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Article

Land Use and Land Cover in Tropical Forest: Global Research

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Abstract: Tropical ecosystems play an important role in the environment. They provide multiple ecosystem services, such as carbon capture and sequestration, food supply, and climate regulation. Studying land use and land cover change makes it possible to understand the land's alterations associated with deforestation, degradation, erosion, soil desertification, and biodiversity loss. The objective of this study is to evaluate the different approaches to land use and land cover research in tropical forests based on the evolutionary and qualitative analysis of the last 44 years of scientific production. The data were collected using the Scopus database and was based on the PRISMA methodology's four phases: (i) identification, (ii) screening, (iii) eligibility, and (iv) included. The results showed a significant increase in the study of land use and land cover consolidated in 4557 articles, with contributions from 74 countries, revealing 14 themes and seven lines of research. Core research areas such as biodiversity, land use, and conservation exist due to the ongoing interest in the value of tropical forests and their response to climate change. The present research allowed us to consider future study topics such as the relationship between sustainable development goals and land use and cover in tropical forests, as well as the evaluation of the environmental impact of economic activities in forests.

Keywords: land cover; land use; tropical forest; bibliometric analysis; knowledge mapping; co-citation; co-occurrence

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1. Introduction

Tropical forests differentiate between neotropical (New World) and paleotropical (Old World) [1,2]. They are mainly found between the Tropic of Cancer and the Tropic of Capricorn, but they can extend outside both tropics to Brazil's southeast and the northeast of Australia [3]. Tropical forests are distributed across four biogeographical areas: the neotropics (South America, Central America, southern Mexico, and the Caribbean islands), which contain 45% of the forests; the Afrotropics (continental Africa, Madagascar, and scattered islands), representing 30%; Asia (India, Sri Lanka, mainland Asia, and southeast Asian islands) with 16%; and Australasia (Australia, New Guinea, and the Pacific Islands) 9% [4]. They are biodiversity centers and serve as home to more than 50% of the planet's flora and fauna species [5], making them an ecologically unique zone [6]. In addition, they store around a quarter of the world's terrestrial carbon reserve [7] and play an essential role in mitigating the effects of climate change due to the amount of carbon they store [8].

Tropical forests are classified according to their elevation, annual rainfall, and degree of seasonality. They fall into four main types: ever-humid, semi-green, dry, and montane deciduous forests [9]. Ever-humid forests, also called tropical rainforests, occupy approximately 30% of the tropical forest biome [10], have a high annual rainfall (>2000 mm of rain per year) [11], and are characterized by their unique species and their ecological interactions and specializations [12,13]. On the other hand, semi-green or seasonally humid forests, like rainforests, receive more than 2000 mm of rain per year [14], and their rainy periods are usually longer than their dry periods [15]. This type of forest comprises about 42% of tropical forests [16] and is known for losing its foliage during the dry season [17]. Finally, the main characteristic of montane forests is their variable altitudinal range (800–3500 m), with a low amount of radiation and high persistence of cloudiness in the upper limits [18,19], which allows for constant contact with water, making this environment play an essential role in the hydrological cycle [20,21].

The Amazon houses approximately 30% of the world's tropical forests [22]. It is the largest tropical forest in the world [23] and extends through Brazil, Colombia, Peru, Venezuela, Ecuador, Bolivia, Guyana, Suriname, and French Guiana [24]. About 60% of the Amazon is located in Brazil, 9% in Peru, and 6% in Colombia; the remaining 25% is in other countries [25]. It is characterized by maintaining a great taxonomic diversity in fauna and flora and being home to several indigenous communities [26].

Tropical forests play a vital role in the conservation of biodiversity, climate change, and the regulation of the water cycle in the region [27]. They are important given the variety of ecosystem services they provide regarding regulation, provision, support, and culture. These ecosystem services include food provision, pest control, and ecotourism [28,29]. In addition, they have global importance in biogeochemical cycles due to their productivity and activity in the water and carbon cycle [30,31]. Locally, they favor the maintenance of soil stability through their roots and inhibit surface washing and erosion [32]. Furthermore, they help regulate floods, act as climate regulators, and help maintain air, water, and soil quality [33,34]. These services result from the interactions between nature and societies; they provide economic, environmental, and social wellbeing and serve as a tool to inform decisions about the use and management of the planet's resources [35,36]. Moreover, the fewer disturbances tropical forests experience, the greater their capacity to provide varied and quality ecosystem services will be [37].

Land use and land cover (LULC) changes directly or indirectly transform the quality of the tropical forests and the resources they provide [38]. The development of different activities in tropical forests, such as the exploitation of natural resources [39,40], road construction [41], the construction of energy infrastructures [42–44], and urban expansion [45] cause forests degradation and generate negative impacts on an environmental, economic, social, and political level [46,47]. All of these activities classify as different land uses that determine the land cover [48] and can influence the water availability in a region [49,50]. They can also alter the richness and biodiversity of the area [51], especially in sectors rich in biodiversity, such as tropical forests [52]. LULC change can also affect soil respiration [53] and influence global food security [54]. In addition, forest loss can degrade their water regulation function, river flow [55], and modulation of precipitation patterns [56].

Land use and land cover is commonly used to describe the Earth's surface coverage [57]. It serves as one of the parameters for correctly identifying exploitation activities through land management changes [58]. LULC changes can cause negative impacts at the urban level, such as reduced air quality, the generation of heat islands, and decreased landscape quality [59,60]. Likewise, it can compromise the ecosystem services rural areas provide [61].

LULC studies can help manage natural resources sustainably [62]. Moreover, LULC change analysis facilitates the analysis and problem solving of current issues such as policy planning in case of diseases [63], urban planning [64], climate change trends [65], sustainable practices for the development of agriculture [66], and in the proposal of public policies for environmental conservation [67].

Tropical forests have been the subject of studies regarding LULC due to their ecological, economic, and social importance. In these studies, various areas are analyzed; some focus on the relationship between LULC and climate change and its effects on the environment [68,69] or on mapping and monitoring forests using remote sensing to analyze LULC and determine implications [70,71]. Other studies include the impacts of different land use in protected areas as a tool to establish conservation policies [72,73]. Some authors, such as Arantes [74], studied the relationship between plant cover and fish biodiversity to find out how LULC affects their ecology. Others, like Chapman, focus on the impact caused by land use change on the phylogenetic diversity of birds due to the importance of these species in pest control [75]. The complexity of the different approaches associated with LULC in tropical environments shows the progress made and the contribution to the discussion of its future impacts and consequences, justifying a systematic review of the subject to contextualize this evolution through time.

The constant growth of published information in the form of academic texts requires knowledge of the tools to measure the performance of the literature [76]. Therefore, a study that includes a better interpretation of the scientific production of LULC in tropical forests would complement previous research and allow the exchange of knowledge, methods, experiences, ideas, and models, supporting tropical forests' conservation and sustainable management. Furthermore, bibliometrics has played an essential role in studying the global dynamics of an area of knowledge by evaluating and comparing scientific production [77]. In general, bibliometric methods facilitate the evaluation of central research themes and the impact of scientific publications and researchers, and help organizations with the future prospecting of the field of study [78].

Over time, various studies on land cover and land use change in tropical regions have taken place, but only a few show this area's growth through bibliometric analyses. Among those studies, there is the study of the causes and effects of fires in tropical forests [79], the remote sensing analysis of wetlands in South America [80], the studies of global deforestation trends [81], the analysis of LULC in the Amazon region [82], and a review on the dynamics of terrestrial and aquatic carbon in tropical peatlands [83]. The present article aims to evaluate the research on LULC in the framework of tropical forests to analyze the scientific production over the last forty-four years.

This study has five sections: the first section, or introduction, discusses the importance of tropical forest land use change, as well as the objective of the study; the second section contains materials and methods that show the database used, as well as the data search and processing; the third section includes results, detailing the main findings and their analysis; the fourth section focuses on the discussion, where the implications of the results are analyzed; and the fifth section includes the conclusions and limitations of the study.

2. Materials and Methods

2.1. Study Area

The study area comprises tropical forests located between the Tropics of Cancer (23.44° N) and Capricorn (23.44° S) (https://pb463.users.earthengine.app/view/fipnee2020, accessed on 5 August 2022) [84,85]. According to the Food and Agriculture Organization of the United Nations (FAO), this tropical area has the highest proportion of forests in the world (45%) [86].

2.2. Methods: Data Processing

Academic literature can be analyzed and explored through systematic and bibliometric analyses. The systematic approach includes rigorous techniques to make the data collection procedure transparent and easily replicated, thus reducing the bias in the information obtained [87,88]. This procedure is similar to bibliometric studies, where the data are verified, thus obtaining a broader vision than the systematic studies [76,78].

Bibliometric analysis can effectively describe a discipline's state of knowledge, characteristics, and trends [89]. This study includes the quantitative and qualitative analysis of publications on a specific topic based on statistics and computer technology [90,91]. This technique has been widely used to assess various academic disciplines such as business and management [92,93], arts and humanities [94,95], earth sciences [96,97], and environmental sciences [98,99] among others.

