federal University of Paraná /UFPR, Curitiba, PR, Brazil – jaspiazzi@gmail.com
[2]Departament of Forest Engineering, Federal University of Rondonia /UNIR, Rolim de Moura, RO, Brazil – manuguarana@gmail.com
[3]Cartography Engineering Section, Military Institute of Engineering – IME, Rio de Janeiro, RJ, Brazil – matheus@ime.eb.br
[4]School of Forest Resources and Conservation, University of Florida, Gainesville, FL, USA – eben@ufl.edu
[5]Departament of Forest Engineering, Federal University of Paraná /UFPR, Curitiba, PR, Brazil – anapaulacorte@gmail.com

ABSTRACT

Endangered species play an important role in studies on the quantification of biomass and carbon since, as their cutting is prohibited by law, they accumulate an essential stock in the forest. Thus, this work aimed to bring a scenario of the research being carried out with this theme with *Araucaria angustifolia* and other species of the same genus. To this end, bibliometric analysis was used, searching for published and indexed works in the Scopus, Web of Science, and Science Direct databases until 2021. We found 38 publications in 30 different journals, accumulating 72.5% of publications from the year 2014. Brazil was the country that produced the most research and also that received the most encouragement from research funding agencies. Biomass and carbon were the objects of most works, totaling 21. The direct method of quantification was the most used in 28 studies. Other methods were fitted models and simulation, muffle, dry combustion, wet combustion, and conversion factor methods to quantify carbon. The non-use of artificial intelligence was considered a gap in the research. Moreover, the little use of remote sensing, combined with artificial intelligence, should offer new methods for estimating biomass and carbon.

KEYWORDS: **Araucariaceae, Bibliometric analysis, Brazilian pine , Mixed Forest, Subtropical Forest.**

RESUMO

As espécies ameaçadas de extinção desempenham um papel importante nos estudos de quantificação de biomassa e carbono, pois, como o seu corte é proibido por lei, acumulam um estoque essencial na floresta. Assim, este trabalho teve como objetivo trazer um cenário das pesquisas que estão sendo realizadas com esta temática com *Araucaria angustifolia* e outras espécies do mesmo gênero. Para tanto, utilizou-se análise bibliométrica, buscando trabalhos publicados e indexados nas bases de dados *Scopus, Web of Science e Science Direct* até 2021. Foram encontradas 38 publicações em 30 periódicos diferentes, acumulando 72,5% das publicações do ano de 2014. Brasil foi o país que mais produziu pesquisas e também o que mais recebeu incentivo das agências financiadoras de pesquisa. A biomassa e o carbono foram objetos da maioria dos trabalhos, totalizando 21. O método direto de quantificação foi o mais utilizado em 28 estudos. Outros métodos foram modelos ajustados e simulação, mufla, combustão seca, combustão úmida e métodos de fator de conversão para quantificar carbono. A não utilização de inteligência artificial foi considerada uma lacuna na pesquisa. Além disso, a pouca utilização da deteção remota, combinada com a inteligência artificial, deverá oferecer novos métodos para estimar a biomassa e o carbono.

PALAVRAS-CHAVE: **Araucariaceae, Análise bibliométrica, Pinhão , Floresta mista, Floresta Subtropical.**

INTRODUCTION

The genus *Araucaria* Juss. belongs to the family Araucariaceae Henkel & W.Hochst (IGANCI and DORNELLES, 2020). According to Garcia (2002), it has typically dioecious trees with exfoliating or intact bark, and sessile spiral leaves with the apex often pungent, scale-shaped to triangular-lanceolate, monomorphic, or heteromorphic. The genus *Araucaria* has about 18 species, 13 endemics to New Caledonia, one to Norfolk Island, and the rest to New Guinea, Queensland, and South America (LAUBENFELS, 1988).

The species *Araucaria angustifolia* (Bertol.) Kuntz occupies a vast area in Brazil (south and southeast regions) and Argentina (eastern region) and produces a seed known as "pinhão" (ALVES et al., 2019). The species, according to Carvalho (2003), has different popular names according to the region of occurrence, such as Araucária, Pinheiro-do-Paraná, Pinheiro-do-Brasil, Pino Paraná (in Argentina) and Parana Pine (commercial name in other countries).

