International Journal of Innovative Research in Computer Science & Technology (IJIRCST)
ISSN: 2347-5552, Volume-10, Special Issue-2, February-2022
Young Researchers' Conference on Indian Literatures, 2022
Organized by Presidency University, Bangalore, India

# Climate Change's Impact on Biodiversity in Forest Ecosystems

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## ABSTRACT:

If climate change continues at its current rate, significant changes in biodiversity are anticipated. Changes in the habitats and compositions of species can have negative repercussions, which can change how an ecosystem function. We conducted a meta-analysis of the responses of species distributions to climate change in order to determine the size of anticipated changes in biodiversity. We concentrated on the number of local species still present and their habitats. In order to measure changes in biodiversity, we synthesized 97 papers and computed two effect-size metrics from their findings.

## KEYWORDS:

Climate Change Habitats, Ecosystem, Fraction Area, Global Mean Temperature, Suitable Climate Area.

## I. INTRODUCTION

If climate change continues at its current rate, significant changes in biodiversity are anticipated. Changes in the habitats and compositions of species can have negative repercussions, which can change how an ecosystem function. We conducted a meta-analysis of the responses of species distributions to climate change in order to determine the size of anticipated changes in biodiversity. We concentrated on the number of local species still present and their habitats. In order to measure changes in biodiversity, we synthesized 97 papers and computed two effect-size metrics from their findings. The proportion of remaining species (FRS) and the fraction of remaining area (FRA) with a climate suited for each species are the metrics in question. Together, the two metrics show whether the biodiversity is still intact by calculating departures from the initial condition of the biodiversity.

With significant reductions of 14% and 35% between a 1–2 °C increases in the world mean temperature, we discovered an expected steady decline in both FRS and FRA. FRS reductions of 19% are expected to have significant effects on both plants and mammals. There are significant differences in how different taxonomic groups and biomes respond to climate change. Beyond a temperature increase of 3 °C, the FRA drops significantly for some taxonomic groups. We come to the conclusion that a significant loss of the original biodiversity is expected even at moderate levels (i.e., 1-2 °C) of temperature increase, despite the fact that these estimates are cautious since we assume that species cannot disperse or adapt. Our research supports the goal of keeping global warming to 1.5 °C or less in order to protect biodiversity. According to numerous studies anthropogenic pressures are posing an increasing threat to biodiversity [1], [2]. Climate change has been cited as a significant factor in biodiversity loss in this century by Parmesan and Yoho, Thomas et al., Warren et al., Ballard et al., Pacifica et al., and Urban. Biodiversity is impacted by climate change because climate factors, also known as a species' climate envelopes, greatly influence the geographic distribution ranges of species. Therefore, depending on their ability to disperse, species move their geographic ranges and go extinct locally in locations where the climate is no longer favorable.

Additionally, impacted are the physiology and phenology of the species, community structures, and ecosystem services. The difficulty of managing and conserving biodiversity is made more difficult by all of these adverse effects (CBD 2019). They all demonstrate that biodiversity is still declining globally as many ecosystems lose the necessary circumstances for some of their species to survive. Some studies project the already noted adverse effects on species, and their findings contribute to the ongoing discussion about limiting the rise in global temperatures e.g., by the Paris Agreement's climate-change target to keep the rise well below 2 °C above pre-industrial levels. However, it is unclear how biodiversity would react to an increase in global mean temperature of 2 °C, or any increase near to this aim, and this poses a fundamental scientific issue.

This study's main goal is to assess the response of terrestrial biodiversity to climate change, with a focus on global mean temperature increases up to 6 °C in 2100 and implicitly taking precipitation change into account as well. To do this, we conducted a meta-analysis of studies that made use of bioclimatic models and possible futures of climate change. These studies described how current ecosystems and various taxonomic groups across the globe are being impacted by climate change. The increase in global mean temperature in these research' climate-change scenarios served as a signal. According to the majority of climate change projections, the average global temperature will continue to rise and reach 2 to 5 °C in 2100. We concentrated on the percentage of remaining biodiversity, similar to earlier modelling studies that evaluated the total reduction of biodiversity. The fraction of remaining species (FRS) at a place and the fraction of remaining area (FRA) with acceptable climate for species were both calculated as effect measures.