Based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology (Figure 1), this study comprises four phases: (i) identification, (ii) screening, (iii) eligibility, and (iv) included. This methodology facilitates an objective, clear, and transparent scientific production analysis [100].

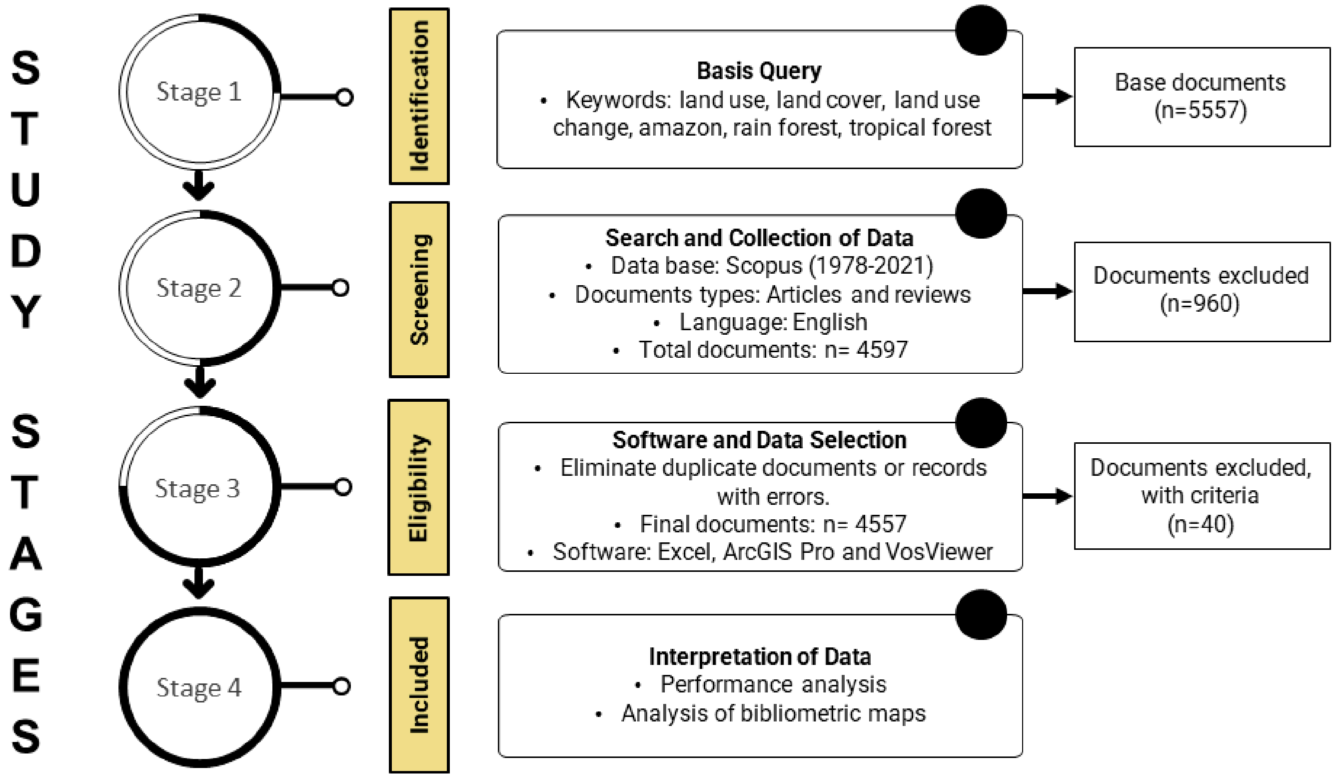

Figure 1. Diagram inspired by the PRISMA statement detailing the four phases of the bibliometric research methodology.

2.2.1. Stage I: Basis Query

This research aims to evaluate the land cover and land use changes in tropical forests worldwide through the bibliometric analysis of scientific publications. The search terms used are related to land use [101], land cover [102], and land use change [82]. These words were combined with the representative names of tropical ecosystems such as tropical forest, rainforest, and Amazon, which are also key terms frequently used to analyze advances and gaps in knowledge regarding restoration, carbon cycle, and knowledge production trends in these areas [103–105]. The selection of these criteria aided in defining the study area and compiling documents to evaluate this analysis.

Based on the above, the defined criteria aim to answer the following research questions (RQ):

- RQ1: What are the scientific production trends regarding LULC in tropical forests?
- RQ2: What are the most relevant publications and the countries that contributed to the growth of this field of study?
- RQ3: Which authors and journals have the most influence in the progress of LULC research on tropical forests?

- RQ4: What are the themes, topics, authors, and journals associated with the intellectual structure in this area?

The data collection occurred exclusively using the Scopus database, with a defined period from 1978 to 2021. The year 1978 was selected because it was when the first articles appeared in the database and the year 2022 was excluded, given that it is in progress at the time of this research.

2.2.2. Stage II: Data Search and Collection

Bibliometric studies generally need appropriate databases with complete and reliable information [106]. Scopus is a suitable database for studies related to bibliometric analysis due to its available bibliographic information [107]. This database has a significant number of unique sources in different research areas not covered by other databases [108], as well as a broad coverage in terms of years, journals, and languages [109]. In addition, Scopus contains links to author affiliation, which facilitates the analysis of researchers' mobility [110]. It has a stricter review process that involves peer-reviewed scientific documents [111]. In addition, its scientific production quality indices are used by research groups such as CiteScore or Scimago Journal Rank (SJR) [112,113].

The article sample analyzed in this study was selected based on a search carried out in February 2022 in the Scopus database using the topic search: TS = ((TITLE-ABS-KEY ("land use") OR TITLE-ABS-KEY ("land cover") OR TITLE-ABS-KEY ("land use change"))) AND ((TITLE-ABS-KEY ("amazon*") OR TITLE-ABS-KEY ("rain forest*") OR TITLE-ABS-KEY ("tropical forest*"))) AND (EXCLUDE (PUBYEAR, 2022)). The search obtained a total of 5557 documents.

Documents that went through a general review process, such as editorials, books, and conference papers, were excluded [114]. Generally, articles and reviews are the most widely used documents in the scientific world because they deepen a researched phenomenon, are of greater length in terms of their content, and have been blind peer reviewed [115]. Therefore, excluding certain documents and only including articles/reviews is a commonly accepted approach to performing a literature review [116]. Under these criteria, 699 documents were excluded. In addition, the search only considered articles in English because it is the global language for scientific dissemination [117]. In fact, the vast majority of peer-reviewed scientific journals only publish articles written in English [105]. As a result, the search found 4597 articles.

2.2.3. Stage III Software and Data Selection

Once collected, the data from the Scopus database were exported to both a Microsoft Excel spreadsheet and a text document for its respective treatment [118]. The database includes information on different variables (authors, institutions, journals, language, keywords, abstract, references, among others) [119] that must be reviewed to obtain the greatest accuracy possible. During the review, the data are cleaned by removing duplicate files and incomplete or erroneous records [99,120]. Under these considerations, 20 documents were eliminated, obtaining 4557 papers.

The Microsoft Excel Office 365 MSO software (Version 2209) performed the descriptive statistical analyses of the studied variables [121]. In addition, the ArcGIS Pro software was used to make the maps, which obtained a cartographic representation that allowed the collection, organization, analysis, and visualization of geographic information [122,123].

The bibliometric maps were built with the VOSviewer tool to visually present the statistical results related to the distribution of authors, institutes, countries/territories, and keywords [124]. The software uses a technique called VOS, which minimizes a weighted sum of squared Euclidean distances between all pairs of elements through an optimization process. This mapping approach will enable elements to be placed on the map so that the distance between each pair of elements represents their similarity as accurately as possible [125]. In addition, it has "zooming" features, which facilitate the detailed examination of the map [126]. This software has been used in various bibliometric analyses performed in diverse subject areas [127–129].

2.2.4. Stage IV Data Interpretation

During the collected data analysis, two bibliometric approaches were used. The first bibliometric approach focuses on the performance of scientific production. The second bibliometric approach involves studying its intellectual structure through bibliometric mapping [130].

Performance analysis evaluates the impact of the scientific publications that make up this structure by contrasting information related to the number and year of publications, authors, affiliations, and journals [76]. Bibliometric mapping, or science mapping, creates a graphic representation of the fields and subfields of the research, facilitating their visualization and understanding of the relationships between them [131]. These maps show the relationships between variables, such as author keyword co-occurrence, co-citation with cited authors, and source citations [132,133]. This combination reveals the studied topic's intellectual structure [134].

3. Results

3.1. Performance Analysis

3.1.1. Scientific Production Analysis (RQ1)

The scientific production of LULC in tropical forests comprises 4557 documents and 206,083 citations over 44 years (1978–2021). Initially, the studies on the subject were scarce; however, over time, the academic world seems to have increased its interest in the topic. This interest is evidenced in 2010, when 69.21% of the research on the topic started (see Figure 2). For analysis purposes, the scientific production was divided into four time periods: Period I (1978–1989), Period II (1990–1999), Period III (2000–2009), and Period IV (2010–2021). This division by decades facilitates the understanding of the field of study development [135]. The number of citations per period refers to the total number of citations received by the publications (articles and reviews) in that period.

