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ANÁLISE BIBLIOMÉTRICA PARA RECUPERAÇÃO DE ÁREAS DEGRADADAS PROVENIENTES DA CONSTRUÇÃO DE HIDRELÉTRICA

BIBLIOMETRIC ANALYSIS FOR DEGRADED AREAS RESULTING FROM THE CONSTRUCTION OF HYDROELECTRIC POWER PLANTS

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Resumo

A utilização inadequada dos recursos naturais acarreta diversas consequências ambientais e sociais nos ecossistemas, comprometendo a qualidade do solo e reduzindo a capacidade de regeneração natural da área utilizada. Nesse sentido, este trabalho teve como propósito analisar o comportamento bibliométrico da produção científica internacional acerca da recuperação de áreas degradadas pela construção de hidrelétricas. A análise foi realizada no período de 1964 a 2023 nas bases de dados 'Scopus' e 'Web of Science', utilizando o termo recuperação de áreas degradadas em combinação com construção de hidroelétricas, compactação do solo, espécies de cobertura e bioindicadores de conservação do solo. O processamento dos dados e a elaboração dos gráficos foi realizada no software VOSviewer, utilizando como método de análise *association strength*. Nos últimos anos houve aumento do número de publicações sobre a recuperação de áreas degradadas provenientes da construção de hidrelétricas e mais estudos não necessários dentro desta área do conhecimento.

Palavras-chave adicionais: compactação do solo; bioindicadores; espécies de adubação verde; mapeamento bibliométrico.

Abstract

The inappropriate use of natural resources leads to several environmental and social consequences for ecosystems, compromising soil quality and reducing the natural regeneration capacity of the area used. In this sense, this work aimed to analyze the bibliometric behavior of international scientific production regarding the recovery of areas degraded by the construction of hydroelectric plants. The analysis was carried out from 1964 to 2023 in the 'Scopus' and 'Web of Science' databases, using the term recovery of degraded areas in combination with hydroelectric construction, soil compaction, cover crop species, and soil recovery bioindicator. Data processing and graphing were carried out in the VOSviewer software, using association strength as an analysis method. In recent years there has been an increase in the number of publications on the recovery of degraded areas resulting from the construction of hydroelectric plants and more studies are not necessary within this area of knowledge.

Additional keywords: soil compaction; bioindicators; cover crop species; bibliometric mapping.

Introduction

Human activity has a significant impact on the degradation of natural ecosystems, especially with the removal of topsoil. This practice can lead to drastic changes in geographic space, as vegetation cover is removed, causing the displacement of local fauna. An example of this degradation is the establishment of areas called 'borrowed land,' which arise from the construction of dams for hydroelectric plants (LIMA et al., 2021; FARDIN et al., 2021; OLIVEIRA et al., 2020). The techniques used to rehabilitate these degraded areas aim to recover the original characteristics of the soil and control the agents responsible for the degradation process. To achieve this objective, it is necessary to study the structure of the communities and assess the resilience capacity of the ecosystem.

There are two main methods for carrying out this recovery: *i*) direct methods, which use mechanical and chemical practices, and *ii*) indirect methods, which use plant species to accelerate the recovery process (CARVALHO et al., 2017). A sustainable technique involves the use of green manures, which establish symbiotic relationships with biological nitrogen (N) fixation (BNF) bacteria, increasing soil nutrients. This can reduce N fertilization costs. Additionally, the high biomass production of green manures contributes to the increase in soil organic matter (SOM) content and improves soil structuring by increasing the capacity to retain water and nutrients, favoring the growth of plants introduced into this

system (GAO et al., 2018; SILVA et al., 2022). The use of different techniques for the recovery of degraded soils has become increasingly frequent (BERTOL et al., 2019). One such technique is the use of organic waste and the implementation of plant species from the Fabaceae family, especially *Acacia mangium*, due to its rapid growth, hardiness, high adaptability to acidic and infertile or low-fertility soils, and its nitrifying potential (SILVA et al., 2020). By implementing fast-growing cover crop species, it is possible to establish organisms in the soil that improve its physical, chemical, and microbiological attributes (MOREIRA; GONÇALVES, 2004; KAMAU et al., 2017).

The study of soil macrofauna plays a crucial role in the soil food chain, as it can accelerate the population growth and activity of microorganisms or intensify the activity of microbial populations responsible for the mineralization and humification of SOM, thus providing nutrients available to plants (KITAMURA et al., 2020). Additionally, arthropods are sensitive to environmental changes, making them useful as bioindicators. Ecological indices, such as diversity, can be used to assess changes in ecological structures, such as the reduction in species richness in communities (PEREIRA et al., 2018). Monitoring restored ecosystems is a crucial step, regardless of the method applied. This process helps identify indicators of ecosystem development and detect the need for adjustments and improvements. Indicators can be grouped into three main categories: compositional, structural, and functional (MARTINS et al., 2022).

