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REVIEW

A Systematic Review of Climate Change and Forest Disease Impacts on Sustainable Forest Ecosystems

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ABSTRACT

Forests all over the world have been dramatically impacted by climate change, which has contributed to an increase in the number of pathogen invasions and the rise in the prevalence of forest diseases. This article presents a systematic review that investigates the intricate relationship between climate change and the prevalence of forest diseases. The study identifies climate-related factors that drive the rising incidence of these forest diseases. Following the PRISMA guidelines, 73 studies were selected and analyzed from a pool of 3,510 articles, focusing on their spatial and temporal patterns, contextual drivers, and linkages to climate change. The findings underscore the critical role of extended drought periods and rising temperatures as key factors exacerbating forest disease outbreaks. Methodologically, only 3% of the studies utilized field sampling, indicating a predominance of laboratory analysis methods at 45%. Geographically, temperate forests accounted for 78% of the studies, forest plantations 20%, and boreal forests 2%. This review highlights the pressing need for sustainable forest management practices to counteract the adverse impacts of climate change on forest ecosystems. By identifying critical

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climate drivers and ecological vulnerabilities, this research provides a foundation for adaptive silviculture and pathogen management strategies.

Keywords: Forest Health; Governance; Climate Change; Forest Disease Variability; Sustainable Forest; Forest Degradation; Systematic Literature Review

1. Introduction

Climate change presents profound challenges to ecosystems globally, influencing ecological processes and altering species interactions. Anthropogenic climate change observed in the early 21st century is intricately linked to the health and functionality of the biosphere [1]. For instance, shifting precipitation patterns, disturbances, variations in soil moisture, outbreaks of pests and diseases, and the spread of invasive species are among the factors anticipated to exacerbate forest vulnerability in various regions [2]. These changes may also enable invasive species to expand their territories or adapt their biology and behavior, thereby posing unexpected risks to ecosystems [3].

The compounding effects of anthropogenic pressures and increasing climatic extremes create unprecedented threats to ecosystems, intensifying existing vulnerabilities [4]. According to the Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC AR6, 2023), future climate risks are projected to be significantly more severe, multifaceted, and challenging to manage. Even with moderate warming of 1.5 °C, these risks encompass threats to health, livelihoods, food security, and water resources, underscoring the urgency of action (IPCC AR6, 2023) [5]. In light of these pressing concerns, stakeholders must implement urgent measures to mitigate adverse effects and safeguard forest ecosystems. This requires an integrated approach encompassing research, risk analysis, and policy incorporation to address the uncertainties associated with climate change impacts on forests [6].

Forests play an essential role in supporting global biodiversity, carbon sequestration, and the provision of ecosystem services, with tropical rainforests being particularly significant [7]. They deliver a wide range of critical benefits, including timber production, habitat provision, pollination, seed dispersal, resistance to windstorms, fire regulation, pest management, carbon sequestration, and cultural benefits. Forests are critical for biodiversity conservation and carbon sequestration [8]. Yet, their vulnerability to climate-driven diseases threatens these ecological functions globally. Recognizing these vital contributions, international frameworks such as the Paris Climate Agreement, the Aichi Biodiversity Targets, and the Post-2020 Global Biodiversity Framework emphasize the necessary role of forests in combating climate change and fostering biodiversity conservation [9,10]. Beyond material services, forests also offer non-material benefits, such as recreational opportunities and biodiversity preservation [11]. Therefore, protecting and restoring intact forests are central to addressing the biodiversity crisis, mitigating climate change, and achieving sustainability goals [12].

Forests are among the ecosystems most affected by climate change, experiencing both positive and negative impacts [13,14]. However, the increase in forest diseases, driven by rising temperatures and altered climatic conditions, poses significant risks to forest health and stability [15]. For example, a 35-year analysis of satellite data (1982–2016) revealed a global forest cover loss of 1.16 million km² (−3.1%), driven predominantly by agricultural expansion in Asia. Of this, 60% was attributed to human activity, while climate change accounted for 40% [16]. To understand this dynamics, process-based models have proven valuable in quantifying the impacts of climate variability, atmospheric CO_2 levels, and forest management practices on ecosystem growth [17].

Mature forest systems are not immune to disease risks linked to changing climate conditions. For instance, studies in Korea have shown that rising temperatures and humidity exacerbate the spread of pine wilt disease, with projections suggesting widespread outbreaks by 2090 [18]. Similarly, climate modeling in China predicts more favorable conditions for the pinewood nematode, *Bursaphelenchus xylophilus*, under future climate scenarios [19]. Meanwhile, in Indonesia, *Acacia mangium* plantations face increased susceptibility to climate-induced diseases, prompting a shift to eucalyptus species for improved resilience. Such large-scale declines in forest productivity threaten the socioeconomic well-being of communities reliant on forests for their livelihoods [20].

