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Trends in global research in deforestation. A bibliometric analysis

Rafael Aleixandre-Benavent[a,1], José Luis Aleixandre-Tudó[b,1], Lourdes Castelló-Cogollos[c], José Luis Aleixandre[b,*]

[a] Ingenio (CSIC-UPV), UISYS (CSIC-Universidad de Valencia), Spain
[b] Instituto de Ingeniería de Alimentos para el Desarrollo (IIAD), Universidad Politécnica de Valencia, Spain
[c] Departamento de Sociologia y Antropología Social, Universidad de Valencia, UISYS (CSIC-Universidad de Valencia), Spain

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ABSTRACT

The main aim of this study was to analyse topics of research, scientific production, collaboration among countries, and most cited papers on deforestation through a bibliometric and social network study of articles found in the Web of Science database. The most productive subject areas corresponded to Environmental Sciences, Ecology and Environmental Studies. The articles were published in 458 different journals. A total of 2051 research articles were obtained. The main challenges identified for deforestation include "land use change", "conservation", "climate change", "rain forest" and "reducing emissions from deforestation and degradation". Social and economic topics are understudied. An important level of international collaboration has been identified, including the triangle of the United States, Brazil and the European Union, as well as others.

1. Introduction

The loss of forest leads to increased insolation due to decreased cloudiness, which also causes additional increased land surface reflectance (Bala et al., 2007). Other major effects include changes in aerosol emissions from contaminated continental atmosphere to the oceans with a subsequent modification of rainfall patterns (Andreae et al., 2004; Butt et al., 2011; Saad et al., 2010), alteration of wind behaviour due to changes in surface roughness and a major impact on atmospheric moisture and thus precipitation (Betts et al., 2004).

The Amazonia forest is one of the planet's most important biological resources and a key player in the Earth's ecosystem. The terrestrial photosynthesis that occurs in Amazonia corresponds to 15% of that overall on the planet (Field et al., 1998), and it is estimated that a quarter of the planet's terrestrial species can be found in this vast territory (Dirzo and Raven, 2003). However, it is today facing increasing stress due to apparently unstoppable deforestation and climatic change conditions (Malhi et al., 2008). Evaporation and condensation of water that occurs in the Amazonia forest are major elements of global atmospheric circulation, and thus negative impacts on precipitation patterns not only affects the surrounding countries of South America but also the entire Northern Hemisphere (Gedney and Valdes, 2000; Werth and Avissar, 2002).

The last available data indicates that a surface corresponding to 13% of the Amazonia forest has been deforested by human activities (INPE, 2012)). Amazonia's deforestation is mainly concentrated along the southern and eastern margins, currently known as the "arc of deforestation", and along the Andean piedmont. A large proportion of the deforested land (62%) is used as cattle pasture, with a serious impact on the region's climatic equilibrium (Lenton et al., 2008; Nobre and Borma, 2009; Malhado et al., 2010). Cattle farming is thought to be the main driver of environmental change (Leite et al., 2012). An additional 6% is used as cropland, mainly dedicated to soybean production, and the remaining 32% is used with the aim of re-growing the lost vegetation (Soares-Filho et al., 2006; Ramankutty et al., 2007). The modification caused by deforestation activities depends to a large extent on the type of activity replacing the forest. As reported by different authors, land use for soybean production reduces precipitation to a greater extent than land converted to cattle farming (Costa et al., 2007; d'Almeida et al., 2007)

Some of the ecosystem services attributed to the Amazonian forest include a high biodiversity reservoir, climate change regulator, source of carbon storage (Soares-Filho, 2010; Nepstad et al., 2008), and living territory for several million people (Pan, 2011) as well as an increasing environment for the production of agricultural resources. Current research based on global and regional climate models has placed a limit of 40–50% deforested surface as critical (Sampaio et al., 2007; Nobre and Borma, 2009; Davidson, 2012, Costa and Yanagi, 2006). The possibility of reaching this "point of no return" has received increasing attention from scientists and policy makers over the past 30 years (FAO, ITTO,

* Corresponding author.
E-mail address: jaleixan@tal.upv.es (J.L. Aleixandre).
[1] These authors contributed equally.

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2011; Malhi et al., 2008; Davidson, 2012).

The expansion and development of protected areas is one, but not the only, strategy adopted by national and international entities when aiming at the conservation of the Amazonian forests and their ecosystem activities (Áreas Protegidas da Amazônia programme: http://www.mma.gov.br/port/sca/arpa/). The creation of new protected areas in combination with governmental laws to prevent deforestation and degradation processes on private lands has resulted in increased conservation of large areas of the Amazonian forests (Assunção et al., 2012; Davidson, 2012; Laurance, 2012)

New evidence has shown a 70% decline in deforestation of the Brazilian Amazonian forests, indicating that it is possible to minimize the loss of forest surface areas. This was achieved through law enforcement, limitations on access to credit, intervention activities in both the soy and beef industries and the aforementioned incremental addition of protected areas. These strategies, in combination with a decrease in the demand for new deforestation, have contributed to the decline. Slowing deforestation is thus possible by using effective territorial approaches, which also contribute to the task of achieving sustainable development of areas subject to deforestation risk (Nepstad, 2014).

The analysis of research trends through bibliometric studies is receiving considerable attention, as they provide valuable information on scientific research and its progression in a specific field of study (Vain, 2007). Despite the increasing public importance of research on deforestation, there are currently no available scientometric studies on the effect of deforestation on agricultural activities. The main aim of this research was to achieve a better understanding of the available scientific knowledge with regards to the effects of deforestation on climate change as well as on the evolution of this phenomenon through published articles included in the Web of Science database

2. Methods

The Web of Science Core Collection from Thomson Reuters was the source from which the articles analysed in this study were obtained. The search was not performed using the Topic field option, which includes the fields Title, Abstract and Keywords in order to avoid the occurrence of a large number of non-relevant results. The search was thus conducted using the Title option as: Title = ("deforest* OR disforest*). The asterisk truncation provides all the possible files that contain the same root (e.g., the terms "deforesting", "deforested" and "deforestation" are extracted from "deforest*"). The amount of records obtained using these terms was 2306. The records were revised to confirm their pertinence to the field, so that a set of 255 records containing book reviews and book chapters (n = 180), news items (n = 43), meeting abstracts (n = 29), and biographical items (n = 3) were excluded, resulting in 2051 papers under study. The keyword standardization was carried out to group synonyms and variations in the spelling of the same concept (mainly, singular and plural, acronyms and derivations).

