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## State of forest research in 2010s – a bibliographic study with special reference to Finland, Sweden and Austria

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### ABSTRACT

Using bibliometric methods, this report analysed the volumes of global forest research and research collaboration between researchers, institutes and countries during the period 2010–2019. The keywords used in the bibliometric search resulted in a good match with the publication lists of three major Finnish forest research organisations. The final corpus of “forest” publications consisted of 355,000 articles, proceeding papers, reviews, books, book chapters and letters listed in the Web of Science database. During 2010–2019, the volume of Finnish publications in forest sciences have increased and the share of internationally collaborative papers has also grown. However, the international position of Finnish and Nordic forest research is slowly declining, owing to the modest growth in publishing, compared to fast-growing countries like China and Russia. When comparing Finnish and Swedish research organisations, those from Sweden were more internationally oriented. In both countries, the five top institutes produced more than three quarters of their country’s respective publications. Analyses based on bibliometric data used in this study reveal the status regarding publication output and trends. These analyses can provide objective evidence that is needed when developing research strategies and policies as well as allocating funding resources.

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Forest research;  
bibliometrics; research  
collaboration

### Introduction

International collaboration is an essential element in assuring the quality of research work. On a country level, the impact of international co-publications has been found greater than that of domestic papers, when impact is measured by the citations received (e.g. Glänzel 2001; Glänzel and de Lange 2002). Also, in the Academy of Finland’s 2018 report on the state of scientific research in Finland (Auranen et al. 2018), it was pointed out that the scientific impact is clearly higher in joint international publications compared to joint domestic publications. The difference is even greater when compared with publications originating from a single domestic institute. This pattern was seen across all scientific fields, including forest research. Scientific impact is also a prerequisite for successful research funding: countries with high bibliometric ranking are also successful when competing for international research grants, e.g. from the European Research Council (Auranen et al. 2018). In addition, cooperation also improves the efficient and cost-effective use of research resources and infrastructures.

When reviewing the available information related to international collaboration within the Finnish forest science and research arena, there is only partial information available and the overall picture is therefore incomplete. It can also

be seen that in some areas the rankings based on bibliometric indicators are mediocre and development trends are not always positive (Päivinen and Saarikko 2017; Piro 2017; World University Rankings 2017; Auranen et al. 2018; Nyons and Mälkki 2019).

One of the most extensive studies on the status of Finnish forest research (Seppälä 2014) was based on published data from major Finnish organisations conducting forest research. The study concluded that domestic and international research networking needs to be increased. Seppälä also stated that the assessment work related to research networking was not easy to carry out because of the incompleteness and lack of records.

Finnish universities and research institutes have also had their research evaluated at regular intervals. In forest research, the proportion of international co-publications has been high. Both Finnish forest universities, University of Helsinki (UH) and University of Eastern Finland (UEF), are above the national average (32%) and at about the same percentage level as that of the field of natural and life sciences (Auranen et al. 2018).

UH carried out one evaluation in 2011–2012 (Forsman et al. 2014) and a second in 2018–2019 (Nyons and Mälkki 2019), based on self-evaluations of departments and utilising bibliometric analyses. The evaluation showed that

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international collaboration in UH's Forest Sciences', increased from 49% in 2012 to 57% by 2016.

According to the latest international evaluation of the research activities at UEF (Liikanen et al. 2019) in the field of "Forests and Bioeconomy", international collaboration networks were not as extensive and established as the national ones, but nevertheless, had yielded a substantial number of joint publications in leading international journals. Furthermore, the evaluators formulated an area of development as follows: "International collaborations could be more numerous and have more depth". In the previous assessment (Liikanen et al. 2014), the numbers of Web of Science (WoS)-listed publications had been among the 10 best in topics such as forest planning, forest inventory, silviculture and forest management.

In the global context, one of the most complete bibliographic studies in the field of forest research was conducted by the French National Institute for Agricultural Research (INRA) (now, since January 2020, the National Research Institute for Agriculture, Food and Environment – INRAE), assessing the status of French forest research and its international status. It was based on a global corpus of 145,000 publications which were classified as forest research based on 90 keywords that were considered forest-related (Tatry and Leiser 2012). This INRA study was further refined at a European scale – a total of 55,700 publications – during the European ERA-NET project "Sumforest" where mapping of forest research capacities and collaboration activities were further analysed (Päivinen et al. 2014).

When reviewing the use of bibliometric analyses in forest research, the following applications were identified: (i) trends in forest research production and networks (Klenk et al. 2010; Bonnell 2012; Tatry and Leiser 2012; Huang et al. 2020; Polinko and Coupland 2020); (ii) research in sustainable forest management (Schrober et al. 2018); (iii) forest and forest-related discourse (Leipold 2014); (iv) forest ecology (Song and Zhao 2013) and (v) forest sector research subjects (Nummelin et al. 2021).

Forestry academic literature often suggests that the scope of forest research has, and is, continuing to change through time (Polinko and Coupland 2020), however, there is limited empirical evidence, apart from that in Polinko & Coupland, to support this hypothesis. Recent bibliometric analyses report an ever-increasing corpus of forest research literature that has changed in focus from traditional sustained-yield-based management of commercially valuable species to sustainable forest management and ecosystem-based management practices often referred to in policy under the three pillars of sustainability: economic growth, environmental protection and social equality (Brundtland 1987; Klarin 2018). The three pillars have been used variously to organise large bodies of knowledge in forest-related fields including carbon capture (Huang et al. 2020), wood fuel (Petrokofsky et al. 2021) and enhancing biodiversity (Ali and Yan 2017).

### The objectives of the study

In order to conduct successful innovation and research policy in Finland, it is necessary to understand how the country performs in forest research internationally and how the country's

status has changed over time. In order to improve the impact of forest research, it is essential to get a better view of the recent developments related to the volume of research, domestic and international collaboration.

The overall goals of this study were to analyse for the period 2010–2019:

- The volume of Finnish forest research and its development over time
- Finnish forest research output compared with outputs from other countries and regions
- Trends in national and international networking within Finnish forest research institutions compared with selected other countries and institutions

To address the overall goals of this bibliometric analysis, a search strategy was devised to find all literature pertaining to forest research. Data from this corpus were then extracted and queried to identify:

- (1) The Global volume of forest research (2000–2019);
- (2) The volume of forest research by country (2010–2019);
- (3) National-level contribution of scientific output (European countries);
- (4) Finnish forest research outputs;
- (5) The number and per cent of publications at institute level (Finland, Sweden, and Austria);
- (6) The contribution of Finland, Sweden and Austria to global forest research;
- (7) The performance of Finland, Sweden and Austria against the global trend;
- (8) The contribution of Finland, Sweden and Austria to the global corpus of forest research;
- (9) The collaboration networks at the country level (Finland, Sweden and Austria) and institutional level (Finland and Sweden).

## Methodology

### The search strategy

The basic data source of this study was the WoS database, consisting of 79 million publications, covering all fields of science.

As Bettinger et al. (2021) point out, the choice of search engine has a large impact on retrieving and analysing published biological research. They concluded that WoS queries returned more articles than AGRICOLA or CAB Abstracts, though the latter probably had higher value in finding older (before 1985) research publications compared with WoS. CAB Abstracts were an attractive proposition for the current work, until it became clear that the database generally only indexed the address of the first author, and our collaboration analyses needed to capture information on all authors in an article. AGRICOLA was not felt to have any advantages for the current work. To ensure that all literature pertaining to forest research were captured in the search, an iterative approach was applied to create, improve and optimise the keywords and search terms following best practice for systematic review (Livoreil et al. 2017).

The 90 keywords that were considered forest-related by Tatry and Leiser (2012) were reviewed and amended in an iterative process that attempted to address limitations in that study (gaps in coverage of some subject fields and ambiguities of terminology), resulting in a list of 175 words or phrases. These terms were combined utilising a Boolean string and used to search the WoS database (Core Collection of the University of Oxford subscription).

The returned literary corpus was then tested for completeness using a complete set of research articles provided by the UH's Department of Forest Sciences, Luke, and UEF's School of Forest Sciences for the years 2017–2018. These institutions have wide international research remits and the test articles were therefore not confined to research focussed on domestic forests or forestry. Search 1 was revised to include additional words or phrases present in the titles of articles which were not found when testing Search 1. These new terms were run against the same test set (2017). Search 2 increased the capture rate of the test set, but also resulted in a large number of false hits (i.e. articles that were not about any aspect of forest research, but which had words in the title, abstract or keywords that matched one or more of those in the search strings). Search 3 optimised the search strings to reduce the total number of records captured, while retaining almost 100% retrieval of test articles. This had 151 words and phrases which successfully managed to capture 97.88% of all forest research literature (see Appendix 1). This process followed standard methods used in systematic reviews in environmental science (Livoreil et al. 2017; Collaboration for Environmental Evidence 2022).

This corpus of 363,246 publications was limited to: Articles; Proceeding Papers; Reviews; Books; Book Chapters and Letters. Finally, a corpus of 354,967 publications was used for all subsequent analysis and is referred to as the Working Corpus. The process used in this study to find the body of relevant research – the Corpus – is illustrated in Figure 1.

### Data mining and extraction

The global volume of forest research 2010–2019 was calculated by adding the total number of publications,

cumulatively. Individual countries' contributions were extracted from the working corpus. The annual growth rate was calculated by comparing the number of publications at time  $t$  with the number one year earlier at time  $t-1$ , using the formula:  $\left(\left(\frac{xt}{xt-1}\right) - 1\right) * 100$ . The number and per cent of publications at institute level were extracted from the working corpus.

### Collaboration analysis

Collaboration analysis was conducted by downloading the bibliographic data of each specified country and/or institutional corpus from the WoS. The following steps were undertaken for all downloaded records: (i) all available author address were extracted from every record; (ii) duplicate addresses were combined to create unique institute and country addresses for each record; (iii) the dataset was cleaned for spelling variances and by combining countries indexed separately by WoS, into political units (e.g. England, Scotland, Wales, Northern Ireland combined as "UK"); (iv) numbers of records from each country and each institute were tallied; (v) any country or institute contributing <1% of the selected sub-corpus was filtered out and co-occurrence matrices were created.