Period I (1978–1989)

The first twelve years show the beginning of scientific production within the prescribed period of study. In this period, there are 65 publications (1.43% of the documents) that add up to 2942 (1.43%) citations. Before the 1980s (1978 and 1979), articles were published on the causes and consequences of rotational cultivation and population pressure in tropical areas [136,137], as well as regarding the importance of forestry for plant and animal conservation and agrosystems development [138,139]. It is important to note that this period is marked by the advancement of geotechnologies, with the increased use of satellite images (for example, Landsat) in mapping and environment monitoring. Among the outstanding publications of the decade is the use of satellite images and data regarding the type of vegetation and land use as a basis for studying climate change [140], as well as the study of land use change and its effects on the carbon content of vegetation and soil using a computer model [141].

Period II (1990–1999)

In this period, a scientific production growth (329 publications) is observed, especially between 1991 and 1997. The number of citations also increased notably, adding 22,966 (11.14%), indicating a growing interest in LULC research of tropical forests and their implications. Publications highlighted the use of satellite, socioeconomic, and vegetation data to study land cover change [142–144]. Other studies focus on the history, structure, diversity, disturbances, maintenance, and recovery of tropical forests [145–147], as well as the role of these forests in biogeochemical cycles [148,149] and the modifications of these cycles due to land use changes [150–153] and land cover change caused by natural and artificial fires in the Amazon [154–156].

During this period, there was an advancement in environmental and climate debates, marked by the United Nations Conference on Environment and Development, also known as Eco-92 (held in Rio de Janeiro (RJ), Brazil, in June 1992). This advancement prompted scientific research on "deforestation" and its relationship with the most diverse aspects of land use and the consequences on the climate and biodiversity of the most diverse terrestrial ecosystems, especially the Amazon.

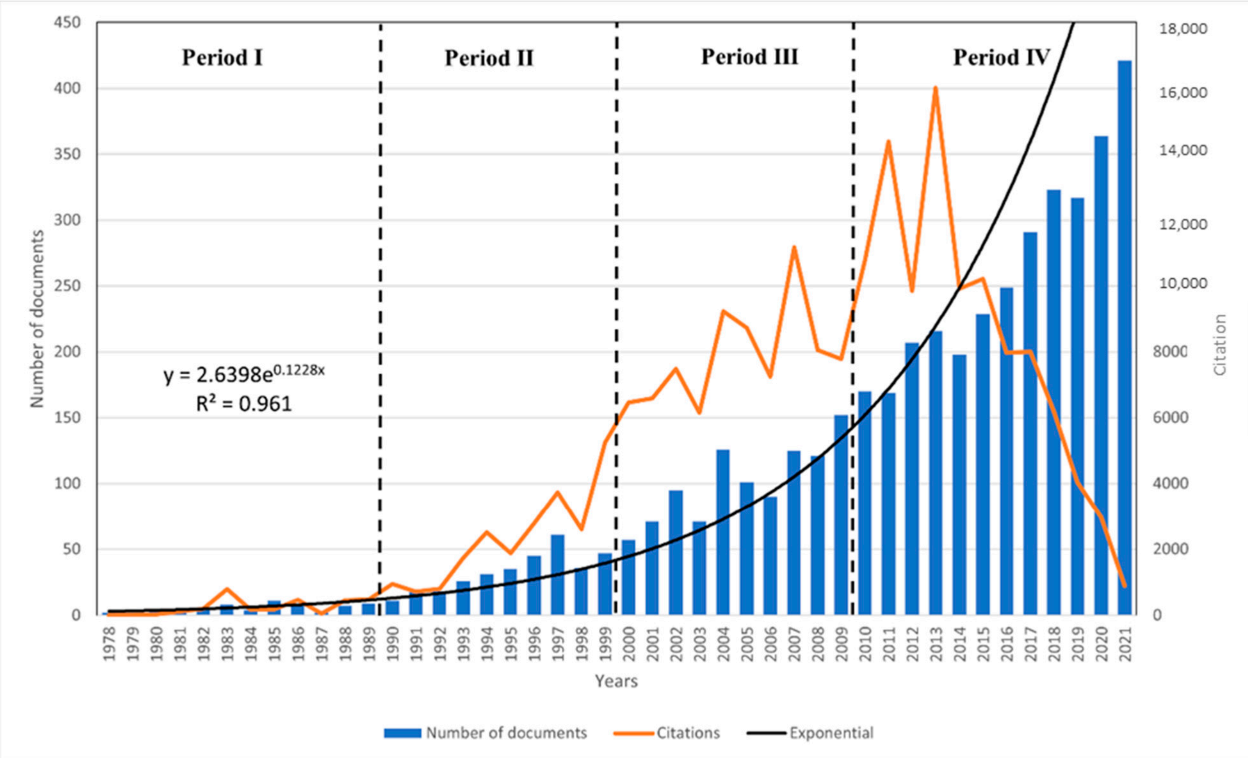

Figure 2. Scientific production in research (1978–2021) on LULC in tropical forests divided into four periods. The data are the annual number of papers (articles and reviews) indexed in Scopus and the number of citations per year.

Period III (2000–2009)

This decade shows more significant growth than the previous one, with 1009 publications and 78,912 (38.30%) citations. The documents represent 22.14% of the total number of publications. Publications with many sources that address biodiversity, species conservation, and the characterization of tropical forests stand out. The most-cited article deals with the preservation of the Brazilian Cerrado due to its biological importance and the intensification of land use. The biodiversity in different types of forests is also quantified [157]. Other studies consider how the constant change in land use can impact regional and seasonal climate trends [158–160], how the legacy of human beings would modify the structure of tropical forests [161,162], and the environmental and social challenges of soybean, sugarcane, and rubber production [163–165].

Historically, it is a consolidation period for environmental research, mainly due to online information, storage platforms, and their public availability for consultation. The "US Geological Survey" [166] site is highlighted during this time because it facilitated an expressive set of information involving the Earth's surface mapping. That data will become a part of the National Aeronautics and Space Administration (NASA)'s EarthData [167] in the following period, making the set of Landsat (and other satellite) images freely accessible, helping researchers who previously needed to pay to access these platforms.

Period IV (2010–2021)

Finally, the last period contains the most significant number of publications, comprising 3154 articles (69.21% of the production). The substantial increase in citations with 101,263 (49.13%) demonstrates the relevance and interest of the topic in the last 11 years. During this period, related studies on tropical forests' carbon capture and sequestration capacity [168–170] and the magnitude, causes, and consequences of carbon dioxide emissions are highlighted [171–173]. The global dynamics of tropical forests and their sustainability is also addressed [174–176]. Other studies carry out total estimates of carbon and biomass using satellite images [177–179] and establish proposals for managing and conserving tropical forests and future challenges [180–182].

In this phase, the Google Earth system was widely used, popularizing the use of geographic information systems in people's daily lives, through the historical analysis of images, providing a quick view of the changes in vegetation cover and the effects of deforestation. Continuing with the Google platform, the Google Engine tool makes the processing of digital images and land cover change analysis independent from commercial programs. In addition, it marks the current advancement in geotechnologies, including drone imaging, which generates high spatial resolution imagery applicable to environmental surveillance and enforcement.

Although Figure 2 represents the scientific production of the studied topic, its evolution is reviewed using Price's law. This law evaluates the increase in publications, where exponential growth allows the consideration that the investigated area is a field of study [183]. For example, in Figure 2, the exponential equation $Y = 2.6398e^{0.12228x}$ and its determination coefficient of $R^2 = 0.961$ obtained was considered high, affirming compliance with this law; consequently, we can call the area of study a field of study.

3.1.2. Top 10 Frequently Cited Documents (RQ2)

Citation evaluation in bibliometric analysis is an indicator of the quality and impact of the research [184]. For this reason, analyzing the publications with the highest number of citations offers a perspective on the topics that dominate the study area. Table 1 identifies the ten documents that have received the most attention from the scientific community regarding LULC in tropical forests. Four studies explained the use of satellite images to analyze different land uses, land cover, and carbon balance [156,175,185,186]; three papers showed the importance and conservation of tropical forests [149,157,174]; two studies made estimates of the carbon pool and carbon dioxide emissions [170,172], and one reviewed the characteristics of secondary tropical forests [147]. However, these documents represent only a tiny fraction of scientific production (0.22%) and contribute 8.24% of the total citations. In addition, seven publications come from UK journals, and the remaining three were published in US journals.

The *American Journal of Science* published the first two most-cited papers. In the first article, the authors use satellite information to map the change in forest cover worldwide. The article verified that tropical forests experienced a significant forest cover loss [175]. The second article presents estimates of the stocks and fluxes of carbon in the world's forests through data inventories and statistical models. It showed that in the tropics, the change in land use is more intense, and they have greater carbon sequestration; however, future carbon cycle studies should be continued [170]. Finally, the third most-cited article was published by the British journal *Nature*, presenting a meta-analysis of 138 studies. This article analyses the impact of land use changes on tropical forests' biodiversity, establishing that primary forests harbor a greater biodiversity than degraded forests [174].