Compositional indicators assess ecosystem biodiversity, including species composition, survival rates, and ecological groups. Structural indicators relate to the quantitative responses of plants and forests, such as height, diameter, biomass, and basal area. Finally, functional indicators represent functions and services performed by the ecosystem, such as physical-chemical attributes and nutrient cycling. The continuous monitoring of these indicators can provide important information for the adaptive or corrective management of the restored ecosystem (PRACH; WALKER, 2019). Often, the natural regeneration of vegetation cover in a degraded area is slow and uncertain due to competition with grasses and routine fires, which hinder plant establishment and reduce the vigor of the seed bank. An effective way to reverse this scenario is to implement silvopastoral systems, which increase biomass inputs and soil cover, favoring nutrient cycling, biological activity, and carbon sequestration (FAUSTINO; MARCIANO, 2021; POLANÍA-HINCAPIÉ et al., 2021; SHIBU; DOLLINGER, 2019). To analyze the bibliometric behavior of the recovery of degraded areas using green manure species resulting from the construction of hydroelectric plants, a search was conducted for research published in the ‘Scopus’ and

'Web of Science' databases. In addition to understanding the global scenario of the topic, the study analyzed the networks that characterize international production through evaluative and relational techniques, aiming to identify relevant publications for future research in the area.

Materials and methods

This work was carried out at São Paulo State University (Unesp), Dracena Campus (21° 28′58″ LS, and 51°31′58″ LW), and developed in four stages. The first stage consisted of choosing the terms that would compose the research focused on the recovery of a degraded area due to the removal of soil for the construction of a hydroelectric dam. Thus, three bibliometric analyses were performed: *i*. Recovery of degraded areas, *ii*. Recovery of degraded areas associated with the construction of a hydroelectric plant or soil compaction, *iii*. Recovery of degraded areas associated with green manure species or bioindicators of soil recovery.

The second stage consisted of collecting data on global scientific production based on articles published in journals and bibliographic reviews indexed in two online databases: Science Citation Indexed Expanded – 'Web of Science' (WoS) and 'Scopus', to integrate the best results. The data were exported in two formats: 'CSV' and 'txt'. The data collection was carried out considering the period from 1964 to 2023, using the "topic" field, which considers the title, abstract, and keywords of the authors of each record. Three analyses were performed as data selection criteria, as follows:

- Analysis 1: The terms "recovery of degraded areas" were used; 2,016 documents were obtained from the 'Scopus' database and 338 from the 'Web of Science' database.
- Analysis 2: The terms "recovery of degraded areas" AND "hydroelectric construction" OR "soil compaction" were used; 41 documents were obtained from the 'Scopus' database and 911 from the 'Web of Science' database.
- Analysis 3: The terms "recovery of degraded areas" AND "green manure species" OR "soil recovery bioindicator" were used; 21 documents were obtained from the 'Scopus' database and 13 from the 'Web of Science' database.

In the third stage, data processing was performed using the VOSviewer software, using association strength as the analysis method through the tools co-occurrence, all keywords, bibliographic coupling, authors, co-authorship, and countries to create graphs that described the co-occurrence of

terms, main authors, citations, publications, most cited journals, and collaboration between countries. The maps generated by the software emphasize the formation of clusters, which are characterized as conglomerates of cooperation, in which the members indicated have made some level of contact.

Results and Discussion

Analysis performed using the term "recovery of degraded areas"

The search for the term "recovery of degraded areas" in the 'Scopus' database returned 2,016 documents from the period 1969 to 2023, of which 1,745 are articles and are distributed, in greater numbers, among five journals: 'Revista Árvore', 'Forest Ecology and Management', 'Restoration Ecology', 'Forest Science', and 'Land Degradation & Development'. Of the published articles, 100 were produced by researchers from Unesp and 94 by the Chinese Academy of Sciences, with 634 published in Brazil. In the 'Web of Science' database, the search returned 338 documents from the period 2002 to 2023, of which 324 are articles and are distributed, in greater numbers, among three journals: 'Revista Árvore', 'Forest Science', and 'Revista Brasileira de Ciência do Solo'. Of the published articles, 42 were produced by researchers from 'Unesp' and 32 by the 'Federal University of Viçosa' (UFV), with 243 published in Brazil.

