climate

Review

Effects of Climate Change on Temperate Forests in the Northwest Iberian Peninsula

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Abstract: This review summarizes the intricate relationship between climate change and forest ecosystems in the Northwest Iberian Peninsula, outlining both their resilience and vulnerabilities. The study asserts the significant impact of climate change on these ecosystems, reinforcing earlier theories about their responsive behavior to global climatic alterations. However, the impacts are highly localized, contingent upon specific forest compositions, topography, and interaction with other environmental stressors. The temperate forests of the Northwest Iberian Peninsula manifest a delicate balance of resilience and vulnerability in the face of these phenomena. Notably, the study underscores that this region's forest ecosystems remain a relatively uncharted research territory, promising fruitful prospects for future exploration. Although existing studies offer vital insights into the climate change impacts, there is a stark need for further research to gain a deeper understanding of, and formulate appropriate responses to, the challenges that these specific ecosystems confront in the wake of climate change.

Keywords: climate change; Northwest Iberian Peninsula; resilience and vulnerability; forest ecosystems; environmental stressors

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1. Introduction

The Northwest of the Iberian Peninsula (Figure 1), a region that includes parts of Portugal and Spain, exhibits a range of forest ecosystems, with particular emphasis on temperate forests, which are vital for the conservation of biodiversity and ecosystem services in the region [1]. This landscape is shaped by a unique combination of geographical, climatic, and biological factors that result in a diversity of species and habitats unmatched in any other region of Europe [2]. As stated by Cantoral et al. [3], the Temperate and Mediterranean macrobioclimates converge on the Iberian Peninsula, with the intricate orography, lithological variety, and differential thermal range also offering a heterogeneity of biotopes, partly explaining its high floristic and vegetational biodiversity in the European context. The significance of these ecosystems transcends the geographical boundaries of the peninsula, given their role in mitigating climate change through carbon sequestration and in conserving global-scale biodiversity [4]. The forests of the transnational region also play a crucial role in the local economy, providing timber and other non-timber forest products that support local and regional economies [5]. Additionally, they offer a range of ecosystem services, including the regulation of water quality, prevention of soil erosion, and regulation of the local climate, among others [6]. Despite their immeasurable value, these forests face increasing challenges due to climate change [7]. Forecasts indicate a rise in average temperatures, as well as shifts in precipitation patterns, which could lead to changes in forest ecosystems and the biodiversity they support [8]. Thus, understanding these changes and their implications is of paramount importance for the conservation and sustainable management of these precious ecosystems.