For Reitz et al. (1988), Araucária wood was the most widely exported timber resource in Latin America for more than a century. Currently, the species has excellent non-timber potential, such as using the seed, a nutritious and energetic food, and its dry needle-like branches (RODRIGUES et al., 2021). Given the intense logging, the species is at risk of extinction, being classified in the List of Threatened Brazilian Flora as “endangered” (BRASIL, 2021) and “critically endangered” by the International Union for Conservation of Nature (IUCN, 2018). Therefore, Araucária is currently protected by the Atlantic Forest Law number 11,428 of 2006 (BRASIL, 2006). Due to legal restrictions, research ends up suffering limitations, especially those involving management regimes of native Araucária forests (ORELLANA et al., 2017), which can contribute to the development of methods for estimating biomass and, consequently, carbon.

Forests appear to be primarily responsible for carbon storage in ecosystems worldwide since biomass formation can store atmospheric carbon, and tropical and subtropical forests are responsible for a large part of this storage (TSEGAY and MENG, 2021; CANADELL and RAUPACH, 2008). Quantifying biomass can be done using the direct method (destructive in the field) or indirect method, which relates variables such as diameter at breast height (DBH), wood volume, commercial height, total height, and canopy diameter with biomass (TEIXEIRA, 2003). In addition to height and DBH, Silveira et al. (2008) and Chave et al. (2005) include wood density as a variable for biomass estimation.

This work used bibliometric analysis to know what is being produced in terms of research with biomass and carbon from Araucária. Bibliometric analysis is a tool that makes it possible to understand the behavior of scientific publications in the academic environment, helping to understand an area of knowledge and helping to direct new research and even those in progress (ANWAR et al., 2022). It uses mathematical and statistical methods to describe a group of documents to be defined using keywords related to the topic (PRITCHARD, 1969).

Therefore, this work is justified because it is the first to survey the production of research involving quantifying Araucária biomass and other species of the same genus. The hypothesis is that the bibliometric review allows us to bring a research scenario with *Araucaria angustifolia*, its biomass, and carbon. This work aimed to bring to light the research status of this species and other species of the genus *Araucaria* sp., as well as possible gaps to be explored in the future.

MATERIAL AND METHODS

The research source chosen to obtain the databases were Scopus, Web of Science, and Science Direct. The search was carried out using keywords according to the methodology proposed by Silva et al. (2020). The chosen databases are globally recognized for being comprehensive and scientifically supported (FALAGAS et al., 2008; KHUDZARI et al., 2018). The databases were consulted for the entire period until 2021 and were downloaded on the same day (February 10, 2022).

The search was performed for titles, abstracts, and keywords of manuscripts. The terms used were: araucaria, biomass, carbon stock, stored carbon, carbon sink, carbon storage, fixed carbon, and carbon sequestration. The search sequence was: TITLE-ABS-KEY ("araucaria" and "biomass" OR "carbon stock" OR "stored carbon" OR "carbon sink" OR "carbon storage" OR "fixed carbon" OR "carbon sequestration").

Each database generated an information set, and duplicates were excluded on that occasion. Subsequently, the texts underwent screening through reading and compatibility with pre-established inclusion criteria to verify those that actually relate to the theme. The inclusion criteria used were: 1) Works that quantified the biomass of *Araucaria* sp.; 2) Research related to carbon stock in the biomass of the species addressed.

For the bibliometric review, the following aspects were observed: 1) Year of publication; 2) Document type; 3) Journal; 4) Authors; 5) Authors' co-citation web; 6)

Institution of the authors' affiliation; 7) Science areas; 8) Promotion agencies. For the state-of-the-art, the aspects were: 1) location of the study; 2) type of vegetation in the area; 3) evaluated biomass component; 4) Type of biomass determination; 5) type of carbon content determination; 6) carbon content values (g.kg-1); 7) carbon stock (Mg.ha-1). The results were analyzed, and the graphics were made using the scientific programming language R 4.2.0 through the integrated development environment RStudio 2022.07.1.