The first visualization and analysis were performed using the keyword method, using data obtained from the 'Scopus' database and imported into the VOSViewer visualization software. The map obtained is presented in Figure 1. The map shows the occurrence of words, that is, words that are mentioned together in the works published and investigated in this study. The map suggests the existence of three clusters of terms. The first, most prominent cluster (in yellow) is centered around restoration. The second most prominent cluster (in orange) is centered around ecological restoration. Finally, the last cluster formed is centered on the theme of vegetation (in pink) and has been standing out since 2014. Other themes are still little studied but should be addressed in future studies, such as germination and remote sensing.

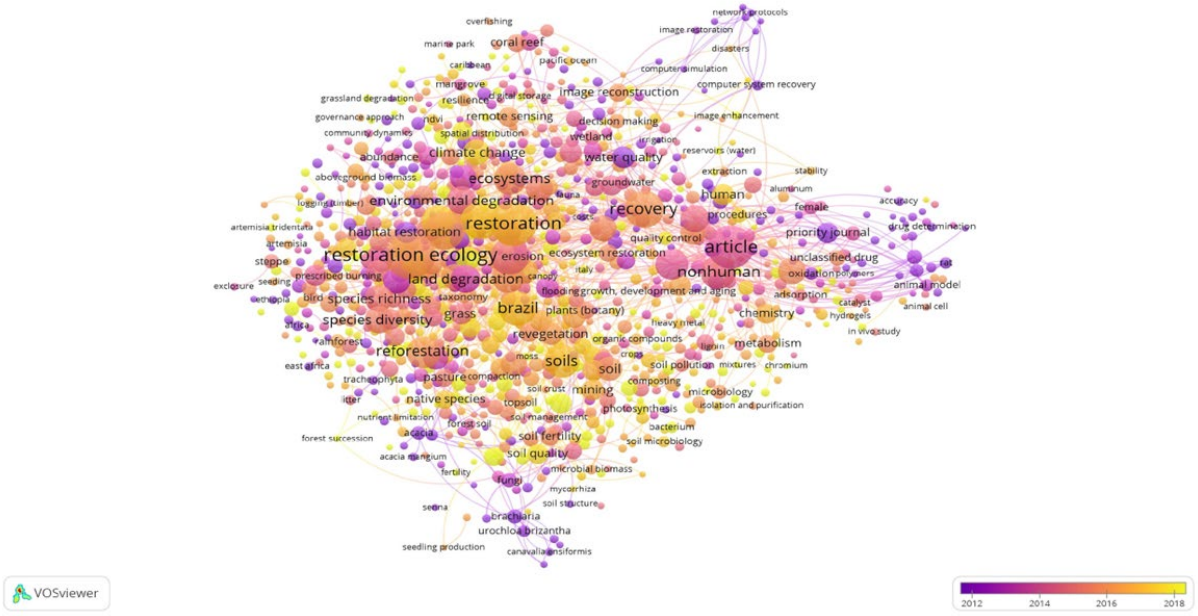

Figure 1. Co-occurrence network of terms from the ‘Scopus’ database.

The second visualization and analysis performed was the bibliometric mapping of the main authors in the two databases consulted. The Scopus database by fractional counting revealed the existence of 1,991 authors, divided into six research groups. We considered that the authors should have at least one published document. The following authors stood out in the analysis: Longo, R. M.; Ribeiro, A. I.; Clark, S.; Edwards, A. J.; Bonini, C. S. B.; Alves, M. C.; Adnan, M.; and Holscher, D. In the ‘Web of Science’ database, co-authorship was evaluated, and 1,380 authors were identified, divided into five research groups. The following stood out in this analysis: Sebastião, M. V.; Paiva, H. N.; Longo, R. M.; and Ribeiro, A. I.

The third analysis was performed in the ‘Web of Science’ database with the number of citations and publications over time (Figure 2). Of the total of 338 publications, 1,311 citations were reported, with an average of 3.88 citations per article. The performance indicator of the authors' scientific production (h-index) was equal to 16. There was progress in research on the subject, especially until 2018 when 26 publications were identified. It was also possible to observe a drop in production from 2019 onwards, and a new advance in 2022.

Studies focused on the recovery of degraded areas have been addressing relevant topics, such as the one developed by Lima et al. (2021), who evaluated the interaction of insects and spiders with *Acacia mangium* seedlings and identified a greater diversity of ants in seedlings with more

branches. Thus, the increase in the arthropod population together with the increase in the age of the seedlings contributes positively to the soil recovery process. Liang et al. (2023) identified the TNI (Terrain Niche Index), drought index, and soil types as the main environmental elements that influence vegetation restoration in cold and arid mountainous areas, through the application of the GTWR (Geographic and Temporal Weighted Regression Model).