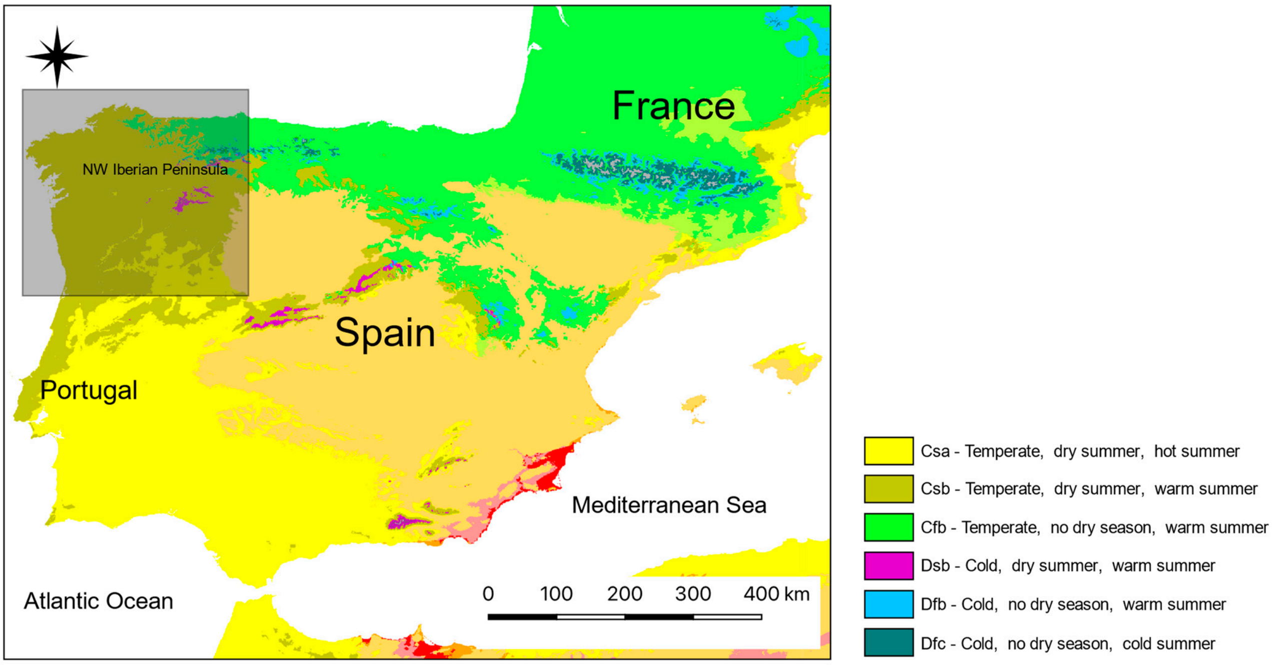

Figure 1. NW Iberian Peninsula location and Köppen–Geiger climate classification map for the present day (1980–2016) (adapted from [9]).

From an ecological perspective, forests represent terrestrial ecosystems with the highest biodiversity, both in terms of species and genotypes [10]. Medáil and Diadema [11] classified the Iberian Peninsula as presenting a high diversity due to its geographical location and varied climate, which have allowed for the emergence and conservation of many endemic species [12]. Economically, the forests of the Iberian Peninsula play a key role, particularly in the timber and cork industries, as well as providing ecosystem services, such as tourism and recreation [13]. These resources are essential to the local economies, especially in rural areas, where the economy is often closely linked to the forest and its resources [14]. From a social perspective, forests provide recreation and relaxation, play a significant cultural role in societies, and are linked to mental and physical health [15,16]. In the Iberian Peninsula, forests are integral to local cultures, traditions, festivities, and folk tales [17]. However, forest ecosystems are facing a period of unprecedented challenges [18]. Global climate changes are rapidly altering the environmental conditions to which forests are adapted, with significant implications for their health and survival [19]. In this context, understanding the response of forest ecosystems to climate changes becomes an important subject of study [20,21]. This need is even more urgent in regions where projections indicate they will face particularly severe climate changes in the coming decades, as are some regions located in the temperate climate zone [22,23]. Figure 2 illustrates the future Köppen–Geiger climate classification for 2071–2100 for the region shown in Figure 1 [9]. This future was derived from an ensemble of 32 climate model projections using the RCP8.5 scenario [9]. Understanding how these forests can respond to such changes will allow for the implementation of more efficient and informed management strategies, protecting these forests and the vital services they provide. It is important to underline that forests are not only passive victims of climate changes, but can also play an active role in mitigating climate changes through carbon sequestration [24]. However, the success of this function will depend on the ability to sustainably maintain and manage forest ecosystems, reinforcing the importance of studying these systems [25].

