

Review

A Bibliometric Analysis of the Mechanisms Underlying Drought-Induced Tree Mortality

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Abstract: Drought intensity and frequency have increased in recent years, which poses significant threats to forest ecosystems, especially in the context of global climate change. This paper is aimed at summarizing the current state of research and global development trends regarding drought-induced tree mortality mechanisms in tree physiology. Developing a robust literature foundation will facilitate in-depth research and foster the exchange of knowledge related to this subject. A literature review was conducted using tools such as VOSviewer, CiteSpace, and the Bibliometrix R-package to review the literature from the Web of Science's core database from 1985 to 2023. We intend to determine the current state and evolution of global research on drought-induced tree mortality mechanisms. The results reveal that research on drought-induced tree mortality mechanisms gained momentum predominantly in the last two decades, with a marked surge post-2012. The United States is the epicenter of research, leading the global scientific community with its preeminence in publication volume, citation rates, and the scope of collaborative networks, with China in close pursuit. *Tree Physiology* stands out as the leading journal in this domain, boasting 129 articles. McDowell NG emerges as the most prolific author, with an H-index of 41, underscoring his influence in the field. There is a clear upward trend in collaborations spanning authors, journals, research institutions, and countries. The analysis of frequently cited keywords and topic evolution suggests that drought and tree mortality will likely remain key research areas for the foreseeable future. The future of research on drought-induced tree mortality mechanisms in physiology is promising, as it emphasizes multidisciplinary approaches and global collaborations.

Keywords: tree; mortality mechanism; bibliometrics analysis; Bibliometrix; VOSviewer; CiteSpace



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1. Introduction

In light of the global climate change phenomenon, the rise in ambient temperatures, exacerbated by severe droughts and the proliferation of pests and diseases, has precipitated a notable escalation in the mortality rates of regional vegetation [1–3]. This development has garnered widespread attention and scrutiny from the scientific community on a global scale. In the context of global environmental challenges, drought stress emerges as the most prevalent and critical environmental stressor, exerting a significant constraint on both the productivity of crop cultivation and the vitality of forest ecosystems [4].

Drought-induced tree mortality mechanisms have been a hot topic in tree physiology. Research has revealed that the interplay of elevated temperatures and persistent drought conditions has contributed to an observable uptick in mortality across various forest ecosystems on a global scale, particularly over the past three decades [5–7]. Such arid conditions intensify plant physiological stress, escalating water loss via transpiration and impeding photosynthesis, which in turn lowers water use efficiency [3,8]. Moreover, severe droughts,

often marked by rising air temperatures and declining relative humidity, are projected to amplify the water vapor pressure deficit (VPD) on a continental scale, heightening atmospheric demand for water [9,10]. Evidence supports that warmer temperatures escalating VPD can intensify transpiration, potentially triggering peaks in plant mortality during periods of extreme drought [11]. Extreme weather events that have happened internationally over the last ten or so years have severely damaged forests in several locations, and significant tree mortality has been documented worldwide [12–16]. For example, the 2010 drought affected about 17% of aspen forests in Colorado and other western U.S. and Canadian regions, resulting in significant tree loss [17,18]. In a similar vein, these extreme weather events have also affected China's broad-leaved evergreen forests in the south and poplar (*Populus* spp.) plantations in the north [19,20].

Considering this, it is especially necessary and vital to carry out research on how drought conditions affect tree survival. Distinguished experts and scholars from international arenas have engaged in extensive experimental validation and scientific inquiry into the mechanisms triggering tree mortality under drought conditions. Their collective research has yielded a corpus of foundational conclusions, with the most salient being the hypotheses of hydraulic failure and carbon starvation.

Hydraulic failure occurs when transpiration water loss exceeds root uptake, leading to increased xylem tension, progressive cavitation, and subsequent loss of conductivity [3,21,22]. Conversely, in the face of drought, trees may experience carbon starvation due to a persistent negative carbon balance. This arises when the carbon generated through photosynthesis, nonstructural carbohydrate (NSC) metabolism, and cellular autophagy fall short of the carbon required for respiration, growth, and stress resistance [7,23,24]. Nevertheless, tree responses to drought stress are highly complex, characterized by significant variation in the regulatory responses and hydraulic traits among different species, as well as among co-occurring species within the same region [25]. Consequently, significant attention has been paid to the response of different trees to drought stress and the mechanisms by which distinct plant hydraulic traits mitigate delayed mortality during drought conditions, thereby reducing the lethal effects of water scarcity [26,27]. An academic consensus on the mechanisms of tree drought mortality remains elusive, attributed to variations in research scopes, methodologies, and the diversity of tree species studied. Understanding the mechanisms behind tree death is essential for identifying key parameters in drought-induced mortality and establishing the lethal thresholds of physiological indicators, which facilitates the prediction of tree death. With the increasing likelihood and intensity of terminal droughts due to rising temperatures, it is imperative to explore the variability in drought response strategies among tree species and to evaluate how their hydraulic traits affect the timing and mechanisms of mortality. A series of events have underscored the imperative need for research into the mechanisms and predictive modeling of tree mortality due to drought conditions.

To advance the study of tree physiology in China and understand the international discourse on tree drought mechanisms and predictions, we employed bibliometric methods and visualization tools like VOSviewer, CiteSpace, and the Bibliometrix package of the R language to analyze the current literature, thereby offering insights and support for related research.

Bibliometrics, a sub-discipline within library and information science, employs mathematical and statistical methods to analyze various characteristics of the published literature, such as keywords, authorship, institutional affiliations, and journals. This analysis is utilized to assess and forecast the development trends in science and technology [28,29]. We conducted a search in the Web of Science's core database for articles pertaining to drought-induced tree mortality mechanisms. Employing cluster analysis and theme mining, we analyzed the historical development and dynamic evolution of these mechanisms globally. This analysis aims to predict future research trends and inform the direction of tree mortality mechanism studies.