To identify trends in scientific research on the topic of study, a bibliometric analysis of journals of publication, subject categories in which the journal is classified, most frequently author key words used in each subject category, articles reviewed that had the highest number of citations and the impact factor of journals were combined. The most prolific countries and the most commonly used keywords were identified using social network analysis (SNA). This was achieved by reporting the number of co-occurrences in the articles extracted from the bibliometric search. Keyword density maps were represented using the VOSViewer software. Pajec software (Batagelj and Mrvar, 2002) was used to investigate the network of co-words as well as the collaboration between countries. Journal impact factor data was extracted from the 2014 edition of the Journal Citation Reports.

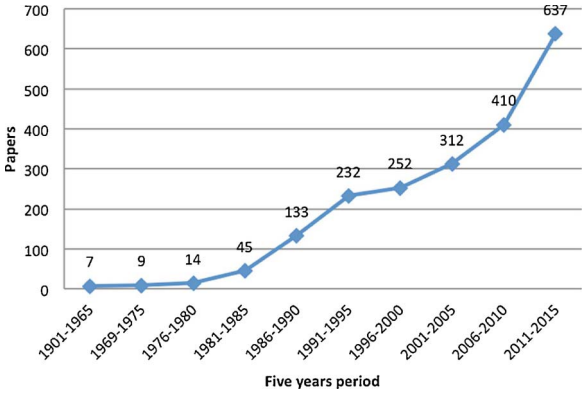

Fig. 1. Evolution of published papers.

3. Results

A set of 2051 published papers were obtained. The first article recorded in WOS dates from 1954 (Fig. 1). The number of publications has shown a steady increase, from 30 in the period before the 1980s (1.46%) to 637 from 2011–2015 (31.06%).

3.1. Annual evolution and journals of publication

The articles were published in 458 different journals. Table 1 shows the 19 journals with more than 20 published papers with the country of publication, citations, impact factor, WOS subject categories and quartile. The journals publishing the most papers are *Forest Ecology and Management* (n = 52), *Science (n = 43), Environment Conservation* (n = 41) and *Ambio* (n = 31). The most-cited journals were *Science* (n = 5.211*), Proceedings of The National Academy of Sciences of the United States of America* (n = 2.418), *Nature* (n = 1.724), *Conservation Biology* (n = 1.720) *and Journal of Climate* (n = 1.709). The ranking of journals according to the ratio of citations per paper is similar, but placing *Conservation Biology* before *Nature*. Additionally, following *Nature* (IF = 41.456) and *Science* (IF = 33.611), journals with a higher impact factor were *Proceedings of the National Academy of Sciences of the United States of America (IF = 9.674), Global Change Biology (IF = 8.044)* and *Global Environmental Change-Human and Policy Dimensions* (IF = 5.089). Most of the journals are included in the first quartile of the Journal Citation Reports.

3.2. Key word analyses and subject categories

The number of published articles during the five-year period and the most frequent keywords are shown in Table 2. In general, all words have increased in frequency. The word "Amazonia", which was present in 9.1% of the articles in the five-year period from 1991–1995, appears in 28.3% of the articles in the five-year period 2011–2105. "Land use change" increased from 2.6% to 29% in the same five-year period. "Conservation" and "climate change" increased from 0.9% to 18.2% and 12.4%, respectively. Some words have declined over the last five years, such as "biodiversity", "tropical forests", "rain forest" and "dynamics". Among the words that have had little variation over the last five years are "land cover change", "vegetation", "climate", "population", "biomass" and "remote sensing".

Web of Science categories with the highest number of published articles, journals with the most articles in each area and the most frequent key words are described in Table 3. The list is topped by Environmental Sciences (n = 496), with the most frequent key words being "Amazonia", "land use change" and "forests", and by the following most productive journals: *Environmental Conservation*, *Ambio* and *Climatic Change*. Two other areas with more than 200 published articles were Ecology (n = 283) and Environmental Studies (n = 233). In

Table 1
Most productive journals, citations, citations per article, impact factor, subject category and quartile.

Journal	Country	N of papers	N of citations	Citations/ papers	Impact factor	Web of Science Subject category	Quartile
Forest Ecology and Management	Netherlands	52	1.623	31,21	2,66	Forestry	Q1
Science	United States	43	5.211	121,19	33,611	Multidisciplinary Sciences	Q1
Environmental Conservation	England	41	999	24,37	2,368	Environmental Sciences	Q2
Ambio	Norway	31	933	30,10	2,641	Environmental Sciences	Q2
International Journal of Remote Sensing	England	28	884	31,57	1,652	Imaging Science & Photographic Technology	Q2
Ecological Economics	Netherlands	27	429	15,89	2,72	Ecology	Q2
Climatic Change	Netherlands	27	1.045	38,70	3,43	Meteorology & Atmospheric Sciences	Q1
Applied Geography	England	25	549	21,96	2,494	Geography	Q1
Proceedings of The National Academy of Sciences of The United States of America	United States	25	2.418	96,72	9,674	Multidisciplinary Sciences	Q1
Plos One	United States	25	159	6,36	3,234	Multidisciplinary Sciences	Q1
Global Environmental Change-Human and Policy Dimensions	England	25	452	18,08	5,089	Environmental Sciences	Q1
Environmental Research Letters	England	24	454	18,92	3,906	Environmental Sciences	Q1
Journal of Climate	United States	24	1.709	71,21	4,435	Meteorology & Atmospheric Sciences	Q1
World Development	England	23	1.072	46,61	1,965	Planning & Development	Q1
Land Use Policy	England	23	295	12,83	2,631	Environmental Studies	Q1
Biological Conservation	England	23	1.235	53,70	3,762	Environmental Sciences	Q1
Global Change Biology	England	22	938	42,64	8,044	Biodiversity Conservation	Q1
Nature	England	22	1.724	78,36	41,456	Multidisciplinary Sciences	Q1
Conservation Biology	United States	21	1.720	81,90	4,165	Biodiversity Conservation	Q1

Ecology, the three most frequent key words are the same as those in the previous research category, but the most productive journals are as follows: *Ecological Economics*, *Biological Conservation* and *Global Change Biology*. In Environmental Studies, the most frequent key word is "land use change", and the most productive journals are *Ecological Economics*, *Global Environmental Change-Human and Policy Dimensions* and *Land Use Policy*. Other represented areas with more than 100 papers were Forestry, Economics, Biodiversity conservation, Meteorology & Atmospheric sciences, Geosciences and Geography.

Table 4 shows the 20 most productive countries and the most

Table 2
Most frequent key words and number of published articles by time periods (> 50).