RESULTS AND DISCUSSION

This study is the first to conduct a survey on research on biomass and carbon in the *Araucaria angustifolia* species and other species of the same genus. In total, 118 publications were found in Scopus, 121 in Web of Science, and 18 in Science Direct related to the object of this work. After screening, removing duplicates, and verifying exclusion criteria, 40 articles were classified as suitable and carefully analyzed.

As for the distribution of works over time, the first publication found was from 1982, and until the first decade of the 21st century, there was only one publication per year (Figure 1). It is worth noting that the work of Enright (1982) was not necessarily the first to be carried out on the subject; however, it was the first to be indexed on one of the platforms.

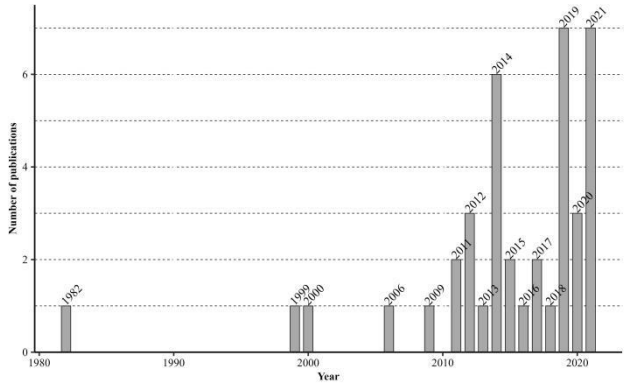

Figure 1. Distribution of published manuscripts over time related to carbon stock or biomass in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

The distribution of manuscripts is irregular, with peaks of publications in 2014 (six publications), 2019, and 2021 (with seven publications). Most of the works were published in the last eight years (29), concentrating 72.5% since 1982. COP-18 may have influenced the increase in work from 2014, held in 2012 in Doha city (Qatar), where, according to the UN (2012), the second phase of the Kyoto Protocol was approved, thus, encouraging research in biomass and carbon. The drop in publications between 2019 and 2021 can be explained by the outbreak of the Covid-19 pandemic (2020), which hampered the displacement in carrying out the work field and a more significant investment of resources for research in the health area.

Regarding the document type, the works were classified into the categories of scientific articles published in journals and works presented at conferences, with articles representing 95% of the publications, a total of 38. It is important to note that there were no restrictions on the publication type in the search. Thirty journals were found responsible for the publications of the articles used in this research, among which ten are Brazilian, with 19 published works; the others originate from other nationalities. The journals that stood out the most in terms of the number of publications were: Revista Floresta, Scientia Forestalis Forest Sciences, Ciencia Florestal, and Floresta e Ambiente, with five, three, two, and two papers, respectively.

A total of 59 institutions were identified. Those who were most involved with research related to biomass and carbon stock in *Araucaria* sp. totaled 15 institutions, 73% of which were Brazilian (Figure 2). Regarding the Brazilian ones, the Federal University of Paraná (UFPR) (12 works), the State University of Centro-Oeste (UNICENTRO) (eight works), the Federal University of Santa Maria (UFSM) (five works), and the Federal University of Rio Grande do Sul (UFRGS) (four works) stood out. The other nationalities the highlights were Technische Universität Dresden (Germany) and Università Degli Studi di Padova (Italy), with three works.

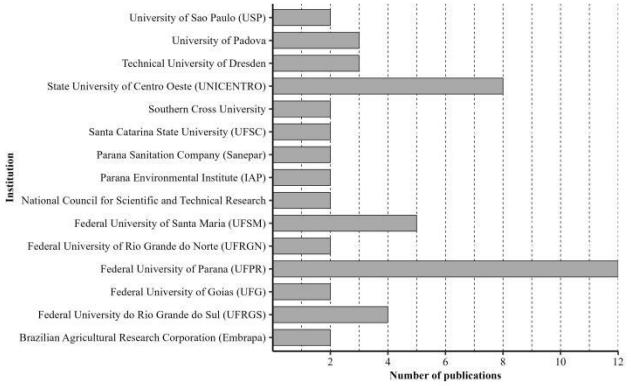

Figura 2. Institution of authors' affiliation with publications related to carbon stock or biomass in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct

databases, until 2021.