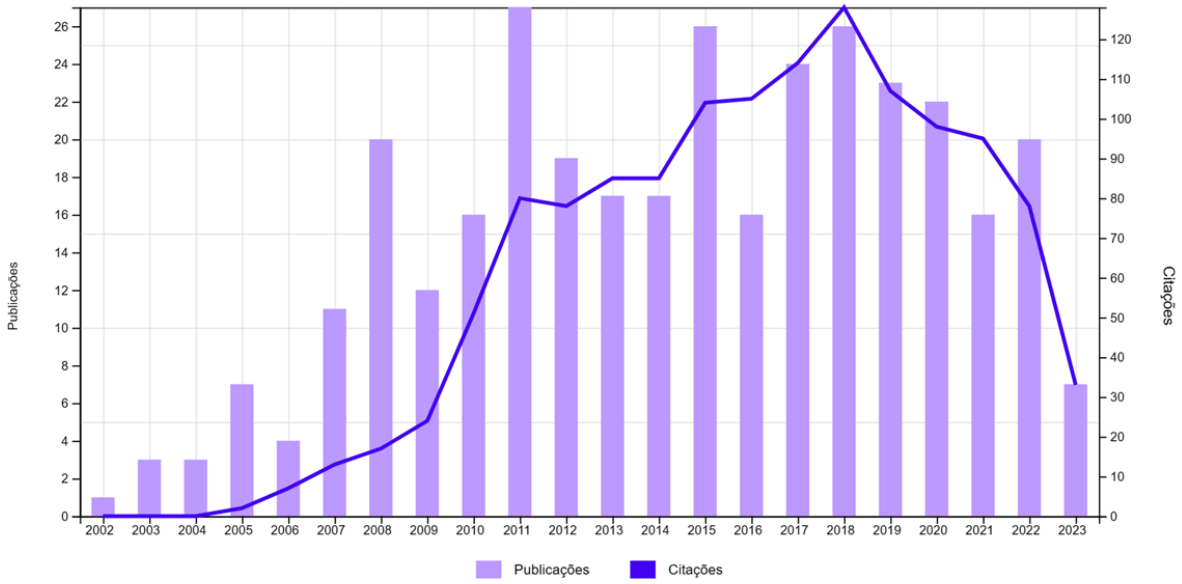

Figure 2. Number of citations and publications over time. Source: 'Web of Science' (2023).

Another promising study was carried out by Zhang et al. (2023), who evaluated the biogeochemical responses to the successional recovery of alpine pastures, through the stoichiometry between carbon (C), nitrogen (N), and phosphorus (P) in the continuous soil-plant-microbe system. They found that different responses of C, N, and P levels in the plant-soil-microbe environment lead to changes in the C:N:P stoichiometric ratio. The multifunctionality of the ecosystem, provided by reforestation, was evaluated by Yan et al. (2023) in a mountainous area of the Loess Plateau in three different vegetation patterns. In general, long-term reforestation can maintain ecosystem multifunctionality based on water conservation, carbon sequestration, nutrient cycling, and productivity. The recovery process of degraded areas varies according to the characteristics of each site, so carrying out the studies previously exemplified can contribute significantly, in addition to directing the application of new soil recovery techniques. For example, an evaluation of the interaction of insects in a recovery area with *Urochloa* spp. associated with the response of C, N, and P levels.

The analysis carried out with the term "recovery of degraded areas" associated with "construction of hydroelectric power plants" or "soil compaction" yielded interesting insights.

The search for the association of the terms "recovery of degraded areas" with "construction of hydroelectric power plants" or "soil compaction" in the 'Scopus' database returned 41 documents from the period 1991 to 2023, of which 37 are articles. These articles are predominantly published in five journals: 'Revista Brasileira de Ciência do Solo', 'Forest Science', 'Agronomic Science Magazine', 'Geoderma', and 'Soil Research and Soil Preparation'. Among the published articles, 15 were produced by researchers from Unesp and six by the State University of Campinas (UNICAMP), with 26 published in Brazil.

In the 'Web of Science' database, the search returned 911 documents from 2002 to 2023, of which 892 are articles. These articles are mainly published in three journals: 'Revista Brasileira de Ciência do Solo' (Brazilian Journal of Soil Science), 'Multidisciplinary Agriculture', and 'Engenharia Agrícola'. Of the published articles, 98 were produced by researchers from the Federal University of Santa Maria (UFSM) and 91 by Unesp, with 579 published in Brazil.

The first visualization and analysis were performed using the keyword method with data obtained from the Scopus database and imported into the VOSViewer visualization software. The resulting map is shown in Figure 3. The word co-occurrence map suggests the existence of three clusters of terms. The most prominent cluster (in orange) is centered around soil compaction. The second cluster (in yellow) is centered around soil quality. The third cluster (in pink) is centered on the theme of plant species, represented by *Urochloa* spp., which has been prominent since 2010. Other themes, such as the integrated agricultural system, visual soil assessment, and multi-story forest management, are still under research but should be addressed in future studies.