These measures evaluate how a region's species richness has changed in relation to its initial state for the chosen research. Both metrics show a departure from the initial state of biodiversity and suggest biodiversity intactness. FRS shows a decline in species in the studied area. FRA denotes an appropriate climate-area constriction within the study region. These measurements do not account for future increases in species or geographic range. As a result, regardless of the global temperature interval, FRS and FRA typically show a reduction. We do not explore the possibility that changes in species composition may have an impact on how ecosystems function. We can generalize expected trends and evaluate implications across a wide variety of climate change scenarios thanks to the findings of our meta-analysis. In models like the GLOBIO model, the established meta-regression models can be utilised to analyses biodiversity change in scenario studies in conjunction with other pressures of global biodiversity loss.

### Techniques and Resources

In order to find bioclimatic modelling works that evaluate the consequences of rising global mean temperatures on terrestrial biodiversity, we searched the ISI Web-of-Science database in June 2016. We evaluated all studies in accordance with the recommendations made by the Collaboration for Environmental Evidence (CEE) for a further explanation of the procedure, see Online Resource 1. The stages for doing systematic research in environmental science are indicated in the recommendations, and these stages have been grouped into three primary processes. By excluding research that did not support our goal, these criteria made it possible to further narrow the choices. By title, all studies were evaluated for their applicability to our research goal [3], [4].

## II. DISCUSSION

The chosen papers were then thoroughly evaluated, both in terms of substance and supporting documentation, even if their abstracts only contained a limited amount of information. The papers that met the inclusion criteria were then chosen after a comprehensive review of the possibly pertinent studies. Finally, the pertinent information was compiled into a biodiversity-impact database by extracting it from all of the chosen studies. Included in these statistics were the number of species and the geographic area where they might exist in both the original and projected climates, as well as taxonomic category, study site, spatial resolution, and the increase in global mean temperature that was employed. The database did not include many research that discussed how the climate affects certain species or foreign species especially weeds, insect pests, and aquatic species. These studies either do not include terrestrial species or do not provide information on the original species makeup.

### Effect Size Calculations

For each chosen trial, we estimated the effect sizes, which are metrics frequently used in meta-analyses. For studies assessing the loss of area with a suitable climate for a species, we used the fraction of remaining area with a suitable climate (fraction remaining area (FRA)) under a projected increase of global mean temperature. We used the fraction of species remaining at a location (fraction remaining species (FRS)) as the effect size for studies assessing the number of species affected by increasing temperatures. In the chosen study, FRS and FRA are both effect sizes relative to the starting point. The ecosystem's condition prior to a change in climate, or the initial location with a suitable climate, is referred to as the original scenario. Results from multiple climate-change scenarios and time periods, or different bioclimatic modeling algorithms e.g., generalized linear model, generalized additive model, maximum entropy modeling that are reported in a study, were all included as separate effect sizes in our database.

We specifically estimated the proportion of remaining biodiversity i.e., a conservative option assuming that species are unable to disperse or adapt for three main reasons on average, the projected climate distributions of species are closer to projections without dispersal than projections with full dispersal uncertainty associated to the capacity of species to disperse under climate change is reduced and FRS and FRA fit into the domain of the

GLOBIO model, more specifically, they relate to the relative Mean Species Abundance (MSA) indicator from GLOBIO and the Biodiversity Intactness Index (BII) of the local remaining biodiversity. After predicted climate change, FRS is determined as the average of ratios between the number of species still present and the number of species present in each locality of the research area's map:

$$FRS=1n\cdot\sum i=1nSdiSoi$$

Where Soi is the number of species present in grid cell i before to climate change and Sdi is the anticipated number of species in grid cell i following climate change as measured by an increase in the global mean temperature (°C). The overall number of grid cells is n. An original species presence score (FRS) ranges from 0 (no original species present) to 1 (all original species present). If a species no longer thrives in one of the research area's grid cells due to the climate, FRS declines. In a particular grid cell, for example, FRS indicates the local response of species to climate change. The ratio between the initial suitable climate area and the surviving suitable climate area is used to compute FRA for each species:

$$FRA=1S\cdot\sum j=1SAdjAoj$$

Where Adj is the area with the species j's suitable climate that still exists after climate change, Aoj is the area with the species j's suitable climate that existed before climate change, and S is the total number of species. The FRA scale ranges from 0 (no initial suitable climate area) to 1 (suitable climate area unchanged). To decide how much weight to give each effect size during the meta-analysis, we assessed sample variances for both effect sizes, FRS and FRA. The Online Resource 1 provides instructions for calculating sampling variances.

## Harmonization of the Consequences of Climate Change

All research included baseline and future climatic information. Following Warren et al., we adjusted the expected temperatures from each study's climate change scenarios to a common pre-industrial baseline (about 1880) (Eq. 3). Accordingly, the assumed temperature rises from pre-industrial to the climatic normal for the years 1961–1990 was 0.3 °C, from pre-industrial to the years 1981–1990 was 0.5 °C, and from pre-industrial to 1990 was 0.6 °C. These are the starting points that the chosen research frequently mentions.

$$GMTIn = Tscen + \Delta Tpre - ref$$

Where Tsuen is the anticipated temperature, Tpre-ref is the assumed temperature increase between the pre-industrial and baseline conditions, and GMTIn is the global mean temperature increase converted to a common pre-industrial reference point for study n, both of which are driven by (or based on) climate change scenarios. For the meta-analysis, we identified four ranges of temperature increase: 1-2 °C, 2-3 °C, 3-4 °C, and 4 °C. Temperature increases between 0 and 1 °C are typically associated with strict mitigation measures and/or low carbon emission scenarios for short-term climate change [5], [6].

## Meta-Analysis

In response to an increase in the global mean temperature, we performed a meta-analysis to determine the pooled effect for all effect sizes. We utilised the Metaphor package and the rma.mv function in the R-3.2.2 Programme, assuming that the effect magnitude and sampling variance are independent variables. From a larger group of bioclimatic modelling research, the papers that are included are a selection. Using random-effect structures, we performed mixed-effect models. Using the Bayesian information criterion (BIC), we compared them. Then, we fitted several taxonomic subsets with random-effect meta-models using limited maximum likelihood (REML). These are all species, plants, vertebrates, birds, mammals, her tiles, and insects, for the effect sizes FRS and FRA, as well as for all four intervals of the rise in the global mean temperature. To identify the origins of heterogeneity, we added the moderator variable biomes.

To achieve the normalcy assumption for the effect sizes in meta-analyses and meta-regression analyses, ratios are frequently transformed using legit or log transformations. We tested the results for robustness using the mixed-effect models for the untransformed, legit-transformed, and log10-transformed effect sizes, FRS and FRA. Additionally, pooled effect sizes FRS and FRA were related to the rise in the global mean temperature using meta-regression studies. In order to investigate the potential for publication bias, we visually examined the funnel plots of asymmetries. By using the official heterogeneity test Q, we evaluated heterogeneity. Due to the various study parameters (such as various taxonomic groups, biomes, and temperature-change intervals), variation in effect magnitude was expected.

## Outcomes

After title filtering, the systematic literature search turned up 302 pertinent studies. These papers were abstract-screened, and 138 of them met the standards for full-text screening. Finally, we chose 97 papers, with publication dates ranging from 1992 to 2015 that examined the species makeup of the native species at a particular area. With the help of the chosen studies, 370 effect sizes for FRS based on data from 60 studies and 146 effect sizes for FRA based on data from 50 studies could be calculated. The studies and the pertinent data gleaned are available in Online Resource 2. In some situations, the bioclimatic model types used in the chosen studies span the whole distribution of each species under investigation. These models, for instance, were developed for endemic species or a continental species distribution. The effects of climate change are likely slightly overstated in other studies where the models do not account for the full range of all species. The meta-analyses reveal comparable results for untransformed, legit-transformed, and log-transformed effect sizes, indicating the robustness of these findings. Here, we show the outcomes of the most popular transformation, log10-transformed FRS and FRA.

