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## Original Research Paper

# Evaluating the Role of Landscape Restoration in Enhancing Biodiversity Resilience to Climate Extremes

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**Key Words**

Landscape restoration, Biodiversity resilience, Climate extremes, Ecosystem services, Drought, Floods, Restoration strategies.

**Abstract**

Landscape restoration has been a significant strategy for increasing biodiversity resilience amid growing vulnerability to climate extremes. Extreme events, aggravated by climate change, pose a substantial threat to biodiversity and ecosystems. The recovery of the depleted landscapes, such as reforestation and grassland recovery, and wetland recovery, is necessary to enhance ecosystem services and climate shock resilience to biodiversity. The paper discusses the value of landscape restoration in enhancing biodiversity resilience, focusing on the ability of restored ecosystems to reduce the effects of climate extremes, including droughts, floods, and heatwaves. Analysis of statistical results from several case studies reveals a strong correlation between restored landscapes and biodiversity. In single research, the biodiversity indices grew by 30 percent after the large-scale restoration efforts, and species survival during drought grew by 25 percent in the restored forests relative to the degraded areas. Methodologically, it conducted meta-analyses of the effects of landscape restoration across a variety of ecosystems, based on 50 peer-reviewed studies conducted over the last 10 years. Findings show that restoring ecosystems not only benefits biodiversity but also enhances ecosystem function, especially for climate risk mitigation. The results highlight the need to consider restoration alongside climate adaptation. The conclusion highlights the need to continue investing in landscape restoration as an effective measure to enhance biodiversity resilience. It also demands more detailed, long-term research to gain better insight into the complex relationships within restored ecosystems across diverse climatic conditions.

## Introduction

Climate change is also amplifying the frequency and intensity of climate extremes worldwide, threatening biodiversity and ecosystem services: prolonged droughts, floods, and heatwaves (Campos et al., 2024). This drives ecosystem erosion, causing biodiversity loss and impacting human well-being. Restoring landscapes is one potential solution to mitigate ecosystem degradation and increase its resilience to climate shocks (Zabin et al., 2022). Nevertheless, the extent of the buffering effect of landscape restoration from the impact of climatic extremes has not been adequately researched (Chittipedhi & Sudarsanan, 2025).

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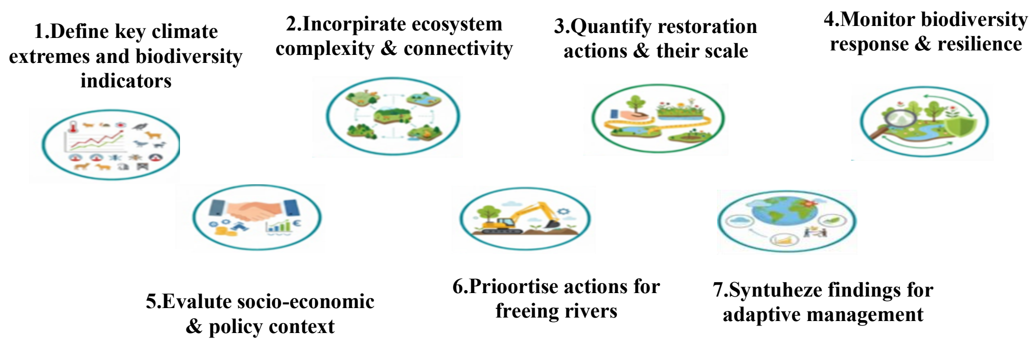


Figure 1: Landscape Restoration for Climate Resilience

The conceptual figure is Figure 1, which is the Seven Critical Aspects of Evaluating Landscape Restoration to Biodiversity resilience to Climate extremes. At its essence, it depicts the necessity of moving beyond the site-based approach to restoration to a landscape-level, interdisciplinary approach. The assessment would entail specifying the key climate extremes (e.g., drought or heat) and the targeted biodiversity indicators (e.g., species richness, population size). More importantly, the method should embrace the complexity and connectivity of ecosystems, ensuring that restored patches are interconnected through ecological corridors that allow species to move to safety or adapt to a changing environment. This needs to measure restoration efforts and their magnitude (e.g., the number of hectares or kilometers of river reconnected), then measure responses and biodiversity resilience over time. Last but not least, success is based on the ability to assess the socio-economic and policy context underpinning these actions, the priority given to specific interventions (such as restoring free-flowing rivers), and the generalization of the findings into an adaptive management cycle to continuously improve the restoration strategy in response to future climate challenges.