The annual citation index is a parameter that establishes the relationship between the total number of citations per article and their respective publication time [131]. This parameter helps determine whether there is a proportional relationship between the total number of citations and the document's age. Table 1 shows this index, where the documents published for a longer time do not necessarily obtain a greater number of citations. On the contrary, the most recent document in the table (2013) is the one with the highest index [175].

Table 1. Top 10 frequently cited documents during 1978–2021 on LULC in tropical forests. R = rank; TC = total number of citations received for document; ACI = annual citation index.

R	Authors	Title	Year	TC	ACI
1	Hansen et al. [175]	High-resolution global maps of 21st century forest cover change	2013	5372	596.9
2	Pan et al. [170]	A large and persistent carbon sink in the world's forests	2011	3788	344.4
3	Gibson et al. [174]	Primary forests are irreplaceable for sustaining tropical biodiversity	2011	1187	107.9
4	Gibbs et al. [185]	Tropical forests were the primary sources of new agricultural land in the 1980s and 1990s	2010	1034	86.16
5	Nepstad et al. [149]	The role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures	1994	1006	35.9
6	Baccini et al. [172]	Estimated carbon dioxide emissions from tropical deforestation improved by carbon-density maps	2012	992	99.2
7	Nepstad et al. [156]	Large-scale impoverishment of Amazonian forests by logging and fire	1999	962	41.8
8	Klink and Machado [157]	Conservation of the Brazilian Cerrado	2005	961	56.5
9	Brown and Lugo [147]	Tropical secondary forests	1990	863	27
10	Houghton [186]	Aboveground forest biomass and the global carbon balance	2005	808	47.5

3.1.3. Top 10 Countries by Number of Documents (RQ2)

The analysis by country is carried out according to the author affiliation, and it reveals the most influential countries and the various relationships between these countries pertaining to knowledge generation [187].

Figure 3 shows the contribution of these countries. Among the top 10 countries, there are four American countries (United States, Brazil, Mexico, and Canada), four European countries (United Kingdom, Germany, France, and the Netherlands), one from Oceania (Australia), and one from Asia (Indonesia). North American and European countries do not have tropical forests in their territory. Regardless, they work with nations from South America, Africa, and Asia to build the intellectual structure of the study area.

The country with the highest number of publications and citations is the United States, with 1893 and 127,366, respectively. Brazil and the United Kingdom rank second and third with 1591 and 610 documents, respectively. In addition, these three countries have published 87 investigations on the subject, with a closer relationship between the United States and Brazil since they have 503 documents together.

From the collaboration between the United States and Brazil, we can highlight publications that study the Brazilian Amazon land cover change through satellite images, as well as the impacts of deforestation, the ecology of tropical forests due to fragmentation by agricultural activities, and the analysis of public policy applications [180,188–190]. These three countries, in collaboration with researchers such as John Adams (University of Washington), Carlos Souza (Instituto do Homem e Meio Ambiente da Amazônia), and Edward Mitchard (University of Edinburgh), presented publications representing a model to monitor land use change [191], as well as the quantification of annual deforestation and degradation [192] and carbon stock mapping [178]. The United Kingdom contributes with research on biodiversity in tropical environments, as well as the ecosystem services offered by tropical forests, conservation implications, and on the perceptions of humanity towards forest changes [193–196].

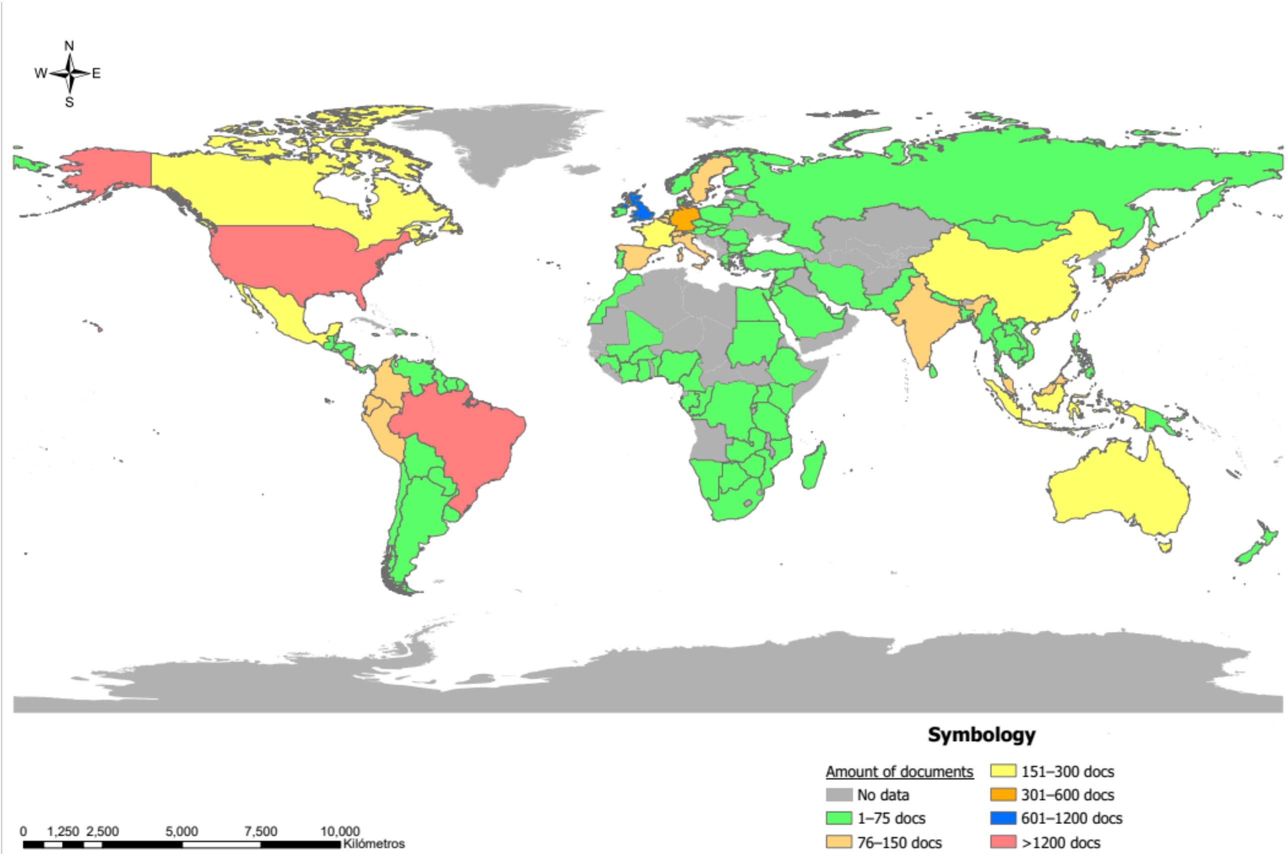

Figure 3. World map showing number of studies about LULC in tropical forest per country.

3.1.4. Top 10 Sources by Number of Documents (RQ3)

Table 2 shows the performance and quality indices of the ten leading journals collaborating to generate knowledge in the area. The top 10 journals contain 920 of the 4557 publications analyzed, representing 20.19% of the scientific production. The table in question shows the performance indicators of journals such as *SJR* and CiteScore with their 2020 figures. Various areas of knowledge such as agricultural and biological sciences are addressed in *Forest Ecology and Management*, *Land Use Policy* and *Biotropica*. *Global Change Biology*, *Environmental Research Letters* and *Ecological Applications* correspond to the environmental sciences. Earth and planetary science are reviewed in the journals *Remote Sensing of Environment*, *International Journal of Remote Sensing*, and *Remote Sensing*. Meanwhile, the journal *PLOS One* is multidisciplinary, addressing topics in the natural, social, health, and engineering sciences.

Forest Ecology and Management is a primary source, with 179 documents representing 3.93%. The source presents a CiteScore of 5.8 and has an SJR index of 1.29. It is the journal with the second longest (45 years) coverage period and has 11,068 citations. The most relevant document in the journal has 758 citations. This document studies the results of the Global Forest Resources Assessment 2015 (FRA 2015), concluding that the net loss of tropical forests in the last five years of the study was more accentuated in Brazil, Indonesia, and Nigeria. The publication also suggests policies for developing public forest conservation strategies [176]. Even though its coverage in years (20 years) has decreased in comparison with the previous journal, the second place is occupied by *PLOS One* with 102 documents and 3531 citations. Its most-cited paper (274 citations) compares protected areas of strict use against those of multiple use using forest fires as an indicator of deforestation and carbon release, finding that protected areas have a lower incidence of forest fires [197]. Both journals are in quartile 1. The following three primary sources are *Global Change Biology*, *Land Use Policy*, and *Remote Sensing of Environment*. The table is generally dominated by journals with greater coverage of years in Scopus. Still, it shows that recent journals could position themselves if they present a greater production of documents in the area.