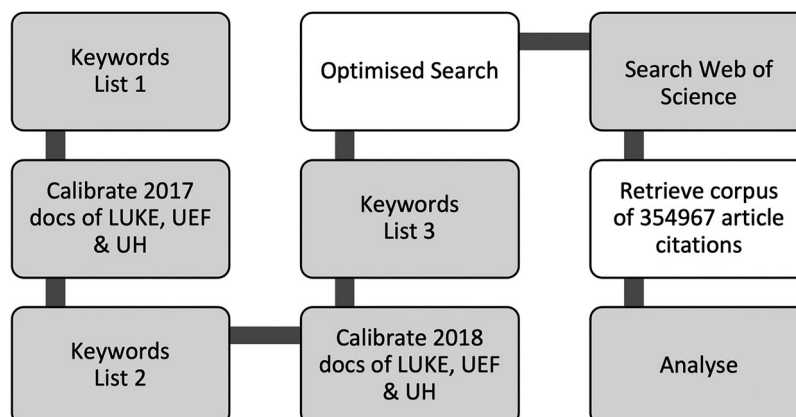
### Use of chord diagrams to visualise collaboration

The aim of the chord diagrams is to provide the user an interactive visualisation tool regarding different types of collaborations. In the following, selected extracts from the diagrams are presented as examples.

A chord diagram represents flows or connections between several entities. The Chord diagrams were designed using the Chord library in Python (Rostami 2020).

Each entity is represented by a fragment on the outer part of the circular layout. Then, arcs are drawn between each entity. The size of the arc is proportional to the importance of the flow.

It should be noted that a single publication may be represented by multiple chords on these diagrams, e.g. a paper with authors from three separate institutes would show



**Figure 1.** Workflow for iteratively developing the most efficient and effective keywords and phrases to find the body of relevant research – the “Corpus” for analysis. See also Appendix 1.

three chords (institution A to institution B; institution A to institution C and institution B to institution B). Therefore, counts will exceed 100%. Chord diagrams are intended to show relationships and can not be used for summing.

We have split the chord diagrams into sections:

- **International Comparison:** International and Institutional collaboration networks for the entire Finnish forest research corpus, the global collaboration network of the “Boreal Forest Research Actors” (BFRA) (for the purposes of this study defined as Finland, Sweden, Norway, Canada and Russia), and the international collaboration networks for the Swedish and Austrian forest research corpora.
- **Finland, Institutes:** International, institutional and BFRA collaboration networks for the top 5 institutes in Finland in terms of number of publications in the corpus (University of Helsinki, Luke, University of Eastern Finland, Aalto University and Oulu University).
- **Sweden, Institutes:** International, institutional and BFRA collaboration networks for the top 5 institutes in Sweden in terms of number of publications in the corpus (Swedish University of Agricultural Sciences, Lund University, Umeå University, Stockholm University and The Royal Institute of Technology).
- These visualisations are optimised for desktop/laptop.

Network analysis was carried out for: (a) Finland, Sweden and Austria at the international level using the corresponding country sub-corpora; (b) “Boreal Forest Research Actors” (BFRA) (for the purposes of this study defined as Finland, Sweden, Norway, Canada and Russia) at the international level using the global working corpus and (c) Finland and Sweden at the institutional level for their “top” Institutes (in terms of number of publications in their respective country corpus) using the corresponding institute sub-corpora.

A complete description of the method and interactive visualisations of the results is available at: <https://www.tapio.fi/chordshome>.

## Results

The global volume of forest research was calculated for the last two decades. The number of publications has increased over time from around 147,000 in the year 2000 to 633,000 in the year 2019. The annual average growth rate during 2000–2019 has been around 8% per year (Figure 2).

## Countries

The volume of forest research publications is presented in Figure 3 and Table 1. In Figure 3, after Austria the next countries are Malaysia (4982), South Africa (4713), Indonesia (4504), Iran (4237) and Norway (4184). Examining these trends by individual countries between 2010 and 2019 shows two dominant players, the USA and China with the largest increase in forest research from China (Appendix 4).

Globally, the USA and China dominate the volume of forest research. The average of the period 2010–2019 is still higher in the USA (See Appendix 4), but in 2019, both have approximately 10,000 forest publications.

Amongst the other countries Germany, Brazil, the UK and Canada have all increased their forest research outputs, particularly within the last five years of this time series. In Figure 4, development of selected European countries is presented. It is worth noting the development of two pairs of countries, having the same volume in 2010 (Sweden growing faster than Finland and Russia overtaking Austria).

Figure 5 shows the total publications over 2010–2019 plotted against the average annual growth rate for each country which has >1% of the total forestry corpus.

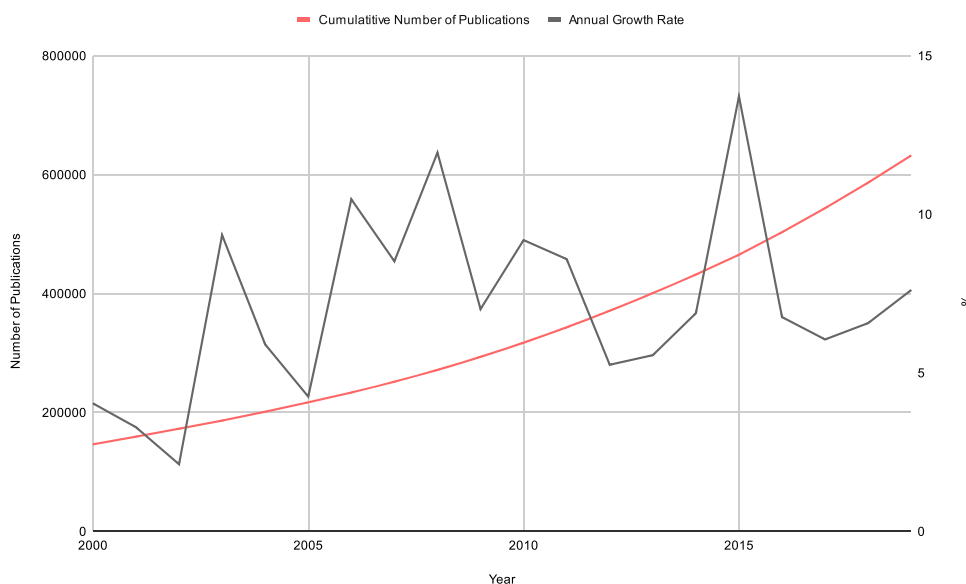


Figure 2. Global volume of forest research (number of publications) and annual growth rate (%).

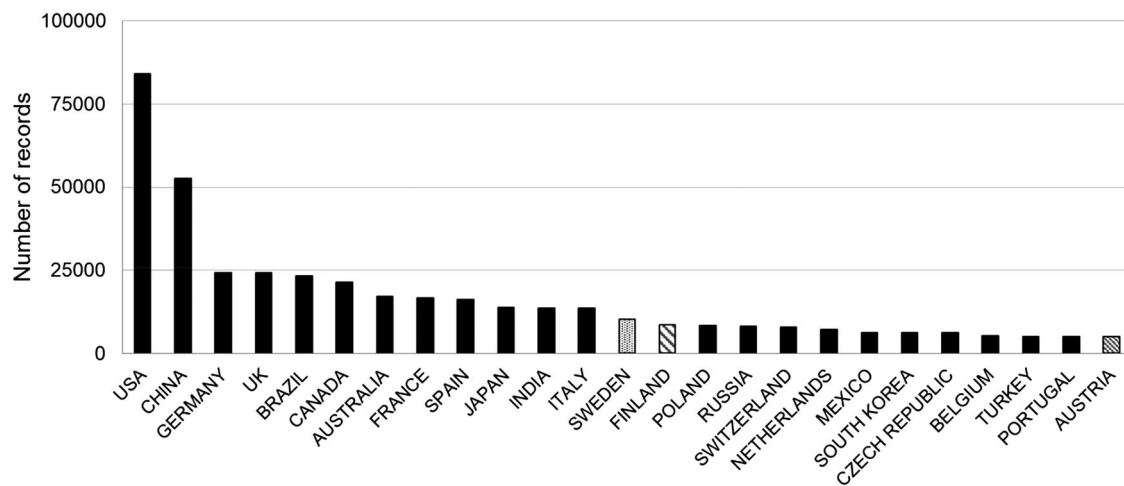


Figure 3. Cumulative number of forest research publications by country (2010–2019).

Table 1. Number of publications defined by the European forestry sub-corpus by country (2010–2019) and as a percentage of the corpus. Only European countries with >1% of the European corpus are listed.

Countries	Number of publications	% of publications
Germany	24,261	12.4
United Kingdom	24,186	12.4
France	16,727	8.6
Spain	16,108	8.2
Italy	13,507	6.9
Sweden	10,270	5.3
Finland	8494	4.3
Poland	8296	4.2
Russia	8123	4.2
Switzerland	7894	4.0
Netherlands	7249	3.7
Czech Republic	6268	3.2
Belgium	5261	2.7
Portugal	5109	2.6
Austria	5081	2.6
Norway	4184	2.1
Denmark	3884	2.0
Slovakia	2582	1.3
Romania	2580	1.3
Greece	2269	1.2

The number of Finnish publications per year has very modestly increased through time and has the third lowest average annual growth rate in this group of countries.

In terms of overall changes in publication behaviour of European countries, we compared our results with Tatrý and Leiser (2012), summarised in Päävinen et al. (2014). Table 2 shows the direction of changes between the two time periods: 2002–2011 and 2010–2019. The percentage contribution of publications to the European sub-corpus was used to allow for the overall large increase in numbers of publications. The average annual growth rate for each country is the same for the two data sets.