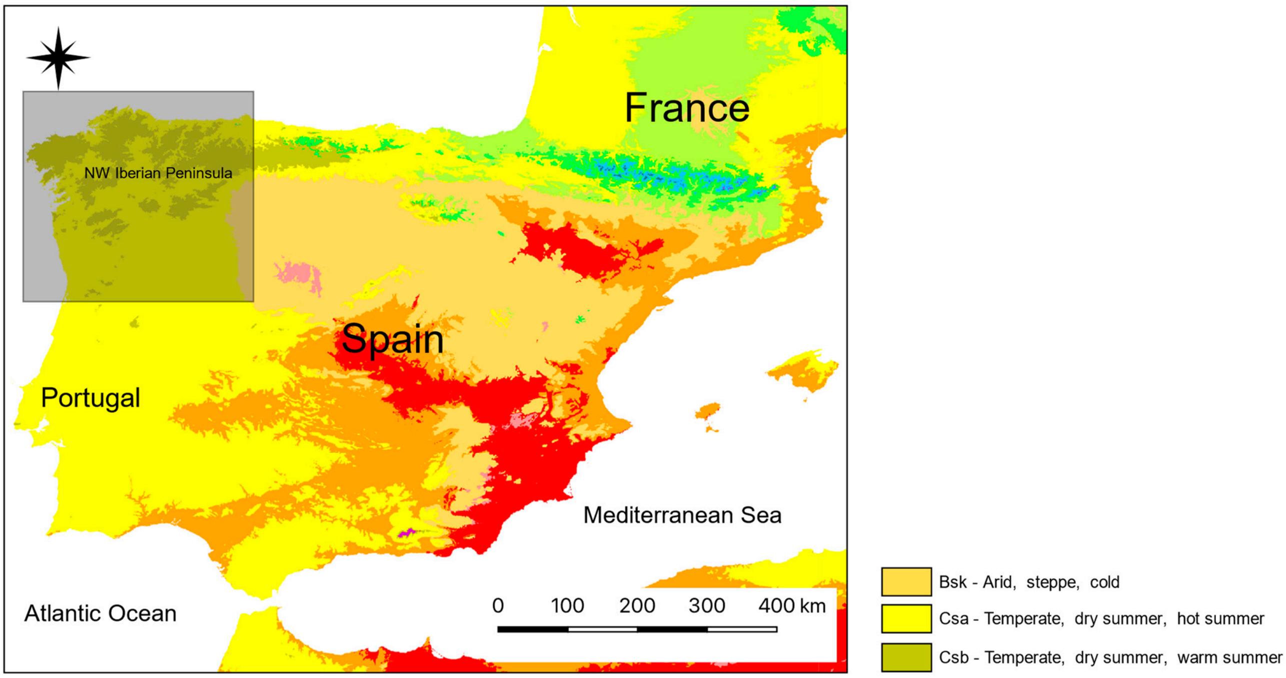

Figure 2. NW Iberian Peninsula location and Köppen–Geiger climate classification map for projected future conditions (2071–2100) under climate change (adapted from [9]).

This study seeks to present a detailed overview of the existing research on the critical issue of climate change's impact on forest ecosystems, particularly in the Northwest Iberian Peninsula. By synthesizing information from various studies, it aims to foster a more comprehensive understanding of the subject matter. The objective is to create a solid theoretical foundation that can guide future research and the creation of effective, sustainable forest management policies in this unique region.

2. Materials and Methods

2.1. Literature Selection

Throughout this literary review on the implications of climate change on the forest ecosystems of the Northwest Iberian Peninsula, a systematic and meticulous procedure was utilized in the selection of the literature. This allowed for a detailed evaluation of studies relevant to the proposed theme, ensuring the inclusion of a variety of perspectives and results that underline the complexity and multifaceted nature of the climate change impact on these ecosystems. The initial research was conducted on reputable and widely used academic databases, specifically, Scopus, Web of Science and Google Scholar, with the aim of capturing as many relevant studies as possible [26]. The search strategy was planned to include a combination of search terms related to the central topic. The terms used were "climate change", "forest ecosystems", "temperate forests", and "Northwest Iberian Peninsula". The terms were used sequentially, used as a reduction criteria, starting from the general and approaching the situation. The initial evaluation resulted in the selection of a considerable set of studies. To ensure the relevance and quality of the selected literature, a two-step screening process was necessary. In the first step, the titles and summaries of the studies were analyzed to verify their relevance to the topic of interest. This step resulted in the exclusion of the studies, around 10% of the total amount analyzed, which, despite mentioning some of the keywords, did not specifically focus on the interaction between climate change and forest ecosystems in the Northwest Iberian Peninsula [27].