2. Research Methodology and Initial Data Statistics

2.1. Data Collection

We conducted a literature review in the Web of Science Core Collection (WoSCC) database, covering the period from 1 January 1985 to 31 December 2023, with the search conducted on 12 January 2024. The search string is as follows: TOPIC = (((TS = (drought OR “water stress” OR “water deficit”)) AND TS = (mortality OR death OR dieback)) AND TS = (tree)) AND TS = (mechanism* OR hydraulic OR NSC OR “nonstructural carbohydrates” OR carbohydrates), including English only. The literature type was set up as “article” and “review”. The data retrieved included a total of 1452 papers, including 1336 articles and 116 reviews. These publications from WoSCC were exported in plain text format. All information from the databases, including the number of documents, the number of citations, authors, affiliations, countries, titles, keywords, publication year, journals, and references, were downloaded and integrated for bibliometric analysis and visualization.

2.2. Research Methodology

Through bibliometric analysis and visualization, we analyze the studies, which integrates mathematics, statistics, and bibliography to quantitatively assess the comprehensive knowledge system [29,30]. The scope of bibliometrics extends beyond traditional literature forms, such as books, journals [31], reports, and conference papers, to include measurable indicators related to the literature, such as author counts, keyword frequencies, citation metrics, dissemination rates, and article quantities.

There are a variety of visualization software tools for mapping knowledge graphs, and we primarily use three software packages: VOSviewer (version 1.6.20) (<https://www.vosviewer.com> (accessed on 23 March 2024)), CiteSpace (version 6.2.6) (<http://citespace.podia.com> (accessed on 20 March 2024)), and the R-based Bibliometrix package (version 4.0.0) (<http://www.bibliometrix.org> (accessed on 25 March 2024)).

VOSviewer, developed by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands, is a free bibliometric tool renowned for its capabilities in co-occurrence network clustering and density analysis [32]. CiteSpace is a bibliometric visualization software developed in Java, utilizing co-citation analysis theory and path-finding network algorithms [33]. Bibliometrix, developed by Massimo Aria and colleagues, offers distinct advantages in bibliometric analysis, statistical evaluation, network analysis, and knowledge mapping. Their team detailed the software’s primary functions and usage procedures, positioning it favorably against other bibliometric tools [34,35].

We employ VOSviewer to visualize collaboration and co-authorship networks in tree drought mortality mechanism research, encompassing temporal trends among authors, journals, institutions, and regions. Additionally, CiteSpace is utilized to analyze and map the top twenty keywords and references with the most significant citation bursts. We also utilized the R-based Bibliometrix package to analyze publication counts, co-citation frequencies, author activity, affiliations, and journals, thereby mapping Bradford’s Law, the activity index of the top ten authors, and creating strategy and thematic evolution maps for studies on drought-induced tree mortality mechanisms. By doing so, we aim to systematically and objectively examine the characteristics of the tree drought mortality mechanism field, delineating its research status, hotspots, and emerging trends to foster a clearer comprehension of its developmental trajectory and future prospects.

3. Initial Data Statistics

The initial publication on drought-induced tree mortality mechanisms in WoSCC appeared in 2002, with a general upward trend observed in annual publication counts for both articles and reviews (Figure 1). It is worth noting that there was a significant increase in 2013, 2015, 2018, and especially in 2021, but a downward trend in 2022. We categorized the totality of the period into four phases according to the number of annual publications and the average number of article citations per year: period I (2002–2007),

period II (2008–2013), period III (2014–2019), and period IV (2020–2023). In period I, annual publications did not exceed ten, yet the citation rate for 2006 was comparatively high. In period II, both publications and citations increased, with an overall stabilizing trend and a significant increase in citation rates. In period III, the number of publications continued to grow, with irregular changes in citation rates. In period IV, the number of publications grew very significantly, but after 2020, the citation rate of publications began to decline.

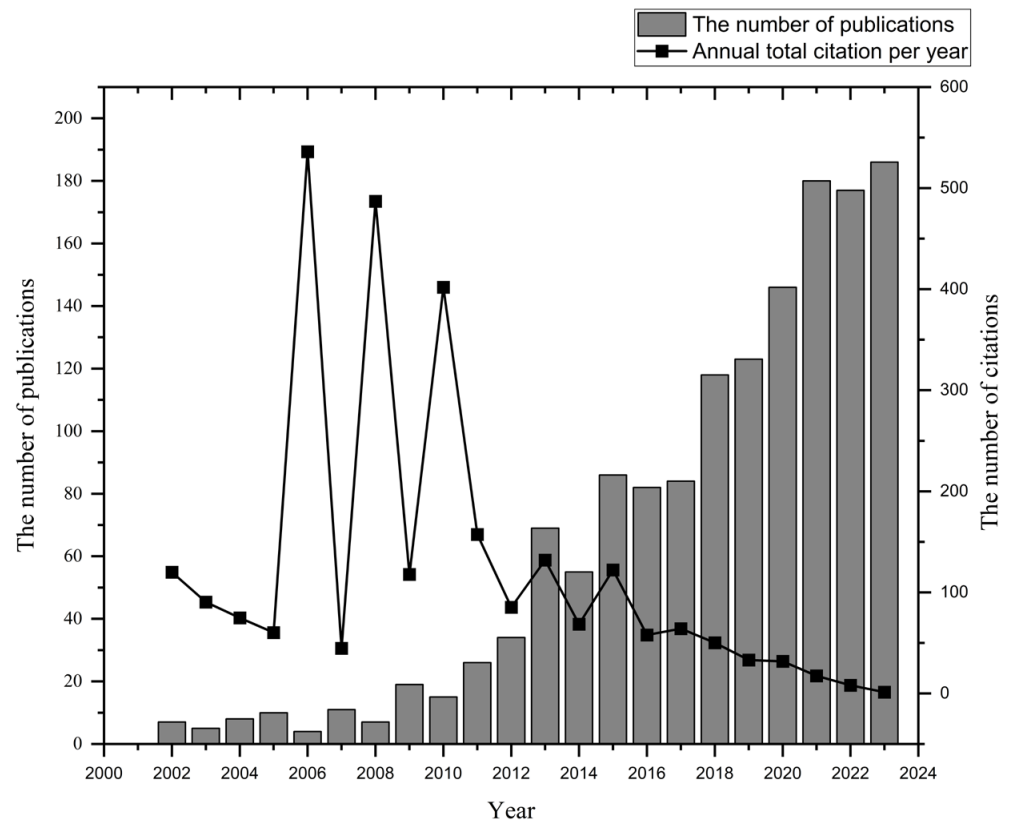


Figure 1. The number of publications and times cited per year in 2002–2023.