Even if these two datasets were collected differently, we can see similarities between results of this study and development shown in Table 2. Development regarding volumes of publications is very positive in Russia, Germany and the UK keeping their strong positions, Sweden doing slightly better than Finland, for instance. Russia has not only increased its position as a large relative contributor to the

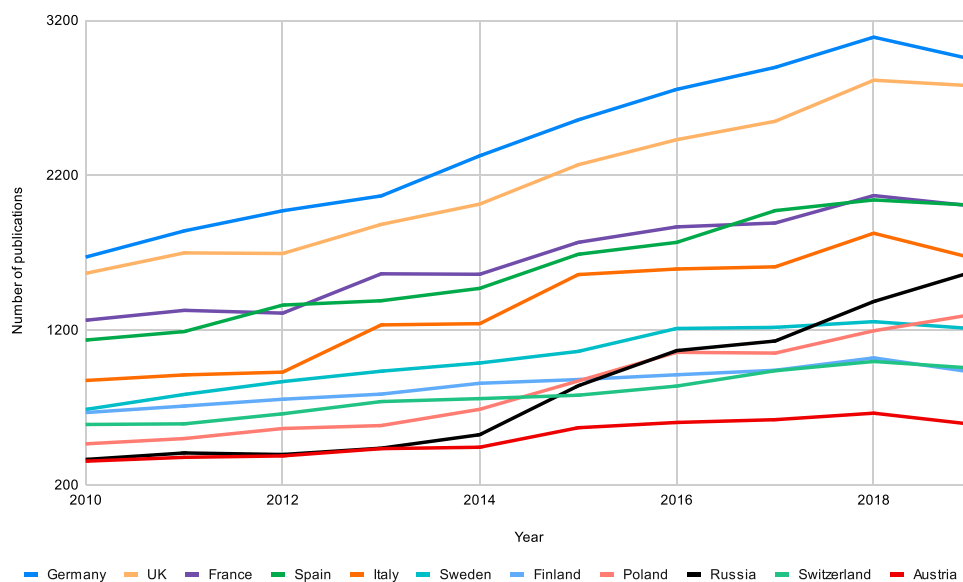


Figure 4. Number of forest research publications of selected European countries per year by country through time (2010–2019). (See Appendix 4).

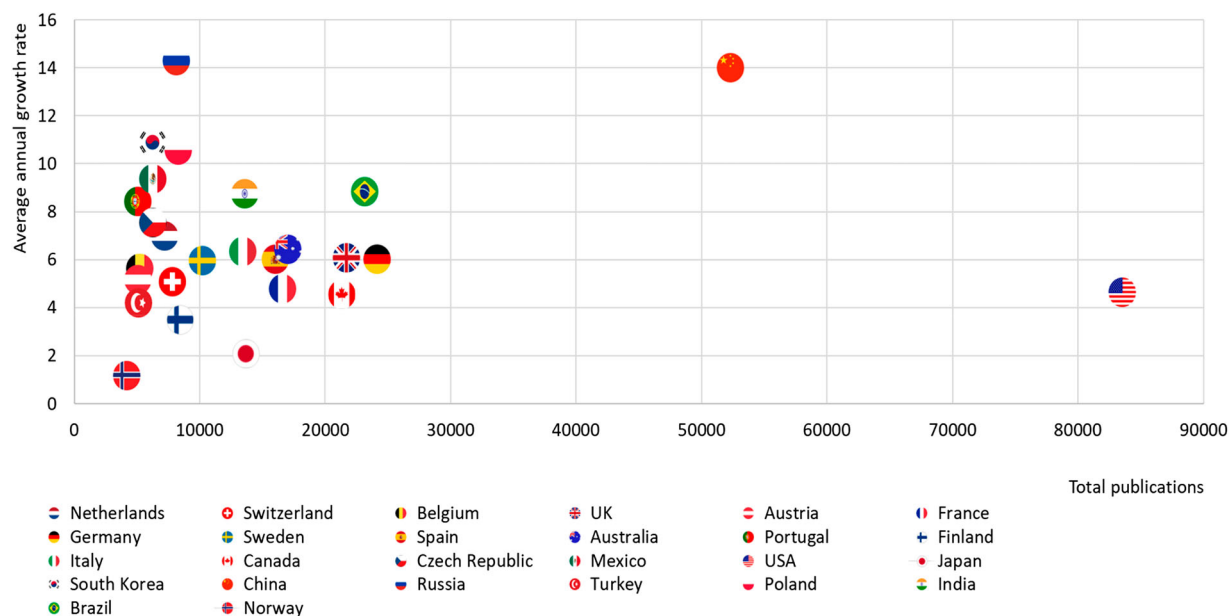


Figure 5. Total number of publications against average annual growth rate (2010–2019). (See also Appendix 4).

Table 2. Changes over two time periods in publication output (%-units of total European corpus) and average annual growth rate for European countries and share of international collaborative publications >1% of total corpus. Data for 2002–2011 are taken from SUMFOREST (Päivinen et al. 2014).

Country	Difference of country's share in Total European Corpus in 2002–2011 and 2010–2019	Difference in Avg. Annual Growth Rate Total Corpus in 2002–2011 and 2010–2019	Difference between International Collaboration in 2002–2011 and 2010–2019
Germany	0	0	+
UK	0	0	+
France	–	–	+
Spain	0	–	+
Italy	++	–	+
Sweden	–	+	++
Finland	–	0	++
Poland	+	–	0
Russia	++	++	–
Switzerland	0	–	++
Netherlands	0	–	+
Belgium	0	–	+
Portugal	+	–	+
Austria	0	–	+
Norway	+	–	NA

**Differences in European corpus:** –: decrease more than 1.5%-units, –: decrease 0.5–1.5%-units, 0: change between –0.5 and +0.5%-units, +: increase between 0.5 and 1.5%-units, ++: increase more than 1.5%-units.

**Differences in growth rate:** –: decrease more than 5%-units, –: decrease 1–5%-units, 0: change between –1 and +1%-units, +: increase 1–5%-units, ++: increase more than 5%-units.

**Differences in international collaboration:** ++: increase more than 10%-units, +: increase 3–10%-units, 0: change between –3 and +3%-units – decrease 3–10%-units.

whole European sub-corpus of forestry, but it has also continued to increase its average annual growth rate, as the only country in Europe. A contributing factor has probably been the change in publishing practices in Russia from Russian-language to English-language publications, aggregated by WoS. Earlier studies have probably under-represented Russian forestry publications. However, Russia

also is the only country with a decreasing rate of international publications.

Italy, Poland, Portugal and Norway have increased their relative contribution to total publications by 0.5% or more, but with reduced average annual rate of growth. Switzerland and the Netherlands have made slight increases in relative contribution to the corpus, with decreased average annual growth rate, which is particularly high for Switzerland, France, Belgium and Austria have slightly decreased both measures. Finland's relative contribution to the corpus has declined, but its average annual growth rate is virtually unchanged. Sweden, by contrast, has reduced relative contribution to the corpus, but has increased its average annual growth rate of publications, the only country other than Russia to have increased average annual growth rate to any great extent. The UK and Germany have made almost no change in either measure. It also should be noted that both Finland and Sweden have been successful in increasing the share of the internationally collaborative publications.

### Institutions

At the European institutional level, the top 3 institutions contributing most to forest research were CNRS, INRA and the Russian Academy of Sciences (Figure 6, Appendix 3). It is important to recognise that name variants and mergers of institutions have taken place over the decade. Many top research organisations listed here consist of several institutes (i.e. CRNS, CSIC and Helmholtz Association). WoS uses a method for identifying, disambiguating and unifying name variants, which makes it possible to treat Institution names in the period 2010–2019 consistently.<sup>1</sup>

Figure 7 also shows that almost three quarters of Finnish forest research volume is produced by three major research organisations in Finland.



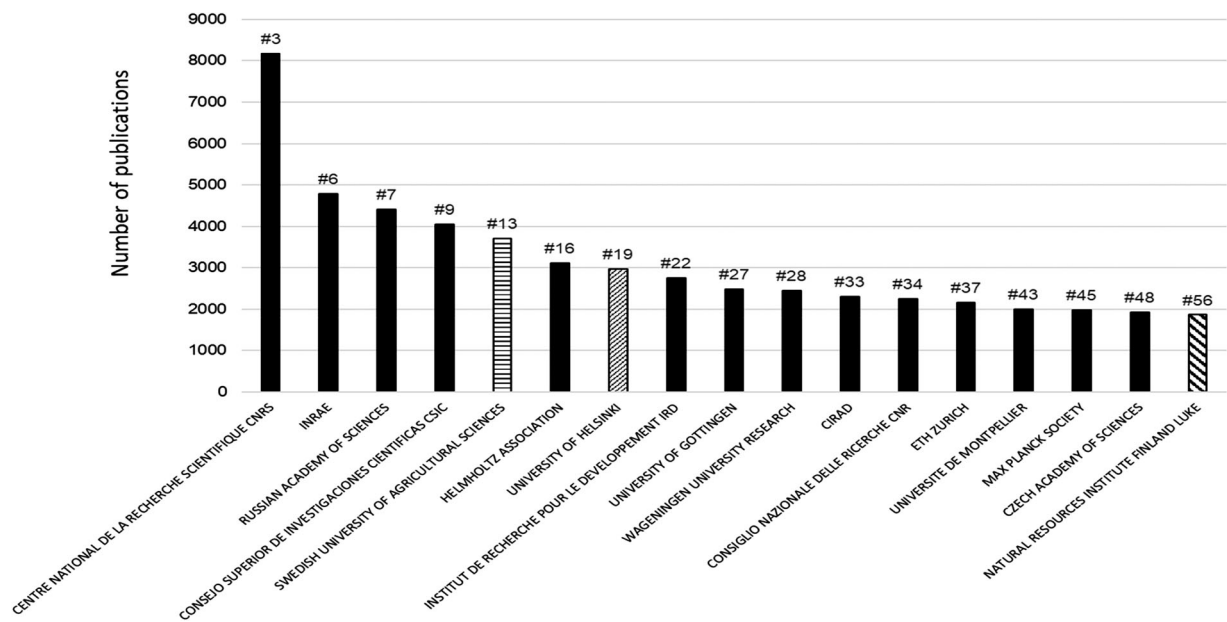


Figure 6. Top 17 European organisations and their global ranking (#). See also Appendix 3.