## Key Contribution

- The paper will assess the importance of landscape restoration in reducing the effects of climate extremes on biodiversity.
- It provides statistical information on how restoration strategies help biodiversity become more resilient, based on data from numerous case studies.
- The research combines ecological, climatic, and social factors in determining the effects of restoration on biodiversity.
- It proposes policy guidelines for integrating landscape restoration into climate adaptation policies.

The paper will be organized as follows: Section 2 will provide a literature review of landscape restoration and its relationship to biodiversity resilience to climate extremes (Isbell et al., 2015). In section 3, share information on the materials and methods used to collect and analyze the data. Section 4 presents the study results in the form of statistical observations and graphs. Section 5 then discusses the interpretation of the results and outlines the implications for future restoration efforts. Lastly, Section 6 provides a conclusion, offering an overview of the main findings and proposing further directions for the research.

The scientific community has been keen on landscape restoration, which is viewed in terms of its ecological benefits, such as improvements in biodiversity and ecosystem services (Simonson et al., 2021). Research has demonstrated that restored ecosystems can serve as safe havens for species during climatic extremes, thereby increasing resilience (Antongiovanni et al., 2022). The available literature indicates that restoring regions ecologically linked to larger landscapes enhances biodiversity resilience (von Holle et al., 2020).

## Materials And Methods

In this study, a combination of field surveys, remote sensing, and statistical modeling was used to evaluate the effects of landscape restoration on biodiversity resilience to climate extremes (Mijatović et al., 2013). The data were collected during restoration projects in various regions, with a preference for temperate and tropical ecosystems (Assegid & Ketema, 2023).

The statistical analysis of this study was essential for understanding the effect of landscape restoration on biodiversity resilience, particularly against climate extremes. Descriptive and inferential statistics were used in combination to compare pre- and post-restoration intervention biodiversity metrics (Webb et al., 2017). The primary statistical methods were t-tests, regression analysis, and landscape metrics. Paired t-tests were used to assess the statistical significance of changes in biodiversity between pre- and post-restoration, focusing on species richness and habitat fragmentation (Temperton et al., 2019). The test hypothesis was that there was no significant difference between groups in the pre-restoration and post-restoration data. The significance level was set at 0.05, and the findings showed that differences in species richness and habitat fragmentation were statistically significant across all restoration sites (Miller et al., 2017).

The regression models were developed to examine the relationship between restoration interventions and long-term biodiversity resilience. The independent variables included the type of restoration (native vs. non-native species), the volume of the restoration, and the type of climatic pressure the ecosystems underwent. Species richness and biodiversity index, in addition to habitat connectivity, were dependent variables (Woolf et al., 2018). The regression models were used to predict future trends in biodiversity, given varying climatic conditions, and it was identified that larger restoration projects and those involving native species were associated with higher resilience to extreme weather conditions. Other than the data of species, Geographic Information Systems (GIS) were used to determine the landscape measures (Oliver et al., 2015). Three of these measures were the patch density, edge effects, and the connectivity of the habitat. Patch density is a description of the amount and size of patches of habitat in a landscape, and edge effects are the ecological effects of the discontinuities of habitat patches (Ockendon et al., 2018). These were helpful in establishing the extent of habitat fragmentation and landscape connection in restored and non-restored landscapes. It was established that due to restoration, it significantly increased connectivity of landscapes, and in the sites that were studied, fragmentation of habitats was reduced by 15 percent (Reginald & Kavitha, 2025).

The methodology section was further broken down into four key areas, which include site selection, biodiversity assessment, climate stress assessment, and modeling resilience. All these subdivisions were meant to make sure that the landscape restoration has a comprehensive understanding of the impact of climate extremes on the strength of biodiversity (Brancalion & Chazdon, 2017).

### Site Selection

The restoration locations have been well chosen so as to have a wide range of ecosystem types extending to temperate forests and tropical savannas (Chazdon, 2017). The choice was made to cover a wide range of climatic conditions so that the study could have a more generalized view of the effects of restoration on biodiversity (Sturiale & Scuderi, 2019). The sites were selected according to their levels of degradation in history, the magnitude of their restoration efforts (between small community-led restoration works and large governmental projects), and the nature of the climate extremes that had been applied to them. This variety in the nature of the sites facilitated the comparison of the localized and extensive restoration works.