2.2. Inclusion and Exclusion Criteria

To ensure the consistency, quality, and relevance of the studies included in this review, we established strict inclusion and exclusion criteria. The study selection process was guided by the use of a set of pre-defined criteria, aiming to ensure the relevance of the studies to the theme under analysis [28]:

1. Inclusion criteria
    - Focus on temperate forests of the Northwest Iberian Peninsula: The study must be based on or include data from temperate forests located in the Northwest Iberian Peninsula. This is crucial to ensure that observations and conclusions are directly applicable to the subject of study [29].
    - Relevance to climate change: The study should explicitly discuss the impacts of climate change on temperate forests. Studies focusing only on the general ecology of forests without a connection to climate change were not included.
    - Availability of complete data: To ensure the integrity of the review, only studies presenting complete data, allowing for adequate quantitative or qualitative analysis, were included [30].
    - Publication in peer-reviewed scientific journals: Given the importance of rigorous evaluations in ensuring the quality of research, only studies published in peer-reviewed scientific journals were considered.
2. Exclusion criteria
    - Studies outside the specified geographical area: Any studies not focusing on temperate forests of the Northwest Iberian Peninsula were excluded, to maintain the geographic specificity of the review.
    - Lack of focus on climate change: While many ecological studies may have tangential relevance to climate change, those not explicitly discussing this topic were excluded.
    - Insufficiency of data: Studies that do not provide sufficient data for analysis, or those whose data are presented in an incomplete or ambiguous manner, were excluded.
    - Studies without peer review: Studies that did not undergo the rigorous peer review process were excluded to ensure the reliability of the analyzed data.

3. Literature Review

3.1. Impact of Climate Change on Temperate Forests

Temperate forests, which encompass around 10 million square kilometers of global terrestrial ecosystems, play a crucial role in preserving biodiversity, participating in the hydrological cycle, and contributing to carbon capture and storage [31,32]. These expansive forest areas are vital in maintaining ecological balance and have significant implications for climate regulation and environmental sustainability. However, the health and resilience of these ecosystems have been compromised by climate change, resulting in noticeable and increasingly severe impacts [33].

The rise in global temperatures is one of the main triggers for changes in temperate forests, as described by Vitousek [34], Saxe et al. [35], or Shaver et al. [36]. Research indicates that a warmer climate can amplify thermal stress and drought events, damaging the survival and distribution of species [37]. Prolonged periods of drought can increase the susceptibility of forests (not exclusively for this type of forest, but also for others) to wildfires, a substantial hazard for biodiversity and for the carbon sequestration capacity of these ecosystems [38]. Changes in precipitation, both in terms of quantity and regularity, also have significant implications. Temperate forests are particularly sensitive to these changes, as they depend on specific levels of humidity for their vital functions [39]. Shifts in precipitation patterns can result in soil water deficits, affecting the growth and reproduction of trees [40]. In parallel, the increase in carbon dioxide (CO_2) concentrations may have a 'fertilization' effect, potentially stimulating plant growth [41]. However, this response is complex and influenced by a multitude of factors, including the availability of nutrients and water, which can be affected by climate change [42]. Temperate forests are also experiencing phenological changes, with alterations in species' seasonal patterns [43]. Changes in the timing and intensity of flowering, as discussed by Morellato et al. [44], can disrupt the interdependent life cycles of plants and their pollinators, damaging both populations. It is important to highlight that the impacts of climate change on temperate forests are not homogeneous [45]. Ecological responses vary considerably, depending on specific site characteristics, including soil type, topography, and specific species composition [46]. The impacts of climate change on temperate forests are a current reality and a future concern [47].

3.2. Specific Studies on the Northwest Iberian Peninsula

The northwest region of the Iberian Peninsula, characterized by a blend of coniferous and deciduous forests, plays a pivotal role in the European ecological balance [48]. However, the impacts of climate change on this ecosystem (not exclusively for this type of ecosystem, but also for other types) are sparsely documented [49–52]. Several studies suggest that the Iberian Peninsula region is facing unprecedented challenges due to climate change [53]. For instance, Pereira et al. [22] emphasize that the region's average annual temperature has increased about 1.2 °C over the last 100 years, more rapidly than the global average. The study by Calheiros et al. [54] reinforces this trend by identifying shifts in precipitation patterns, with extended periods of drought. Thus, many researchers have concentrated their efforts on studying the impacts of these changes on the forest ecosystem. An example can be found in the work conducted by González-González et al. [55], which documented phenological changes in several tree species, with budding and flowering occurring earlier. Changes in the timing and intensity of flowering can disrupt the interdependent life cycles of plants and their pollinators, thus impacting both populations. Another study, by Guada et al. [56], revealed that deciduous species, especially the English oak (*Quercus robur*), show surprising resilience to drought, perhaps due to their ability to store water during periods of abundance for use during droughts. Such resilient species might then be prioritized in future adaptive forest management plans. In terms of biodiversity, Benito Garzón et al. [57] observed a shift in species composition in response to climate change. In this study, the authors observed that thermophilic species, such as the cork oak (*Quercus suber*), are expanding, while species that prefer cooler climates are receding, raising an alarm about the risks of biodiversity loss, especially considering the rich and unique fauna and flora inhabiting the region.