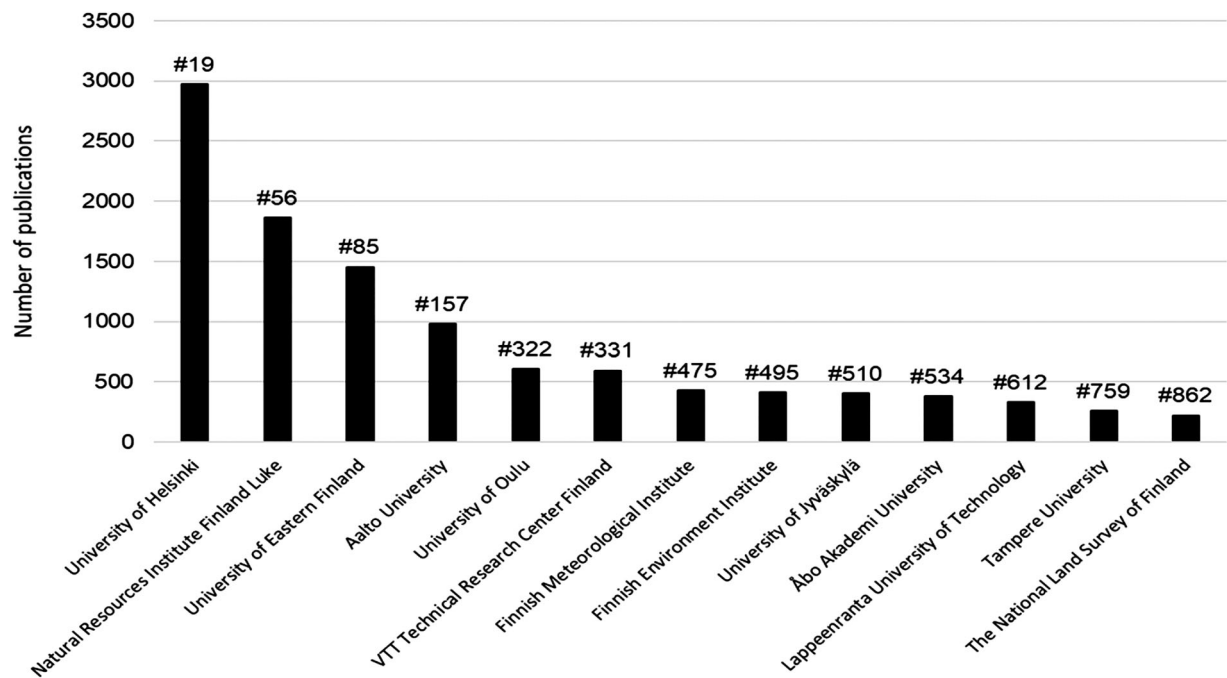


Figure 7. Top 13 Finnish organizations and their global ranking (#).

## Collaboration

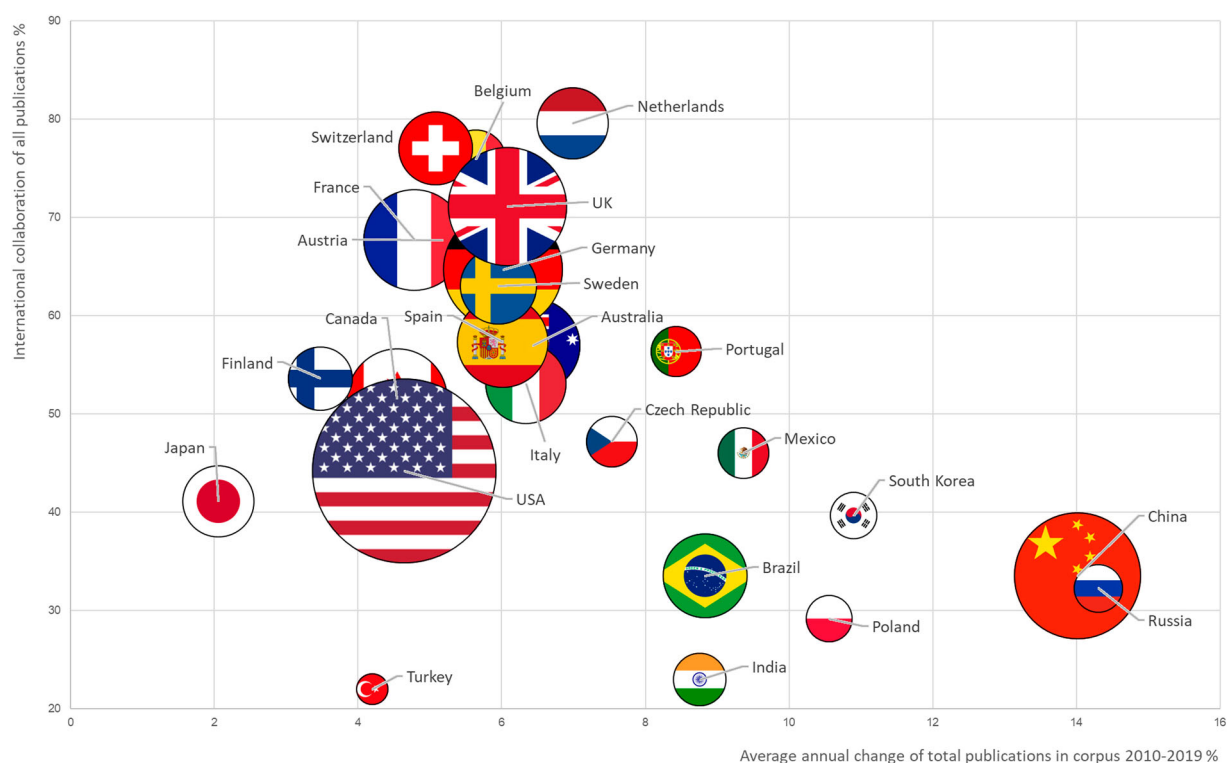
### Countries

As can be seen in Figure 8 the top international collaborating countries are the Netherlands, Switzerland and Belgium. The top international collaborating countries are the Netherlands, Switzerland and Belgium. China and Russia have increased their total volume of publications from 2010 to 2019 by the greatest amount, while Japan and Finland have increased

their number of publications at the lowest rate over the period.

In Finland, the number of internationally collaborative publications for this period is 53%. This percentage has increased in Finland from 42% in 2010 to 61% in 2019 (see details in Appendix 2).

The relative incidence of international collaborations were studied for three countries: Finland, Sweden and Austria. They are indicated in Table 3, which plot the percentage of



**Figure 8.** International collaboration for 25 countries (>1% total corpus) 2010–2019 and change in total corpus. Circle size represents the total number of internationally collaborative papers. (See also Appendix 4).

all collaborations with 25 top countries. Finland collaborates most with Sweden, the USA, Germany and the UK; Sweden with the USA, Germany, the UK and Finland; and Austria with Germany, the USA, Italy and the UK. In all three countries, Germany, the UK and the USA are within five top collaborators. In the Finnish national data, including all branches of science, the top collaborators in 2012–2015 were the USA, Sweden, the UK, Germany and France (Auranen et al. 2018).

### Chord diagrams

Chord diagrams in their full interactive form are available at <https://www.tapio.fi/chordshome>. Figures 9–12 show extracts of the different forms of these international collaborations.

Figure 9 shows the collaboration network of Finland and its 17 closest collaborators. This comprises 3984 publications, which represents 47% of the Finland corpus of 8493 publications. To be included in this diagram an article has: (a) at least 1 Finland author address and (b) at least 1 author address from one of the 17 closest collaborating countries. The dataset was downloaded from the WoS dynamic database on 05/02/2021 (<https://www.tapio.fi/chordsic>). The links between other countries than Finland refer to authors from more than two countries.

International collaboration networks between the “Top 5” institutes in Finland are defined as the highest number of publications in the Finland corpus. Each diagram was produced from the corresponding institute corpus as downloaded from the WoS dynamic database on 05/02/2021. To be included in the dataset an article has: (a) at least 1 address from the institute of interest and (b) have at least 1 author address from another country. The diagrams all

display a top institute and the 15 countries with which that institute most frequently collaborates.

Below are three examples: University of Eastern Finland (Figure 10), University of Helsinki (Figure 11) and Luke (Figure 12).

The Boreal Forest Research Actors (BFRA) collaboration network for University of Helsinki indicates that its largest collaborators are Sweden, Norway and Canada (Figure 11). BFRA collaboration networks of the “Top 5” institutes in Finland are defined as the highest number of publications in the Finland corpus. Each diagram was produced from the corresponding institute corpus as downloaded from the WoS dynamic database on 05/02/2021. To be included in the dataset an article has: (a) at least 1 author address from the institute of interest and (b) at least 1 author address from a different BFRA country. All the diagrams display Finland’s top institute and the other BFRA countries.

The institutional collaboration network for Luke indicates that its largest collaborators are University of Helsinki, University of Eastern Finland and University of Oulu (Figure 12). The institutional collaboration networks are defined as the highest number of publications in the Finland corpus. Each diagram was produced from the corresponding institute corpus as downloaded from the WoS dynamic database on 05/02/2021. To be included in the dataset an article has: (a) at least 1 author address from the institute of interest and (b) at least 1 author address from another institute. The diagrams all display a top institute and the 15 institutes with which it most frequently collaborates.