The two institutions with the highest number of publications are located in the southern region of Brazil, contributing 50% of the research carried out. As they are located in the forest typology of the Mixed Ombrophylous Forest, it is natural that their researchers invest in the existing forest formations where they were installed. Likewise, the journal with the highest number of publications was Revista Floresta, linked to UFPR. Although a third of the journals are of Brazilian nationality, most of the articles published in them are in English, 52%, which is positive because it has a greater reach in the dissemination of results and scientific dissemination.

The surveys were carried out in eight different countries (Table 1) and one by Papú et al. (2021), where the location was not specified, possibly in Argentina or Chile due to the study species being *Araucaria araucana* (Molina) K. Koch and the institutions where the researchers are linked. Due to the *Araucaria* genus occurring naturally only in the southern hemisphere, it was expected that the works would be found only in these countries.

Tabela 1. Distribution of works by country related to the stock of carbon or biomass in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

Country	Reference	N
Brazil	Alabrace e Dillenburg, 2012; Alabrace e Dillenburg, 2014; Alves et al., 2019; Amaral et al., 2014; Bull et al., 2021; Caldeira et al., 2015; Duarte e Dillenburg, 2000; Garcia et al., 2019; Inkotte et al., 2015; Lipinski et al., 2017; Orellana e Vanclay, 2018; Orellana et al., 2017; Rex et al., 2019; Rodrigues et al., 2021; Roik et al., 2020; Rossa et al., 2011; Rosenfield e Souza, 2014; Zilli Ruiz et al., 2021; Sanquetta et al., 2013; Sanquetta et al., 2014a; Sanquetta et al., 2014b; Schumacher et al., 2011; Sevegnani et al., 2019; Souza e Longhi, 2019; Vieira et al., 2019; Watzlawick et al., 2012; Watzlawick et al., 2014.	27
Chile	Kutchartt et al., 2021; Lusk et al., 2006; Pirotti et al., 2020.	3
Australia	Bubb et al., 1999; Grace e Basso, 2012.	2
Argentina	Gallia et al., 2021.	1
India	Jain et al., 2019.	1
Papua Nova Guiné	Enright, 1982.	1
Pakistan	Dilshad et al., 2020.	1
Uganda	Orikiriza et al., 2009.	1
Not specified	Papú et al., 2021.	1

N = number of papers.

Among the research funding agencies, the National Council for Scientific and Technological Development (CNPq) was the agency that most financed research in the area, followed by the Coordination for the Improvement of Higher Education Personnel (CAPES), of the Ministry of Science, Technology, and Innovation (MCTI) and the Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) (Figure 3). The first three agencies belong to Brazil, while the last mentioned belongs to Argentina. Brazil was the country that most participated in these surveys, accounting for 27 works, followed by Chile with three; this demonstrates the importance of research funding agencies since three of the 12 mentioned in the works are from Brazil, representing 50% of the works financed by them.

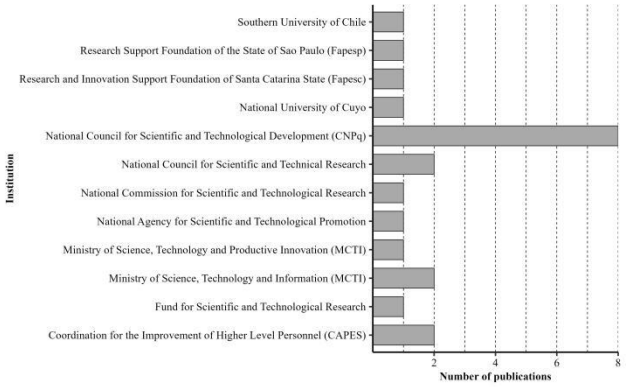

Figura 3. Development agencies related to carbon or biomass stock in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

The main area of science covered by the publications evaluated was Agriculture and Biological Sciences, with the most publications, 52%, followed by the area of Environmental Sciences, 22%. Biochemistry Genetics and Molecular Biology, Energy, Computer Science, Earth, and Planetary Sciences added up to 16%, while Chemical Engineering, Chemistry, Engineering, Medicine, Physics and Astronomy, and Social Sciences added up to 10%. Most of the works are linked to the area of knowledge of Agriculture and Biological Sciences, followed by