Key words	1991–1995		1996–2000		2001–2005		2006–2010		2011–2015		N
	N	% (on 232 papers)	N	% (on 252 papers)	N	% (on 312 papers)	N	% (on 410 papers)	N	% (on 637 papers)	
Amazonia	21	9,1%	41	16,27%	76	24,4%	124	30,2%	180	28,3%	442
Land Use Change	6	2,6%	29	11,51%	59	18,9%	104	25,4%	185	29,0%	383
Forests	19	8,2%	32	12,70%	52	16,7%	95	23,2%	143	22,4%	342
Conservation	2	0,9%	11	4,37%	21	6,7%	60	14,6%	116	18,2%	210
Climate Change	2	0,9%	10	3,97%	20	6,4%	36	8,8%	79	12,4%	148
Biodiversity		0,0%	3	1,19%	16	5,1%	55	13,4%	69	10,8%	144
Tropical Forests	3	1,3%	10	3,97%	19	6,1%	42	10,2%	56	8,8%	130
Land Cover Change		0,0%	2	0,79%	7	2,2%	37	9,0%	75	11,8%	121
Model	2	0,9%	11	4,37%	26	8,3%	35	8,5%	45	7,1%	119
Rain Forest	9	3,9%	15	5,95%	21	6,7%	34	8,3%	37	5,8%	117
Dynamics	4	1,7%	8	3,17%	15	4,8%	41	10,0%	41	6,4%	109
Vegetation	6	2,6%	22	8,73%	27	8,7%	20	4,9%	34	5,3%	109
Impact	5	2,2%	16	6,35%	20	6,4%	12	2,9%	54	8,5%	107
Reducing Emissions from Deforestation and Forest Degradation		0,0%		000%		0,0%	19	4,6%	88	13,8%	107
Carbon	1	0,4%	5	1,98%	24	7,7%	20	4,9%	36	5,7%	86
Climate	6	2,6%	11	4,37%	13	4,2%	20	4,9%	28	4,4%	78
Population	3	1,3%	11	4,37%	18	5,8%	17	4,1%	25	3,9%	74
Brazil	7	3,0%	11	4,37%	12	3,8%	15	3,7%	28	4,4%	73
Biomass	4	1,7%	11	4,37%	15	4,8%	19	4,6%	22	3,5%	72
Patterns	1	0,4%	7	2,78%	9	2,9%	22	5,4%	31	4,9%	70
Remote Sensing	1	0,4%	8	3,17%	9	2,9%	17	4,1%	34	5,3%	70
Emissions	3	1,3%	3	1,19%	10	3,2%	10	2,4%	41	6,4%	67
Fragmentation	2	0,9%	5	1,98%	7	2,2%	20	4,9%	31	4,9%	65
Protected Areas		0,0%		000%	1	0,3%	21	5,1%	40	6,3%	62
Basin	5	2,2%	9	3,57%	6	1,9%	12	2,9%	26	4,1%	59
Fire	2	0,9%	6	2,38%	11	3,5%	16	3,9%	22	3,5%	57
Diversity	4	1,7%	6	2,38%	9	2,9%	9	2,2%	26	4,1%	54
Management	1	0,4%	5	1,98%	6	1,9%	19	4,6%	21	3,3%	52
Tropical	2	0,9%	7	2,78%	9	2,9%	14	3,4%	19	3,0%	51

N: number of papers including the key word. %: The percentage refers to the total number of occurrences by five-year periods of the papers.

Table 3
Most productive subject categories, most frequent key words and most productive journals.

Subject categories	N	Most frequent key words						Most productive journals					
		key word 1	n	key word 2	n	key word 3	n	Journal 1	n	Journal 2	n	Journal 3	n
Environmental Sciences	496	Amazonia	154	Land Use Change	131	Forests	106	Environmental Conservation	41	Ambio	31	Climatic Change	27
Ecology	283	Amazonia	77	Land Use Change	52	Forests	58	Ecological Economics	27	Biological Conservation	23	Global Change Biology	22
Environmental Studies	233	Land Use Change	70	Amazonia	69	Forests	49	Ecological Economics	27	Global Environmental Change-Human And Policy Dimensions	25	Land Use Policy	23
Forestry	168	Land Use Change	37	Forests	34	Amazonia	32	Forest Ecology And Management	52	International Forestry Review	20	Forest Policy And Economics	19
Economics	156	Land Use Change	37	Forests	24	Amazonia	22	Ecological Economics	27	World Development	23	Land Economics	20
Biodiversity Conservation	146	Amazonia	59	Conservation	49	Biodiversity	39	Environmental Conservation	41	Biological Conservation	23	Global Change Biology	22
Meteorology & Atmospheric Sciences	141	Amazonia	30	Impact	26	Climate Change	26	Climatic Change	27	Journal Of Climate	24	Environmental Research Letters	24
Multidisciplinary Sciences	134	Amazonia	29	Forests	27	Conservation	23	Science	43	Proceedings Of The National Academy Of Sciences Of The United States Of America	25	Plos One	25
Geosciences, Multidisciplinary	120	Amazonia	34	Land Use Change	25	Climate Change	20	Geophysical Research Letters	18	Journal Of Hydrology	14	Earth Interactions	8
Geography	108	Amazonia	23	Forests	25	Land Use Change	21	Applied Geography	25	Global Environmental Change-Human And Policy Dimensions	25	Singapore Journal Of Tropical Geography	8

frequent key words (n > 100 times used). For the United States and Brazil, the most used key words have been "Amazonia", followed by "land use change", "forests" and "conservation". The United Kingdom also highlights "biodiversity". For Germany, Indonesia, Canada, China, Mexico and Japan, among others, "land use change" is the most used. Fig. 2 shows graphically the relations between countries and key words. The size of the bubbles in the diagrams is proportional to the amount of papers including each key word, and the thickness of the lines linking the bubbles is proportional to the number of articles including both key words. The United States and Brazil had similar words such as "Amazonia", "climate change", "forests" and "land use change", among others.

Fig. 3 is an SNA of the co-words. This network is helpful to obtain a broad overview of the key words that characterize the papers and permits us to understand the importance of some concepts stated in the published articles, as well as the relationships with other concepts. The network highlights the place of greatest centrality of three words: Amazonia, land use change and forests. Other relevant words are biodiversity, conservation, climate change, tropical forests, rain forest and REDD (Reducing Emissions from Deforestation and Forest Degradation).

