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Review

Scientometrics of Forest Health and Tree Diseases: An Overview

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Abstract: Maintaining forest health is a worldwide challenge due to emerging tree diseases, shifts in climate conditions and other global change stressors. Research on forest health is thus accumulating rapidly, but there has been little use of scientometric approaches in forest pathology and dendrology. Scientometrics is the quantitative study of trends in the scientific literature. As with all tools, scientometrics needs to be used carefully (e.g., by checking findings in multiple databases) and its results must be interpreted with caution. In this overview, we provide some examples of studies of patterns in the scientific literature related to forest health and tree pathogens. Whilst research on ash dieback has increased rapidly over the last years, papers mentioning the Waldsterben have become rare in the literature. As with human health and diseases, but in contrast to plant health and diseases, there are consistently more publications mentioning "tree health" than "tree disease," possibly a consequence of the often holistic nature of forest pathology. Scientometric tools can help balance research attention towards understudied emerging risks to forest trees, as well as identify temporal trends in public interest in forests and their health.

Keywords: bibliometrics; data science; disturbance ecology; forest ecosystems; *Hymenoscyphus fraxineus*; long-term monitoring; publication growth; research assessment; sustainable development; tree diseases

1. Introduction

Forest health is an important aim of ecosystem management [1–3]. Forests deliver essential ecosystem services from boreal to tropical latitudes [4–6]. Without healthy forests, humanity and many other species would be in trouble [7–9]. There is thus concern about the impacts of global change on forest health, and much research is focusing on how to predict and manage such impacts [10–13].

But what is a healthy forest [14–16]? Researchers are increasingly realizing that a certain amount of disease plays a key role in the functioning of forest ecosystems, e.g., by diversifying uniform stands, recycling nutrients and facilitating adaptation to changing environmental conditions [17–19]. At the same time, exotic tree diseases can jeopardize the existence of native tree species, as shown by Dutch Elm Disease, chestnut blight, ash dieback and other emerging tree diseases [20–23]. Outbreaks of exotic tree pathogens can lead to a sudden spike in research on particular pathosystems (Figure 1), potentially leading to a relatively reduced research attention on the many other risks to tree health. Our understanding of forest health is also developing due to the availability of new tools to study the microbiome of forest trees and its role in maintaining forest health despite human activities and other biotic disturbances [24–26]. Just as importantly, there is increasing recognition of the role that various stakeholders play in shaping how societies react to new challenges to forest health [27–29].

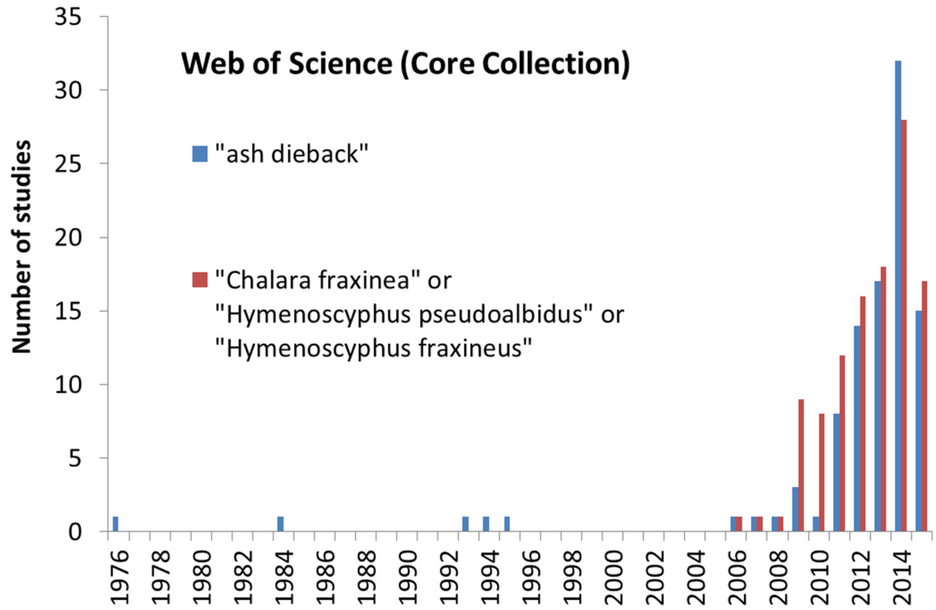

Figure 1. Temporal trend in Web of Science (core collection, since 1975), as of September 2015, of the number of studies retrieved with the keywords "ash dieback" (total = 98) and the names of its causal agent ("*Chalara fraxinea*" OR "*Hymenoscyphus pseudoalbidus*" OR "*Hymenoscyphus fraxineus*") (total = 111), an ascomycete shown in 2006 to be responsible for the dieback of *Fraxinus excelsior* in Europe [30–32]. Note that many relevant studies are not included in this database. Even so, the sudden increase in research shown by the figure is likely to reflect what happened in reality.