4. Bibliometric Analysis

4.1. Author Analysis

Table 1 reveals a distinguished group of ten authors who have made significant contributions to the field of tree physiology, as evidenced by their publication counts. These scholars have established themselves with impressive H-index scores, ranging from 20 to 41, which is a testament to both the impact and the volume of their scholarly output. In the realm of scholarly output, McDowell N.G. emerges as the most productive author with 74 publications and an extensive citation record of 10,988. Anderegg W.R.L. follows with a significant contribution of 42 publications and 6379 citations. Martinez-Vilalta J. also ranks high, amassing 33 publications and a notable 3634 citations. Martinez-Vilalta J. and Camarero J.J. initiated their scholarly contributions to tree physiology with pioneering publications in 2002. McDowell N.G. tops the activity index with an H-index of 41, while Allen C.D. leads in mean citations per publication, with 26 articles garnering 15,044 citations, showcasing a meaningful engagement with the subject matter and a substantial impact on the field.

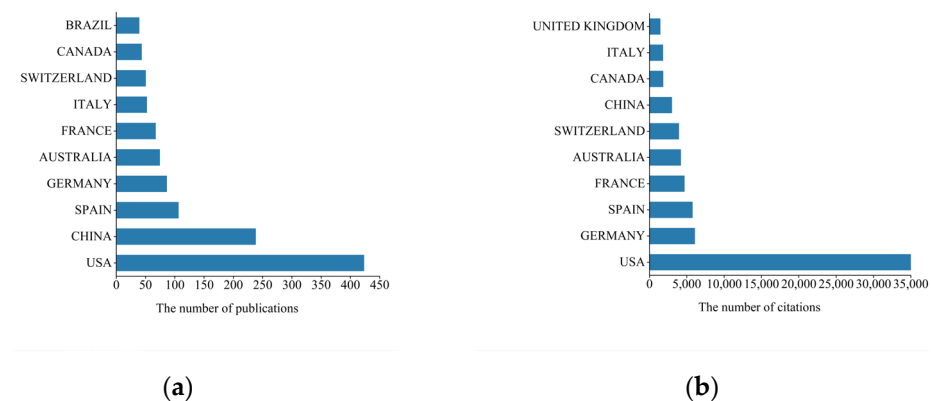
Table 1. Impact of the top ten authors.

Authors	H-Index	TC	NP	PY-Start
McDowell N.G.	41	10,988	74	2007
Anderegg W.R.L.	32	6,379	42	2012
Martinez-Vilalta J.	26	3,634	33	2002
Delzon S.	24	2,601	38	2013
Cochard H.	22	2,765	41	2013
Hartmann H.	22	4,172	31	2011
Allen C.D.	21	15,044	26	2008
Camarero J.J.	21	2,958	39	2004
Pockman W.T.	21	6,226	25	2002
Choat B.	20	2,781	31	2013

NP: Number of publications; TC: The total number of citations; H-index: an author-level metric; PY-start: Year of the first publication.

4.2. Active Countries

From January 2002 to December 2023, our analysis identified that research on drought-induced tree mortality mechanisms has been conducted by scholars across 51 countries. The ten countries with the most substantial publication output represent approximately 81.13% of the worldwide research contributions in this field, totaling 1178 publications (Figure 2a). Considering the notable disparities in national rankings, we conducted a normalization analysis of both the publication counts and citation frequencies for all countries featured in the reviewed publications (Figure S1). The results show that the United States emerged as the foremost contributor, with 423 articles published on tree mortality mechanisms, surpassing China, which had 238 articles, and Spain, with 106. The U.S. also exhibited the highest citation frequency, amassing 36,131 citations (refer to Figure 2b), suggesting a significant scholarly impact and a pronounced research advantage on the global stage. Regarding citation counts, the United States, Germany, and Spain secure the top positions, with France and Australia following at a considerable distance.

**Figure 2.** The number of publications (a) and citations (b) in the top 10 countries.

4.3. Journal Analysis

Our analysis encompassed 212 journals that featured research on drought-induced tree mortality mechanisms. The leading journals were evaluated based on publication volume and citation counts (Figure 3). *Tree Physiology* dominated with 122 articles (Figure 3a), while *New Phytologist* garnered the highest citation tally, closely trailed by *Tree Physiology* (Figure 3b). This positions *Tree Physiology* as the preeminent journal in the field, excelling in both publication and citation metrics. Furthermore, employing Bradford's law to identify the most influential journals, our dataset pinpointed 223 core journals (Figure 4). The quintet of the most active journals is as follows: *Tree Physiology* (ISSN: 0829-318X), *New Phytologist* (ISSN: 0028-646X), *Forest Ecology and Management* (ISSN: 0378-1127), *Global Change Biology* (ISSN: 1354-1013), and *Forests* (ISSN: 1999-4907). These journals have consistently published

significant research, shaping the discourse and advancing knowledge in the study of tree physiology under drought conditions.