### Finnish and Swedish institutions

When looking closer at the Finnish and Swedish forest research scene, it is interesting that in both countries the

**Table 3.** Percentage of international collaborations for Finland, Sweden and Austria.

Finland total collaborations 7986	
Country/Territory Global	% of collaboration
Sweden	8.7
United States	8.6
Germany	6.8
United Kingdom	6.7
Spain	4.5
France	4.2
Norway	4.0
China	3.9
Italy	3.4
Canada	3.3
Switzerland	3.2
Netherlands	3.1
Denmark	2.9
Estonia	2.6
Austria	2.5
Russian Federation	2.1
Czech Republic	1.9
Brazil	1.8
Belgium	1.7
Portugal	1.6
Poland	1.5
Australia	1.5
Japan	1.5
Hungary	0.9
Sweden total collaborations 9547	
Country/Territory Global	% of collaboration
United States	9.1
Germany	7.7
United Kingdom	7.3
Finland	6.2
Norway	4.4
France	4.3
Canada	3.8
Denmark	3.6
Spain	3.4
Australia	3.4
Switzerland	3.3
Italy	3.1
Netherlands	3.0
China	3.0
Austria	2.5
Belgium	2.3
Brazil	2.0
Poland	1.7
Czech Republic	1.5
Estonia	1.5
Japan	1.2
Russian Federation	1.2
South Africa	1.1
New Zealand	1.1
Austria total collaborations 4625	
Country/Territory Global	% of collaboration
Germany	13.4
United States	7.0
Italy	5.4
United Kingdom	5.0
Switzerland	4.9
France	4.9
Sweden	4.0
Spain	3.5
Netherlands	3.3
Finland	2.9
Czech Republic	2.5
Canada	2.3
Australia	2.3
China	2.2
Belgium	2.1
Norway	1.8
Denmark	1.7

(Continued)

**Table 3.** Continued.

Austria total collaborations 4625	
Country/Territory Global	% of collaboration
Poland	1.5
Slovakia	1.4
Portugal	1.3
Slovenia	1.3
Hungary	1.3
Brazil	1.2
Russian Federation	1.2

top five institutes produced about the same amount of publications per year (Finland 7874 and Sweden 7754) in 2018 (Figures 13 and 14).

Both countries have one dominating institute, i.e. SLU in Sweden and University of Helsinki in Finland. The five top Swedish institutes publish a bigger share of their papers in cooperation with international partners compared to the top Finnish institutes. On the other hand, a larger proportion of the Swedish papers are not collaborative and originate from a single institute while institutes in Finland produce more papers jointly with their domestic partners (Figure 13).

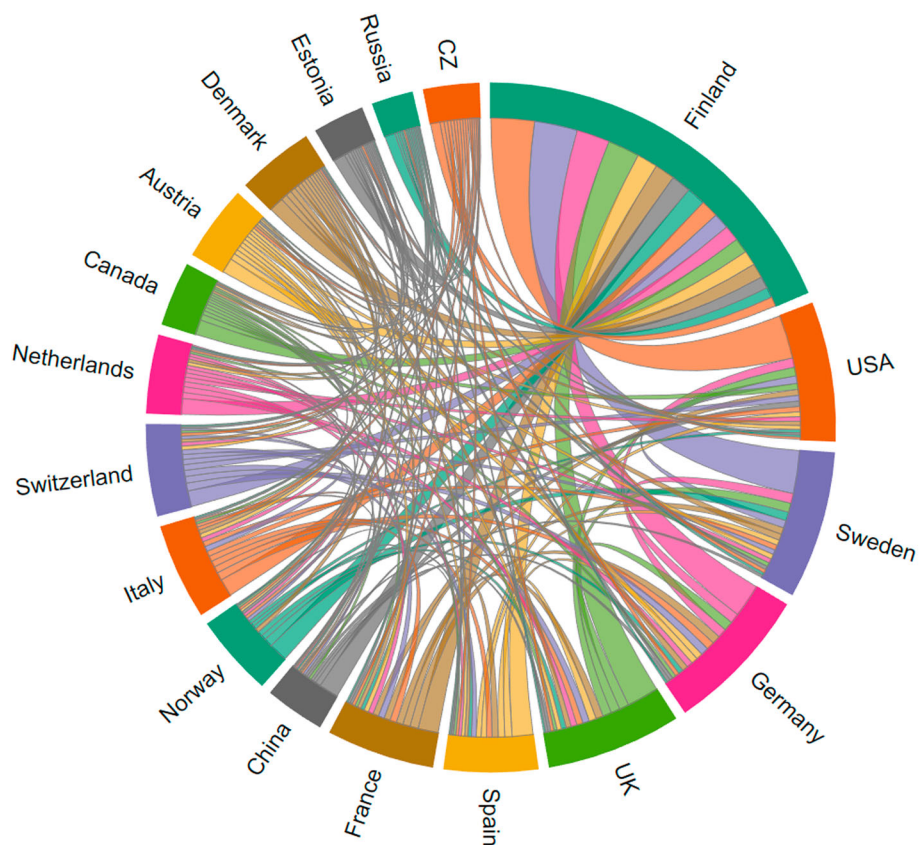
When looking more closely at the international cooperation network (Figure 14) in the interactive website, for Swedish organisations, the key collaborating country for SLU and Stockholm University is the USA; for Lund University it is Germany, while for Umeå University and for the Royal Institute of Technology it is Finland (<https://www.tapio.fi/chordssc>). In comparison, for all the top Finnish institutes, Sweden is the most important partner, except for the University of Helsinki, whose most important partner is the USA followed by Sweden (<https://www.tapio.fi/chordsfc>).

## Discussion

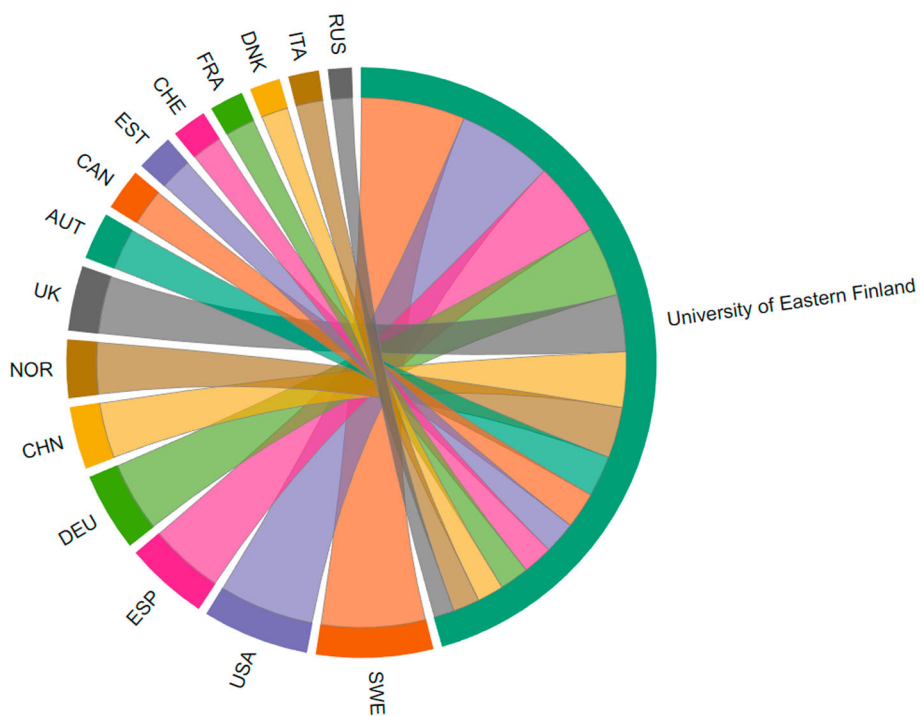
A comparison with the INRA's study results (Tatry and Leiser 2012; see also Päivinen et al. 2014; Päivinen and Saarikko 2017) shows that the ranking of countries has changed rather modestly in one decade (see Tables 1 and 2). Four top countries, Germany, the UK, France and Spain have kept their positions, Italy, Poland and Russia have moved upwards two steps and Czech Republic five steps. Finland, Sweden, Norway and Belgium have fallen one step, Switzerland and Netherlands two steps and Austria three steps.

The comparison also reveals that during the period 2002–2011 the combined Finnish and Swedish publications accounted for some 18% of the European forest publications whereas our study shows that this share has in one decade dropped to about 9% of the European corpus. Compared to the biggest European forest science publishers – Germany, the UK, France, Spain and Italy – who continue to account for about half of the European corpus, the relative volume of the Nordic countries has decreased rather dramatically during the past 10 years.

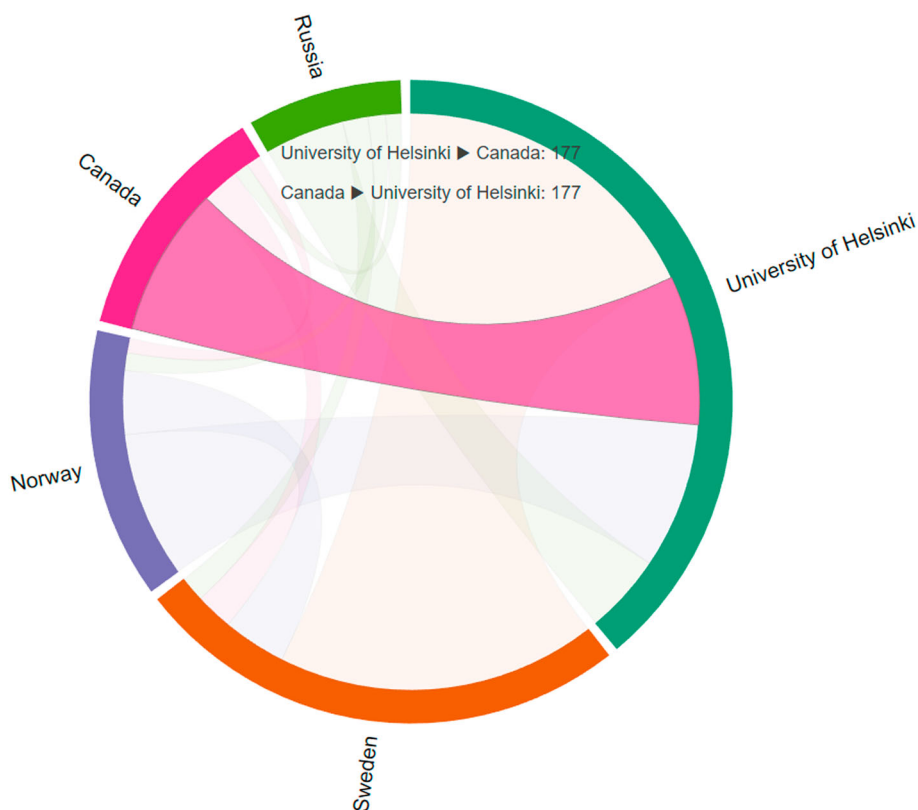
For the politicians, media and the general public – who are increasingly demanding evidence-based information to inform policy making on complex issues like biodiversity and climate change, the shrinking role of Nordic forest research can be seen as a problem from the Nordic perspective.