Barrio-Anta et al. [58] also discussed the landscape fragmentation caused by eucalyptus plantations. Their study also noted the wide-ranging suitability and importance of eucalyptus plantations across the region, with a particular relevance in areas like A Coruña and Pontevedra due to the temperate climate conditions that are favorable for eucalyptus species. Interestingly, the economic relevance of eucalyptus in districts with lower suitability and occupancy is surprisingly high due to the high productivity of *Eucalyptus nitens* and the hidden area occupied by the eucalyptus. Another subject discussed in the paper is the landscape fragmentation caused by eucalyptus plantations. The study notes that areas with large continuous eucalyptus plantations should be avoided due to high biotic, abiotic, and financial risks, as well as potential negative impacts on the native species. In fact, in the region of Galicia, the extreme fragmentation of the native broadleaf forest stands as a significant environmental concern, driven primarily by the rapid expansion of eucalyptus within the territory. This invasive proliferation has led to the replacement of patches of native forest, thereby disrupting the natural ecosystem in Galicia. The authors demonstrated that current policies regarding forest management and eucalyptus plantations are woefully insufficient to address this ecological imbalance under both present and future climatic conditions. Interestingly, the economic importance of eucalyptus in districts with lower suitability and occupancy is surprisingly high perhaps because of the noted productivity and frost resistance superiority of Eucalyptus spp. over native species. The study's recommendations are both timely and vital, advocating for the implementation of strict regulations governing the establishment of new eucalyptus plantations, as well as increasing the monitoring of native broadleaf forests to prevent further replacement.

Moreover, it underscores the pressing need for decision makers to exert control over the substitution of previous coniferous plantations, emphasizing the strategic importance of preserving native flora and maintaining ecological integrity within the region.

Another important topic is the resilience of forests to fires. Marey-Perez et al. [59], who analyzed responses from a total of 19 common lands, ranging from 95 to 1800 hectares, with a median of 350 hectares. In the region under study, common lands represent a distinct category of ownership, differing from individual private forest holdings. These common lands are often concentrated in singular or a few plots, governed by public communities ranging from 32 to 800 members. The members exhibit diverse educational and professional backgrounds, most frequently having achieved secondary education. Many are part-time workers in the primary sector. Some communities prioritize economic output, while others seek a balance among economic, environmental, and social considerations. One community places social considerations above all else. However, these stated priorities do not always lead to significantly different management practices. Timber production, mainly of *Pinus pinaster*, is consistent across communities, and most follow conventional techniques supplemented by other forest goods and services, such as game, fuelwood, and chestnuts. Animal husbandry is prevalent, found in nearly a third of communities, while tourism contributes minimally to income. Other significant income sources include quarries, water supply installations, wind farms, and landfills. Most communities handle decision making internally, often with technical advice. Labor is typically local, and hiring practices vary widely, with a trend toward one full-time worker per 150–200 hectares. Compliance with technical management plans is usually high, with general satisfaction in their implementation. Profits vary substantially among communities, and reliance on public subsidies also differs. Success factors include strong leadership and regular economic inputs, and many communities believe their model could be replicated or scaled up. Wildfires are frequent, but have generally impacted less than 1% of the total area per year, with community resilience seen in the face of these fires. Only two communities experienced significant wildfire damage. Measures have been implemented to mitigate fire impact, and changes introduced were usually adaptations rather than overhauls. Common adaptations include reducing stand densities and increasing animal presence or species diversity. However, changes are often motivated by wildfires originating in neighboring properties, indicating a broader challenge at the landscape scale.