Despite these findings, there remains a lack of comprehensive reviews examining the intricate relationships between climate change and forest diseases. While current studies provide valuable insights, they often fail to integrate data, identify overarching trends, or pinpoint the primary drivers of forest disease dynamics under changing climatic conditions. This systematic review aims to address these gaps by exploring temporal trends in disease incidence and severity across varying climate scenarios, identifying periods or seasons of heightened vulnerability, and discussing data and methodological limitations.

The main aim is to enhance understanding of climate change's impacts on forest diseases and propose effective mitigation strategies. Specifically, this paper will (1) synthesize the existing body of literature on climate change and forest diseases, categorizing research themes, and (2) identify knowledge gaps and future research priorities to support sustainable forest management. The insights gained from this review will be invaluable for forest managers, policymakers, and researchers in their efforts to mitigate climate-related risks and safeguard forest ecosystems.

2. Research Methodology

2.1. PRISMA Statement

The systematic review study adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses 2020 (PRISMA 2020) guidelines (Page et al., 2021). PRISMA 2020 represents an updated framework that builds upon the original PRISMA 2009 statement developed by Moher et al. (2009). This guideline is structured into seven main categories comprising 27 distinct items, some of which include supplementary components. PRISMA was selected for its robust framework, which facilitates transparent and systematic reporting of review findings. The updated version incorporates contemporary advancements in methods for study identification, selection, and appraisal [21,22]. Additionally, PRISMA's adaptability allows it to be effectively applied in mixed-method systematic reviews and biodiversity conservation research [23–25]. For example, Abas [26] utilized the PRISMA framework in a review of biomonitoring methods to evaluate forest health.

2.2. Formulation of the Research Question

The formulation of research questions in this study employed the PICo mnemonic. PICo is a structured, evidence-based approach designed to frame questions effectively, aiding in the identification of knowledge gaps. According to Nishikawa-Pacher [27], PICo serves as a universal framework applicable across disciplines, extending beyond clinical research or specific study designs to academic writing and teaching. The PICo framework is built upon three core components: population or problem (P), interest (I), and context (Co).

In this study, these elements are represented by forest diseases (problem), the relationship between climate change and forest diseases (interest), and changing climatic conditions (context). Based on this framework, the study aims to address the following research questions:

1. Which extreme climatic conditions are the primary contributors to forest diseases?
2. What contextual factors are highlighted in related studies?
3. What themes can be identified to develop effective forest management strategies for mitigating the impact of climate change on forest health?

2.3. Systematic Searching Strategies

The systematic searching strategies consist of three main steps: identification, screening, and eligibility (**Figure 1**).

2.3.1. Identification

The identification phase involves determining keywords to construct effective search strings. These keywords are derived from the research questions and encompass their synonyms, related terms, and alternative variations. For this study, the keywords 'climate change' and 'forest disease' were selected. Boolean operators were employed in the search strings to ensure comprehensive retrieval of pertinent information from relevant articles. The search terms utilized included both titles and keywords, as outlined in **Table 1**. Articles were sourced from the Web of Science (WoS) and Scopus databases. To ensure temporal relevance to contemporary climate trends, the search was conducted exclusively on December 31, 2024. This process yielded 3,510 articles deemed relevant to the research questions.