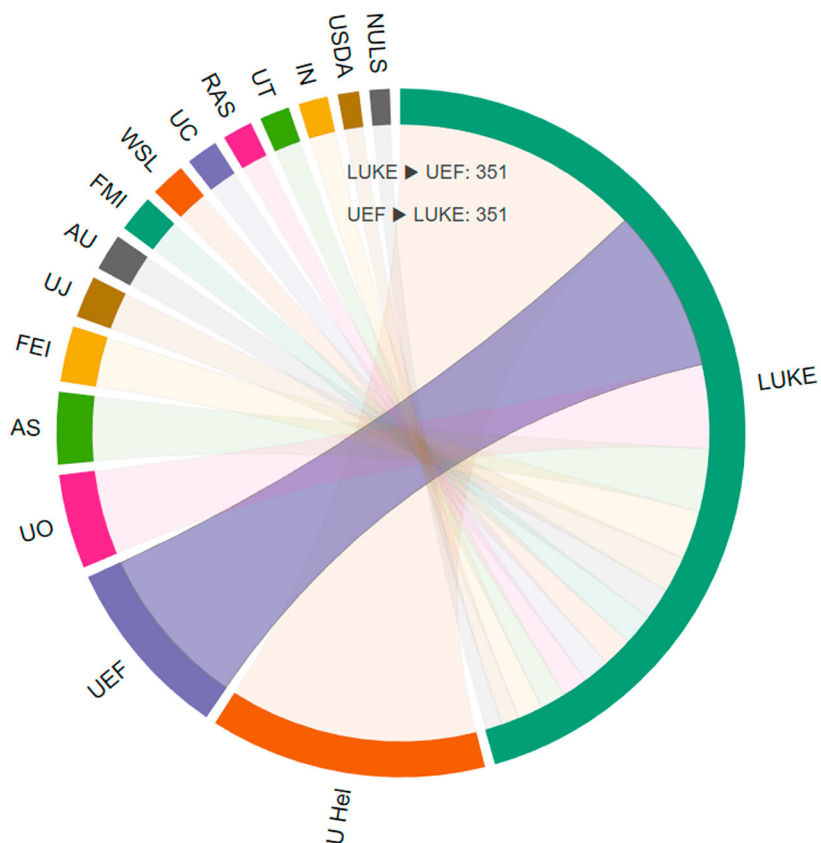
**Figure 9.** The international collaboration network of Finland and its 17 closest collaborators. The international collaboration networks for the top 5 institutes in Finland and Sweden are presented in an interactive website. <https://www.tapio.fi/chordshome>.



**Figure 10.** The international collaborative dataset of the University of Eastern Finland comprises 662 publications. This is 46% of the University of Eastern Finland corpus of 1453 publications. The international collaboration network for the University indicates that its largest collaborators are Sweden, the USA and Spain. (<https://www.tapio.fi/chordsfc>).



**Figure 11.** This diagram comprises 654 publications. This is 22% of the University of Helsinki corpus of 2973 publications. BFRA collaboration network for University of Helsinki showing the collaboration chord of 177 publications with Canada (<https://www.tapio.fi/chordsfb>). Legend: AUT-Austria, FRA-France, CAN-Canada, ITA-Italy, CHE-Switzerland, NOR-Norway, CHN-China, RUS-Russia, DEU-Germany, SWE-Sweden, DNK-Denmark, UK-United Kingdom, ESP-Spain, USA-United States of America, EST-Estonia.



**Figure 12.** Institutional collaboration network for Luke showing the collaboration chord of 351 publications with UEF (<https://www.tapio.fi/chordsfi>). Legend: AS-Swedish University of Agricultural Sciences, AU-Aalto University, FEI-Finnish Environment Institute, FMI-Finnish Meteorological Institute, IN-INRAE, NULS - Norwegian University of Life Sciences, RAS-Russian Academy of Sciences, U HEL-University of Helsinki, UC-University of Copenhagen, UEF-University of Eastern Finland, UJ-University of Jyväskylä, UO-University of Oulu, USDA-United States Department of Agriculture, UT - University of Turku, WSL-Swiss Federal Institute for Forest Snow Landscape Research.

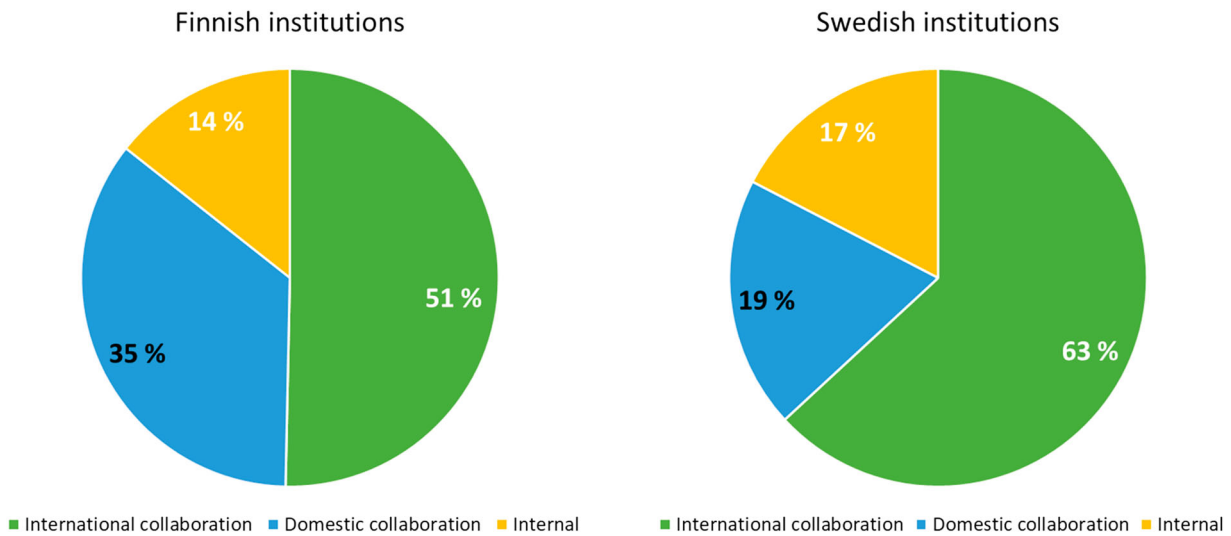


Figure 13. Cumulative share of international and domestic collaboration in top 5 institutes in Finland and Sweden.

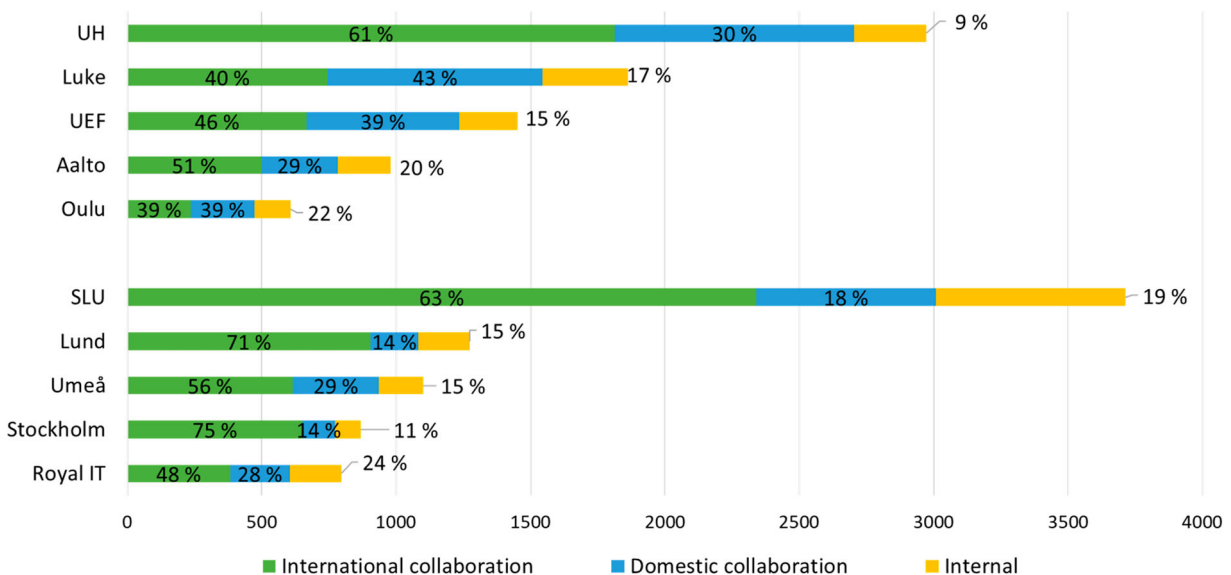


Figure 14. Share of international and domestic collaboration in top 5 institutes in Finland and Sweden.

It should be noted that even if there were differences in keyword lists between the earlier analyses by Tatry and Leiser (2012) and our current research, together they provide an opportunity to compare results across two decades.

The current research used a systematic, iterative approach to develop a search strategy that could extract a “forestry corpus” from the WoS. In this research, we adopted the method for defining and checking a search strategy used for systematic evidence synthesis (Livreil et al. 2017), which is considered a robust method for reducing bias in literature reviews.

The method by which the INRA study created their forestry corpus was slightly different. They had a different set of keywords, which probably did not reflect the broad topic of “forest” research. Their corpus was a lot smaller. Had we used our search terms for the years 2002–2011 we would

have retrieved 198,425 records, which is 27% larger than their set of 144,850 records.