The bioenergy production and availability can also be affected by climate change, as demonstrated in the study conducted by Fernández-González et al. [60], which provides insightful results on forest management communities, particularly focusing on those involved in bioenergy production and those not utilizing their resources for energy purposes. The study identified two distinct populations for examination: one consisting of communities engaged in bioenergy production, averaging 140 members, and another with no energy use, averaging 79 members. Research revealed that over 40% of forest management communities do not meet administrative obligations, limiting the sample size for the analysis. A significant finding from the study is the consistent positive economic trend within forest communities involved in bioenergy production from 2011 to 2019. Indicators, such as Return on Assets (ROA), Return on Equity (ROE), debt ratio, and Earnings Before Interest and Taxes (EBIT) margin, have all shown profitability, although year-to-year variations exist. However, the study notes that certain unpredictable variables, like biophysical conditions, soil regeneration speed, species adaptation, biomass characterization, and seeding results, could influence the project's economic success. Organizational alliances among forest owners, local institutions, and biomass production companies have improved the economic performance of the bioenergy project communities. This cooperation led to economies of scale, boosting production and asset returns, except in 2018 due to environmental factors. An analysis of financial data from 2011 to 2020 shows a positive shift for communities involved in bioenergy projects, including more than a fivefold increase in the median operating income. Conversely, communities without energy usage exhibited a declining trend in income. The study also explored a crisis in wood production in Galicia, with eucalyptus wood prices falling by 10% since 2012. Efforts to export wood to Portugal were mostly unsuccessful. Performance indicators from 2011 to 2020 reveal a steady increase for communities involved in bioenergy projects and a decrease for those without energy utilization. The main activities of these communities include timber harvesting, pasture harvesting, and mycological cultivation. Median values for financial indicators show an overall positive change for communities with bioenergy projects and a negative change for those without.

Forest land involved in current and future bioenergy production presents special consideration. Forest land devoted to bioenergy production is a promising economic land management option with many emerging markets. These bioenergy plantations are perceived to be needed to meet regional and national goals to reduce the dependence on fossil fuels. Despite the apparent success of these community-managed forests, continued climate change may challenge the current resilience of both stands and communities. In addition, these community ownerships need to be brought into the broader discussion about the future of the region.

4. Discussion

In this review, clear observations are discerned regarding the ecological status and projected trajectory of forests within the Northwest Iberian Peninsula. The forests in this region, characterized by a rich biodiversity, are pivotal for carbon sequestration, ecosystem services, and the conservation of biodiversity. However, the expansion of monocultures, both of native and non-native species, threatens these forest ecosystems, notwithstanding their economic benefits. The heterogeneity in land ownership and respective management strategies in this region poses further challenges for effective conservation initiatives. Evidently, the effects of climate change have begun to manifest in the region. A recurrent theme in the studies indicates that the forest ecosystems are experiencing considerable stress due to climatic shifts. There have been notable observations in changes, such as precipitation patterns, temperature elevations, and modifications in species phenology. Interestingly, certain species, like the English oak, show surprising resilience to drought, perhaps due to their ability to store water during periods of abundance for use during droughts. Such resilient species might then be prioritized in future adaptive forest management plans. The proliferation of eucalyptus plantations, particularly in areas like Galicia, offers economic opportunities, but simultaneously amplifies environmental challenges, underscoring the pressing need for enhanced regulations and the preservation of native broadleaf forests. Moreover, the academic discourse sheds light on the forests' adaptive capacities towards wildfires and the prospective economic returns from bioenergy production, suggesting potential alternative management strategies.

A part of the emergence of alien species, such as *Acacia* sp., among others, one of the most common findings is related to the alteration in the phenology of tree species, which has been consistently associated with climate change [61]. This phenomenon has been occurring, leading to changes in the timing of the budding, leafing, and leaf fall of various species. The implications of these alterations are significant, as they may affect biodiversity, interspecies competition, and the overall resilience of the ecosystem to disturbances [62]. Several studies, such as those by Ojeda et al. [63], Lorenzo et al. [64], or Noguera et al. [65], have also revealed an increase in the occurrence of extreme drought events. These events have substantial effects on forests, including tree mortality and changes in species composition. Droughts can exacerbate the susceptibility of forests to pests and diseases, leading to increased mortality [66].