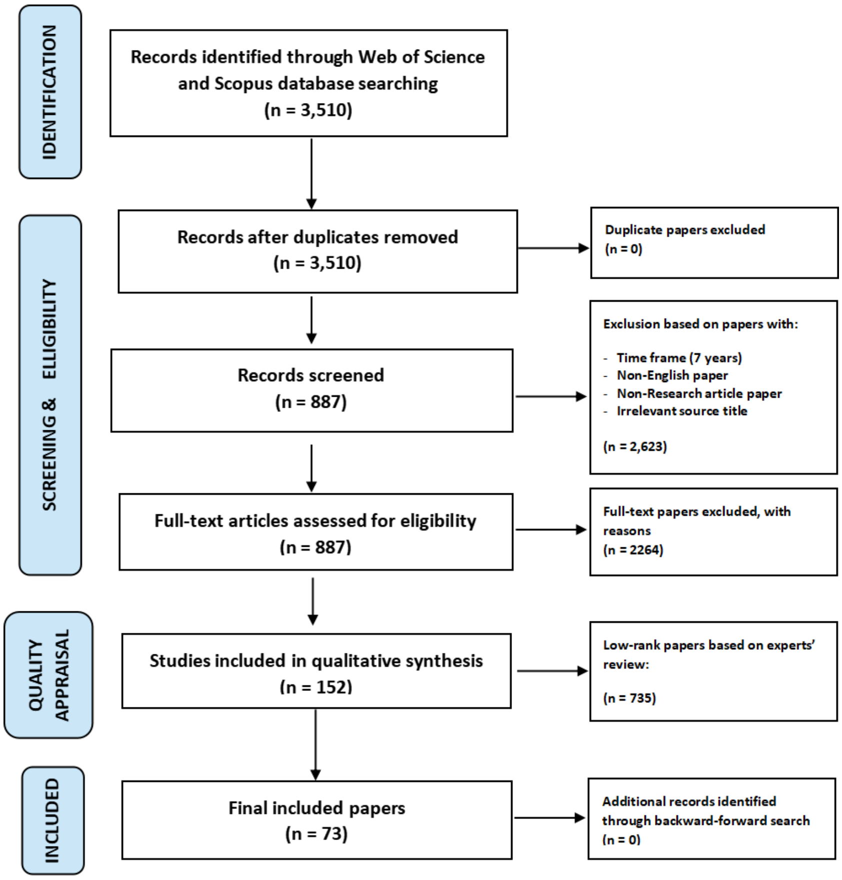

Figure 1. Flow diagram.

Table 1. The search strings.

Database	Search Strings
Web of Science	TS=(((climat* chang*) OR (climat* risk*)) AND ((forest*) AND (diseas*) OR (forest* diseas*) OR (plant* diseas*)) AND ((inter-connection*) OR (relat*)))
Scopus	TITLE-ABS-KEY ((climat* chang*) OR (climat* risk*)) AND ((forest*) AND (diseas*) OR (forest* diseas*) OR (plant* diseas*)) AND ((inter-connection*) OR (relat*))

2.3.2. Screening and Eligibility

The remaining 3,510 papers were rescreened to affirm the requirements set by the authors (**Table 2**). Only articles published in the past 7 years were selected. A total of 1,440 papers published between 1967 until 2017 were removed. Only publications that have empirical data and are in the format of an article in the journal were accepted. Hence, 513 papers were removed due to this criterion. To prevent misinterpretation of the contents, only publications in English were selected. This exclusion procedure eliminated 30 articles. The remaining 1,527 screened articles were brought to the next procedure, which is eligibility.

Table 2. Screening criteria used.

Screening Criterion	Details
Time frame	7 years
Publication type	Articles
Language type	English
Focus findings	Relevant subject area Relevant Source title

In the eligibility procedure, authors personally make an observation on the remaining articles to make sure all of the remaining articles meet the requirements. The articles with irrelevant subject areas were removed. Only articles in the subject area of environmental science, agriculture, biological science, crop science, and forestry were selected. This step removed 640 articles. The author then read the titles of 887 articles to screen out irrelevant titles. A total of 735 were excluded because the study was focusing on irrelevant topics outside of the focus study, leaving 152 articles for the quality appraisal process.

2.4. Quality Appraisal

The remaining articles from the previous step were reviewed and appraised by two experts in the field of forest pathology and climate change. Using the method established by Petticrew and Roberts [28], the remaining articles were reviewed and grouped into three categories: good, moderate, and low. The criteria for expert selection included academic qualifications, publication records in forest pathology and climate change, and peer recognition within these fields. Only the article that was classified as good or moderate was selected for the systematic review analysis. The expert reached a consensus that 61 articles were rated as good, 16 articles as moderate, and 79 as bad. A total of 73 articles were finally selected to be analyzed for this review.

2.5. Data Abstraction and Analysis

Data abstraction and analysis were conducted by utilising Braun and Clarke's [29] six-phase guide to performing thematic analysis. Thematic analysis is a technique that is generally used for finding, interpreting, and reporting patterns (themes) within data. The raw data set is briefly organised and richly described. Following a detailed analysis, four common topics were identified in all our studied articles: 1) prolonged drought; 2) warm temperature; 3) Pathogen distribution; and resistance 4) viable conditions for the pest.

3. Results and Discussions

3.1. Spatial and Temporal Distribution of the Selected Articles

A total of 73 articles were meticulously analyzed for this review. As illustrated in **Figure 2A**, the temporal distribution of articles exhibits fluctuations, with two peaks observed in 2019 and 2024. The highest number of publications occurred in 2024, with sixteen articles, followed closely by 2019 with fifteen articles. This increase in 2024 suggests a renewed research interest in the subject, possibly due to emerging scientific advancements or policy-driven research initiatives related to climate change [30]. This temporal variation also reflects shifting research priorities influenced by global events during that period. For example, the peaks in 2019 might correlate with heightened research activities during the COVID-19 pandemic, as reported by Añazco et al. [31] and Aviv-Reuven and Rosenfeld [32]. From 2020 to 2023, the number of publications remained relatively stable, fluctuating between nine and eleven articles annually. This fluctuating trend post-2019 could be attributed to factors such as the conclusion of specific research initiatives, limited funding, or changing scientific priorities as the pandemic subsided globally. However, the sharp increase in 2024 indicates a resurgence of interest, potentially driven by global environmental concerns or new technological capabilities in forest disease research [33].