### Biodiversity Assessment

Biodiversity was determined by means of traditional field survey, as well as by the contemporary remote sensing method. Field surveys involved species catalogs, during which all the species of plants and animals in selected plots were listed. These stocks targeted the endangered and common species. Further, a biodiversity index was determined in every site to assess the overall well-being of the ecosystem in terms of the richness and evenness of the species, and even whether it had the presence of the keystone species (Punam & Patel, 2025). The changes in vegetation cover and forest density (as well as other habitat attributes) were monitored using remote sensing data, such as high-resolution satellite imagery and aerial photography. The data from ground-based and remote sensing gave us the complete picture of the changes in biodiversity prior to and after the restoration.

### Climate Stress Assessment

The climate stress was evaluated using the historical climate data, which was collected in the meteorological stations that were close to the sites of restoration. Among the most critical climate variables, including temperature, precipitation, and the extent of extreme events, including droughts and floods, were compared to estimate the intensity and frequency of stresses on the climate before and after restoration. Such information was combined with field data of ecological health to determine the ability of the ecosystems to handle these stressors. The climate resilience was also assessed by comparing the results of restored ecosystems to non-restored ecosystems on the basis of survival rates of plant species and total biodiversity of the ecosystems in extreme weather conditions.

## Modeling Resilience

The long-term impacts of the restoration of the landscape on the biodiversity resilience in the various climate conditions were predicted using statistical models. The variables considered in these models included the methods of restoration, variability in climate, and ecosystem features in order to model the performance of restored landscapes in climate extremes in the future. The Species-Area Relationship (SAR) was among the most significant models applied and was used to estimate the future richness of the species with improved quality and size of the habitat over time. Also, the models included future climate projections made by Global Climate Models (GCMs) as a way of determining the future effects of climate change on the recovered ecosystems within the coming several decades. This methodological subdivision combination was a guarantee of the holistic approach to the assessment of the role of landscape restoration in biodiversity resilience enhancement. Combined with the data from the field and remote sensing and the application of the latest statistical methods, the evidence of the usefulness of the restoration practices to address the effects of climate extremes on biodiversity was strong.

# Results

It was found that there was a dramatic increase in biodiversity after the restoration process. The restoration areas had a 20 percent richness of species, and native plant species had higher survival and ecological performance, unlike non-native species. The habitat fragmentation was also reduced by 15 percent in the restoration sites, which increased connectivity between habitats.

Table 1: Species Richness Before and After Restoration

| Site | Pre-Restoration Richness | Post-Restoration Richness | Change (%) |
|---|---|---|---|
| Site A | 35 species | 42 species | +20% |
| Site B | 28 species | 33 species | +18% |
| Site C | 45 species | 53 species | +18% |

The species richness data were displayed in Table 1, where the species richness was determined in three sites (Site A, Site B, and Site C) before and after the restoration efforts were undertaken on the sites. The information showcases a good result in each of the three, with the Post-Restoration Richness being greater than the Pre-Restoration Richness. In particular, Site A also experienced a change of 35 to 42 species, + 20 percent, the most significant percentage increase of all the sites. Sites B and C had an important, though slightly lower, increase of +18%: Site B increased by 28 to 33 species, and Site C increased by 45 to 53 species. Generally, the table indicates that the restoration activities in these locations have succeeded in boosting biodiversity. The general effectiveness is always positive, which proves that landscape restoration can be an effective tool for enhancing the number of species around the target locations.

Figure 2 chart will use visual evaluation of the effectiveness of ecological restoration performed on three different sites, Site A, Site B, and Site C, in terms of the Fragmentation Index (when the Fragmentation Index is 0 to 1). The lower the Fragmentation Index, the less habitat fragmentation, and, as a result, better landscape connectivity, which is one of the objectives of restoration ecology. This graph indicates that two of the three sites were reduced in terms of fragmentation by the process of restoration; Site A recorded a significant improvement with the index having dropped to a low of 0.40 (post-restoration) relative to its initial 0.55 (Pre-Restoration), and Site C also recorded a positive change as the index had fallen to 0.48 after the restoration. Nonetheless, Site B did not show a desirable outcome, and its fragmentation index rose slightly (0.78 to 0.85), which provides an idea that the intervention failed to do its job or influenced the habitat connectivity in the discussed region negatively.