Given the importance of forest health, over the past decades, an increasing number of studies have dealt with this topic each year. For example, of the nearly 1700 studies retrieved in Scopus by searching for "forest health" (as of September 2015), about half appeared since 2007 and a third since 2010. Similarly, of the 162 items retrieved in Web of Science searching for "tree disease*" (core collection, 1991–2015, as of September 2015), about half were published since 2008 and a third since 2011. This is not a special feature of the literature related to forest health, as the number of scientific papers published each year has been increasing through time for most topics [33–35].

This increase in publication growth rates can have unintended consequences: although we have at our disposal much more information on forest health than, e.g., at the time of the Waldsterben (the 1980s), thus in principle leading to more pondered and hopefully evidence-based forest management decisions, it is now more difficult to keep updated with the literature, which becomes outdated more rapidly. A solution to the problems due to this growing number of studies is to try and summarize the gist of papers by writing reviews of the literature. However, literature reviews can also contribute to information overload. In addition, it is possible to study patterns in the literature using scientometric approaches [36–38].

Incidentally, the Waldsterben is a clear exception to the rule that scientific attention to most topics tends to increase through time (Figure 2), thus providing a potential example of a paradigm shift. Whilst this topic rapidly became the object of much research in the 1980s [39], the improved forest health conditions in the following decade, likely due to reduced air pollution and rarer acid rain events, both in North America and in Europe, resulted in a decreased use of this keyword. However, research on the links between forest health and air/soil pollution continued after the 1980s [40–42]. The forest damages due to air pollution currently observed in China [43–45] do not seem to be leading to a resurgence in the literature of the use of the term "Waldsterben".

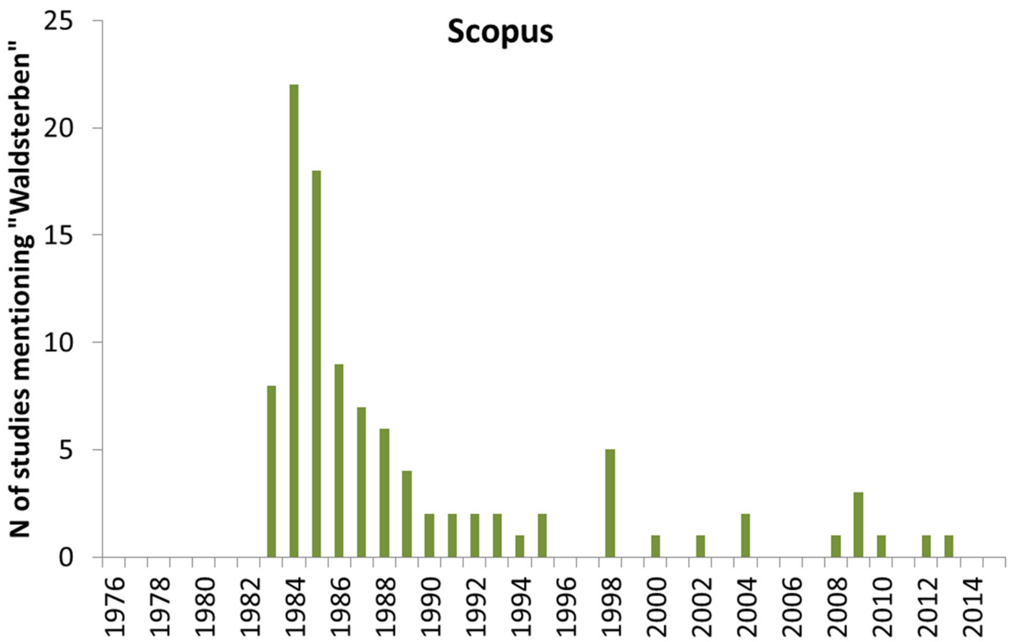

Figure 2. Number of studies mentioning “Waldsterben” (German for “forest mortality”) in Scopus, as of September 2015. Total number = 101.