Figure 2B highlights the geographic distribution of the analyzed articles, with significant variation observed across countries. The United States leads with 16 articles, comprising the largest share of publications. This dominance is likely due to the presence of a robust and well-established research ecosystem in the United States. Notably, four of the top 12 global research institutions in forestry, based on output from 2010 to 2020, are located in the United States [34]. Spain follows with seven articles, while Australia and Italy contribute six and five articles, respectively. Poland ranks next with four publications, whereas Canada, Finland, and Germany each produced three. The remaining countries, including China, Portugal, and South Korea, contributed between one and two articles. This distribution reflects the global interest in forest disease research, with a noticeable concentration of studies in North America and Europe. **Figure 2C** illustrates the distribution of articles by continent, revealing that Europe and North America collectively accounted for 45 publications. These continents host several G9 countries, characterized by significant governmental research funding, which enhances their capacity for scientific output compared to other regions [35].

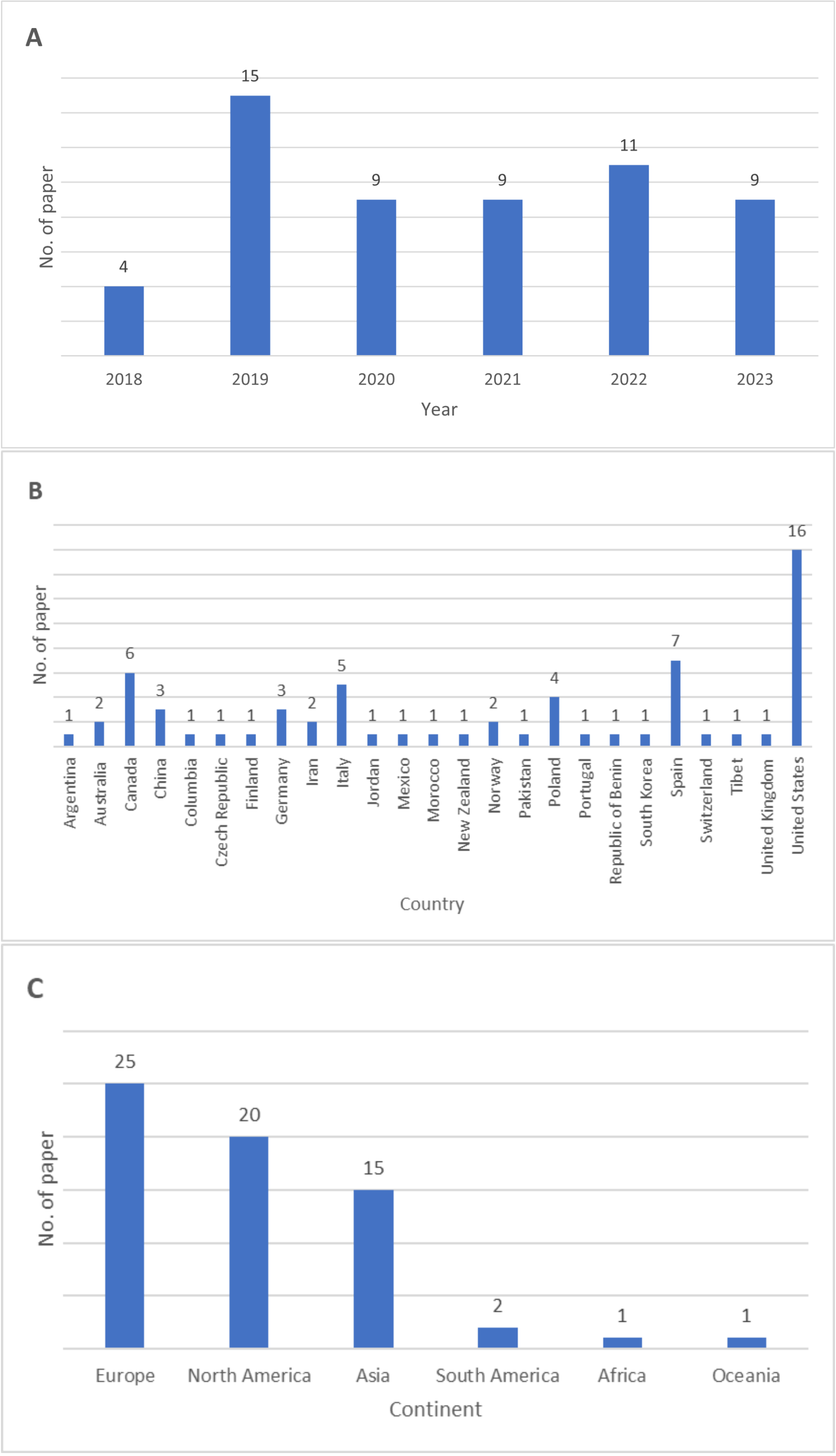

Figure 2. (**A**) Temporal distribution of selected articles (n = 73); (**B**) Country distribution of selected articles (n = 65); (**C**) Continent distribution of selected articles (n = 64).