## Meaning

Continual declines are depicted in both the FRS and FRA's overall estimates. According to this, local species richness has decreased 14% on average at a 2 °C rise in the global mean temperature and many species' habitats are no longer suited for them 35% on average at the same rate. According to these findings, a large number of species will become extinct locally and vanish from their current habitats. This finding is corroborated by other studies such as and will undoubtedly present difficulties for species conservation in many regions. However, this does not necessarily imply that the total species richness will decline as new species may be able to establish themselves and increase their ranges depending on their ability to spread. However, such emergent species are logically omitted in our effect sizes. As the global mean temperature rises above 2 °C, we predicted that reductions get worse. As an illustration, a 3 °C rise in the world mean temperature resulted in a 17% average decline in local species richness and a 50% increase in the proportion of species that can survive in the region's climate. As the global mean temperature rises by one degree, these consequences are predicted to not only worsen biodiversity losses but also speed up. In light of this, it is likely that all local declines will result in worldwide extinctions.

According to taxonomic groups and biomes, different FRS and FRA findings were obtained. As a result, it can be inferred that each species' reactions are highly correlated with its own experience to temperature fluctuations and sensitivity. As an illustration, the drop in FRS on average 10% at a 2 °C increase in global mean temperature and FRA on average 47% at a 2 °C increase in global mean temperature was a response of vertebrate species to increases in global mean temperature. Mammals are expected to experience the biggest local species drop among the vertebrate group. Our results are in line with earlier research which came to the conclusion that many vulnerable mammals are also adversely impacted by climate change. When the global mean temperature increased by 2 °C, the anticipated FRS and FRA for plant species fell by 18% and 34%, respectively. According to the Q test for heterogeneity and the funnel plots of asymmetry in Online Resource 3, the variability for the FRS of plant species was larger than the variability for vertebrate species.

This led to a lower FRS response for the plant species, which was likely the consequence. This large variability most likely stems from methodological problems such as various modelling algorithms that are fundamental to bioclimatic modelling and that have an impact on species-range shifts and abundances. Despite the fact that aquatic and exotic species were left out of our analysis, the many ways in which each of these groups have responded to climate change add to the difficulty of establishing a climate-protection objective. There was less variety in impact sizes in our study using the mixed-effect model with biomes as a moderator than there was for plants and vertebrate species. This suggests that biomes are a crucial explanatory variable when evaluating the predicted impact of rising global mean temperature on biodiversity.

With the conservative premise of no dispersal, FRS and FRA concentrate on evaluating the biodiversity's remaining share. According to Medley et al. and Hellmann et al., the majority of species rarely disperse at all. Consequently, it follows that FRS and FRA typically signal declines. The FRS is compatible with measures of naturalness or intactness like the BII or the MSA. Our findings can also be applied in international assessments of biodiversity change, such as the Global Biodiversity Outlook and other global studies as these indices are officially recognized by the Convention on Biological Diversity to indicate the expected responses of originally occurring species. FRS, however, varies from other biodiversity indices, such as the Species Richness Index, in that it overlooks new species for which the future climate becomes suitable. FRA takes local species reduction into consideration in a suitable climate-area manner. Similar methods were used in earlier research that examined suitable habitat of species to estimate worldwide patterns of species richness and/or the average proportionate change in species distributions to predict risks of species extinction.

These studies help in the development of objectives for the protection of local biodiversity and the creation of protected areas. Such studies, however, also fail to account for local species declines and changes in the demographic makeup of communities in locations with favorable climates. Climate change, in contrast to some non-climatic anthropogenic pressures that result in an abrupt loss of biodiversity, causes more gradual and long-term effects on species therefore it is important to take into account these temporal dynamics when interpreting the results of the FRS and FRA. In this study, we estimated the effects of global mean temperature increase assuming that any increase materializes simultaneously, but in reality, higher temperature increases are projected to occur at the end of this century, whereas increases of 2 °C are already possible in 2050. Our findings do not give evidence that biodiversity is protected by a climate objective of keeping the global temperature well below 2 °C, despite the fact that they do support the idea that higher temperatures will have greater impacts from climate change [7], [8].