The second visualization and analysis involved bibliometric mapping of the main authors in the two databases. The 'Scopus' database, using fractional counting, revealed 40 authors divided into four research groups. Authors who stood out in this analysis include Araújo, A. O.; Mendonça, L. A. R.; Alves, M. C.; Nascimento, V.; and Bonini, C. S. B. In the 'Web of Science' database, the co-authorship analysis identified 2,785 authors divided into six research groups, with notable authors including Reichert, J. M.; Dias Junior, M. S.; Souza, Z. M.; and Tormena, C. A.

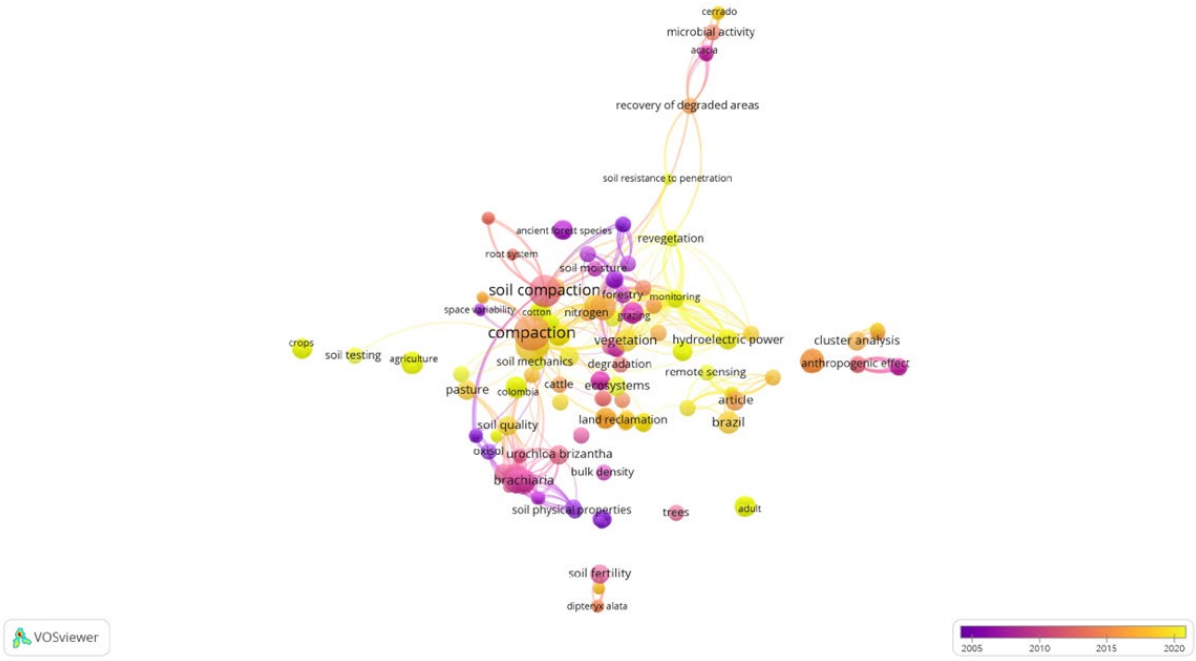

Figure 3. Co-occurrence network of terms from the 'Scopus' database.