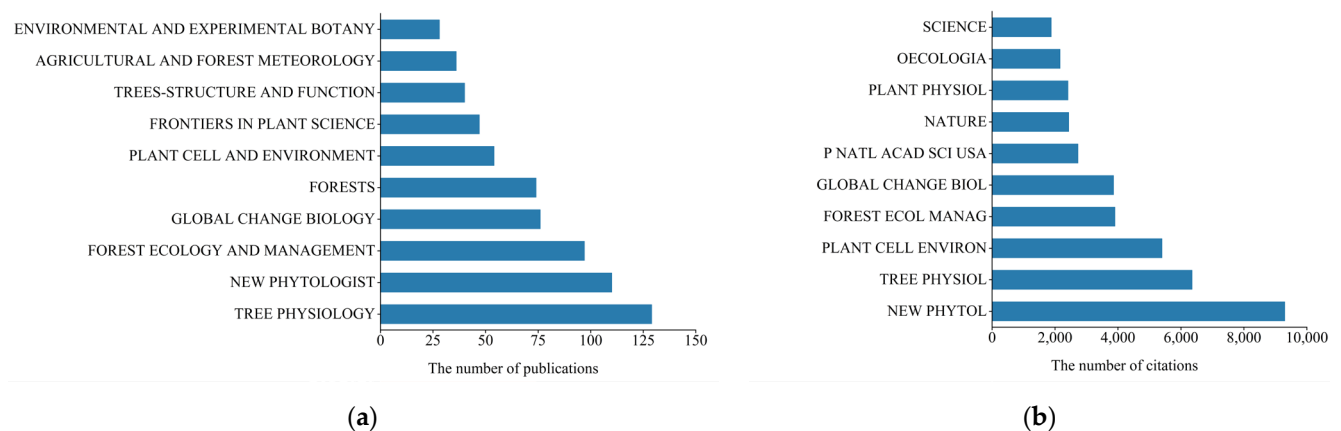


Figure 3. The number of publications (a) and citations (b) in the top 10 journals.

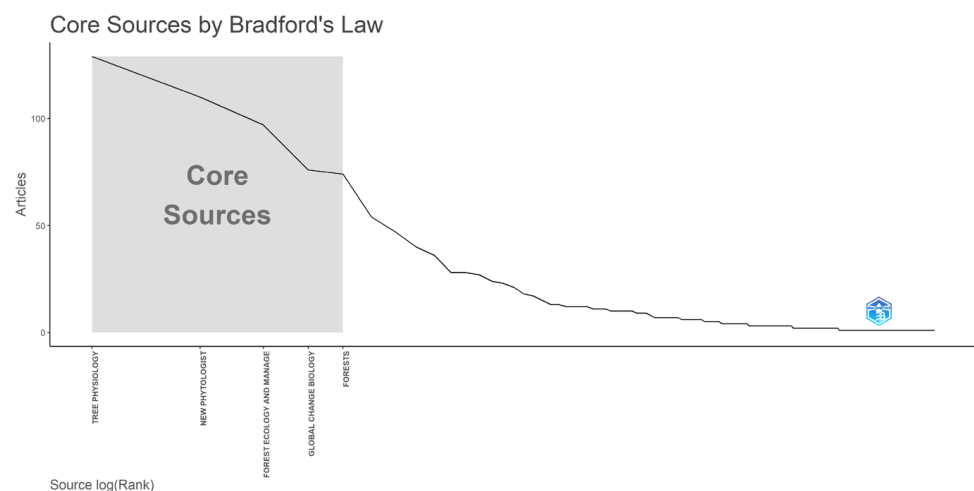


Figure 4. Bradford's law.

4.4. Citation Burst Detection of Keywords and References

Citation burst detection analysis elucidates the dynamics of terminological frequency, pinpointing terms that undergo rapid change and have garnered significant attention within a brief temporal frame. Such terms often emerge as focal points for scholarly interest, subsequently driving the evolution of the field. We configured the CiteSpace software to capture annual time slices and selected 'Keyword' as the Node Type for analysis. Figures 5 and 6 present the twenty most cited keywords and references, highlighting the most notable increases in citation activity, with the onset years of these bursts indicated in bold. We discovered that the terms "die off", "induced tree mortality", and "global change" experienced the most significant citation surges, with 'die off' maintaining its prominence over a more extended period compared to the other key phrases. The "Mountain pine beetle" emerged earliest and its occurrence spanned over seven years, as depicted in Figure 5.

Top 20 Keywords with the Strongest Citation Bursts

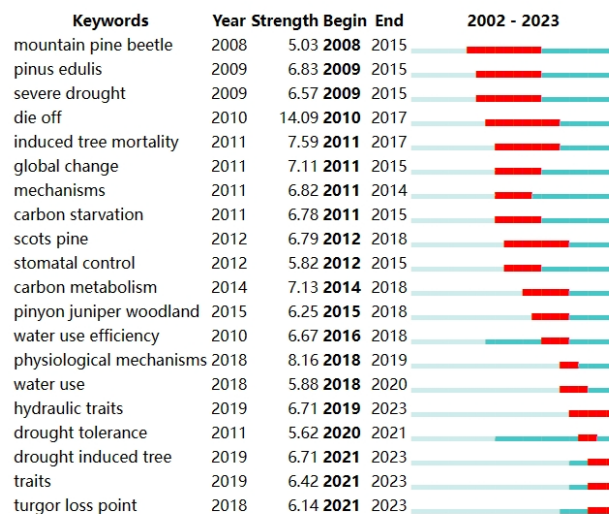


Figure 5. The top twenty keywords with the strongest citation bursts.