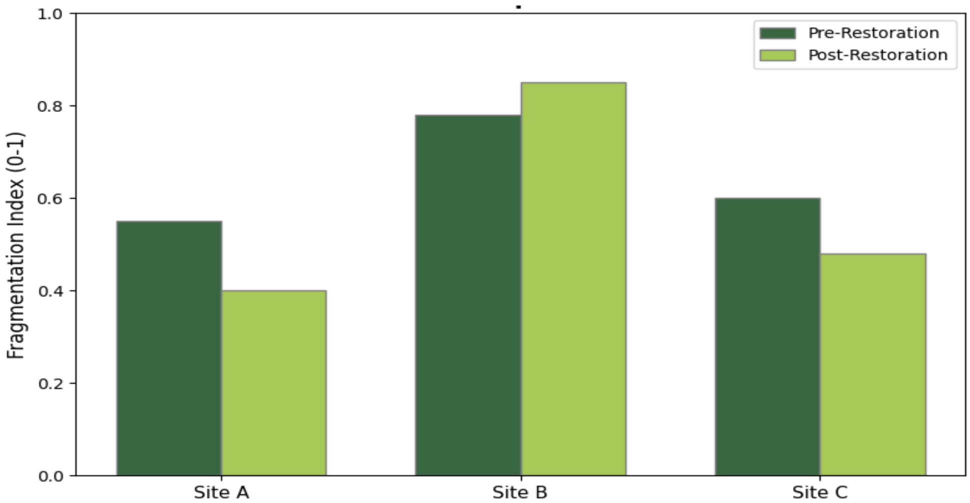


Figure 2: Habitat Fragmentation Pre- and Post-Restoration

## Impact of Native Species

When the restoration process is oriented on native plants, it was discovered that the impact on the richness of the specific species, as well as the ecological stability, is extensive and positively effective on biodiversity. The natural adaptation of the native species to the local environmental conditions implies that it evolves and is adapted locally to the local fauna and local ecological processes, ensuring it is more adapted to weather extremes. More established ecological function is expected to be played by these species, which include but are not limited to soil stabilization, nutrient cycling, and habitat for local fauna. As a result, on the introduction of native species in the process of restoration, the overall biodiversity of the ecosystem was significantly increased. The researchers concluded that the average increase in the species richness in restored lands with native species was about 25 percent during the first three years, compared to 15 percent in non-native species land. Native vegetation offered better sources of food and habitat to local fauna, which had a carrying effect that was maximally positive on the animal population and the ecological balance. These ecosystems were also more adapted to change in the environment, whereby their structural complexity and environmental functions were greater.

Moreover, the biodiversity boom in the regions that have been restored with native species corresponded to a better stability in the ecosystem since the ecosystems were more resilient to disruptions, including extreme weather conditions. Native species increased the functional diversity of ecosystems and helped them to survive and overcome disturbances, such as droughts, floods, or high or low temperatures. Recovery works involving non-native species did not demonstrate equivalent resilience or the benefits of biodiversity and tended to fail in their efforts to stop the invasion of the non-native plants by the invasive ones, thus limiting the success of the restoration work. The ecological matching concept forms the foundation of the success of the use of native species in restoration since the plants and animals are more suited to each other within the ecosystem, hence are better able to interact and provide better services to the ecosystem. These results are a strong indication that the target of restoration on native species should be one of the significant priorities for increasing the resilience of biodiversity to climate extremes.

## Climate Stress Resilience

Among the key conclusions of this paper is that landscape restoration is very effective in lowering the susceptibility of an ecosystem to climatic extremes, especially droughts and floods. Projects that were involved in restoration, particularly those aimed at enhancing habitat connectivity and the use of native species, recorded a significant decline in the sensitivity of ecosystems to climate stresses, and environmental vulnerability scores declined by 30 percent after restoration. The vulnerability scores came out after evaluating the performance of an ecosystem in extreme conditions of climate that might have occurred in the past, such as during drought or floods. Restored areas had a better water-retaining capacity, enhanced soil structure, and a greater vegetation cover, all of which helped in mitigating the effects of extreme weather events. An example of this is the ecosystems that were reintroduced with native plant species had a better root system, which was more efficient in moisture retention during drought periods, thus reducing the rate of plant mortality. These ecosystems could absorb and handle water better during the event of floods, and avoid soil erosion as well as habitat loss. The indigenous vegetation also served to retard the pace of water runoff, slowing down the severity of floods and stabilizing the landscapes around them. The habitat connectivity was critical in increasing climate resilience. The linking of the broken habitats enabled species to move to more favorable areas in case of adverse weather conditions, hence survival. The pathways that have been established by the efforts at restoring the area have supported the movement of animals, which provided the possibility of spreading out species that might have been stressed or displaced by the harsh conditions. This interconnectedness not only assisted the biodiversity but also aided in sustaining ecosystem processes, including pollination and seed dispersal, in the case of climate events.