2. What is Scientometrics?

Scientometrics is the quantitative study of patterns in the scientific literature [46–48]. This approach can be applied, e.g.,:

(i) to examine temporal trends in the number of publications on a certain topic [49–51],
(ii) to investigate the spatial distribution of the research attention given to a certain topic [52–54],
(iii) to study the relative number of papers dealing with various research areas [55–57],
(iv) to analyze the reception of papers (or items therein, e.g., anecdotes) by posterity [58–60],
(v) to assess the productivity of researchers and its likely quality [61–63],
(vi) to compare the research performance and diversity of institutions and countries [64–66],
(vii) to document patterns and determinants of the length of peer review processes [67–69], and
(viii) to study interdisciplinary collaboration activities [70–72].

As with all scientific endeavours, scientometrics needs to be carried out carefully and its findings must be interpreted with caution [73–75]. For example, not all research papers on forests, forestry and forest health are published in forest-, forestry- or forest health-related journals, respectively [76,77]. Moreover, scientometric patterns can differ among different databases, e.g., Web of Science and Google Scholar, as the latter includes more journals and also tends to cover the full text of articles available online [78].

Even though more and more attention is given to scientometric issues such as the impact factor of journals and the h-index of researchers, often these metrics have limited predictive, comparative and explanatory power [79–83]. However, despite the increasing popularity of scientometric approaches over the last years across the spectrum of scientific fields, there has been relatively little use of such tools in forest pathology. This brief overview aims to present some examples of scientometric studies related to forest health and tree pathogens.

3. Scientometrics of Forest Health and Tree Pathogens

3.1. Scientometrics of Forest Health

There is evidence that, over the last two decades, the proportion of forest-related research studies mentioning "forest health" has been fairly stable, despite a steady increase in the number of both forest-related studies and those mentioning "forest health" [26]. The same pattern applies to the proportion of forest-related studies mentioning "tree diseases." The stable proportion of forest-related studies mentioning forest health (or tree diseases) over the last two decades is remarkable, given the emergence of many new threats to forests, some of which have attracted considerable research interest (e.g., Sudden Oak Death [84], the Emerald Ash Borer [85] and European ash dieback [32]).

Interestingly, fewer publications are retrieved when searching for "tree disease" compared to "tree health" (as well as for "forest disease" compared to "forest health"). This pattern tends to be consistent regardless of the publication year, so that the literature on forest health and diseases resembles that on human health and diseases (where publications mentioning "human health" tend to be more frequent than those mentioning "human disease") and differs from the literature on plant health and diseases, where the opposite is the case (Figure 3). This pattern might be a consequence of the traditional focus on specific crop diseases in plant pathology, whereas the science of forest pathology often has to deal with abiotic stressors, complex diseases and many factors other than diseases contributing to tree and forest health.