3.3. Highly cited papers

Papers receiving more than 300 citations are listed in Table 5. Two papers stand out with near 900 citations. The most cited paper was published in 1993 by Skole and Tucker in *Science* (n = 882), two researchers of the Department of Forestry of Michigan State University and the Goddard Space Flight Center of NASA, United States, respectively. The topic of the paper is the extent of deforestation and habitat loss in the tropical Amazon using satellite data. The second most cited paper (n = 877), was also published in *Science* in 2002 by Achard et al., a multinational research team with institutions from Italy (Istituto Superiore per la Protezione e la Ricerca Ambientale), the United Kingdom (Conservation Technology Ltd) and the European Union (Brussels, Belgium). The paper investigates the current deforestation rates of some of the humid tropical forests found in the world. Two other papers with nearly or more than 700 citations published in *Bioscience* and *Atmospheric Chemistry and Physics* discuss the causes and subsequent forces that drive tropical deforestation, and the contribution of deforestation to global fire emissions, respectively. It is noteworthy that reference to Amazonian deforestation is in most of the highly cited papers.

3.4. Funding

Fig. 4 shows the evolution of the percentage of papers with and without funding from 2007 (since this information is available on WOS) to 2015. The number of funded papers was 982 (49.6% of the published articles). As seen, funding has been growing, with 2015, 2013 and 2012 with a greater number of funded papers. The main funders (Table 6) have been the National Science Foundation (NSF) (n = 61), Brazilian National Council for Research and Scientific Development (CNPq) (n = 45), the National Aeronautics and Space Administration (NASA) (n = 41) and European Union (n = 31). The annual evolution of funding shows a growing trend for CNPq, the European Union, Fundacao de Amparo a Pesquisa do Estado de Sao Paulo (FAPESP) of Brazil and the Natural Science Foundation of China, among others. In contrast, NSF shows a decreasing trend in the number of funded papers since 2012, as well as the Gordon and Betty Moore Foundation, both of which are in the United States. Finally, the trend is irregular for NASA of the United States.

3.5. Country productivity and global network of collaboration

Scientific production at the global level is presented in Fig. 5, where the leadership of the United States stands out, as well as the

Table 4
Most productive countries and most frequent key words.

Key Word Country	Amazonia	Biodiversity	Climate Change	Conservation	Dynamics	Forests	Impact	Land Use Change	Model	Rain Forest	REDD[a]	Tropical Forests	Vegetation	Frequency
United States	471	115	139	176	85	290	73	393	117	113	67	113	110	2886
Brazil	241	38	45	93	42	104	37	104	26	75	24	67	41	1126
United Kingdom	72	45	29	52	12	44	15	52	22	26	34	27	11	555
Germany	30	17	12	17	3	36	8	49	23	15	11	20	6	311
France	34	26	17	34	6	27	7	28	12	7	16	17	13	306
Australia	29	25	16	31	8	37	4	28	6	11	12	12	8	288
Indonesia	24	16	10	23	3	19	1	30	4	5	14	11	3	215
Canada	27	9	8	7	7	17	6	27	2	8	4	10	9	200
China	9	6	15	9	3	21	9	30	14	10		6	13	197
The Netherlands	32	6	7	18	5	19	6	15	1	4	15	2	4	174
Mexico	14	6	3	14	7	30	3	31	6	8	3	7	2	170
Spain	18	8	13	14	7	10	2	16	2	7	1	8	1	139
Japan	3	8	9	7	8	9	3	21	4	1	10		4	137
India	5	9	10	11	1	16	2	13	6	2	1	2		119
Colombia	27	6	3	14	6	9		13	1	3	1	12		112
Sweden	10	3	4	5	3	15	3	14	3	1	8	6	6	95
Italy	15	1	5	2	4	12	2	8	5		4	7	2	92
Belgium	7		3	6	3	7	1	15	2		7	6	1	74
Argentina	12		1		5	4		13		1		4	9	65
Denmark	3	2	6	3		14	1	3	1		4	1	3	55

[a] REDD: Reducing Emissions from Deforestation and Forest Degradation.

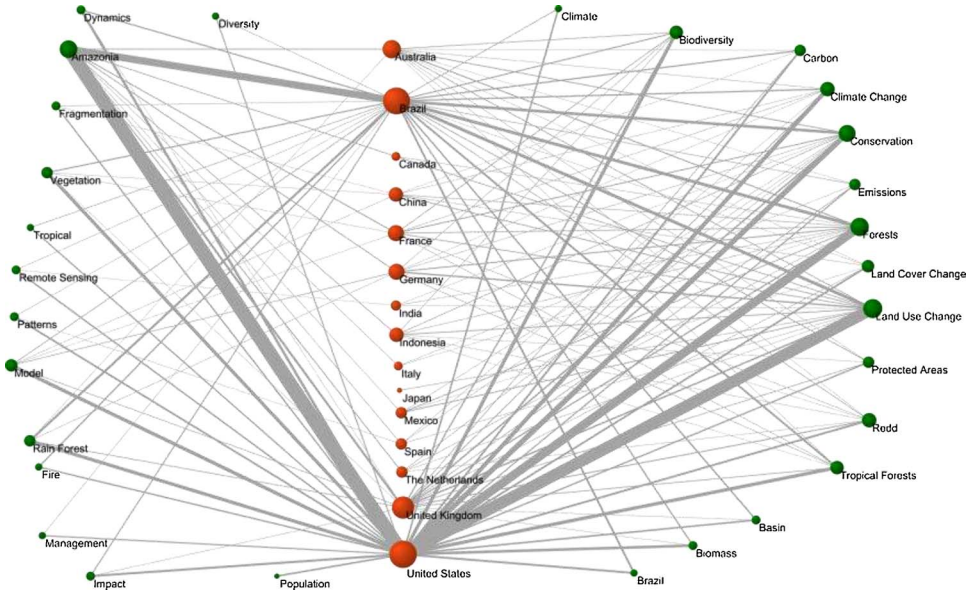

Fig. 2. Network of countries and key words.

concentration of research in European countries, especially in the United Kingdom, Germany and France. In addition, in the Americas, Brazil, as well as Canada and Mexico, are prominent. In Asia, the most active countries are Japan, Indonesia, China and India. In Oceania, Australia is the country with the highest number of published works.

Collaboration among countries can be observed in Fig. 6, where two countries stand out with intense cooperation among themselves and the rest of the countries of the world: the United States and Brazil. Co-operation between these two countries and Europeans predominantly prevails, as well as with some Asian countries and Australia.