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Tabela 2. Distribution by species related to carbon stock or biomass in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

Specie	Reference	N
A. angustifolia	Alabrace e Dillenburg, 2012; Alabrace e Dillenburg, 2014; Alves et al., 2019; Amaral et al., 2014; Bull et al., 2021; Caldeira et al., 2015; Duarte e Dillenburg, 2000; Garcia et al., 2019; Lipinski et al., 2017; Orellana e Vanclay, 2018; Orellana et al., 2017; Rex et al., 2019; Rodrigues et al., 2021; Roik et al., 2020; Rossa et al., 2011; Rosenfield e Souza, 2014; Zilli Ruiz et al., 2021; Sanquetta et al., 2013; Sanquetta et al., 2014a; Sanquetta et al., 2014b; Schumacher et al., 2011; Sevegnani et al., 2019; Souza e Longhi, 2019; Vieira et al., 2019; Watzlawick et al., 2012; Watzlawick et al., 2014	26
A. araucana	Kutchartt et al., 2021; Lusk et al., 2006; Pirotti et al., 2020.	3
A. cunninghamii	Bubb et al., 1999; Grace e Basso, 2012.	2
A. hunsteinii	Gallia et al., 2021.	1
A. cookie	Jain et al., 2019.	1

N = number of papers.

Only 13 studies aimed to estimate and quantify biomass and eight to quantify carbon (Table 3), accounting for 46.7% of the research. The other works had different objectives, which biomass was used to achieve.

Table 3 – Distribution of works according to the proposed objectives, related to the stock of carbon or biomass in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

Objective	Reference	N
Biomass	Caldeira et al., 2015; Garcia et al., 2019; Inkotte et al., 2015; Kutchartt et al., 2021; Lipinski et al., 2017; Orellana et al., 2017; Pirotti et al., 2020; Rex et al., 2019; Roik et al., 2020; Rosenfield e Souza, 2014; Sanquetta et al., 2014a; Schumacher et al., 2011; Watzlawick et al., 2012	13
Carbon	Caldeira et al., 2015; Lipinski et al., 2017; Roik et al., 2020; Sanquetta et al., 2013; Sanquetta et al., 2014a; Sanquetta et al., 2014b; Watzlawick et al., 2012; Watzlawick et al., 2014	8
Biochemistry (nutrition, defense, and pigments)	Alabrace e Dillenburg, 2012; Alabrace e Dillenburg, 2014; Bubb et al., 1999; Bull et al., 2021; Dilshad et al., 2020; Gallia et al., 2021; Papú et al., 2021.	7
Growth	Enright, 1982; Lusk et al., 2006; Orellana e Vanclay, 2018; Orellana et al., 2017; Orikiriza et al., 2009; Rossa et al., 2011; Vieira et al., 2019	7
Energy	Alves et al., 2019; Rodrigues et al., 2021; Zilli Ruiz et al., 2021	3
Gas emissions	Amaral et al., 2014; Grace e Basso, 2012	2
Structure, dynamics, and diversity	Sevegnani et al., 2019; Souza e Longhi, 2019	2
morphology and physiology	Duarte e Dillenburg, 2000; Papú et al., 2021.	2
planting conditions	Jain et al., 2019	1

N = number of papers.

The direct method, with the destruction of the material, was the most used by the authors, totaling 28 works. The other methods used were mathematical modeling using fitted equations to perform the estimation (seven works) and simulation (three works). Mostly, the material used was aboveground biomass (Table 4), present in 87% of the works, and all that made the root biomass were not carried out in native forests. AGB was not necessarily obtained from adult plants in plantations or native forests.