3.2. Contextual Issues

This study identified four key contextual issues: (1) methodologies employed in the selected studies; (2) forest types; (3) pathogen types; and (4) climatic factors influencing forest diseases. A detailed analysis of research methodologies revealed a wide array of approaches, reflecting efforts to address the multifaceted nature of climate-driven forest diseases. According to **Figure 3A**, 45% of the articles employed mixed methods, which integrated statistical modeling, field sampling, molecular analyses, experimentation, and spatial analysis using GIS. The growing preference for mixed-method approaches stems from their ability to synthesize diverse data sources, such as oral histories, field-based observations, and aerial imagery. This comprehensive approach enables a deeper understanding of landscape changes and eco-cultural responses to environmental disturbances [36]. Statistical modeling was the second most common approach, comprising 30% of the studies, emphasizing the role of quantitative techniques in analyzing disease occurrence and its relationship with climatic variables. Experimentation accounted for 12% of the articles, while literature analysis and spatial analysis using GIS represented 6% and 4%, respectively. Field sampling was the least utilized method, appearing in only 3% of the studies. The variation in methodological choices reflects the interdisciplinary nature of forest disease research, with a strong emphasis on integrative and data-driven approaches.

The analysis of pathogen types showed a pronounced dominance of fungi, which accounted for 82% of the pathogens linked to forest diseases [**Figure 3B** and **Table 3**]. This finding underscores the critical role of fungal pathogens in the ecological dynamics of climate-related forest diseases. Their remarkable capacity for horizontal gene transfer enables the emergence of novel traits and hypervirulent strains, further exacerbating disease spread [37–39]. Additionally, bacteria (7%), nematodes (9%), and viruses (2%) also contributed to the overall disease landscape, although to a lesser extent.

In terms of forest types [**Figure 3C**], the analysis revealed a dominant focus on temperate forests, which comprised 78% of the research sites. This trend likely reflects the prevalence of temperate forests in regions with well-established research infrastructure and visible environmental challenges, making them attractive subjects for scientific inquiry. Forest plantations accounted for 20% of the studies, underscoring the importance of understanding disease dynamics in monoculture systems, while boreal forests were underrepresented, comprising only 2% of the study sites. This disparity highlights the need for greater research emphasis on less-studied forest ecosystems.

Climatic factors were consistently emphasized across the selected due to their significant and lasting impacts on forest health, particularly their role in increasing susceptibility to pests and diseases. Understanding these variables is crucial for assessing ecosystem vulnerability and developing strategies to mitigate their effects. As illustrated in **Figure 3D**, prolonged droughts and rising temperatures were the most frequently studied climatic variables, with 26 and 19 articles addressing these factors, respectively. These findings highlight the pivotal role of drought and temperature increases in shaping forest disease dynamics, emphasizing the need for targeted research and management approaches to address these challenges under current climatic shifts.