Top 20 References with the Strongest Citation Bursts

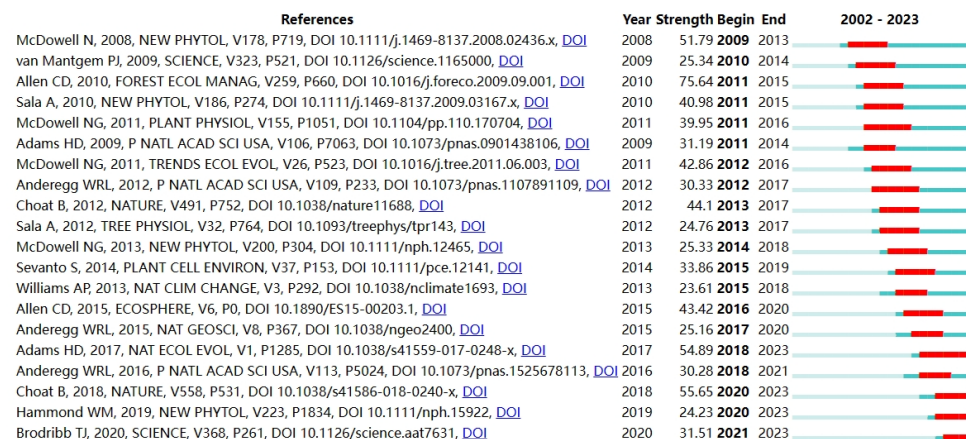


Figure 6. The top twenty references with the strongest citation bursts.

Notably, upon analyzing the top 20 keywords with the strongest citation bursts, we identified two keywords associated with tree species: “*Pinus edulis*” (*Pinus edulis* E.) and “*Scots pine*” (*Pinus sylvestris* L.). In light of this discovery, we undertook an in-depth examination of the pertinent literature. The surge in the keyword “*Pinus edulis*” commenced in 2009, predominantly attributed to extensive mortality of this species in western North America, a consequence of drought induced by global climatic shifts [36–39]. Furthermore, our analysis indicates a significant surge in the keyword “*Scots pine*” since 2012. Delving deeper, we discovered that over the past decade, widespread drought in Europe has led to substantial Scots pine mortality [40–42], garnering considerable attention from the academic sphere. In addition, to achieve a more profound comprehension of the tree species impacted by extreme weather conditions within the retrieved publications, we compiled an exhaustive table, the details of which are presented in the Supplementary Material (Table S1). The susceptibility of these arid-adapted species to drought-induced decline underscores the significant repercussions of water scarcity on tree species survival.

In Figure 6, the most representative references, selected based on burst duration, intensity, and timing from the previous clustering analysis, are highlighted with the beginning of each burst marked in bold. Notably, the articles by Allen CD, Choat B, and Adams HD

exhibit the most pronounced burst intensity. Furthermore, the citation burst for McDowell N's article commenced in 2008, prior to those of the other authors.

5. Network Analysis of Publications

5.1. Author Collaboration Network Analysis

Figure 7 displays a timeline visualization of the author collaboration network, where the color coding of nodes represents the average time of collaboration between authors, and the sizing of nodes corresponds to the frequency of associations.

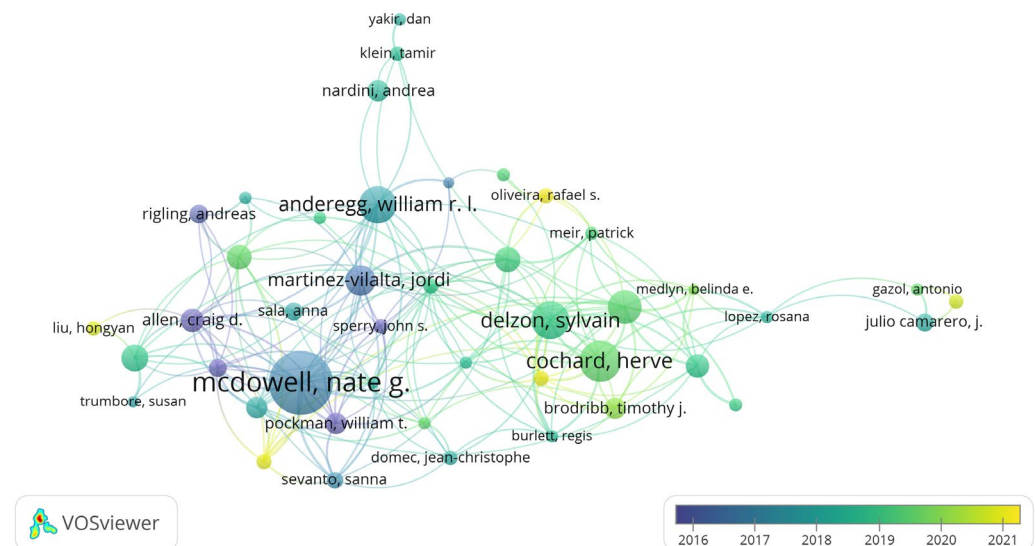


Figure 7. Timeline visualization of cooperation amongst authors.

In the visualization, the link thickness and the distance between nodes represent the level of cooperation among authors. By establishing a threshold at 10 for the minimum number of papers an author must publish within the field, out of 5386 authors, 45 were found to be eligible. The majority of the authors maintain regular communication with one another, with the exception of a single author who does not engage in collaborative efforts. The network of collaborations among these authors is notably centralized. McDowell NG has the highest number of collaborative relationships among the authors, succeeded by Choat B and Cochard H. There has been a noticeable decline over time in the number of authors participating in cooperative relationships. The majority of these author collaborations are concentrated in the period between 2017 and 2020.

5.2. Institute Collaboration Network Analysis

The timeline visualizations of the institutions' co-authorship networks, which were created in the same manner as those of the authors, are displayed in Figure 8. This procedure demonstrated the connections between several institutions. We established a minimum requirement of 20 publications for an institute. Out of the 1547 institutes, 44 were ultimately chosen. There is a clear quantitative difference in the cooperative network. At the heart of the collaborations and the top institution with the greatest number of collaborative ties is the Chinese Academy of Sciences (CAS). Furthermore, it is noteworthy that the CAS continues to have close working relationships with the majority of institutes. Over time, the number of institutions collaborating with the CAS has steadily increased, with the majority being centered in the 2020s.