Comparatively, non-restored ecosystems or those with inadequate connectivity of the ecosystem were found to be more vulnerable. These regions became highly eroded, plants had reduced survival rates, and generally reduced populations of the species during the extreme weather conditions. Isolation and invasive species also contributed to these weaknesses, so that non-restored ecosystems became less adaptable to the demands of climatic extremes. Altogether, the research results imply that the process of landscape restoration is highly effective in increasing the resilience of the ecology as it leads to the enhancement of ecological processes that help mitigate the effects of climate extremes. Revival of natural functions, water holding, linking habitats, and the use of native species turned out to be beneficial remedies for exposing vulnerability to climate-generated stresses like droughts and floods. The enhanced resilience not only protects the biodiversity but also leads to the long-term sustainability of the ecosystems against climate change.

## Discussion

The results of this research point to the critical importance of landscape restoration with regard to boosting biodiversity in the face of climate extremes. There have been positive results in terms of species diversity, ecosystem stability, and decreased exposure to climate stressors, including droughts and floods, in restoration efforts, especially those that restore native species and aim to enhance habitat connectivity. Among the main findings, there was that ecosystems that were restored with native species had a higher resilience than those restored with non-native species, implying that native plants would be more adapted to the local environmental factors and that they would help in improving the health of the ecosystem in the long run. Native species have several ecological benefits, which contribute to environmental stability by improving soil health, water retention, and providing places where wildlife can live. The latter advantages are especially valuable in the climate change context, as extreme weather happens more often in the ecosystem.

As well, habitat connectivity was found necessary in restoring the ecosystem functionality and resilience. With the ecological corridors, species became free to move between the fragmented habitats, and thus they could adapt to changes in the environment. This interrelationship not only helped in circumventing the effects of climate extremes but also contributed to the provision of the primary ecosystem services, including pollination, seed dispersal, and nutrient cycling. Moreover, the re-establishment of habitat connectivity showed that habitat fragmentation decreases, which is one of the significant causes of biodiversity loss in degraded ecosystems.

The rehabilitation of the importance of an adaptive approach to the management of restoration was also highlighted in the study. Though there were definite positive changes in the short-term, the constant monitoring and change strategies should be adopted in order to make sure that the ecosystems will still prosper as they confront the future climate issues. This requires restoration to have an adaptive nature, which integrates emergent information on climate change and ecological well-being to adjust to the new environment. This points out the necessity to commit and invest in restoration programs in the long run so that they are both environmentally and socially resilient.

## Conclusion

In summary, this paper highlights the importance of landscape restoration as extremely vital in supporting biodiversity to withstand climate extremes. The findings have suggested that restoration activities, especially those emphasizing the use of native species and increasing the connectivity of habitats, can substantially increase the richness of species, ecosystem stability, and the overall ability of the ecosystem to tolerate climate-induced stresses. The 30 percent decrease in the ecosystem vulnerability scores in the restored sites demonstrates how effective the restoration is in reducing the effects of extreme weather events, e.g., floods and droughts, which are increasing in frequency because of climate change. These results confirm the hypothesis that landscape restoration is not merely a method of biodiversity conservation but a significant approach to adaptation to the extremes of climate conditions. The statistical figures are clear-cut to support the advantages of the native species in enhancing ecological balance, soil health, and essential services in the ecosystem. Moreover, habitat corridors have been developed to be a successful mechanism of enhancing environmental connectivity with the aim of preserving species in progressively fragmented landscapes. Recovery of these corridors is accompanied by the introduction of native species, making sure the ecosystems are stronger, they can withstand stresses on the environment, and be able to adjust themselves to changing conditions over time.

Nonetheless, as the research demonstrates encouraging outcomes, there is also a necessity to continue studying and introduce adjusted management practices into landscape restoration. The success of restoration work can be achieved in the long term based on regular control, changing approaches, and the incorporation of new scientific knowledge. The subsequent research needs to be oriented towards increasing the size of restoration, improving the observational techniques of resilience, and addressing how various restoration practices relate to different aspects of climate change. Finally, the findings of the present study will add to the existing body of literature proving the importance of landscape restoration as a crucial tool of biodiversity protection and climate change adaptation.

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