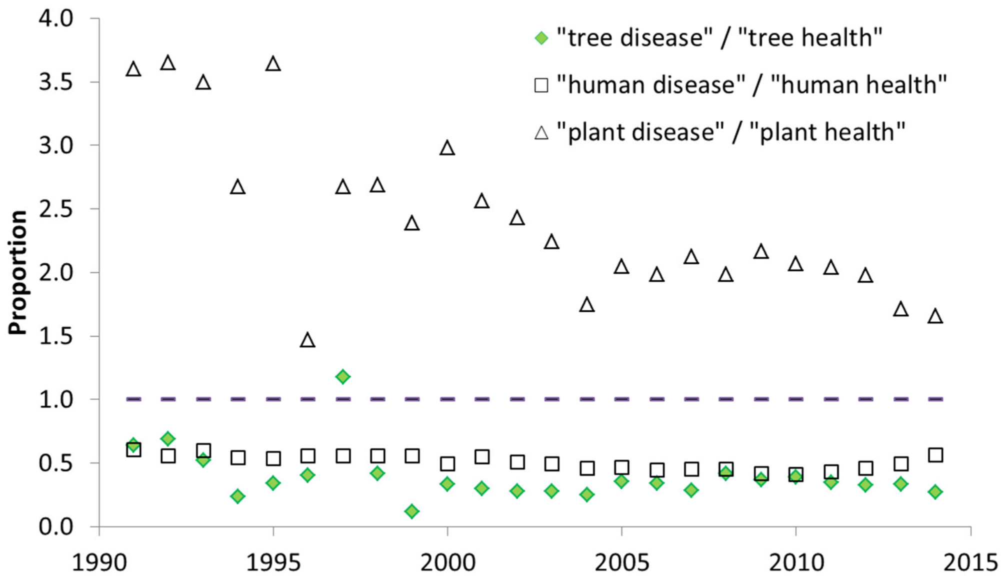

Figure 3. Number of publications retrieved in Google Scholar (1991–2014, as of September 2015) searching for the keyword "tree disease" relative to the number of publications retrieved using the keyword "tree health", and for human/plant disease in comparison with human/plant health, respectively. Modified from [86].

Tree mortality is an important component of forest health. In a sample of 67 studies modeling tree mortality published between 1997 and 2006, about 40% of the studies were based on data retrieved from studies shorter than five years [87]. This pattern might be inevitable due to the short-term nature of many current research projects, but basing models on short-term data is problematic when trying to predict the long-term effects of climate changes on forest health.

Scientometric studies can deliver insights about long-term trends in the literature, thus ultimately helping improve our long-term management of forests. For example, although fungi are essential organisms in forest ecosystems, fungi are relatively rarely mentioned in the scientific literature on forests (only about 3%–5% of the papers mentioning forests also mention fungi) [88]. Nevertheless, there is evidence for a slow increase in the proportion of forest-related papers mentioning fungi over the last two decades from Web of Science [88]. Although the proportion of forest-related papers mentioning insects is similar to that mentioning fungi, there has been no such increase through time for forest-related papers mentioning insects over the last two decades. These findings call for increased funding, training and hiring of mycologists, entomologists and forest pathologists at Universities and research institutions.

3.2. Scientometrics of Tree Pathogens

Scientific attention given to exotic tree pathogens appears to be skewed towards a few famous ones, with many tree fungal diseases receiving little attention. About ~20% of the exotic tree pathogens reported in Switzerland account for ~90% of the publications on such pathogens indexed in Web of Science [89]. This skewed attention is confirmed when searching within a more comprehensive database (Google Scholar) (Figure 4). Although there is a positive correlation between the numbers of findings on a certain tree pathogen in the two databases, the correlation is not perfect, thus confirming the importance of using multiple databases when searching the literature (Figure 4).

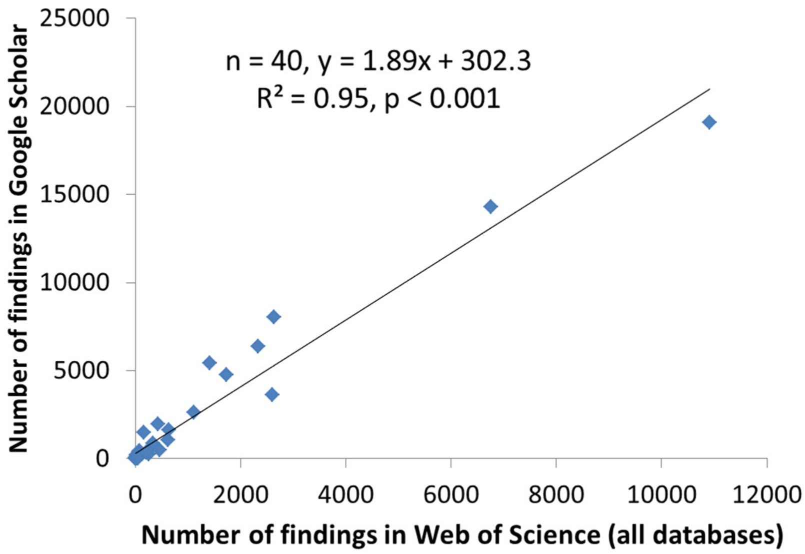

Figure 4. Correlation between number of findings in Google Scholar and Web of Science on the exotic tree pathogens reported in Switzerland up to October 2011 (as in [89], data kindly provided by Ottmar Holdenrieder, with addition of *Hymenoscyphus fraxineus*, the causal agent of ash dieback; searching for just this current name [90] will generally not retrieve publications only using the previous name *Hymenoscyphus pseudoalbidus* or the name of its anamorph, *Chalara fraxinea*).