4. Discussion

This study has investigated the evolution and current situation of deforestation research at a global level by analysing bibliometrically the best key words, thematic areas of journals, most cited papers and financial aspects as reflected in the scientific literature. Management and decision-making in science and technology have benefited from the role played by bibliometric analysis studies. In the field of global deforestation, bibliometric research will add a new perspective to the current status, which may help to identify hot spots. Several papers have been published employing bibliometric techniques to evaluate a particular subject area or topic of research: plant genetic resources (Dudnik et al., 2001); biotechnology (Dalpe, 2002; Vain, 2007); food and feed safety (Vain, 2007); environmental marketing (Leonidou and Leonidou, 2011); production of bioenergy from biomass (Konur, 2012); viticulture and enology (Aleixandre et al., 2013); soil contamination (Guo et al., 2014); and climate change (Li et al., 2011; Wang et al., 2014; Bjurstrom and Polk, 2011; Aleixandre-Benavent et al., 2017). However, only a few papers have used bibliometric and social network analysis to measure and map the scientific knowledge of the forestry sciences (Dobbertin and Nobis, 2010; Perez et al., 2004).

4.1. General comments

As seen, deforestation research is now part of an important and

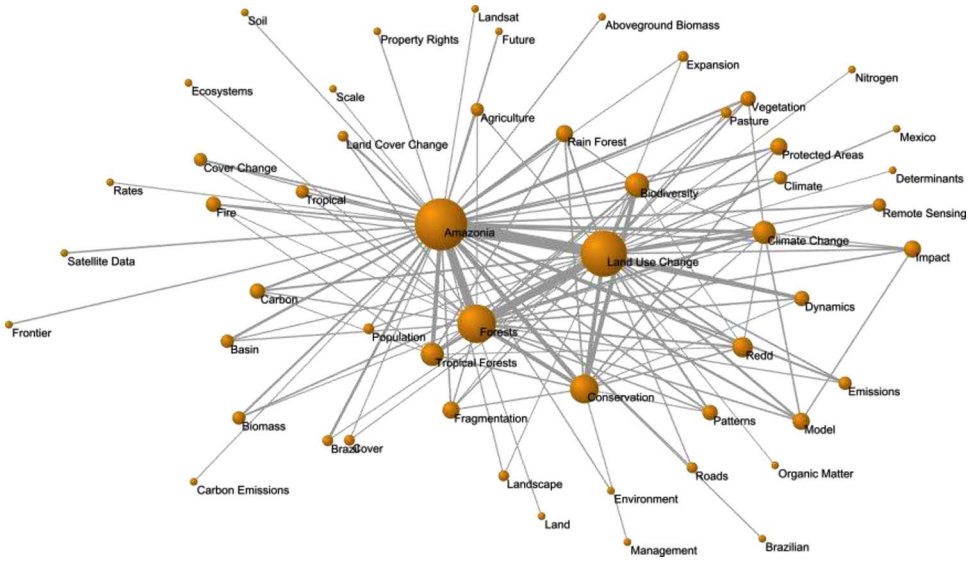

Fig. 3. Network of co-words.

intense field of environmental and ecological research. During the period from the second part of the 20th century to the beginning of the 21st century, continuous drought in North and South America (Amazonia), Europe, Africa, as well as Australia has led to a significant change in weather patterns, resulting in major effects on the earth carbon balance, overland ecosystems and food health-related safety issues. These regions have consequently focused on deforestation studies (Breshears, 2005).

Although a few publications related to deforestation were identified before the 1980s, it is from this point where a clear interest in deforestation research was observed. The number of publications is continuously increasing and includes a large number of specialized subjects. Within forestry studies, works such as the investigations of transgenic plants from a molecular and genetic perspective or global climate change impacts on tropical forest biodiversity are commonly observed. The dynamic behaviour of science and technology research is bringing new global research fields to the scientific community. The literature in the field is thus showing these trends, which include an extensive range of topics. It is also worth mentioning that today scientific information in the forestry field is highly influenced by the fields of botany, ecology, plant science, agronomy, environmental science and chemistry (Stefanovic and Vidakovic, 2014; Kelsey and Diamond 2003).

An additional example of growing research in the field of deforestation was the increasing number of articles and citations that were found. The number of papers grew from 232 in 1991–1995 to 312 in 2001–2005 to 637 in 2011–2015. Approximately 50% of the scientific

Table 5
Most cited papers.

Authors	Title	Source	Citations
Skole, D; Tucker, C	Tropical deforestation and habitat fragmentation in the Amazon - Satellite data from 1978 to 1988	SCIENCE 1993; 260(5116): 1905–1910	882
Achard, F; Eva, HD; Stibig, HJ; Mayaux, P; Gallego, J; et al.	Determination of deforestation rates of the world´s humid tropical forests	SCIENCE 2002; 297(5583): 999–1002	877
Geist, HJ; Lambin, EF	Proximate causes and underlying driving forces of tropical deforestation	BIOSCIENCE 2002; 52(2): 143–150	778
van der Werf, GR; Randerson, JT; Giglio, L; Collatz, GJ; Mu, M; Kasibhatla, PS; et al.	Global fire emissions and the contribution of deforestation, savanna, forest, agricultural, and peat fires (1997–2009)	ATMOSPHERIC CHEMISTRY AND PHYSICS 2010; 10(23): 11,707–11735	697
Shukla, J; Nobre, C; Sellers, P	Amazon deforestation and climate change	SCIENCE 1990; 247(4948): 1322–1325	512
Malhi, Y; Roberts, JT; Betts, RA; Killeen, TJ; Li, WH; Nobre, CA	Climate change, deforestation, and the fate of the Amazon	SCIENCE 2008; 319(5860): 169–172	454
Nobre, CA; Sellers, PJ; Shukla, J	Amazonian Deforestation and Regional Climate Change	JOURNAL OF CLIMATE 1991; 4(10): 957–988	454
Borneman, J; Triplett, EW	Molecular microbial diversity in soils from eastern Amazonia: Evidence for unusual microorganisms and microbial population shifts associated with deforestation	APPLIED AND ENVIRONMENTAL MICROBIOLOGY 1997; 63(7): 2647–2653	440
Dickinson, RE; Henderson-Sellers, A	Modeling Tropical Deforestation - A Study of Gcm Land Surface Parametrizations	QUARTERLY JOURNAL OF THE ROYAL METEOROLOGICAL SOCIETY 1988; 114(480): 439–462	380
Houghton, RA; Skole, DL; Nobre, CA; Hackler, JL; Lawrence, KT; Chomentowski, WH	Annual fluxes or carbon from deforestation and regrowth in the Brazilian Amazon	NATURE 2000; 403(6767): 301–304	380
Morton, DC; DeFries, RS; Shimabukuro, YE; Anderson, LO; Arai, E; Espirito-Santo, FDB; et al.	Cropland expansion changes deforestation dynamics in the southern Brazilian Amazon	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA 2006; 103(39): 14,637–14641	358
Uhl, C; Kauffman, JB	Deforestation, fire susceptibility, and potential tree responses to fire in the eastern Amazon	ECOLOGY 1990; 71(2): 437-449	342
Chazdon, RL	Beyond deforestation: Restoring forests and ecosystem services on degraded lands	SCIENCE 2008; 320(5882): 1458–1460	333
Bala, G; Caldeira, K; Wickett, M; Phillips, TJ; Lobell, DB; Delire, C; Mirin, A	Combined climate and carbon-cycle effects of large-scale deforestation	PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA 2007; 104(16): 6550–6555	323