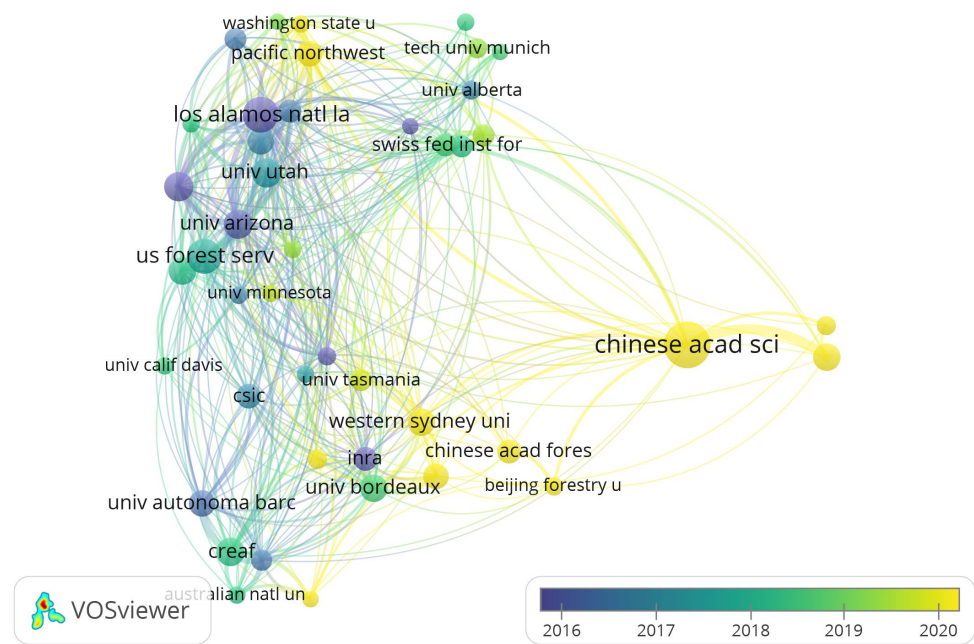


Figure 8. Timeline visualization of cooperation among institutes.

5.3. Journal Collaboration Network Analysis

We established a minimum citation requirement of 20, and out of the 9341 journals, 344 journals satisfied it. Every circle in the graphic denotes a journal, and the circle's size reveals how many citations the journal has accumulated. Based on co-citations, a cluster is represented by each color. Links between journals show their synergistic interactions; stronger link lines indicate more citations for a certain journal. Four unique categories comprise the most often cited publications in the subject of drought-induced tree mortality mechanisms: yellow, red, blue, and green. These are, in order, *Global Change Biology* (ISSN: 1354-1013), *Forest Ecology and Management* (ISSN: 0378-1127), *Trees: Structure and Function* (ISSN: 0931-1890), and *New Phytologist* (ISSN: 0028-646X) (Figure 9). As can be seen from Figure 9, the journal *New Phytologist* has the biggest circle, signifying the highest amount of citations for this publication.

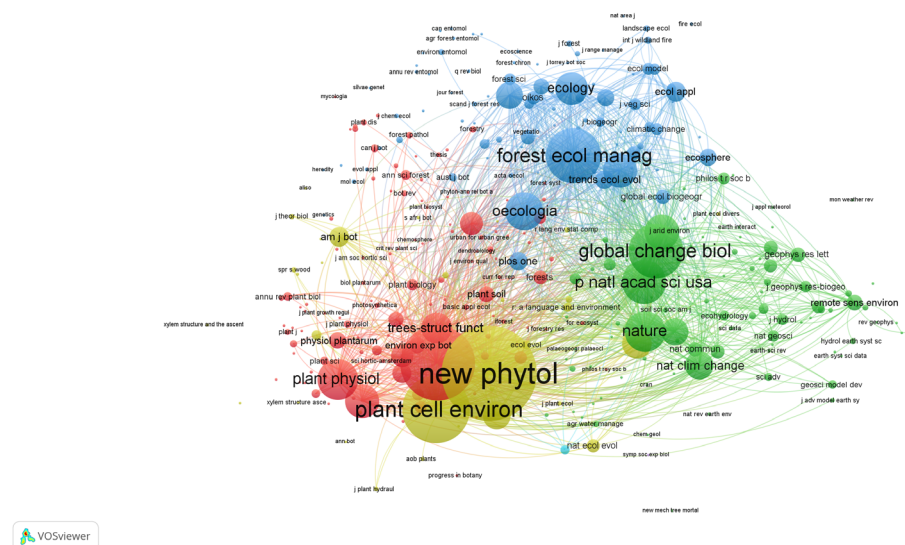


Figure 9. Timeline visualization of cooperation amongst journals.

5.4. Country Regional Cooperation Analysis

The country collaboration map shows that although African countries are somewhat less involved, Asia, Europe, the Americas, Africa, and Oceania are all engaged in tree physiology research (Figure 10). The research landscape is predominantly characterized by collaborations between the US, China, Australia, and various European nations, creating an intricate network. The visual representation, with its colors and lines, indicates that the US publishes the most research and engages in the most extensive and diverse partnerships. Collectively, the US and China emerge as leading forces in tree physiology research, fostering robust international collaborations.

Country Collaboration Map



Figure 10. Country collaboration map.

6. Main Research Directions of Drought-Induced Tree Mortality

6.1. Emerging Research Areas in Drought-Induced Tree Mortality Mechanisms

Figure 11 illustrates the evolution of studies on drought-induced tree mortality mechanisms over time by classifying the time since the occurrence of these studies into four sequential sub-phases based on the number of publications: 2002–2007, 2008–2013, 2014–2019, and 2020–2023. The strategy map clearly identifies the study's crucial research subjects by dividing all topics into four quadrants based on centrality and density. The cohesion within a cluster is reflected by its density, while the interactions between clusters are quantified by their centrality. Motor themes are displayed in the first quadrant (top right), demonstrating how well-developed and significant the subject is already, in addition to its strong specialization. Niche themes are shown in the second quadrant (top left), which suggests that although the topic is well-developed, it has not attracted many scholars and is not significant in the area right now. Emerging or declining topics are represented by the third quadrant (bottom left), which highlights emerging topics with less development. Basic themes are represented by the fourth quadrant (bottom right), which shows that although research on the mechanisms underlying drought-induced tree mortality is essential, it is still in its infancy. The most common keyword is used to identify the theme represented by each circle. The area of the circle grows with frequency, and the size of the circle is determined by how frequently the keyword appears. The themes of “climate-change”, “drought”, and “mortality” have appeared three times in each of the four sub-phases of the study of drought-induced tree mortality mechanisms since they first appeared in the first phase. The area of the circle has always been large, indicating that the themes of “climate-change”, “drought”, and “mortality” have grown in importance.