Table 2. Top 10 sources with the highest number of documents. R = rank; CY = coverage; ND = number of documents; TC = total number of citations received for document; SJR = Scimago Journal Rank.

R	Source	Scopus CY	ND	TC	SJR	CiteScore
1	*Forest Ecology and Management*	1976 to present	179	11,068	1.29	5.8
2	*PLOS One*	2001 to present	102	3531	0.99	5.3
3	*Global Change Biology*	1995 to present	93	9115	4.15	15.5
4	*Land Use Policy*	1984 to present	89	3285	1.67	7.5
5	*Remote Sensing of Environment*	1969 to present	82	8356	3.61	17.6
6	*International Journal of Remote Sensing*	1980 to present	81	3742	0.92	5.9
7	*Remote Sensing*	1992 to present	75	1431	1.29	6.6
8	*Biotropica*	1979 to present	75	2502	0.81	3.6
9	*Environmental Research Letters*	2006 to present	74	2552	2.37	8.6
10	*Ecological Applications*	1991 to present	70	5278	1.86	7.8
	Total top 10 journals		920	50,860		
	Total documents		4557	20,608		

3.1.5. Top 10 Leading Authors (RQ3)

The authors' analysis reveals the most productive researchers and facilitates the finding of research collaborations by other academics [198]. Table 3 lists the LULC authors in tropical forests by their number of publications and total citations. In addition, a quality indicator, the H-index, is observed. The author with the most significant number of publications is Yoshio Shimabukuro (National Institute of Space Research), who stands out with publications that include the study of land cover change through remote sensing [199–203], as well as the impacts of LULC [204–206]. Eric Davidson (University of Maryland Center for Environmental Science) is the most influential researcher due to his publication of documents in collaboration with other authors. The topics include studying the role of tropical forests in biogeochemical cycles [149,207,208] and the relationship between LULC and biogeochemical cycles [153,209–211].

Table 3 shows the top 10 authors. Three are Brazilian, with Yoshio Shimabukuro and Luiz Aragao, who have 11 publications together. They study issues related to LULC in the Brazilian Amazon, e.g., [205,212,213]. On the other hand, Philip Fearnside and Luiz Aragao have a joint publication that aims to analyze fire-affected areas through satellite images [214]. In addition, Fearnside studies land use and climate change [42,215–217]. Two authors have affiliations in the United Kingdom: Jos Barlow and Carlos Peres. They have 16 publications studying aspects related to the quantification and importance of biodiversity in tropical forests, e.g., [174,218,219]. Finally, the five authors with the most significant number of documents have American affiliations. Stephen Perz presents publications with Gregory Asner and other pieces with Robert Walker that include the study of the relationship of small farms with land cover change [220,221]. Emilio Morán presents a collaboration with Robert Walker investigating the relationship between humans and LULC [222]. His most influential publications study the Brazilian Amazon through remote sensing [143,223,224]. While Eric Davidson has no collaborations with US-affiliated authors, his work includes studies analyzing tropical forest transition and mortality due to land use [225,226].

Table 3. Top 10 leading authors by their number of publications and number of citations. ND = number of documents; TC = total number of citations received for document; HI = H-index.

Author	Country	Affiliations	Intellectual Structure		Global Publication		HI
			ND	TC	ND	TC	
Shimabukuro Y.E.	Brazil	Instituto Nacional de Pesquisas Espaciais	50	2820	251	7797	41
Barlow J.	United Kingdom	Lancaster Environment Centre	46	5386	210	13,691	60
Asner G.P.	United States	Arizona State University	44	4970	582	54,423	112
Fearnside P.M.	Brazil	Instituto Nacional de Pesquisas da Amazonia	42	3186	226	16,543	67
Peres C.A.	United Kingdom	University of East Anglia	41	4468	374	25,103	86
Morán E.F.	United States	Indiana University	39	2762	166	14,732	50
Aragão L.E.	Brazil	Instituto Nacional de Pesquisas Espaciais	36	1529	224	13,444	54
Perz S.G.	United States	University of Florida	36	1554	99	3101	30
Davidson E.A.	United States	University of Maryland Center for Environmental Science	35	5730	241	36,007	93
Walker R.	United States	University of Florida	35	2464	92	4025	35

3.2. Bibliometric Mapping Analysis

Bibliometric mapping gives access to visual representations in the form of an analysis unit network (authors, keywords, journals, or countries), facilitating the observation of their development and interaction in a network made up of nodes and grouped in clusters [227]. In addition, these maps illustrate a deeper and more detailed understanding of the intellectual structure of an area of research [228].

3.2.1. Co-Occurrence Author Keyword Network (RQ4)

This analysis allows the detection of central research topics and themes and their trends in the field of study [229]. Figure 4 shows the co-occurrence network of author keywords, finding 554 nodes (relevant topics) and 14 clusters. The minimum number of co-occurrences was five. In the figure, the nodes (circles) represent the topics, which, when grouped (clusters of the same color), determine the themes or lines of research [134,230].

Cluster 1 (red), "Tropical forest, biodiversity, and fragmentation", presents 69 nodes with 1490 occurrences. Relevant topics are tropical forests, biodiversity, and rainforest. In this cluster, there are articles related to the value of tropical forests and their biodiversity [218,219,231], impacts of different land use [38,232,233], biodiversity according to land use [234,235], anthropogenic activity, and biodiversity [51,162,236]. In addition, other authors consider studies referring to deforestation predictors and causes [237,238], history of land use and vegetation [239,240], and biodiversity recovery [241]. The topics addressed in this cluster are of great importance due to tropical forests' economic, social, ecological, and political interests since they provide multiple benefits, making it necessary to know their value and threats.

Cluster 2 (green), "Land use change", consists of 69 nodes and 1360 occurrences. The publications in this cluster present research on soil structure changes [242–244], soil composition, and tropical forest structure [245–247] and management [248,249]. Other publications explain the impacts of land use change on carbon stocks [250–252], carbon emissions [253–255], and deforestation patterns [199,256]. In this cluster, the most relevant keywords are land use change and tropical rainforest. The cluster considers determining and making visible the impacts of land use change at different levels of the tropical ecosystem.

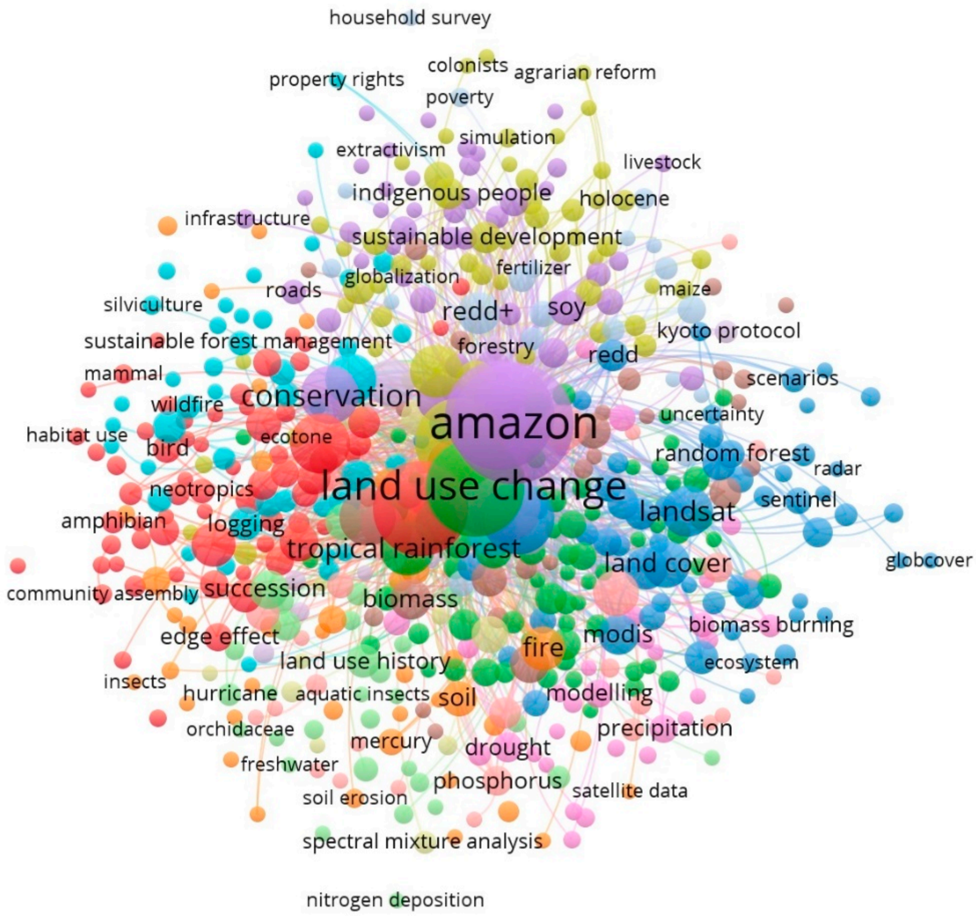

Figure 4. Visualization of themes of research (clusters of the same colour) based on the analysis of keyword co-occurrence.