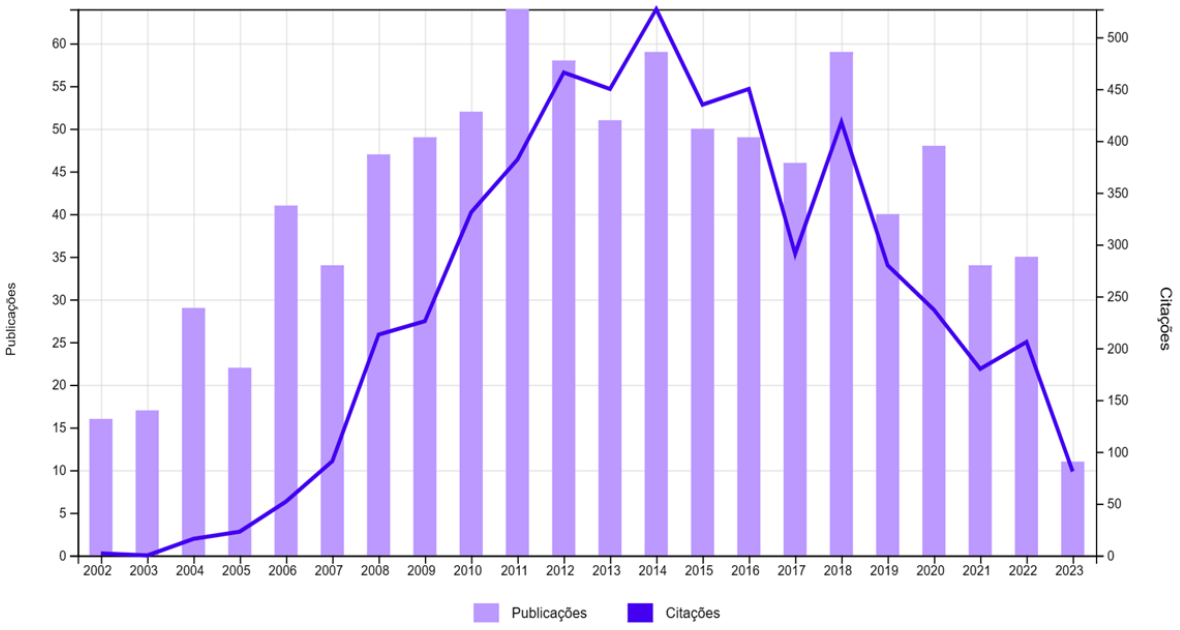

Figure 4. Number of citations and publications over time. Source: 'Web of Science' (2023).

The third analysis, conducted in the 'Web of Science' database, examined the number of citations and publications over time (Figure 4). Of the 911 publications, there were 5,360 citations, with an average of 5.88 citations per article. The h-index, a performance indicator of the authors' scientific production, was 30. Research on this topic advanced significantly until 2011, with 64 publications identified that year. However, there was a decline in production in 2019, 2021, and 2022. Studies on the environmental impacts on soil

caused by the construction of hydroelectric plants have gained prominence in recent years. For example, Wan et al. (2023) identified the timing and magnitude of abrupt changes using an integrated method based on remote sensing (NDVI). They found that the timing of significant NDVI changes coincided with the construction and operation of hydroelectric plants and periods of climate change.

Lopes et al. (2021) evaluated the hydrodynamic attributes and potential hydrophobicity (soil water repellency) of soil undergoing recovery with legumes. Contrary to expectations, the soil's hydrodynamic response showed increased absorption capacity despite greater soil compaction. This indicates that potential levels of hydrophobicity affect hydrodynamic attributes, and revegetation with legume species can lead to the recovery of the soil's natural conditions. Manoel et al. (2021) investigated gene flow, focusing on the dispersal of pollen and seeds from a regenerating population of *Astronium fraxinifolium* in a degraded area resulting from the construction of a hydroelectric plant. They demonstrated that the closest trees contributed pollen and seeds to the recovery of the degraded area, indicating spatial reproductive isolation between the sampled populations due to the damming of the river.

The use of a silvopastoral system to restore the physical quality of degraded pastures has proven to be efficient in Caquetá State (1°36'50" LN and 75°36'46" LW), Colombia (POLANÍA-HINCAPIÉ et al., 2020). Faustino and Marciano (2021) also evaluated the recovery of a degraded pasture in the Rio de Janeiro State, Brazil using the optimum water range (IHO) indicator in revegetation with legumes, and identified an IHO lower than the available water, due to the penetration resistance values found being higher than the critical limit of 3.0 MPa. Fardin et al. (2021) showed that the incorporation of residues from aquatic macrophytes and sugarcane bagasse ash, together with the planting of ‘Cerrado’ tree species, is efficient in the ecological recovery of degraded areas for the construction of a hydroelectric plant in Selvíria, Mato Grosso do Sul State, Brazil. In the same study site, Kitamura et al. (2020) evaluated soil macrofauna using different vegetation cover types and consisting of six treatments and were able to identify an increase in the soil macrofauna population by approximately four to six times more with the application of the treatment of *Astronium fraxinifolium* + *Urochloa decumbens* + sewage sludge, after three years of evaluation. The process of recovering degraded areas resulting from the construction of hydroelectric plants varies according to the characteristics of each location. Thus, carrying out the studies previously exemplified can contribute significantly, in addition to directing the application of new soil recovery techniques. For example, the implementation of a silvopastoral system or the evaluation of the contribution of pollen dispersion in the recovery of species from degraded soil.

The analysis performed with the term "recovery of degraded areas" associated with "green manure species" or "bioindicator of soil recovery" yielded interesting insights.