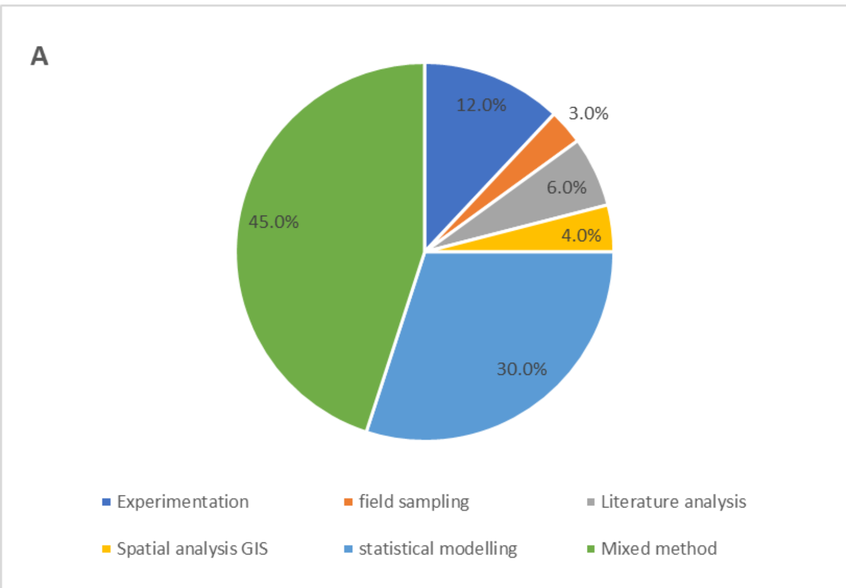

Figure 3. *Cont.*

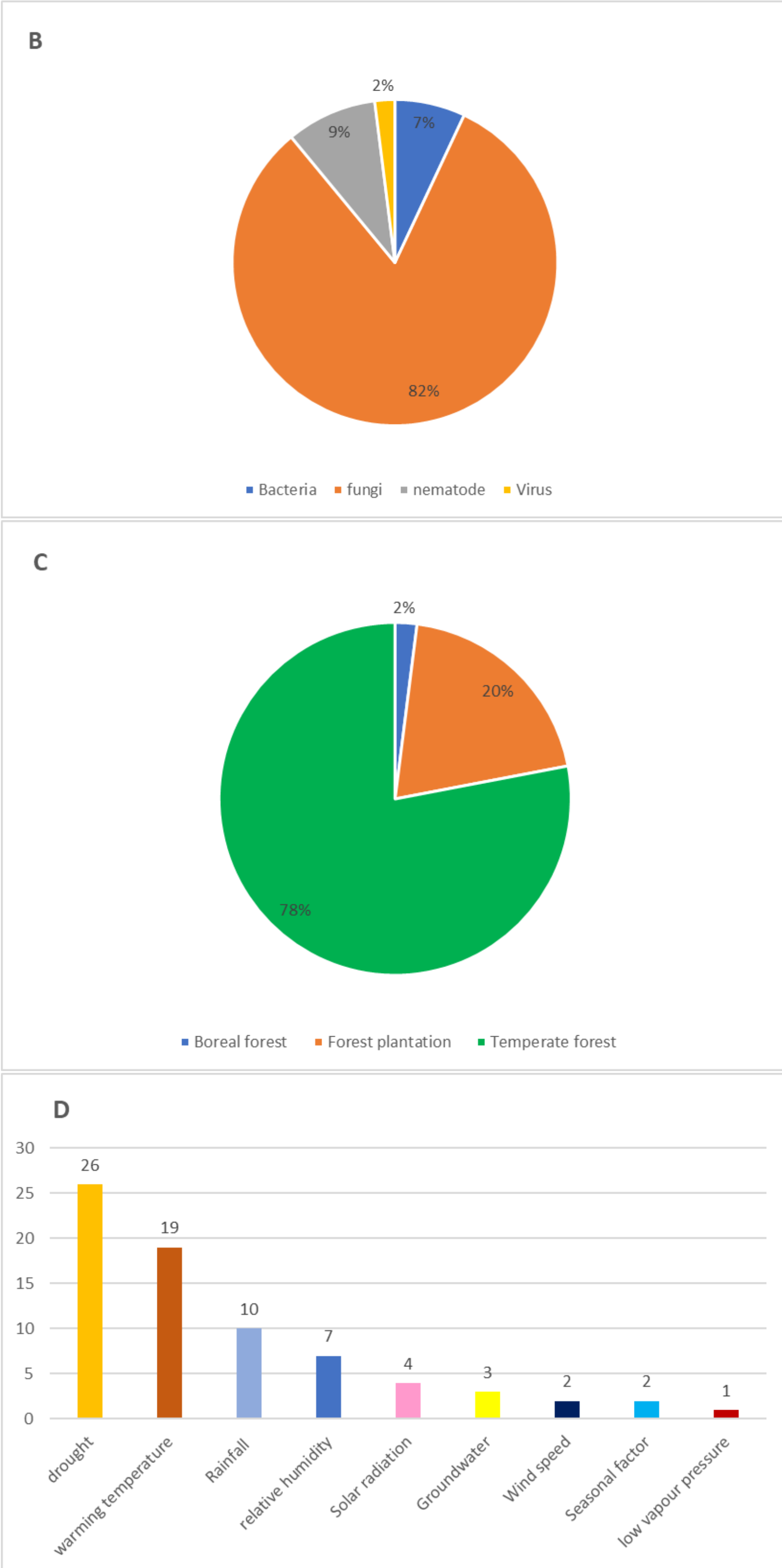

Figure 3. (**A**) Methods used from the selected articles; (**B**) Type of forest; (**C**) Type of pathogen; (**D**) Type of climatic factors affecting forest disease.

Table 3. Summary of forest types and characteristic diseases.

Forest Type	Diseases
Temperate Forests	Needle cast, root rot
Tropical Rainforests	Fungal wilt, canker diseases
Boreal Forests	rust diseases
Plantation Forests	Pine wilt, leaf spot

3.3. Thematic Analysis – Relationship Between Climate Change and Forest Diseases

3.3.1. Prolonged Drought

Forest drought refers to a condition in which trees experience periods of significantly reduced rainfall, leading to accelerated soil drying, water shortages, stress, and eventual damage to the trees. This natural phenomenon has intensified over recent decades [40,41]. The effects of drought on forests are influenced not only by water availability but also by factors such as latitude, soil moisture, slope gradient, and increased pest infestations [42].

Prolonged droughts have been linked to widespread forest dieback, particularly in temperate regions [43–46]. A similar pattern of dieback has been observed in Canada's arboreal forests (Chen et al., 2018). Notably, the Atlas cedar (*Cedrus atlantica* (Endl.) Manetti ex Carrière) in Morocco's xeric Middle Atlas region has experienced extensive dieback attributed to severe drought conditions [47]. Species-specific population declines, such as those of oak (*Quercus* spp.), cedar (*Cedrus* spp.), European beech (*Fagus sylvatica*), subalpine fir (*Abies lasiocarpa*), and pine (*Pinus* spp.) have also been linked to drought-induced stress [48–50]. With climate change exacerbating the intensity and frequency of droughts, such phenomena are becoming more prevalent, especially in the Northern Hemisphere [51].