Figure 11. Strategic diagram of tree drought death mechanism-related publications (2002–2023).

The inaugural phase from 2002 to 2007 witnessed the rise of the topic “tree mortality”, accompanied by the nuanced development of concepts such as “growth”, “drought”, and “seedlings”. This trend foreshadowed a future where “tree mortality” and “climate change” would become instrumental in directing the course of research and development. During the second phase, the themes of “climate change”, “drought”, and “mortality” remained at the forefront, with a growing focus on the reduction in tree mortality as a key future direction. In the third phase, the intricate mechanisms of “climate change” and “drought” continued to be refined, and new areas of interest such as “trees”, “rainforests”, and “tree density” began to gain recognition as emerging themes. However, the period spanning 2020 to 2023 did not introduce any groundbreaking or dominant themes; instead, the emphasis remained on deepening the understanding of “tree mortality”, “vulnerability”, and “xylem”. These areas of study continue to be pivotal, serving as essential topics and significant pathways for ongoing research and exploration.

6.2. Thematic Evolution in Publications Related to Drought-Induced Tree Mortality Mechanisms

We present an overview of the development of issues in publications pertaining to mechanisms of drought-induced tree mortality in Figure 12. From the first to the second phase, themes like “tree”, “drought”, “vulnerability”, and “photosynthesis” came together and were deduced as “mechanisms”. Themes such as “stomatal conductance”, “tree mortality”, and “embolism repair” coalesced from the first phase to the second phase, which was developed as “climate-change”. In the subsequent phase, a strategic reorganization and refinement of the original topics took place, leading to the emergence of novel thematic areas. For example, the concept of “balance”, introduced initially in the second stage, is derived from the theme of “wood density” that was prominent in the third stage. This, in turn, traces its origins back to the discussions surrounding “mortality” that were central to the fourth stage. In conclusion, the topic evolution makes it clear that the core concepts that formed the basis of the research themes were “mortality” and the particular subset of “tree mortality.”

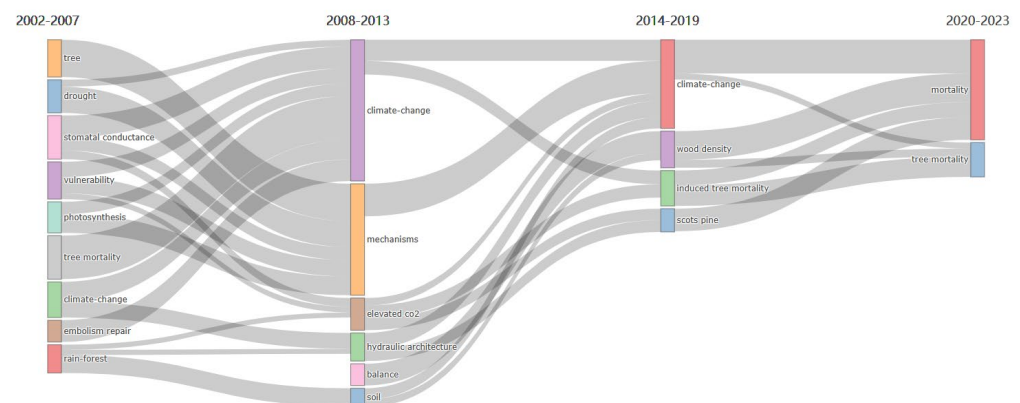


Figure 12. Thematic evolution of tree drought death mechanism-related publications (2002–2023).

7. Discussion

We have carefully outlined the theoretical frameworks and emerging developments in the field of research on the mechanisms underlying drought-induced tree mortality in this paper. We have identified the key themes that have been emphasized and predicted the likely paths that future research in this area will take according to our study.

The scholarly works authored by McDowell NG and Allen CD are especially impactful within the realm of research on tree drought-induced mortality mechanisms and are worthy of the focused consideration by researchers actively involved in similar areas of study. The peak in citation counts observed in 2006 and 2008 can be ascribed to the sustained discourse on the carbon starvation hypothesis, which emerged in the aftermath of McDowell et al.’s comprehensive examination of both the hydraulic failure and carbon

starvation theories [43]. Due to the absence of direct evidence supporting carbon starvation at the time, the theory was a subject of contention, a debate that persists to some extent today [8,44,45]. Nonetheless, since 2008, an abundance of research in this field has progressively substantiated the notion that carbon starvation is a viable cause of tree mortality, with the work of Sevanto et al. being particularly noteworthy in this regard [46]. There is obviously a strong scholarly interest in the study of drought-induced increases in tree mortality, as evidenced by the large body of published research and the significant citation frequency. Amidst the advancements in science and technology and the evolving landscape of our era, a growing cadre of scientists has turned their focus towards investigating the mechanisms behind tree mortality caused by drought. This trend is reflected in the consistent annual increase in academic publications on the subject since 2002, with an especially marked acceleration in the rate of new publications following the year 2013. This might be related to the fact that in 2013, a number of climate extremes, such as heat waves and droughts, seriously harmed the world's agricultural productivity [20,47–49]. The IPCC finalized the Synthesis Report for the Sixth Assessment at its 58th Session, which was held in Switzerland from 13 to 19 March 2023. The report draws attention to a sobering fact: future droughts will become more common as the world's temperature rises [50]. We have reason to think that the number of research publications published on drought and climate change will continue to exhibit a large increase in the next years, based on the analysis and projections of this authoritative report.