## Conclusions

The global forestry corpus has continued to increase each year, with fluctuations in the rate of increase between years. Today, we have 5 times more forest publications than 20 years ago. The USA is the leading publisher. China has advanced to the second place, and is likely to reach the level of the USA in the near future. Within Europe, Germany and the UK publish most, followed by France and Spain.

In the bibliographic databases developed during the past two decades, we have material for assessing the scientific performance of forest research. Our experiences confirm that bibliometrics provides an objective and transparent method

to analyse research performance of organisations and countries. However, the results depend on how forest research is defined and how the reference set of publications is collected. In this study, we calibrated the keywords and terms used in the bibliometric search in a systematic way that resulted in a good match with the publication lists of three major Finnish forest research organisations.

The total volume of research publications defined as forest research between 2010 and 2019 was 355,000. These publications were generated by 10,000 institutions from over 200 countries. The results revealed that new major players have entered the arena of forest research, i.e. China, Russia and South Korea. The reasons behind the growth in publication volumes of these countries were not analysed in this study. Whether it is an increase in publishing in general, an increase in publishing in the English language, or something else, remains to be clarified in future studies. There will certainly be many other questions on the reasons behind the developments that require deeper analysis.

The global volume of forest research has been growing during the last decade. A substantial part of forest research is carried out in research institutions that are not traditional forest research institutes or faculties; in Finland this amounts to a quarter of all forest research, for instance. The main finding of this study was that the growth of Finnish forest research compared to forest research in similar countries, including Sweden, has been slow. The Finnish share of global forest research is diminishing. International collaboration has been growing in Finnish forest research, and it is today above the average when measured across all Finnish scientific fields. However, it is still below other corresponding forest research countries.

We believe that the findings from this study can provide valuable and up-to-date input for the formulation of future Finnish forest research strategies, establishing funding programmes and developing international mobility facilities for researchers.

In order to monitor the direction of developments, this study should be repeated frequently. Expanding the scope can be done by analysing more countries or institutions to learn best practices for successful research performance. The future studies could also include analyses on the development of research themes and the respective impact assessments (at least on academic level).

In the context of this research project, a number of important questions still remain, especially when it comes to the use of research results, e.g. what is the impact of science on forest practices and policies? Analysing the impact of research on the forest sector as a whole could also be addressed using additional metrics, including, e.g. social research methods. Thematically, it would also be interesting to cover not only forestry, but the whole field of bioeconomy.

Our main aim was to investigate the present situation and summarise it for a selected part of global forest research. The databases we have assembled provide ample information also for similar analyses for other countries and institutions.

## Note

1. [https://images.webofknowledge.com/images/help/WOS/hs\\_organizations\\_enhanced.html](https://images.webofknowledge.com/images/help/WOS/hs_organizations_enhanced.html).

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

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## Appendix 1. Search validation results

### Search 1 (keywords and phrases combined using Boolean logic (n = 166))

TS = (“afforestation” OR “agroforestry” OR “amelioration of forest sites” OR “amenity forests” OR “amenity value of forests” OR “arboriculture” OR “artificial regeneration” OR “building timbers” OR “charcoal” OR “cleaning” OR “clear strip felling” OR “community forestry” OR “controlled burning” OR “coppice” OR “coppicing” OR “degraded forests” OR “delimiting” OR “demonstration forests” OR “dendro\*” OR “dendrochronology” OR “disturbed forests” OR “even-aged management” OR “farm forestry” OR “farm woodlands” OR “felling” OR “felling” OR “fire detection” OR “fire prevention” OR “fire suppression” OR “firebreaks” OR “forest administration” OR “forest damage” OR “forest decline” OR “forest ecology” OR “forest economics” OR “forest inventories” OR “forest management” OR “forest ownership” OR “forest pests” OR “forest plantations” OR “forest policy” OR “forest products” OR “forest products industries” OR “forest railways” OR “forest roads” OR “forest taxation” OR “forest trees”

OR “forestry” OR “forestry development” OR “forestry engineering” OR “forestry engineering” OR “forestry law” OR “forestry machinery” OR “forestry operations” OR “forestry practices” OR “forestry workers” OR “forests” OR “fuel appraisals” OR “fuel plantations” OR “green tree retention” OR “group fellings” OR “high forest system” OR “intensive silviculture” OR “irrigated stands” OR “IUFRO” OR “linear plantations” OR “logging” OR “mensuration” OR “national forests” OR “non-wood forest products” OR “partial cutting” OR “patch cutting” OR “pollarding” OR “private forestry” OR “protection forests” OR “protection of forests” OR “pulp and paper industry” OR “pulp mill workers” OR “pulping” OR “pulping materials” OR “pulpwood production” OR “pulpwood production” OR “pulpwood” OR “reserved forests” OR “sawmills” OR “secondary forest products” OR “seed orchards” OR “selection forests” OR “selection system” OR “selective felling” OR “shelterwood system” OR “short rotation forestry” OR “silvicultural characters” OR “silvicultural conversion” OR “silvicultural systems” OR “silviculture” OR “site class assessment” OR “social forestry” OR “stand improvement” OR “state forests” OR “stumpage value” OR “timber production” OR “timber supply” OR “timber trade” OR “timberyards” OR “uneven-aged management” OR “urban forestry” OR “wood” OR “wood products” OR “wood pulp” OR “forest planning” OR “forest bioeconomy” OR “multi functional forestry” OR “forest biomass” OR “forest bioenergy” OR “forest energy” OR “wood energy” OR “forest information” OR “forestry decision support” OR “forestry optimisation” OR “forest certification” OR “climate change” OR “peatland forest” OR “forest drainage” OR “forest recreation” OR “wood procurement” OR “wood material” OR “wood construction” OR “forest governance” OR “forest monitoring” OR “forest survey” OR “forest statistics” OR “forest industry” OR “tree nursery” OR “tree physiology” OR “forest mushrooms” OR “forest berries” OR “forest herbs” OR “forest growth” OR “allowable cut” OR “sustainable forestry” OR “forest owners” OR “forest administration” OR “forestry services” OR “wood-working industry” OR “forest protection” OR “forest fire” OR “forest restoration” OR “forest disturbances”) OR ((forest\* or wood\*) AND (“edible fungi” OR “growing stock” OR “increment” OR “logs” OR “management units” OR “mixtures” OR “panels” OR “pulp” OR “recruitment” OR “resins” OR “rotations” OR “waste paper” OR “working plans” OR “yield regulation” OR “logistics” OR “multiple use” OR “regeneration” OR “concessions” OR “primary sector” OR “thinnings”))

### Search 2 (keywords and phrases combined using Boolean logic (n = 161))

TS = (((“afforestation” OR “agroforest\*” OR “arboriculture” OR “artificial regeneration” OR “building timber\*” OR “charcoal” OR “cleaning” OR “community forest\*” OR “controlled burn\*” OR “coppic\*” OR “degraded forest\*” OR “delimiting” OR “dendro\*” OR “disturbed forest\*” OR “farm forest\*” OR “farm woodland\*” OR “felling” OR “fire detection” OR “fire prevention” OR “fire suppression” OR “firebreaks” OR “FLEGT” OR “REDD” OR “forest administration” OR “forest damage” OR “forest decline” OR “forest ecology” OR “forest economics” OR “forest inventor\*” OR “forest management” OR “forest ownership” OR “forest pest\*” OR “forest plantation\*” OR “forest polic\*” OR “forest product\*” OR “forest railway\*” OR “forest road\*” OR “forest taxation” OR “forest tree\*” OR “forestry” OR “forestry development” OR “forestry engineering” OR “forestry engineering” OR “forestry law” OR “forest law” OR “forestry machin\*” OR “forestry operation\*” OR “forestry practice\*” OR “forestry worker\*” OR “forest worker\*” OR “forests” OR “forest\*” OR “fuel plantation\*” OR “high forest system” OR “silvicultur\*” OR “irrigated stand\*” OR “IUFRO” OR “linear plantation\*” OR “lignin” OR “logging” OR “mensuration” OR “national forest\*” OR “nonwood forest products” OR “partial cutting” OR “patch cutting” OR “peatland\*” OR “pollarding” OR “private forest\*” OR “pulp and paper industry” OR “pulpmill” OR “pulping” OR “pulpwood” OR “reserved forest\*” OR “sawmill\*” OR “forest products” OR “seed orchards” OR “selection forest\*” OR “selection system” OR “selective felling” OR “shelterwood” OR “short rotation forestry” OR “site class” OR “social forest\*” OR “stand improvement” OR “state forest\*” OR “stumpage” OR “timber\*” OR “urban forest\*” OR “vegetative propagation” OR “wood\*” OR “wood products” OR “wood pulp” OR “forest planning” OR “multi functional forestry” OR “forest biomass” OR “forest energy” OR “wood energy” OR “climate change” OR “forest drainage” OR “forest recreation” OR “wood



procurement" OR "wood material" OR "wood construction" OR "forest monitoring" OR "forest survey" OR "forest statistics" OR "forest industry" OR "tree nurser\*" OR "tree physiology" OR "forest mushroom\*" OR "forest berries" OR "forest herbs" OR "allowable cut" OR "sustainable forestry" OR "forest owners" OR "forest administration" OR "forestry services" OR "wood-working industry" OR "forest protection" OR "forest fire" OR "forest restoration" OR "forest disturbances") OR ((forest OR wood\* OR tree\*) AND ("edible fungi" OR "growing stock" OR "increment" OR "logs" OR "management units" OR "mixtures" OR "panels" OR "pulp" OR "recruitment" OR "resins" OR "rotation\*" OR "waste paper" OR "working plans" OR "yield regulation" OR "logistics" OR "multiple use" OR "regeneration" OR "concessions" OR "primary sector" OR "thinning\*" OR "information" OR "certification" OR "governance" OR "green economy" OR "energy" OR "bioeconomy" OR "bioenergy" OR "circular economy" OR "growth" OR "ecosystem\*" OR "seedling\*" OR "pathology" OR "litter" OR "bark" OR "canopy" OR "soil" OR "mycorrhiz\*"))))