In cluster 3 (blue), "Remote sensing, land cover, and GIS", the terms "remote sensing" and "Landsat" predominate. This cluster presents studies using remote sensing to determine forest changes over time [21,200,212], biomass mapping [24,245,257], and biodiversity characterization [258,259]. On the other hand, deforestation [260,261], management [262,263], and associated ecosystem services [54,233] are also evaluated. In this cluster, there are 59 nodes and 1253 occurrences, highlighting the importance of different techniques such as remote sensing to study tropical forests and their ecological and structural dynamics.

Cluster 4 (yellow) is "Land use and indigenous people". This cluster has 54 nodes and 1019 occurrences. The predominant themes are land use and agriculture. In addition, it includes articles referring to the economic value of non-timber products and the risk they face due to deforestation [264,265], land use in protected or rural areas [266–268], and the observation of agroforestry system benefits [269,270]. In this case, the study of these topics aims to investigate and highlight the importance and impacts of different land uses and their opportunities and threats to indigenous communities.

Cluster 5 (purple), "Amazon, deforestation, and public policy", shows land use dynamics in the Amazon [238,271,272] and the bases for conserving tropical forests [249,273,274], and explains the relationship between degradation and palm oil plantations [275,276]. The cluster has 48 nodes with 2141 occurrences. The main topics are studied due to the taxonomic importance and natural regulation of the Amazon, where the patterns and causes of deforestation are analyzed. In addition, it includes public policies for the management, restoration, and remediation of tropical forests.

Cluster 6 (sky-blue) is "Ecosystem service, logging, and forest management". The main terms in this cluster are pasture and ecosystem service. In this group, 45 nodes with 641 occurrences are presented and include research on the importance of ecosystem services [193,277] and the impacts at different organizational levels of forest exploitation [75,278]. These issues particularly highlight the benefits that tropical forests provide to humans and the planet and the effects on ecosystem services due to the conversion of forests to pasture.

Cluster 7 (orange) is "Fire, human disturbance, and climate". In this cluster, there are 39 nodes and 430 occurrences. These topics are mainly related to articles that study the change of forest cover due to fires [279,280] and the impact of anthropogenic activities [281,282]. In addition, the topics focus on explaining how natural and arson fires, as well as disturbances due to the intensification of human activity, directly influence the climate in the short and long term.

Cluster 8 (brown) is "Secondary forest and carbon cycle". The main characteristics of this cluster are research on biodiversity [188,283] and the carbon cycle in secondary forests [148,186]. It presents 32 nodes and 520 occurrences, which address issues related to the taxonomic value and structural variations that secondary forests contribute due to their different disturbances.

Cluster 9 (violet) is "Climate change, land cover change, and water cycle". In this cluster, the central terms are climate change and land cover change, with 32 nodes and 603 occurrences. The effects of climate change and its impacts [160,284] are one of the main topics in this cluster. In addition, it studies the modeling of biogeochemical cycles in tropical forests [285,286] and biodiversity dynamics [287,288]. Climate change is related to the different dynamics in tropical forests, so its study is of interest due to the value of forests for the planet.

Cluster 10 (pink), "Land use and land cover change, disturbance", includes 32 nodes with 510 occurrences. Among the most common topics are carbon and nitrogen dynamics due to land use [210,289], biomass estimates, carbon and nitrogen in tropical forests [290,291], and composition and microbial dynamics [292,293]. The central nodes of this cluster are carbon, land use and land cover change, and disturbance. These topics are studied due to the importance of the biogeochemical cycles on the planet. These cycles maintain a balance in the biotic and abiotic components and help to understand their role in climate change.

Clusters 11 to 14 (light green, mustard, light blue, and lilac) are small clusters with familiar topics, which is why they have been grouped under the name "Global change, protected area, and Amazon basin". This cluster contains 74 nodes with 162 occurrences. The central topics include publications referring to the general analysis of the Amazon basin, its different land uses and changes in vegetation structure [43,209] and disturbances, and the management and conservation of protected areas in tropical forests [294,295].

3.2.2. Co-Citation Analysis (RQ4)

This analysis makes it easier to determine the papers that are more likely to be related or belong to a similar study area [296]. It establishes the relationship between the co-cited articles and determines their influence [297]. This analysis forms clusters where it identifies thematic areas [298]. Large clusters include a more significant number of publications, and the distance between two clusters indicates the relationship between them. If they are close, they tend to be strongly related [299]. Co-citation can be used as a unit of analysis for authors and journals.

Author Co-Citation Analysis (ACA)

This analysis aims to show the structure and connections of the most frequently cited authors [300]. In addition, it makes it possible to understand the various schools of thought or topics that comprise the field's base knowledge [301]. In Figure 5, the nodes represent the authors, who are grouped in a cluster of the same color to represent collective knowledge [302]. The figure shows a structure of eight clusters and 3833 authors with more than 30 co-citations. The clusters and their most relevant authors will be examined next.

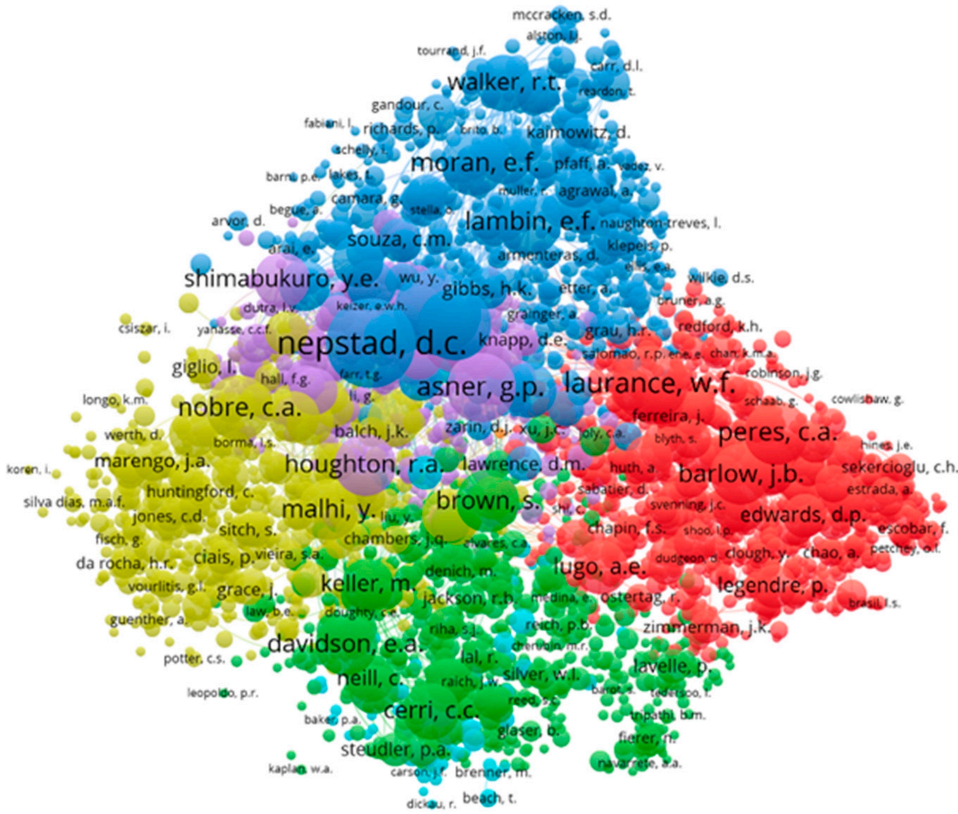

Figure 5. Network and grouping of co-cited authors. Clusters of the same color represent authors with collective knowledge.

Cluster 1 (red), "Deforestation and value of tropical forests", includes 1120 authors. This cluster comprises different topics that refer to deforestation for other land uses, the importance of tropical forests structure, and their biodiversity and conservation. William Laurance, with 1854 citations, leads the cluster, presenting publications on the analysis of deforestation [237,273], and tropical forests' response to global changes and their conservation [303,304]. Carlos Peres (1351) and Jos Barlow (1224) present 15 joint studies that analyze the value of diversity in different tropical forest environments, whether disturbed or not [219,236]. The three primary authors share a meta-analysis that studies the value of biodiversity in tropical forests and highlights its importance [174].

Cluster 2 (green) is the "Carbon and nitrogen cycle". This cluster features 733 authors who discuss topics relating to carbon and nitrogen reserves, emissions, and sequestration. For example, Sandra Brown (1283) makes estimates of carbon density, biomass, and carbon pools [178,305,306]. Eric Davidson (1264) focuses on carbon and nitrogen dynamics in the Amazon [211,307,308], and nutrient activity in tropical forests [309,310]. On the other hand, Carlos Cerri (1056) studies the biochemical dynamics associated with land conversion in different land uses [152,189,254].