As a result, we back the commitment to limit global warming below 1.5 °C, if possible lower, as doing so helps to preserve the makeup of local communities and their climatically suitable places. Prioritizing biodiversity conservation strategies can be achieved by being aware of the effects of climate change on biodiversity. In general, our findings show a connection between biodiversity loss and climate change. By highlighting the significance of keeping climate change well below 2 °C and assessing the relative negative effects of various climate change scenarios, this relationship is helpful. Our findings can also be applied to assess the consequences of interactions between other pressures on biodiversity loss, such as climate change, and to examine connections between them. Inferring that slowing the rate of biodiversity loss is essential and only feasible if all stressors are diminished or removed. In order to solve a number of pressing environmental issues, it would be beneficial if the UN Conventions on Biological Diversity and Climate Change closely cooperated.

## Climate Change and Biological Diversity in Forests

By absorbing greenhouse gases, forests help to lessen the effects of climate change. However, alterations in climatic circumstances can have a direct and indirect impact on the biological richness of forests. These modifications raise concerns about how well forests will be able to trap carbon emissions in the future. According to the Millennium Ecosystem Assessment, there are between 335 and 365 billion tons of carbon stored in the world's forests. However, the ability of forests to store carbon is being hampered by land use change, which is mostly the result of deforestation. Forest ecosystems serve as significant carbon sinks; hence their removal will have a significant impact on climate change. Ecosystem and climate models predict that climate change will affect ecosystem function and composition, as well as the distribution of forest creatures and populations.

Habitats are anticipated to move up in elevation and towards the poles in general. The shifting of these habitats will require forest biodiversity to adapt, changing species compositions in forests and perhaps causing the extinction of already vulnerable species and populations. Moreover, as a result of climate change, catastrophic weather events like floods and droughts would occur more frequently. These kinds of things can make forests more vulnerable to disturbances like fire and disease and will further influence the populations of forest plants and animals. In general, there is mounting evidence that climate change will have a significant impact on forests. Mangroves, boreal, and tropical forests are among the forest ecosystems predicted to be most vulnerable to the effects of climate change [9].

## What is the biological diversity of forests?

A broad word used to describe all living forms found in wooded environments and the ecological functions they play is forest biological diversity. As a result, in addition to trees, forest areas are home to a wide variety of plants, animals, and microorganisms, all of which have a diverse genetic makeup. The ecosystem, landscapes, species, populations, and genetics are just a few of the numerous levels at which the biological variety of forests can be examined. These tiers are capable of complex interactions both within and between them. This complexity enables organisms to adapt to constantly changing environmental conditions and to maintain ecosystem functioning in biologically varied forests. The Conference of the Parties acknowledged in the annexed to resolution II/9 that Forest biological variety comes from evolutionary processes spanning thousands or even millions of years, which are, in and of themselves, driven by ecological pressures like as climate, fire, competition, and disturbance. Additionally, forest ecosystems exhibit high degrees of adaptation, a characteristic of forest ecosystems that is an essential part of their biological diversity, as a result of the diversity of their physical and biological traits. The preservation of biological diversity is necessary for the ecological processes in certain forest habitats to continue.

## III. CONCLUSION

Understanding the biological effects of global climate change and establishing successful conservation strategies depend critically on analyzing the impact of climate change on biodiversity in forest ecosystems. Scientists have been able to clarify the intricate relationships between climate change and forest biodiversity through thorough research and analysis. The results repeatedly emphasize the significant and varied effects of climate change on forest ecosystems. Changing disturbance regimes, shifting precipitation patterns, and rising temperatures are a few of the main factors affecting forest biodiversity. These modifications may result in alterations to the species composition, phenology, distribution patterns, and susceptibility to pests and diseases.

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