Table 4 – Distribution by material related to carbon or biomass stock in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

Material	Reference	N
Above ground biomass	Alabrace e Dillenburg, 2012; Alabrace e Dillenburg, 2014; Amaral et al., 2014;	33

	Bubb et al., 1999; Bull et al., 2021; Caldeira et al., 2015; Dilshad et al., 2020; Duarte e Dillenburg, 2000; Enright, 1982; Gallia et al., 2021; Garcia et al., 2019; Grace e Basso, 2012; Jain et al., 2019; Kutchartt et al., 2021; Lipinski et al., 2017; Lusk et al., 2006; Orellana et al., 2017; Orellana e Vanclay, 2018; Orikiriza et al., 2009; Papú et al., 2021; Pirotti et al., 2020; Rex et al., 2019; Roik et al., 2020; Rosenfield e Souza, 2014; Rossa et al., 2011; Sanquetta et al., 2013; Sanquetta et al., 2014b; Schumacher et al., 2011; Sevegnani et al., 2019; Souza e Longhi, 2019; Vieira et al., 2019; Watzlawick et al., 2012; Watzlawick et al., 2014	
roots	Alabrace e Dillenburg, 2012; Alabrace e Dillenburg, 2014; Bubb et al., 1999; Bull et al., 2021; Duarte e Dillenburg, 2000; Enright, 1982; Gallia et al., 2021; Grace e Basso, 2012; Jain et al., 2019; Lusk et al., 2006; Orikiriza et al., 2009; Papú et al., 2021; Rossa et al., 2011; Sanquetta et al., 2013; Sanquetta et al., 2014b; Schumacher et al., 2011; Vieira et al., 2019	17
litter	Inkotte et al., 2015; Sanquetta et al., 2014a; Schumacher et al., 2011	3
branches	Dilshad et al., 2020; Rodrigues et al., 2021; Zilli Ruiz et al., 2021	3
Seeds	Alabrace e Dillenburg, 2012; Alabrace e Dillenburg, 2014; Alves et al., 2019; Gallia et al., 2021	4
Deadwood and non-timber vegetation	Sanquetta et al., 2014a	1

N = number of papers.

The works that presented AGB and C values, quantified and estimated, for adult plants in native forests or plantations totaled 10. The values ranged from 0.853 to 292.62 Mg/ha; when considering the individual biomass, the values ranged from 112.79 to 2,125.5 kg/ind. The values of C per unit area ranged from 16.98 to 87.86 Mg/ha, while the individual stock ranged from 111.63 to 935.8 kg/ind. The carbon content was obtained in only one work, 41.52%, in Watzlawick et al. (2012).

The methods used for carbon determination among the works that carried out this evaluation were the Conversion of organic matter (Mufla), three works (AMARAL et al., 2014; RODRIGUES et al., 2021; ZILLI RUIZ et al., 2021). Dry combustion, five papers (ALVES et al., 2019; ROIK et al., 2020; SANQUETTA et al., 2013; SANQUETTA et al., 2014a; SANQUETTA et al., 2014b); Humid combustion, three papers (CALDEIRA et al. al., 2015; WATZLAWICK et al., 2012; WATZLAWICK et al., 2014). Moreover, in two works, the Conversion Factor (GRACE and BASSO, 2012; ROSENFIELD and SOUZA, 2014) used a factor of 0.5 (BALBINOT, 2014; HOUGHTON, 2007; GIFFORD, 2000a, GIFFORD, 2000b).

Although geotechnologies are already widespread for biomass and carbon estimates (WATZLAWICK et al., 2009; ALONZO et al., 2016; WAN-MOHD-JAAFAR et al., 2017; d'OLIVEIRA et al., 2020), only two works adopting remote sensing were found. Rex et al. (2019) adopted the LiDAR sensor – Light Detection and Range, and Pirotti et al. (2020) with the Landsat 5, 7, and 8, Sentinel-2 and Palsar series satellites; in addition, Google Earth Engine was used as a data and processing provider.

What caught our attention was that none of the published works used artificial intelligence techniques such as machine learning algorithms. Such algorithms have already been implemented in biomass estimates, including Random Forest, Artificial Neural Network - ANN, k-Nearest Neighbor - k-NN and Support Vector Machine - SVM (MARCHESAN et al., 2020; REX et al., 2020; SCHUH et al., 2020).

A total of 139 authors were counted, and those who stood out the most in terms of the number of publications were Dr. Callos Roberto Sanquetta, followed by Dr. Ana Paula Dalla Corte, Dr. Luciano Farinha Watzlawick and Dr. Aurélio Lourenço Rodrigues (Figure 4). As the first author, Dr. Carlos Roberto Sanquetta had the most published works, adding up to three publications (SANQUETTA et al., 2013; 2014a; 2014b). Another three authors appeared twice as the first author, Dr. Fernanda da Silva Alabarce (ALABARCE and DILLENBURG. 2012; 2014), Dr. Enrique Orellana (ORELLANA et al., 2017; ORELLANA and VANCLAY, 2018) and Dr. Luciano Farinha Watzlawick (WATZLAWICK et al., 2012; 2014).