The research capabilities and strategic focus of an academic institution can significantly shape the influence and level of interest in the research topics it addresses. When it comes to the quantity of publications and level of collaboration amongst the institutions that the relevant research is affiliated with, the Chinese Academy of Sciences (CAS) holds a prominent place. The CAS is regarded as China's leading natural science institution, serving as both the country's most important advisory body for science and technology and a hub for natural science and innovative technology research and development. With its programs in physics, chemistry, materials science, mathematics, environmental and ecological studies, and earth sciences ranking among the most advanced in the world, the CAS has painstakingly built a comprehensive framework of natural science disciplines. Furthermore, the CAS is well positioned to ascend to the pinnacle of worldwide scientific brilliance in a few specific study fields and directions. This research institution introduced several key aspects of drought resistance in trees as early as 1983, including morphological and anatomical responses and adaptations primarily involving changes in leaves and roots, physiological responses, and adaptations mainly concerning osmotic regulation, proline accumulation, stomatal reactions, and hormonal use.

Our analysis of publication volume and international collaboration networks reveals the US as a leading force in drought-induced tree mortality research, a status likely attributed to its robust research community. With 423 articles, or 29.13% of the total, having American corresponding authors, the US also claims five of the top ten most productive research organizations globally in this field. It appears that domestic study in this field has been sparked by the protracted drought in some parts of the United States, which has caused widespread die-offs of forests. Many academics have predicted that the number of trees in the western and southern United States will significantly decrease this century, and that the stress caused by forest drought will probably be greater than that of the worst drought in the previous millennium [51–53].

While drought is a significant factor contributing to the reduction in forested regions, it is essential to recognize that a multitude of additional elements are responsible for the observed decrease in forest cover. These include, but are not limited to, the synergistic effects of pest infestations and diseases, the increasing prevalence and severity of wildfires, and the overarching influence of climate change [54–56]. Additionally, it has been forecasted that future forests would progressively give way to shorter, drought-tolerant plants that are better suited to these conditions as climate change and drought severity increase [57]. In response to this pressing ecological challenge, the development of globalization has

facilitated a shift towards international collaboration in scientific research. As a result, an increasing number of studies are being conducted through mutual cooperation between different countries and institutions. This collaborative approach has not only fostered a more comprehensive understanding of the issue but has also led to research outcomes with higher impact and scientific value [58].

Keywords serve as concise encapsulations of scholarly research, highlighting the principal themes and subjects while also reflecting shifts in research focal points [59]. Their evolution is both expansive and inheritable, given that subsequent studies often build upon the foundation laid by previous work [60]. The citation burst detection of keywords and its thematic development point to a wide range of research topics related to drought-induced tree mortality mechanisms, such as “wood density”, “climate change”, “stomatal conductance”, “hydraulic structure”, and “Scots pine”. The word “die off” was the most prominent with a burst intensity of 14.09, spanning seven years from 2011 to 2017. This dominance highlights how important it was in determining the research agenda at the time, reflecting the academic community’s priorities. Early study subjects that emphasized understanding the mechanisms behind tree drought mortality included “stomatal conductance”, “vulnerability”, “photosynthesis”, and “embolism healing”. Keywords like “drought”, “climate change”, “mechanisms”, and “tree mortality” are indicative of the scientific community’s continuous and changing interest, probably due to drought conditions’ increasing severity over time. Our analysis of the keyword “hydraulic architecture” and associated articles during phase III has uncovered that extensive research has progressively clarified the part water metabolism plays in tree drought mortality [8,61–63]. However, the function of carbon starvation processes remains to be further explored [45]. It is our projection that future studies will place a heightened emphasis on examining the carbon metabolism.

8. Conclusions

By conducting a metrics analysis of the relevant literature, this study condenses the research dynamics, key contributors, developments, and focal points within the field of drought-induced tree mortality processes. The purpose of this is to function as a guide for future studies in this field. First of all, there is a steady upward trend in the annual publishing output in this field, and it is anticipated that this increase will continue in the years to come. The investigation into the mechanisms of drought-induced tree mortality commenced on an international scale approximately two decades ago, with the United States, China, and Spain emerging as the leading nations in terms of the volume of scholarly articles published on this subject. Considering publications, citations, and collaborative networks, the United States holds a dominant position in scientific research, with China demonstrating robust growth and following closely behind. Additionally, journals like *Tree Physiology* and *New Phytologist* have become prestigious academic platforms that offer insightful analyses of the field of botanical research. Prominent among the scholars contributing to this field is McDowell Ng, whose extensive and impactful work is reflected in an impressive H-index of 41. Meanwhile, a key role in the ecosystem of academic collaborations is played by the Chinese Academy of Sciences (CAS), which is recognized as the premier organization due to its extensive and regular joint operations. A significant hub for knowledge sharing and intellectual collaboration, the CAS has developed a robust network of academic relationships and exchanges with a broad spectrum of research organizations. These authors and organizations are the most academically prominent research forces in this field, and their research outcomes and latest advancements warrant the close observation of fellow academics. Analyzing the collaboration network in this area reveals an interesting pattern: the relationships between authors, journals, research centers, and geographic areas have become more complex over time. This intricate web of cooperation highlights how dynamic and team-oriented scientific advancement is. In conclusion, it is clear from a thorough examination of keyword citation frequencies, burst detection analysis, and theme evolution that the mechanisms causing drought-induced tree mortality are currently hotly debated topics. It is increasingly anticipated that the

mechanisms underpinning tree adaptation to arid settings will emerge as the primary study trend in this academic discipline, signaling a substantial area of concentration for future research endeavors.

Supplementary Materials: The following supporting information can be downloaded at <https://www.mdpi.com/article/10.3390/f15061037/s1>, Figure S1: Normalized analysis of the number of publications (a) and citations (b) metrics for the top 10 countries; Table S1: Tree species particularly vulnerable to extreme drought conditions [42,64–85].

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