One prominent example of an exotic tree pathogen that has received increased attention from the scientific community is *Phytophthora ramorum* (the oomycete responsible for Sudden Oak Death in the USA and Sudden Larch Death in the British Isles), now the object of just as many publications (Figure 5) as, e.g., *Cryphonectria parasitica*, the long studied causal agent of chestnut blight both in North America and Europe [91]. Figure 5 shows that few early publications on a topic tend to accumulate citations by the many late publications on the same topic, even if those early publications to some extent inevitably become outdated, as they could not consider all the knowledge made available in later publications. Note that not all articles retrieved by searching for "*Phytophthora ramorum*" are really on *Phytophthora ramorum*, as some only mention it as an aside.

4. Conclusions

Scientometric studies can illustrate the temporal development in the research focus towards particular issues. The drivers for such attention include overall interest in such topics, the number of researchers working on them, administrative incentives and funding availability. Scientometrics needs to be used carefully and interpreted with caution. Indeed, "not everything that can be counted counts and not everything that counts can be counted" [92]. Most scientometric indexes are (sub)field specific, thus making comparisons of publications, researchers, journals and institutions among (sub)fields of little value [93–95]. For example, whilst about 27% of the papers published in Australasian Plant Pathology between 2001 and 2007 were not cited as of 2011 [96], the proportion of not cited papers (as of 2014) was 40% for entomological papers published between 2005 and 2009 [97] and only about 7% for papers published in 2004 (as of 2010) in eight mathematical journals [98].

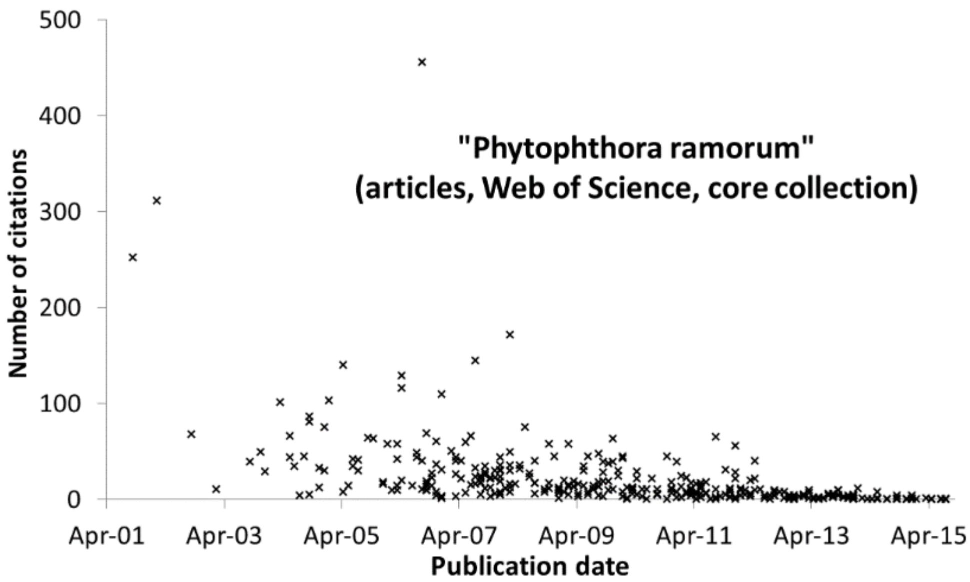

Figure 5. Number of citations received by the 353 articles (April 2001–September 2015) retrieved with the keyword "*Phytophthora ramorum*" in Web of Science (core collection, as of September 2015, excluding reviews, book reviews, meeting abstracts, editorials and news items). Note that the Web of Science database also lists some review papers as articles (but the pattern shown is essentially the same even if further refining the list of articles considered).

Just as when searching the literature for writing a literature review or a research paper, there is the need to use multiple databases and to be creative with the keywords used [99]. It is worth repeating that different databases have their strengths and weaknesses; for example, Web of Science focuses on journals with an impact factor, thus excluding much of the grey literature. Conversely, Google Scholar includes literature in languages other than English (as long as this is available on the internet), but does not exclude papers that have not been peer reviewed [100]. A clear documentation of the search strategy is needed, so as to enable repetition of the same search at a later stage.

It is important to keep in mind that the number of publications or of citations is a rough and insufficient indicator of the scientific importance of a topic or of the achievements within individual articles and of researchers [101–103]. But studying trends in the scientific literature, when combined with other lines of evidence, can help document gaps in knowledge and research priorities [104]. Of course, this approach needs to be complemented with the actual reading and pondering of the retrieved publications, as shown by an assessment of research intensity and its perception by experts on ecosystem services in mountain regions [105].