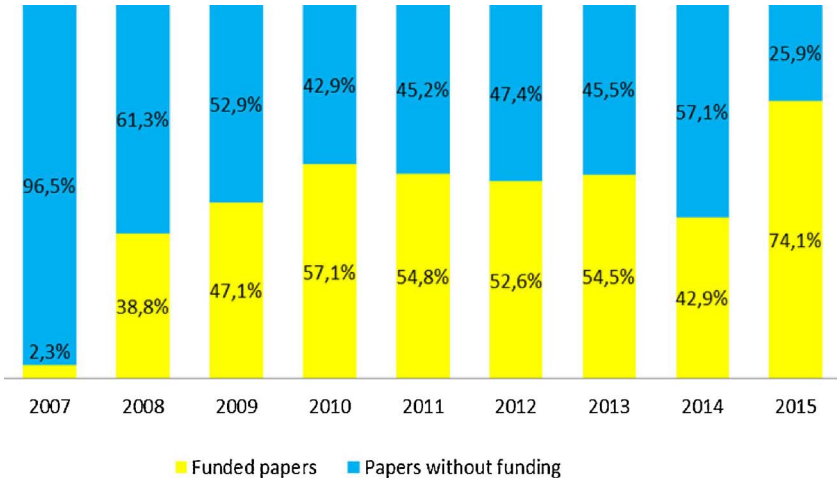

Fig. 4. Evolution of the percentage of papers with and without funding.

literature on the topic of deforestation has been published over the last ten years. The increasing number of papers reveals an important accumulation of knowledge. In addition, the average number of citations per paper on deforestation has reached 26.08. This average is, for example, higher than that found for global biodiversity research (16.30) (Liu et al., 2011). The mentioned scientific output indicators revealed a solid development in the field of deforestation in terms of increasing scientific production and impact.

4.2. Subject categories and major journals

As seen, the journals that contain the largest number of articles published are related to the facets covered by deforestation, such as forestry, ecology, environment, remote sensing, climate change and geography, among others. This can be observed in the most productive journal *Forestry Ecology and Management*. The journal focuses on scientific articles that link forest management to forest ecology. It focuses on the application of biological, ecological and social facts applied to the management and conservation of natural forests as well as plantations. The second ranked journal is *Science*, one of the world's top multidisciplinary academic journals. The journal focuses on matters of interest concerning the wide implications of science and technology. Other relevant publishing journals address global environmental change, world development, land use, and biological conservation, among others. Interestingly, other multidisciplinary high-impact factor journals such as *Nature*, *Proceedings of the National Academy of Sciences of the United Satiates of America* and *Plos One* also showed a strong presence. Because of the importance and interest currently drawn, deforestation can be included as a hot research topic. These features are also supported by the wide diversity of subject categories in journals that contribute to research conducted on deforestation.

Journal classification into research areas contributes to increasing the scientific knowledge in the field and is thus essential for bibliometric studies. The most common categories covered (Environmental Sciences and Studies, Ecology, Forestry, Economics, Biodiversity Conservation) suggested that topics related to the environment remained a top priority within the various concerns being investigated in deforestation research. Other major subject categories included

Table 6
Most frequent funding agencies and number of funded papers per year (n > 4 papers funded).

Funding institutions	Country	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total number of funded papers	Percentage
National Science Foundation (NSF)	United States	1	3	7	6	5	13	11	8	7	61	5,69%
Brazilian National Council for Research and Scientific Development (CNPq)	Brazil			5	5	7	5	6	5	12	45	4,13%
National Aeronautics and Space Administration (NASA)	United States		2	10	10	3	7	1	1	7	41	3,86%
European Commission	Belgium			1	2	4	3	5	3	13	31	2,85%
Fundacao de Amparo a Pesquisa do Estado de Sao Paulo (FAPESP)	Brazil			4	4	4	1	1	5	8	27	2,48%
Gordon and Betty Moore Foundation	United States			3	2	4	2	6	3	3	23	2,11%
Natural Science Foundation of China	China		1			1	2	2	4	6	16	1,47%
Natural Environment Research Council (NERC)	United Kingdom		1			2	2	6		4	15	1,38%
Consejo Nacional de Ciencia y Tecnología (Conacyt)	Mexico			1		1	2	3	3	3	13	1,19%
Brazilian Ministry of Education (CAPES)	Brazil		1	3		2	2	1		2	11	1,01%
Inter-American Institute for Global Change Research (IAI)	Uruguay		1	2				2		4	9	0,83%
Norwegian Agency for Development Cooperation (NORAD)	Switzerland					1	2	2		4	9	0,83%
World Wildlife Fund	Norway		2		1	1	1	2	2		9	0,83%
David and Lucile Packard Foundation	Brazil		1		2	1	1		1	1	7	0,64%
Instituto Nacional de Pesquisas da Amazonia (INPA)	United States			1		1	1	1		3	7	0,64%
Royal Society	United Kingdom			1		3		1		1	6	0,55%
Critical Ecosystem Partnership Fund (CEPF)	Sweden			4			1				5	0,46%
Fulbright Commission	United Kingdom					1	1	2		1	5	0,46%
Leverhulme Trust	United Kingdom		1	2		1	1				5	0,46%
Swedish International Development Cooperation Agency	United States						1	1		3	5	0,46%