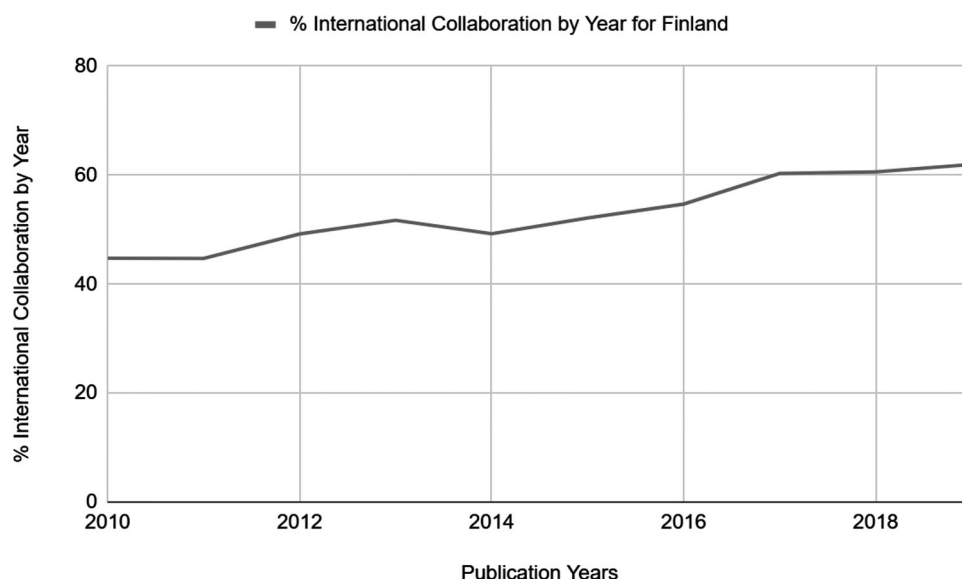
### Search 3 (keywords and phrases combined using Boolean logic (n = 151))

TS = (((("afforestation" OR "agroforest\*" OR "arboriculture" OR "artificial regeneration" OR "building timber\*" OR "charcoal" OR "community forest\*" OR "controlled burn\*" OR "coppic\*" OR "degraded forest\*" OR "delimiting" OR "dendro\*" OR "disturbed forest\*" OR "farm forest\*" OR "farm woodland\*" OR "felling" OR "FLEGT" OR "REDD+" OR "forest administration" OR "forest damage" OR "forest decline" OR "forest ecology" OR "forest economics" OR "forest inventor\*" OR "forest management" OR "forest ownership" OR "forest pest\*" OR "forest plantation\*" OR "forest polic\*" OR "forest product\*" OR "forest railway\*" OR "forest road\*" OR "forest taxation" OR "forest tree\*" OR "forestry" OR "forestry development" OR "forestry engineering" OR "forestry engineering" OR "forestry law" OR "forest law" OR "forestry machin\*" OR "forestry operation\*" OR "forestry practice\*" OR "forestry worker\*" OR "forest worker\*" OR "forests" OR "fuel plantation\*" OR "high forest system" OR "silvicultur\*" OR "irrigated stand\*" OR "IUFRO" OR "linear plantation\*" OR "lignin" OR "logging" OR "mensuration" OR "national forest\*" OR "nonwood forest products" OR "partial cutting" OR "patch cutting" OR "pollarding" OR "private forest\*" OR "pulp and paper industry" OR "pulpmill" OR "pulpwood" OR "reserved forest\*" OR "sawmill\*" OR "forest products" OR "seed orchards" OR "selection forest\*" OR "selective felling" OR "shelter-

wood" OR "short rotation forestry" OR "site class" OR "social forest\*" OR "stand improvement" OR "state forest\*" OR "stumpage" OR "timber\*" OR "urban forest\*" OR "vegetative propagation" OR "wood\*" OR "wood products" OR "wood pulp" OR "forest planning" OR "multi functional forestry" OR "forest biomass" OR "forest energy" OR "wood energy" OR "forest drainage" OR "forest recreation" OR "wood procurement" OR "wood material" OR "wood construction" OR "forest monitoring" OR "forest survey" OR "forest statistics" OR "forest industry" OR "tree nurser\*" OR "tree physiology" OR "forest mushroom\*" OR "forest berries" OR "forest herbs" OR "allowable cut" OR "sustainable forestry" OR "forest owners" OR "forest administration" OR "forestry services" OR "wood working industry" OR "forest protection" OR "forest fire" OR "forest restoration" OR "forest disturbances") OR ((forest OR wood\*) AND ("edible fungi" OR "growing stock" OR "increment" OR "logs" OR "management units" OR "mixtures" OR "panels" OR "pulp" OR "recruitment" OR "resins" OR "rotation\*" OR "waste paper" OR "working plans" OR "yield regulation" OR "logistics" OR "multiple use" OR "regeneration" OR "concessions" OR "primary sector" OR "thinning\*" OR "information" OR "certification" OR "governance" OR "green economy" OR "energy" OR "bioeconomy" OR "bioenergy" OR "circular economy" OR "growth" OR "ecosystem\*" OR "seedling\*" OR "pathol\*" OR "pathog\*" OR "litter" OR "bark" OR "canopy" OR "soil" OR "mycorrhiz\*"))))

Search validation	No. Articles	%
Total Corpus Search 1 (WoS 2010-2019)	441882	NA
Total Corpus Search 2 (WoS 2010-2019)	662831	NA
Total Corpus Search 3 (WoS 2010-2019)	363246	NA
Working Corpus Search 3 (WoS 2010-2019)	354967	NA
Total publications checked (2017 test set)	853	100.0
Total publications not forestry (2017 test set)	381	44.7
Total publications checked (2018 test set)	729	100.0
Total publications not forestry (2018 test set)	301	41.3
Records not indexed in Web of Science 2017	0	0.0
Records not indexed in Web of Science 2018	3	0.4
Found Search 1 (2017)	427	90.5
Not Found Search 1 (2017)	45	9.5
Found Search 2 (2017)	468	99.2
Not Found Search 2 (2017)	4	0.9
Found Search 3 (2018)	416	97.9
Not Found Search 3 (2018)	9	2.1

## Appendix 2. Development of international collaboration from 2010 to 2019 for Finland shows a positive trend



### Appendix 3. Number of forest research publications produced at the institutional level in Europe (2010–2019)

Institute	# of Publications	% of Total Global Corpus
Centre National de la Recherche Scientifique CNRS	8176	2.3
INRAE	4788	1.3
Russian Academy of Sciences	4401	1.2
Consejo Superior de Investigaciones Cientificas CSIC	4055	1.1
Swedish University of Agricultural Sciences	3711	1.0
Helmholtz Association	3118	0.9
University of Helsinki	2970	0.8
Institut de Recherche pour le Developpement IRD	2746	0.8
University of Gottingen	2490	0.7
Wageningen University Research	2441	0.7
CIRAD	2296	0.6
Consiglio Nazionale Delle Ricerche CNR	2241	0.6
ETH Zurich	2155	0.6
Universite de Montpellier	1993	0.6
Max Planck Society	1977	0.6
Czech Academy of Sciences	1929	0.5
Natural Resources Institute Finland Luke	1862	0.5
University of Eastern Finland	1453	0.4

### Appendix 4. Number of publications annually, average annual growth rate (AAGR), total number of publications 2010–2019 (TOT), percentage of internationally collaborative publications (INT%) and total number of internationally collaborative publications in 2010–2019 (INTT).

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	AAGR	TOT	INT%	INTT
USA	6526	7170	7299	7426	7970	8551	9049	9556	9938	10047	4.6	83,532	44	37,096
China	2491	3121	3533	3877	4376	4985	5767	6561	7799	9781	14	52,291	34	17,640
Germany	1671	1840	1970	2066	2325	2557	2754	2896	3091	2948	6	24,118	65	15,672
Brazil	1447	1535	1737	1850	2067	2511	2663	2868	3133	3351	8.8	23,162	34	7808
UK	1566	1698	1694	1882	2013	2267	2429	2548	2813	2777	6.1	2,1687	71	15,524
Canada	1734	1823	1872	1940	2049	2228	2270	2319	2464	2641	4.5	21,340	52	11,061
Australia	1179	1349	1456	1558	1666	1815	1885	1935	2030	2154	6.4	17,027	57	9748
France	1263	1327	1309	1563	1560	1766	1866	1891	2068	2001	4.8	16,614	68	11,314
Spain	1135	1190	1361	1389	1469	1689	1766	1971	2040	2006	6	16,016	57	9217
Japan	1250	1079	1253	1304	1292	1405	1455	1554	1588	1549	2.1	13,729	41	5665
India	849	916	898	1018	1129	1424	1690	1767	1922	1982	8.8	13,595	23	3140
Italy	874	910	928	1233	1241	1558	1594	1608	1825	1665	6.3	13,436	53	7164
Sweden	687	784	867	934	987	1062	1210	1217	1254	1209	6	10,211	63	6467
Finland	667	709	753	786	856	880	911	940	1020	928	3.5	8450	54	4545
Poland	465	499	564	583	688	871	1056	1051	1195	1300	10.6	8272	29	2421
Russia	364	406	396	437	524	840	1067	1129	1384	1575	14.3	8122	32	2627
Switzerland	590	594	659	738	757	779	838	937	997	954	5.1	7843	77	6072
Netherlands	448	528	595	651	696	765	821	838	969	881	7	7192	80	5755
Mexico	378	416	473	508	575	678	682	761	888	926	9.4	6285	46	2907
South Korea	333	417	492	553	537	688	717	704	853	981	10.9	6275	40	2496
Czech Rep	388	338	401	461	561	773	787	814	866	845	7.5	6234	47	2954
Belgium	370	391	420	464	476	572	605	603	680	637	5.6	5218	76	3983
Turkey	452	387	349	377	398	466	633	681	659	717	4.2	5119	22	1132
Portugal	289	335	399	415	592	531	605	590	641	683	8.4	5080	56	2876
Austria	353	378	387	434	443	569	603	621	663	591	5.2	5042	68	3432