Approaches related to scientometrics can be used to monitor the attention of the media to forest and tree health [106], as well as public interest in various tree diseases, e.g., ash dieback [107], and, more generally, in forests (Figure 6). Figure 6 suggests that whilst in India there has been no clear trend or seasonality of public interest in forests over the last years, in Japan there appears to have been a decline through time, whereas in the UK there has been marked seasonality, with public interest peaking during the summer. A similar method can be used to study bibliometric patterns. For example, the proportion of published books mentioning "forest pathology" appears to have declined in recent decades for books in American and British English, French, German and Italian [108]. This finding is of concern, given the importance of books in inspiring students to study a certain topic, although this influence of books on career and lifestyle choices might now have been largely replaced by the internet and social media [109]. There has partly been a counter-trend for books mentioning "forest health" in the same languages [108].

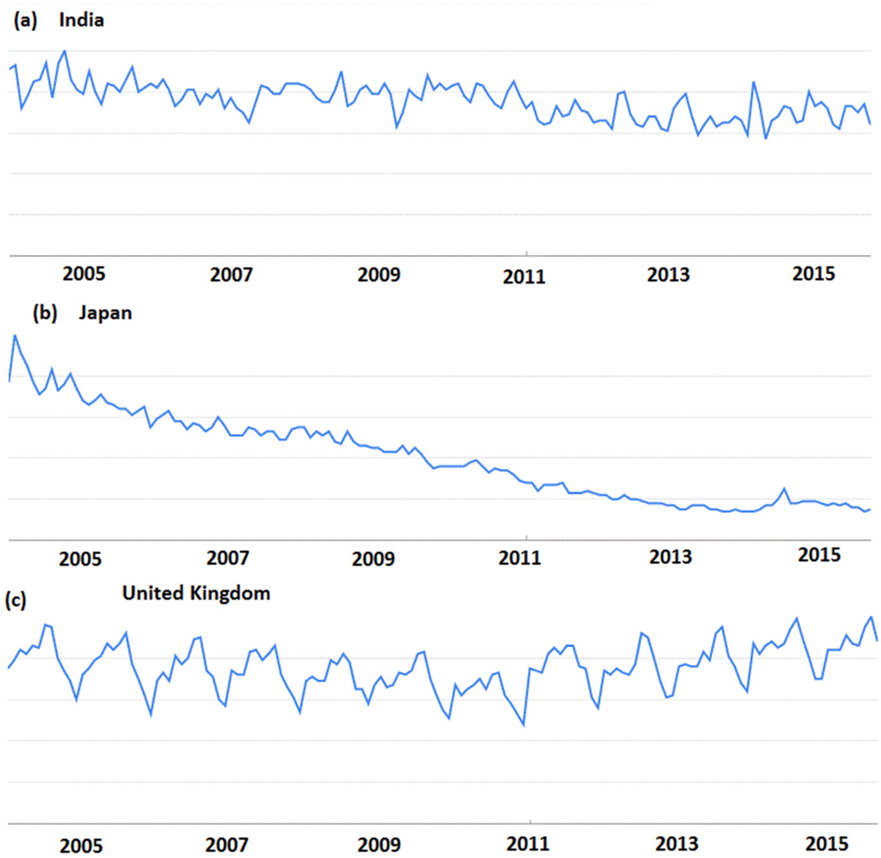

Figure 6. Temporal trend (2004–September 2015), as of September 2015, in Google searches by the general public for "forest" in (**a**) India; (**b**) Japan; and (**c**) the UK.

The absolute number of published papers per year is increasing for most scientific topics, including various tree fungal pathogens (although not all of them). Documenting an increase in the absolute number of papers per year for a certain topic is thus not particularly informative, although it can raise awareness of the amount of literature already available and the frequent lack of enduring value of many papers [97,110]. More interesting than documenting an absolute increase in publications is to study whether there is a temporal trend in the proportion of studies on a certain topic relative to the number of studies retrievable in a related area [111–113]. Given the skewed focus in research attention and funding to a few tree fungal pathogens, scientometric studies can help rebalance scientific priorities to a larger suite of potentially emerging threats to tree health under changing environmental conditions.

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