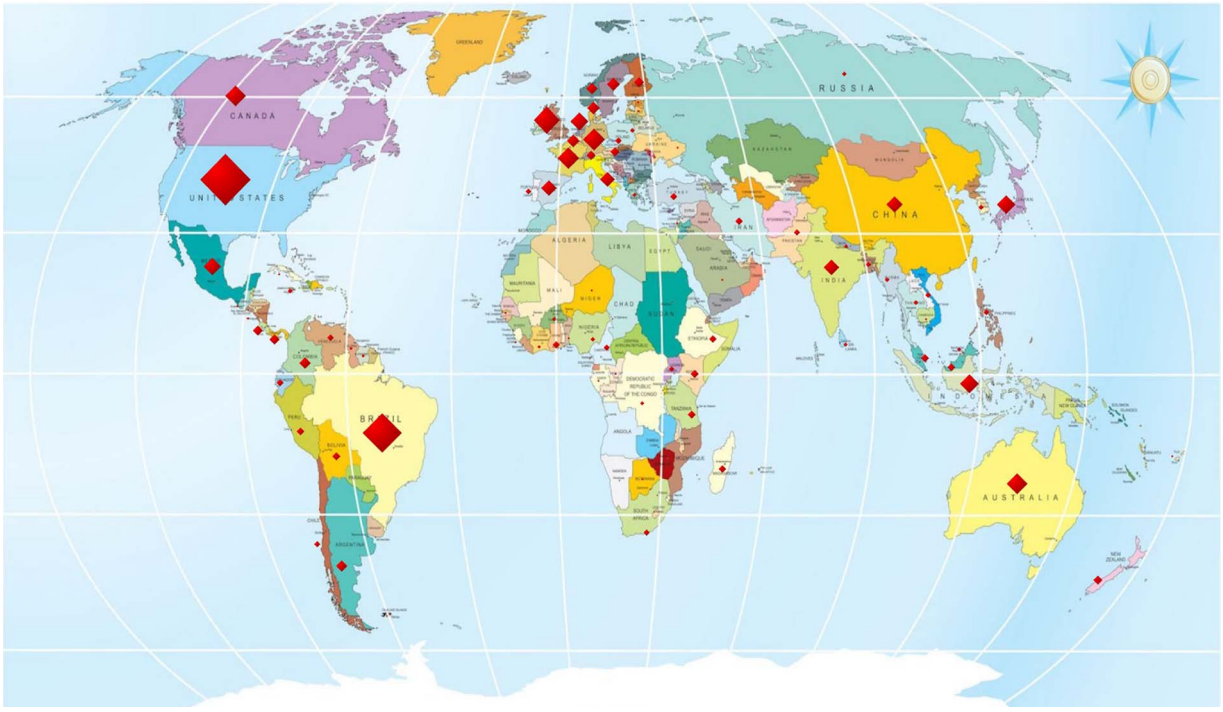

Fig. 5. Global scientific production on deforestation.

Meteorology and Atmospheric sciences and Geosciences and Geography, suggesting the importance that topics related to the earth, the air and the sky have for forestry.

4.3. Most frequent key words

Although reporting the absolute increase in publications provides valid information, it is of the highest importance whether there is a temporal trend in the proportion of the studies in relation to the retrievable studies on a particular topic. To achieve this, we used a keyword analysis, as it provides a relatively comprehensive overview of research trends in deforestation (Chiu and Ho, 2007; Xie et al., 2008; Malarvizhi et al., 2010; Liu et al., 2011).

The subject analysis showed that the addressed subject area plays a key role on key word prioritization in deforestation-related scientific journals. In the subject categories of Environmental Sciences, Ecology, Biodiversity Conservation, Meteorology and Atmospheric Sciences, Geosciences, Geography and Multidisciplinary Sciences, the key word "Amazonia" is common; in Environmental studies, Forestry and Economics, a common key word is "land use change".

The keyword with the highest rank was "Amazonia", whose use could be explained because of the large extent of Amazonian forests

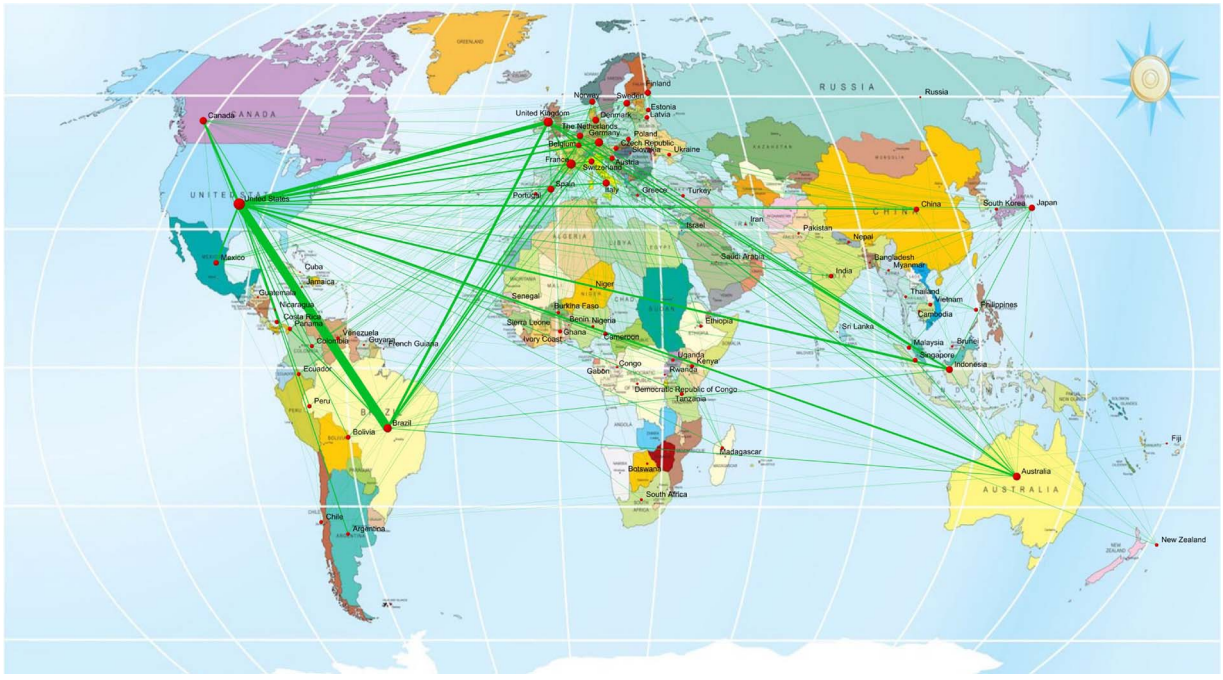

Fig. 6. Global international collaboration on deforestation.

facing massive threats, including not only deforestation but also changes in the bioclimatic conditions of the region. To be able to address these threats, a complex coordinated cross-sector action would thus need to be conducted taking into account the best available scientific evidence (Guedes dos Santos et al., 2015; Coe, 2013; Costa and Pires, 2010; Malhi et al., 2008; Shukla et al., 1990).