Interestingly, the complex ecosystems of mixed-species forests demonstrate greater resilience to drought [52]. Elevation and soil moisture variability also influence resilience, with higher elevations enhancing resistance and greater soil moisture variability reducing it [53]. Tree size is another determinant of resilience; larger trees exhibit higher mortality rates and lower recovery capacities following drought events [54]. Forest recovery from drought and warming disturbances requires increased seed production and successful recruitment [55].

Correlation analyses between climatic variables and tree growth consistently demonstrate that drought stress significantly contributes to growth declines and triggers dieback events. To mitigate the escalating impacts of drought stress, effective monitoring and adaptive strategies are urgently required [42]. Recent advances in genomics have enabled researchers to identify genetic traits linked to long-term drought adaptation, offering valuable insights for developing drought-resistant tree species [56].

As severe drought regimes intensify, they threaten forest sustainability and carbon storage, posing significant risks to terrestrial carbon sinks and efforts to mitigate climate change [57]. Addressing the multifaceted drivers of forest health decline requires immediate attention. Effective forest management practices, including identifying drought-prone landscapes and implementing adaptive strategies, are essential first steps toward enhancing forest resilience and recovery.

3.3.2. Warming Temperatures

Beyond direct water stress, drought creates warming conditions that heighten vulnerability to diseases. For instance, phloem diseases, such as those affecting Spain's Aleppo pine forests, are exacerbated under prolonged drought conditions and increasing temperatures [58]. Pine wilt disease (PWD), caused by the pine wood nematode (*Bursaphelenchus xylophilus*), tends to spread more extensively during summer dry seasons [59]. Studies have shown a strong correlation between increased growth rates of the PWD pathogen and summer temperatures ranging from 28 to 29 °C [60]. Due to its temperature sensitivity, the pathogen is less likely to survive in colder regions [61]. However, global warming has led to increased precipitation across much of the Northern Hemisphere, combined with the migration of pine species into areas overlapping with *B. xylophilus* distribution, potentially leading to broader pathogen dispersal in the future [62]. Additionally, drought-induced stress is often linked to growth declines that synchronize with warming trends. For example, trembling aspen (*Populus tremuloides*) exhibits substantial growth reductions due to severe drought [42].

Research on the synergistic effects of rising temperatures and drought underscores their profound impact on increasing tree mortality, particularly in arid regions facing extreme heat [63]. Warmer and drier conditions have been directly linked to reduced conifer growth and widespread dieback, with the Atlas cedar forests being a prominent example [64]. Predictive models further highlight the adverse effects of hotter droughts, forecasting significant reductions in the radial growth of Atlas cedar [58]. Compounding these challenges, such environmental stressors also promote invasions by non-native pathogens, as observed in regions with rising temperatures [65].

3.3.3. Pathogen Distribution and Resistance

Another critical link between climate change and the rising incidence of fungal-related forest diseases is the facilitation of fungal spore dispersal by drought. Prolonged periods of drought combined with elevated temperatures have heightened the prevalence of fungal pathogens that thrive under these conditions. Although fungal growth and fruiting body formation are typically highest in humid environments, certain pathogens, such as the sooty bark disease agent *Cryptostroma corticale*, are significantly influenced by drought and seasonal variations. This pathogen produces hydrophobic spores during drought conditions, which have become increasingly common. The hot and dry years of 2018–2019, which created ideal conditions for *C. corticale*, corresponded with a rise in dieback cases in sycamore forests in Germany [44].

The unpredictability of future global temperature increases introduces uncertainties in the relationships between pathogens and their environmental contexts, rendering them less predictable [66]. For instance, Quesada et al. [66] found that isolates of the US pitch canker disease pathogen exhibit enhanced adaptation and resilience to elevated temperatures (25–28 °C). The natural exposure of these isolates to such environments could promote the emergence of more virulent strains, further facilitating the spread of pitch canker disease.

3.3.4. Viable Conditions for Pests and Pathogens

The frequency and severity of droughts are anticipated to increase due to climate change, leading to significant disruptions in plant-insect dynamics that may accelerate tree mortality [67]. Evidence suggests that warmer temperatures during early spring, rather than drought conditions, are the primary drivers of insect outbreaks. This implies that prolonged warming in spring could exacerbate insect infestations, further intensifying growth decline and tree mortality in North America's aspen mixed forests [42]. Drought-induced physiological stress weakens trees, reducing their resilience to pest infestations [67] and further compounding growth declines. Sánchez-Agudo et al. [68] highlighted that *Pinus sylvestris* and *Quercus pyrenaica* growing in regions with lower climatic suitability, such as the Spanish Iberian Peninsula, exhibit higher pest defoliation rates, demonstrating the interactive effects of climate and biotic stressors on forest health.