Cluster 3 (blue), "Wildfires and land use dynamics", presents 720 authors who focus on studying the effect of fires in tropical forests and the impacts of land use change. The most relevant publication by Daniel Nepstad (2640) focuses on the positive and negative effects of forest fires [154,156,225]. Another author, Philip Fearnside (2421), studies the threats posed by land use change [42,163,215]. Finally, Ruth DeFries (1722) focuses on deforestation impacts and the conservation opportunities that this activity entails [199,201,256,273].

Cluster 4 (yellow), "Rainforest", includes 694 authors mainly studying tropical forests and their dynamics and interactions. Among the most relevant authors is Carlos Nobre (1369), who presents studies on changes in the Amazon due to logging and fires [156,311], and the risks of climate change in the Amazon due to anthropogenic activities [312,313]. In addition, Yadvinder Malhi (1200) and Oliver Phillips (946) present nine joint publications that mainly focus on carbon balance, biodiversity, and environmental changes in the Amazon region, e.g., [304,314,315].

Cluster 5 (purple), "Remote sensing and monitoring", which contains 468 authors, deals with issues related to estimating carbon cycle products and changes in coverage visualized through satellite images. Gregory Asner (1580) studies estimates of biomass and greenhouse gas emissions [171,316], as well as land cover and its different uses, using satellite images [317,318]. For his part, Matthew Hansen (1352) focuses on cover change detection to determine an area's vulnerability [319,320]. Finally, Richard Houghton (1266) performs multi-temporal analyses of carbon stock and estimates emissions [168,170,172].

Cluster 6 (sky-blue), "Mining and historical LULC", has 96 authors, and the publications are related to mining activity in tropical forests and LULC multi-temporal analysis. Timothy Killeen (398) studies land use biodiversity evolution [304,321]. Mark Bush (339) explores LULC multi-temporal changes [322,323]. At the same time, Miles Silman (224) covers the study of deforestation, degradation, and mercury impact on soils as a result of mining activity [324,325].

Cluster 7 (orange) and Cluster 8 (brown), "Logging, fire, and evaporation", have an author in each of their clusters. Jeffrey Gerwing (42) presents papers on forest degradation caused by logging and fire [326], while Tatiana Sá (35) studies the evaporation process of secondary tropical forests [327].

Journal Co-Citation Analysis (JCA)

This analysis considers the similarity of the journals according to the received reference patterns, where two journals are cited by several documents that are related to one another [328,329]. This analysis allows us to understand the theme structures of the various areas of knowledge [330].

Figure 6 illustrates this journal co-citation network, visualizing the different journals and their connections. This structure has seven clusters, including 541 journals (nodes) with at least 30 citations.

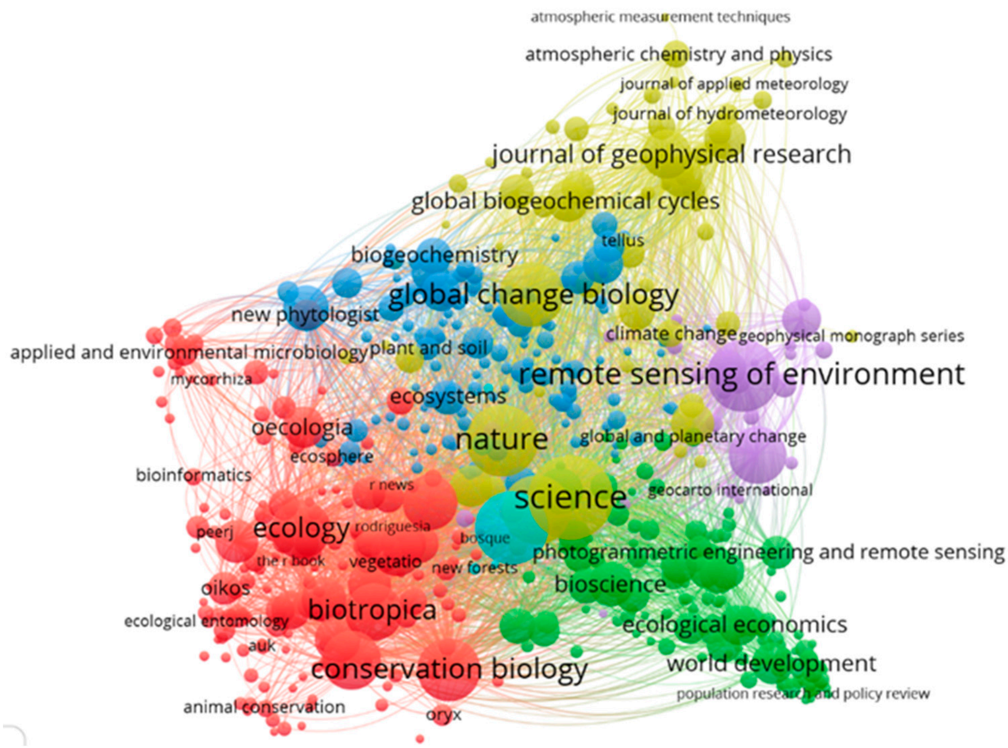

Figure 6. Network and grouping of co-cited journals. Clusters of the same color represent areas of knowledge.

Cluster 1 (red), "Biology", represents 164 journals totaling 48,030 citations. In this group, the main journals are: *Conservation Biology* (the United Kingdom, 3554 citations), *Ecology* (the United States, 3045 citations), *Biological Conservation* (the Netherlands, 2913 citations), *Biotropica* (the United States, 2853 citations), and *Ecological Applications* (the United States, 2436 citations). This group's journals mainly study different areas of biology such as ecology, conservation, biogeography, and evolution.

Cluster 2 (green), "Environment, land use, and development", includes 144 journals totaling 28,462 citations. The journals of this cluster stand out for their topics encompassing various aspects of the environment, and land use and its ecological, economic, social, and political implications. Among the journals, we find: *Agriculture, Ecosystems and Environment* (the Netherlands, 1645 citations), *Bioscience* (the United States, 1532 citations), *World Development* (the United Kingdom, 1249), *Ecological Economics* (the Netherlands, 1138 citations), and *Land Use Policy* (the United Kingdom, 1038 citations).

Cluster 3 (blue), "Soil and biogeochemistry", contains 140 journals, totaling 22,566 citations. Usually, the journals that belong to this group present publications on the study of soil structure, soil dynamics, and biogeochemical cycles, their function, and interactions. These journals include: *Soil Biology and Biochemistry* (the United Kingdom, 1588 citations), *Journal of Hydrology* (the Netherlands, 1193 citations), *Geoderma* (the United Kingdom, 1081 citations), *Soil Science Society of America Journal* (the United States, 996 citations), and *Biogeochemistry* (the Netherlands, 873 citations).

Cluster 4 (yellow), "Multidisciplinary sciences", groups 58 journals and 39,796 citations. These journals address various academic disciplines such as environmental, biological, agricultural, planetary, and earth sciences. Journal examples include: *Science* (the United States, 7251 citations), *Nature* (the United Kingdom, 4810 citations), *Proceedings of the National Academy of Sciences of the United States of America* (the United States, 4320 citations), *Global Change Biology* (the United Kingdom, 3771 citations), and *Journal of Geophysical Research* (the United States, 1949 citations).

Cluster 5 (purple), "Remote sensing", consists of 26 journals with 12,186 citations. In this cluster, the journals that stand out are: *Remote Sensing of Environment* (the United States, 4687 citations), *International Journal of Remote Sensing* (the United Kingdom, 2857 citations), *IEEE Transactions on Geoscience and Remote Sensing* (the United States, 1071 citations), *Remote Sensing* (Switzerland, 1002 citations), and *ISPRS Journal of Photogrammetry and Remote Sensing* (the Netherlands, 372 citations). The journals of this group focus on publications related to remote sensing in different ecosystems, covering aspects such as ecology, environmental sciences, and engineering.

Cluster 6 (sky blue) and Cluster 7 (orange), "Forest", includes nine journals with 6110 citations. The journals of this group refer mainly to the study of forest sciences, ecology, management, and conservation. Some examples include the journals *Forest Ecology and Management* (the Netherlands, 5053 citations), *Frontiers in Ecology and Environment* (the United States, 384 citations), *Canadian Journal of Forest Research* (Canada, 287 citations), *Forest Science* (the United States, 171 citations), and *New Forests* (Holland, 58 citations).

All of the topics mentioned in each cluster are related to tropical forests. They are made up of different biological structures, as well as topics ranging from the biodiversity, ecology, and conservation of tropical forests to the dynamics of the different environmental matrices.

4. Discussion

This paper investigates the scientific trends and evolution of LULC research in tropical forests. Regarding environmental sciences, this bibliometric research adds a new perspective to the current forest situation by identifying the countries that contribute the most to LULC studies. At the same time, the management, conservation, and implementation of public policies that help control environmental problems such as global warming, deforestation, and forest degradation are increasingly crucial for researchers, world leaders, and organizations. For this reason, a bibliometric analysis can serve as a starting point to determine the topics of most significant interest in this field of study.