The search for the association of the terms "recovery of degraded areas" with "green manure species" or "bioindicator of soil recovery" in the 'Scopus' database returned 21 documents from 2006 to 2021, all of which were articles. These articles are predominantly published in five journals: 'Revista Brasileira de Ciência do Solo' and 'Bragantia'. Among the published articles, nine were produced by researchers from Unesp and two by other universities, with 15 published in Brazil. In the 'Web of Science' database, the search returned 13 documents from 2007 to 2023, of which 12 are articles. These articles are mainly published in the 'Revista Brasileira de Ciência do Solo'. Of the published articles, six were produced by researchers from Unesp and two by the UFV, with 10 published in Brazil. The first visualization and analysis were performed using the keyword method with data obtained from the 'Scopus' database and imported into the VOSViewer visualization software. The resulting map is shown in Figure 5.

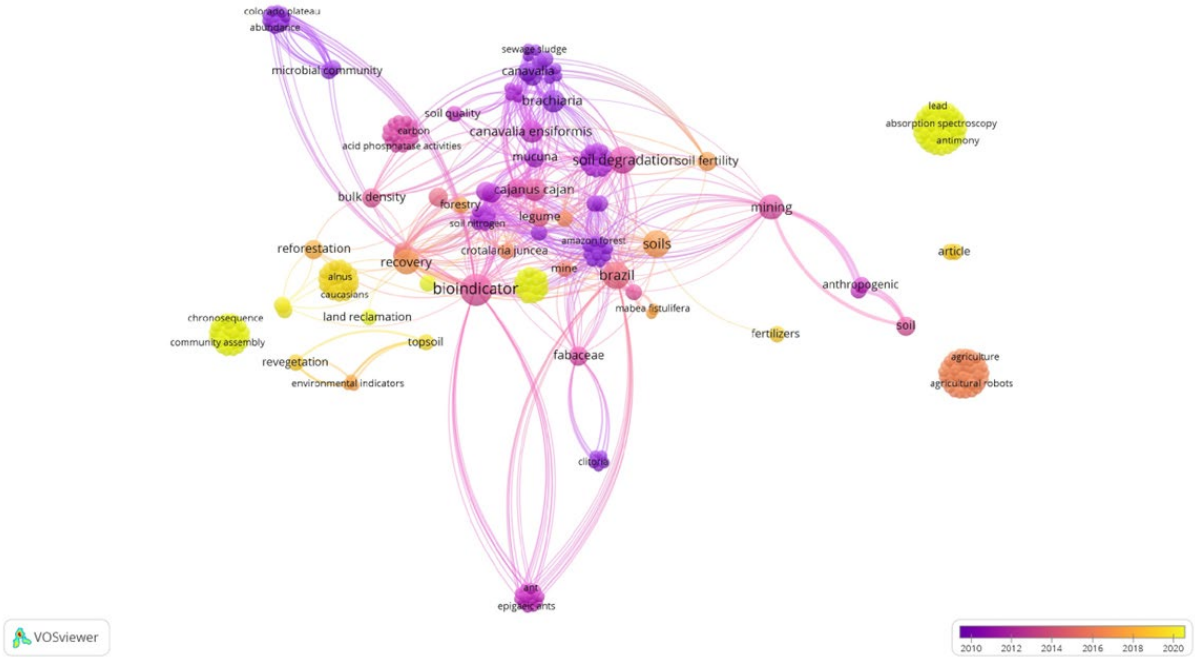

Figure 5. Co-occurrence network of terms from the 'Scopus' database.

The word co-occurrence map suggests the existence of three clusters of terms. The most prominent cluster (in pink) is centered around the microbial community as a bioindicator. The second cluster (in purple) is centered around soil degradation associated with the names of green manure species, such as *Mucuna pruriens*, brachiaria (*Urochloa* spp.), *Cajanus cajan* (pigeon pea), and *Canavalia ensiformis* (pig bean). The

third cluster (in yellow) is centered around reforestation and has been gaining prominence since 2018. Other topics, such as *Mabea fistulifera* (castor bean), *Carpinus betulus* (a botanical genus belonging to the Betulaceae family), and environmental indicators, are still under researched but should be addressed in future work.

The second visualization and analysis involved bibliometric mapping of the main authors in the two databases. The ‘Scopus’ database, using fractional counting, revealed 19 authors divided into four research groups. Authors who stood out in this analysis include Longo, R. M.; Calinoiu, I.; Alves, M. C.; and Kitamura, A. E. In the ‘Web of Science’ database, the co-authorship analysis identified 43 authors divided into two research groups, with notable authors including Alves, M. A. and Kitamura, A. E. The third analysis, conducted in the ‘Web of Science’ database, examined the number of citations and publications over time (Figure 6). Of the 13 publications, there were 81 citations, with an average of 6.23 citations per article. The h-index, a performance indicator of the authors' scientific production, was four. Research on this topic advanced significantly in the years 2008, 2011, and 2018, with up to 13 publications identified. However, there were gaps in 2009, 2010, 2013, 2015, 2016, 2019, and 2022, with no new publications related to the researched topic.