Moreover, interconnected factors, such as forest domestication and the establishment of plantations with non-native species, have heightened the risk of forest diseases [69]. These forestry practices have been linked to epidemic outbreaks of endemic pathogens, such as Swiss needle cast, a foliar disease of Douglas fir caused by *Nothophaeocryptopus gaeumannii*. Contributing factors to these outbreaks include rising winter and spring temperatures and changes in summer precipitation patterns [70].

4. Recommendations for Future Research

Future research should explore the impacts of additional factors potentially linked to climate change, including human behavioral changes, microbial soil properties, topography, and land use modifications. Notably, tropical forests, critical for global carbon storage and biodiversity, were absent from the reviewed literature, leaving climate-disease interactions in these ecosystems (e.g., humidity-driven fungal proliferation in rainforests) poorly understood. Investigating these multidisciplinary elements is crucial for understanding the complex interplay between climate change and tree forest diseases.

Furthermore, future investigations could assess the effectiveness of various mitigation strategies in preventing or minimizing disease outbreaks, particularly in understudied tropical regions where climate-driven pathogen spread may disproportionately threaten biodiversity hotspots. Such research should also consider the genetic diversity of tree species to evaluate their susceptibility to climate-induced diseases and identify potential resistance genes. According to Poelle et al. [56], three physiological mechanisms, such as osmotic adjustment, antioxidative defense, and enhanced water use efficiency, play a critical role in improving tree resilience against drought. Advancements in predictive modeling could be leveraged to forecast the relationships between climate change and forest diseases. By integrating numerical climate parameters and advanced modeling techniques, researchers can gain valuable insights into the potential spread of diseases and their capacity to emerge as global pathogens.

To address existing gaps in the literature, future research should focus on examining the interplay between specific climatic variables and forest disease dynamics. Investigating the mechanisms behind pathogen emergence and understanding pest viability under changing climate conditions will be essential for developing effective mitigation measures. Enhancing forest ecosystem health and stability can contribute to global climate change mitigation efforts and promote sustainable forest management.

5. Conclusion

This systematic review offers crucial insights into the relationship between climate change and forest diseases. Our analysis of 73 papers, with a focus on studies up to 2024, reveals a distinct spatial distribution of research, with the United States, Spain, and Australia being the most frequently studied geographical areas. The findings consistently highlight drought and rising temperatures as dominant drivers of pathogen proliferation and forest tree mortality worldwide, indicating a shift towards a post-disease and pathogen-prone climate for forests. Regarding contextual issues, the review found that 45% of the analyzed articles employed mixed methods. Notably, only 3% of the studies involved field sampling, indicating a reliance on laboratory analyses and modeling approaches in this research area.

The findings of this review provide a foundation for diverse approaches to forest management. By elucidating the impacts of climate change, particularly prolonged droughts and warming temperatures, the review informs adaptive silvicultural practices. Forest managers can utilize this knowledge to adopt standardized operational practices that strengthen the resilience of forest ecosystems and promote sustainable timber production capable of withstanding climate change. Despite the critical role of forests in global carbon sequestration and biodiversity, a significant research gap exists, especially in tropical forests where the planet's drought severity is most pronounced. Research on acidic climate parameters and successful climate-adaptive models is also limited. Therefore, future research should be strongly promoted in these areas.

This review underscores the urgency of integrating climate-adaptive silviculture, pathogen genomics, and landscape-scale monitoring to mitigate forest disease risks under global warming. By emphasizing forest susceptibility to shifting climatic conditions, policymakers can incorporate climate-sensitive decision-making into comprehensive forestry strategies, with a focus on climate risk and mitigation frameworks. This review can serve as a resource for policy development that balances economic interests with the imperative to sustain forest resources for future generations.

In conclusion, this study enhances our understanding of the climate change-forest disease relationship and offers essential insights that support informed decision-making in forest management practices and policy formulation.

Author Contributions

Conceptualization, A.S.M.U., S.D.R.P., and A.A.; methodology, A.S.M.U., S.D.R.P., and A.A.; formal analysis, A.S.M.U.; investigation, A.S.M.U., S.D.R.P., M.F.A., S.A.S., and A.A.; writing—original draft preparation, A.S.M.U.; writing—review and editing, A.S.M.U., S.D.R.P., M.F.A., S.A.S., and A.A.; visualization, A.S.M.U., S.D.R.P., M.F.A., S.A.S., and A.A.; supervision, S.D.R.P. and A.A.; project administration, M.F.A. and A.A.; funding acquisition, M.F.A. and A.A. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement

Not applicable.

Data Availability Statement

Data sharing is not applicable to this article, as there is no new data generated apart from the one listed in the article.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this review paper. During the preparation of this work the author(s) used [ChatGPT 3.5] in order to [improve language, literature management and readability, with caution.]. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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