Tropical forests play an important ecological, social, and economic role. In addition to having rich biodiversity, they are home to multiple human communities and providers of various ecosystem services [29,331]. Despite their value, these ecosystems are subjected to deforestation, degradation, and forest fragmentation caused by forest fires during drought, in addition to the replacement and loss of forests caused by human activities such as housing, food, and infrastructure [38,43,332]. These tropical forest alterations are identified over time with the help of satellite images, which has made it possible to study changes in land cover and land use. This research examined the intellectual structure of this study field through 4557 documents and the contribution of 74 countries, most of which are developed countries (Figure 2). The first study concerning LULC in tropical forests analyzed the different applications of Landsat images in various tropical forest studies [333]. At the same time, the most recent publication merged data from Sentinel-1 and -2 to model the characteristics of the vegetation structure in GEE for the Paraguayan Chaco [334].

On the other hand, Brazil has a considerable extension of tropical forests. Their participation is important due to their interest in Amazon conservation, which represents approximately 60% of the Brazilian territory [335]. Guyana, Bolivia, Cambodia, Malaysia, Nigeria, and other regions with tropical forests have an important collaboration with developed countries. This collaboration may be related to the funding provided by international organizations and the large volume of partnerships from the United States, Brazil, the United Kingdom, and the European Union [81,336]. Research usually requires economic, technological, and material resources, which are not readily available in less developed countries; as a result, collaboration is necessary. Some biodiversity hotspots are found in Southeast Asia, Madagascar, Liberia, Central America, and the Amazon rainforest. The same regions tend to present a high deforestation rate [337,338], a known environmental, social, and economic problem. For these reasons, LULC studies with close collaboration with the United States have been necessary.

The importance and conservation of tropical forests and their carbon reserves and emissions belong to topics analyzed through satellite images. These images also facilitate the exploration of different land uses, land cover, and the carbon balance [170,174,175,185]. The research interest in these topics can be linked to current climate change concerns and the importance of the conservation of different ecosystems for the maintenance and reduction of greenhouse gases, not to mention the current interest in the sustainable management of these forests' resources, so their study is kept regular and uninterrupted.

The Sustainable Development Goals (SDGs) established in 2015 would also benefit the development and conservation of tropical forests. Several researchers analyzed the relationship of LULC with the SDGs in these ecosystems. These studies include public policy proposals to allow the sustainable management of tropical forests, coverage mapping [339], and land use change and biomass as a baseline to achieve the objectives [340]. The SDGs related to activities within tropical forests and their conservation are: the end of poverty (SDG 1), zero hunger (SDG 2), health and wellbeing (SDG 3), affordable and non-polluting energy (SDG 7), responsible production and consumption (SDG 12), action for the climate (SDG 13), and life in terrestrial ecosystems (SDG 15). Tropical forests are the most biodiverse, so their conservation, restoration, and sustainable management are essential. In this sense, goals 13 and 15 are directly linked to this challenge. Similarly, tropical forests are important carbon reservoirs that serve as a local and global buffer against the effects of climate change. However, deforestation contributes to the emission of greenhouse gases, so it serves as a matter requiring urgent attention.

Remote sensing has been a tool used since the beginning of LULC research in tropical forests. Since 1972, Landsat satellite data has made it possible to analyze changes in global coverage, such as deforestation and the expansion of agricultural and urban areas. Starting in 2008, corrections were made regarding the errors presented in the datasets to improve their coverage [341]. Therefore, the evolution and appearance of different sensor networks have offered opportunities to the scientific community in biology, ecology, and the conservation of the tropics to develop a complete analysis of how the various tropical ecosystems respond to global environmental and climate changes [342,343].

Despite continuous advances in LULC research techniques in tropical forests, forest degradation retains various unknows in many human impact analyses [344,345]. Nevertheless, a positive trend is maintained in the LULC impact study since these activities have long-term effects on biodiversity, the structure of terrestrial communities, climate, and landscapes, which are affected by ever-rising deforestation rates. According to the World Resources Institute portal, there has been a loss of around 3 to 4 million hectares of primary tropical forests in the last two decades. By 2020, the losses had increased compared to the previous year [346].

The three bibliometric maps and intellectual structure analyses allowed us to analyze the relationships between the different topics and schools of thought:

- First, the keyword co-occurrence analysis made it possible to analyze the most prominent themes (Figure 4). For this case, the clusters are superimposed, demonstrating their complementarity between the clusters and the various topics (keywords). The issues are closely related to multiple areas of biology, land cover and use, and remote sensing. For example, biodiversity (red cluster) and land use change (green cluster) were among the most-studied topics in tropical forests due to the interest in understanding and analyzing the response of various taxa to cover change, and different land uses [347,348].
- The author co-citation analysis reveals the interconnections between different authors (Figure 5). At the same time, the journal's co-citation analysis (Figure 6) shows clusters where a specific school of thought is studied. For example, authors such as Daniel Nepstad and Robert Walker (blue cluster) have been pioneers in studies focused on the activity and importance of tropical forests. These topics are studied mainly in the red and green (most significant) clusters of the JCA, which include the most-analyzed general areas in tropical forests, referring to the different aspects of biology and the environment. In the analysis of the author co-citations, cluster 5 (purple cluster) related to clusters 3 (blue cluster) and 4 (yellow cluster), which cover research structures such as sciences and environmental studies, ecology, and agricultural and biological sciences. The studies of these clusters deal with issues related to remote sensing and monitoring and its usefulness in analyzing topics such as fires and deforestation in tropical forests and their impact on carbon and nitrogen values.

This research facilitates the analysis of the interrelationships between researchers, countries, and schools of thought where the different areas of LULC in tropical forests are studied. The development of this theme aims at the continuous understanding of the LULC impacts using newer mathematical, computer, and technological models, satellite missions [349,350], and the constant advance in conservation and sustainability [351,352].

An integrated analysis indicates that the scientific research on tropical forests has a greater focus on the Amazon region, which may be related to the fact that this area represents the largest tropical forest in the world, as well as to its fundamental role in conservation and in the fight against climate change. It also concerns land use and land cover alterations, which South American institutions and other countries are widely investigating, particularly in the United States and Europe. There is an inequality between Brazil and the other Amazonian countries regarding scientific production, since the Andean countries have a much lower percentage of research. This inequality creates a differentiated understanding of Amazonian problems and decreases the use of these studies in the development of public policies to control deforestation throughout the region.

Another important region for tropical forest assessment is Africa, where research production is reduced. The United States appears as a producer of knowledge about other areas of the planet, which reflects its dominance of information storage platforms, which have made satellite and radar images of the Earth accessible to the public, becoming a global generator of geospatial information. This situation implies that many countries with no surveillance systems use these external databases as the primary source of information, thus generating a direct intervention in their geopolitics.

Finally, although LULC research in tropical forests is not recent, and its growth in the last decade has been prominent, it is necessary to consider what other topics within the area could be analyzed. The following are some gaps in the research that future studies could address:

1. Studies linking compliance with SDGs concerning LULC in tropical forests are required. Few studies address this issue, and the ones that do focus mainly on how deforestation and degradation monitoring can be used to manage these objectives.
2. Studies of specific activities such as oil exploitation and mining focus solely on the effects on human health, and there are few publications on its impact on the environment.
3. LULC studies in the Andean–Amazonian region should be expanded. A large part of the analyses use optical satellite images, where the presence of cloud cover is a problem that limits the generation of maps regarding land use and land coverage in these regions.

This study has some limitations, such as i) the exclusive consideration of scientific articles in English, and ii) the fact that the data analysis was limited to data from the Scopus database. As a result, the present study may have ignored some contributions in this field. Subsequent studies could consider these limitations to broaden the subject of study.

5. Conclusions

This study demonstrates that in the last four decades, there has been an increase in the scientific production of tropical forests' LULC due to the collaboration of 74 countries. The intellectual structure in this field of study records collaborations of greater scientific production concerning (i) researchers: Shimabukuro Yosie and Barlow Jos; (ii) countries: the United States and Brazil; and (iii) journals: *Forest Ecology and Management* and *PLOS One*, as well as the collaborations with the highest number of citations: (i) author: Eric Davidson; (ii) country: the United States; and (iii) journal: *Science*.

The different approaches associated with LULC tend to focus on research topics related to the analysis of multiple anthropogenic activities that cause forest degradation and changes in their ecological dynamics. In addition, a growing interest in conserving these ecosystems due to their high biological, economic, and social value is revealed. The use and evolution of different technological tools that allow a multi-temporal analysis of the dynamics and structure of tropical forests were also evidenced.

This research serves as a contribution to future studies that explore the areas of knowledge focused on LULC in tropical forests because (i) it facilitates access to information on the most studied topics and the most representative authors, (ii) it guides researchers to form networks of collaboration when developing projects according to their area of study, (iii) it is a management tool for researchers to understand, in a general way, the intellectual structure of the area, and (iv) it is a complement for the identification of tendencies in the area that allow the generation of knowledge in favor of the sustainable management of forests.

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