The loss of the Amazonian forest will have a highly negative impact on the diversity of species that rely on the atmospheric chemistry. The alteration of the essential ozone naturally produced in the Amazon will also play a major role in the alteration of tropospheric chemistry (Shukla et al., 1990). The high rate of deforestation (between 25,000–50,000 km^2 per year), especially in the Brazilian portion of the Amazonian forest, will thus probably have an effect on regional climatic conditions.

"Land use change" was the second most common keyword in the ranking, related to "land cover change". This pair of words can be considered the consequences of deforestation. The third keyword, "forest", does not need discussion because it is a word that is implicit in this field, and the same can be said of "tropical forests". "Conservation" was the keyword in fourth position in the ranking. Two possible causes may explain this selection. First, conservation is a significant focus of many other research fields, such as ecology, biodiversity and climate, among others (Liu et al., 2011). Second, the conservation of forests is crucial to maintain a wide variety of plant and animal species, as has been noted in the case of Amazonia.

Other key words related to deforestation with a high-ranking of citation included "climate change" and "biodiversity". The fact that words such as "climate change", "climate" and "rain forest" are frequent is not surprising because these are the result of one of the most serious consequences of deforestation. As many studies have shown, forest ecology is affected by changing climate conditions. On the other hand, "biodiversity" is a topic closely related to worldwide environmental changes and globalization issues (Gude et al., 2007). Local climate factors, which include precipitation and radiation, were thought to determine the distribution of global vegetation. However, there may also be a dynamic equilibrium between vegetation and climate that could be modified by either of the two players.

Not surprisingly, another relevant key word is "Reducing Emissions from Deforestation and Degradation (REDD)", an important topic that could be defined as the main international mechanism to avoid deforestation and reduce climate change (Sukhdev et al., 2010). As has been stated by the United Nations, the REDD mechanism is an important economic player that aims for the conservation of forests with a subsequent reduction of the emissions derived from deforestation and from ecosystem degradation, especially in developing countries. The United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries has been operating since 2008 and joins the technical expertise of the United Nations Development Programme (UNDP), the United Nations Environment Programme (UNEP) and the Food and Agriculture Organization of the United Nations (FAO). The UN-REDD Programme supports nationally led REDD actions and instigates the involvement of all stakeholders, indigenous peoples and other forest-dependent communities in a national and international REDD implementation (http://www.un-redd.org).

The key words found in our study have some similarities with the bibliometric study of Stefanovic and Vidakovic (2014) analysing forest research trends from 2006–2010. The most frequent key words in this study were as follows: "growth", "forest management", "climate change", "species richness" and "disturbance", among others. Other significant key words are in line with a previous bibliometric study analysing global forest ecology research from 2002–2011, where the most frequent key words were "patterns", "models", "management", "ecology" and "ecosystem" (Song and Zhao, 2013). In contrast, it is worth mentioning that social, economic and political aspects are not represented in the set of key words. Specifically, the social component is almost non-existent in our research, as was also reported in other studies (Helms, 2002; Innes, 2005).

4.4. Funding

The countries with the largest number of funding agencies are the United States, Brazil, the United Kingdom and the European Union. The fact that Brazil—an emerging country included among the BRICS—is one of the main countries that provides funding is not surprising given the importance of the conservation of Amazonia for this country.

As far as funding agencies are concerned, our results differ in ranks compared to Song and Zhao (2013) reported rankings in forest ecology. In both cases, the first funding agency is the National Science Foundation, but in our case, the second is the Brazilian National Council for Research and Scientific Development (CNPq) (while for Song it was the National Natural Science Foundation of China), the third NASA (while for Song it was the Natural Sciences and Engineering Research Council of Canada) and the fourth the EU (while for Song it was the fifth). Therefore, the growing role of Brazilian institutions in this area is confirmed.

4.5. International collaboration

As has been shown, the United States, Brazil, the United Kingdom, Germany, France and Australia are the countries with the most published research. A significant change in weather patterns and variability that occurred from the late 20th century to the early 21st century, which included severe warm droughts in Europe, the United States and Australia, has been well-documented. The number of studies reporting the changes observed in the forest ecosystems of those regions were impacted accordingly. In a previous study (Song and Zhao, 2013) the authors found that the countries publishing the highest number of articles indexed in WOS on forest ecology from 2002–2011 were the United States, followed by Canada, Germany, Brazil and Australia.

As observed in other bibliometric studies (Xie et al., 2008; Tarkowski, 2007), the economic development of a country positively correlates with academic output. Industrialized countries such as the United States, United Kingdom, Germany, Canada, and France, with Brazil and China (two major developing countries belonging to BRIC), were the most productive countries in terms of research. The percentage of articles that include international collaboration indicates that academic research in deforestation is becoming more internationally connected, a fact that can be observed in the map of global collaboration (Liu et al., 2011) where the United States, Brazil and the European Union have taken the central position in the collaboration network, forming a "collaborative triangle", which was the main collaborator with other productive countries, such as China, Indonesia and Australia.

5. Conclusions

The application of bibliographic and bibliometric methods to map the reported research on deforestation has been found to be a valid approach. Moreover, the main relevant ideas were identified in the literature together with the understanding of the evolution and interaction of the research trends in the field. It is shown that other related disciplines (plant science, environmental science, ecology, botany, agronomy) strongly influence the scientific literature on deforestation. The main challenges identified for deforestation include "land use change", "conservation", "climate change", "rain forest" and "REDD". Social and economic topics are understudied. An important level of international collaboration has been identified, where the triangle of the United States, Brazil and the European Union is highlighted. Funding agencies are mainly from the countries of this triangle, with the addition of others such as China and Mexico. Finally, future research should include the information contained in additional journals included in other bibliographic databases and a more in-depth analysis

of thematic content. It will also be interesting to see the evolution of the research trends in future years, as well as the consolidation of current collaboration and funding, and the emergence of new countries that become part of this research field.

5.1. Limitations

It has to be understood that these studies always carry a number of limitations. It is important to keep in mind that the number of publications or citations is a an approximate estimation of the scientific relevance of a subject. The study could be complemented with an extended analysis, which could include critical information on the content of the papers provided by experts on forestry science and deforestation. The current method is thus only an approach. The selection of the key words by the authors influenced the quality of the conceptualization of the results from the co-word analysis as well as the validity of the maps.

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