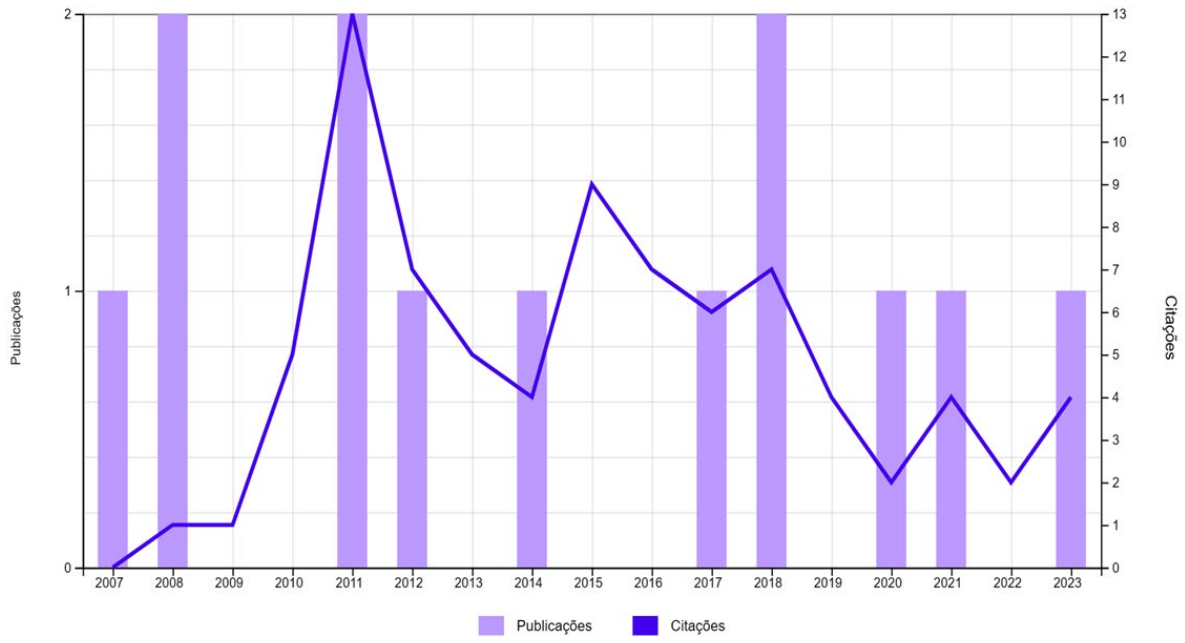

Figure 6. Number of citations and publications over time. Source: ‘Web of Science’ (2023).

The study of the green manure species application in the recovery of degraded areas has been gaining prominence in recent years. For example, Fonseca et al. (2023) used species of *Cajanus cajan*,

Crotalaria juncea, and *Stylosanthes guianensis* to evaluate the recovery of soil degraded by mining, which proved to be efficient in promoting rapid vegetation cover and increasing the levels of SOM and total N in the soil. Rocha et al. (2020) also studied the recovery of an area degraded by mining in the Pará State through the use of four species of legumes: *Cajanus cajan*, *Canavalia ensiformis*, *Crotalaria juncea*, *and Mucuna pruriens*, implanted in three soil conditions: exposed soil, surface soil, and hydrogel. They identified that the species *C. ensiformis* and *M. pruriens* present better development when cultivated in soils with surface deposition of the soil as a reshaped substrate. The structural complexity of a habitat can be described by the use of ant fauna as a bioindicator of the environmental conservation status. Lutinski et al. (2018) presented the potential of ants in the evaluation of the regeneration process of a permanent preservation area of a hydroelectric plant. The selection of green manure species to be used in the process of recovering degraded areas varies according to the characteristics of each location. Therefore, carrying out the studies previously foremplified can contribute significantly, in addition to directing the application of new techniques and the choice of bioindicators of soil recovery.

Conclusions

The bibliometric study of international scientific production on the theme of the restoration of degraded areas in association with the construction of hydroelectric plants or the use of green manure species provided valuable insights. It enabled the identification of the number of publications, the most cited journals, and the countries with the most published authors. Additionally, it facilitated the analysis of co-authorship relationships between authors using relational techniques.

Regarding the semantic clusters formed around the central theme, Brazil and its authors held a prominent position in the international production investigated. Unesp emerged as the most consolidated organization in this research area, followed by the UFV.

The publications by Alves, Kitamura, Martins, Paiva, and Reichert were particularly significant, consistently appearing in the analyses and being recognized as important contributors in the field.

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