Global warming, a key manifestation of climate change, has been conspicuously impacting species distribution worldwide [67]. In the region under analysis, researchers have noted a marked trend of certain tree species shifting their range towards higher altitudes [50,68–72]. Such alterations in their spatial distribution are essentially species' responses to seek optimal growth and survival conditions in the face of escalating temperatures [73]. This relocation phenomenon, however, may provoke a series of ecological consequences [74]. Foremost among these is the potential habitat loss for endemic species [75]. As these species are often adapted to very specific local conditions, changes in their habitats might leave them with no alternative places to thrive [15]. Consequently, this could lead to significant biodiversity loss in these regions, compromising the ecological balance and health of these ecosystems [76]. As the native species migrate, this could open the door for the introduction and establishment of invasive species [77]. These species, often characterized by their adaptability and high reproductive rates, could seize the opportunity to occupy the vacated habitats [78]. Therein, they might outcompete the native species for resources, further exacerbating the stress on the local biodiversity [79]. Thus, the dynamics of climate change unfold as a cascading chain of ecological consequences, underscoring the urgency of focused attention and action in this domain [80].

Recent research suggests that the pervasive effects of climate change are altering the nutrient cycle within temperate forests [81]. Shifting precipitation regimes and temperature fluctuations stand to influence organic matter decomposition and soil mineralization processes, possibly leading to profound implications for both forest productivity and the global carbon cycle [82]. Such alterations could potentially modify the ecosystem's equilibrium, which in turn could affect the ability of forests to sequester carbon and, thus, play their part in combating climate change [83]. These transformations present a formidable challenge to the effective management and conservation of these ecosystems. The evolving circumstances underscore the necessity for the development and implementation of adaptation strategies that are flexible and dynamic, taking into account the myriad of ecological responses engendered by climate change [84]. This entails both understanding and preparing for a wide range of potential outcomes, and recognizing that best practices for forest management may need to change over time, in line with evolving climatic conditions and the corresponding responses of forest ecosystems [85].

Climate change poses a substantial challenge to the preservation and sustainable management of temperate forests in the Northwestern Iberian Peninsula. The analyzed data, as discussed in the previous section, highlight a range of tangible impacts that demand attention. Firstly, variability in average annual temperatures has profound implications for the phenology of plant species [86]. With rising temperatures, flowering is occurring earlier [87]. This has complex ecological repercussions, with cascading effects throughout the food chain [88]. The decrease in annual precipitation, combined with an increase in rainfall variability, could lead to a reduction in soil water availability [89]. This reduction, in turn, may heighten water stress in plants, potentially leading to higher tree mortality rates and decreased forest productivity [90]. The decreased water availability can also increase forests' vulnerability to fires, a significant threat already in the Northwestern Iberian Peninsula [91].

The escalation of extreme weather events is another alarming facet of climate change [92]. More frequent and intense storms, prolonged heatwaves, and extreme droughts are causing direct physical damage to forests in this region and may also heighten the risk of forest fires and pest infestations [93]. Such extreme events can surpass the adaptation capacity of species, leading to changes in forest communities and the structure of ecosystems [94]. Climate changes may facilitate the spread of invasive species, which may be more capable of adapting to new climatic conditions than native species [95]. This could lead to a decrease in biodiversity, which has implications for forest resilience [96]. Consequently, it is evident that climate change poses a significant risk to the preservation of forests in the Northwestern Iberian Peninsula [97].

5. Conclusions

There is already strong evidence that climate change is impacting forest ecosystems in the Northern Iberian Peninsula. This review reveals that while climate change is global, its effects on forests are localized and depend on factors such as forest composition, topography, and interaction with other environmental stressors. In the Northwest Iberian Peninsula, temperate forests exhibit both resilience and vulnerability to these phenomena. Additionally, this region remains a relatively unexplored area of study, presenting opportunities for future research. Despite existing studies offering valuable insights, the necessity for further investigation is clear to comprehensively understand and address the challenges these ecosystems encounter. This review suggests that as climate change and its impacts continue to unfold, a broader discussion and inclusion of voices will be needed to understand, to address, and to mitigate and adapt to these changes. The forests of the Northern Iberian Peninsula are an underappreciated resource—there are current and rapidly emerging risks to them.

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