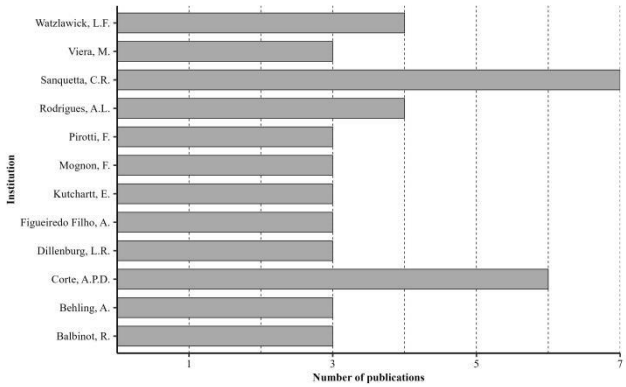

Figure 4 – Authors with at least three publications related to carbon stock or biomass in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

In the web of authorship and co-authorship, it can be seen that research groups were formed, and in six of them, a collaborative network was created in the research carried out, forming a large group of authors that can be seen in the highlight of Figure 5. The other groups were restricted to their research niches, with no collaboration between them or the large group. The most relevant authors, that is, those with the highest occurrence in the participation of authorship and co-authorship, also stand out in the production of research with biomass and carbon in addition to the species *Araucaria angustifolia*, which can be observed in Dalla Corte et al. (2012), Sanquetta et al. (2019), Watzlawick et al. (2009).

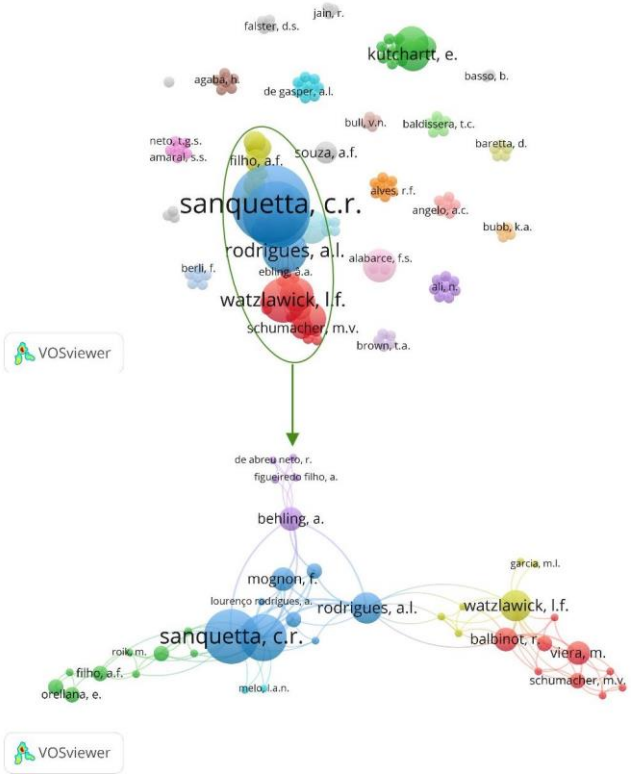

Figure 5 – Web of integration, co-citation, of authors with publications related to carbon or biomass stock in *Araucaria* sp. and indexed in Scopus, Web of Science, or Science direct databases, until 2021.

CONCLUSÕES

From the results obtained by this work, it was concluded that the direct method for quantifying biomass is still the most used, and only some works are dedicated to quantifying carbon. Despite the possibility of making estimates by indirect methods, only some studies have used them. It drew attention to the low number of publications using remote sensing data and the non-use of artificial intelligence. Therefore, a gap is identified in the research that can be explored in future research, as technological advances in remote sensing and data analysis become essential tools for researching biomass and carbon. Finally, funding agencies played an important role in research funding since the countries with more incentives also published the most.

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