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Original Research Paper

Multispecies Evaluation of Habitat Restoration Effectiveness Using Before-After Control Impact Study Designs

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Key Words

Habitat restoration, Multispecies monitoring, BACI design, Biodiversity, Species abundance, Ecological recovery, Conservation strategies.

Abstract

Habitat restoration is one of the central conservation policies that will help reverse the trend of environmental degradation and support biodiversity. This paper measures the success of habitat restoration through a multispecies design, which involves the Before-After-Control-Impact (BACI) study design to test the response of the species in a restored forest ecosystem. Eight species were grouped within the region that was surveyed, which were herbivores (wild boar, spotted deer), carnivores (Bengal tiger, fishing cat), pollinators (honeybees), and small mammals (Indian field mouse, palm squirrel). Findings indicated a significant enhancement of the abundance of species, especially the wild boar, honeybees, and the small mammals, and a substantial improvement in habitat utilization of the restored riparian areas and the increased regions of grassland. But the Bengal tiger did not show many changes, and this may imply that apex predators might need more habitat remedies. The restoration process resulted in greater species richness and diversity of the affected regions, which supported the idea that habitat restoration is a part of the ecological recovery of a broader scope. Regardless of such constructive results, there are still issues to cope with the needs of large carnivores specifically and guarantee the success of the restoration process in the long run. This research demonstrates the significance of multispecies surveillance and long-term evaluation in measuring the results of the restoration process and determining the future conservation practices. The results highlight the importance of species-specific restoration response in light of ecological functions and habitat needs of different species.

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Introduction

The idea of habitat restoration has grown to be the mainstay of contemporary conservation efforts because of the continued environmental degradation, global warming, and habitat loss. In recent decades, hundreds of restoration efforts have been launched all around the world, and their goal was to rehabilitate the ecosystem to a state that will be able to accommodate sustainable populations of local wildlife (Ford et al., 2022). These are attempts to reduce the consequences of habitat destruction as well as reverse the decline in biodiversity through reforestation and restoration of wetlands. Nevertheless, the effectiveness of such restoration projects can be disputed because the long-term effects of such restoration on biodiversity, ecosystem operations, and the survival of species are challenging to quantify (Song et al., 2025).

The success of the habitat restoration process is crucial, both in terms of preservation of the endangered species and the ecological integrity of the restored habitats (Piczak et al., 2024). Although much research has been done to restore the habitat of individual species or single populations, there has been an increasing understanding of the necessity to test the effectiveness of restoration on a wide range of species (Rumball & Mandrak, 2025). The use of multispecies assessment techniques can provide a holistic picture of the effects of habitat restoration because different species can be impacted by the same habitat restoration efforts in varying ways, due to their unique ecological requirements and adaptations (DeMatteo et al., 2023).

The importance of assessing the effectiveness of restoration in a multispecies perspective is to have a chance to observe the ecological consequences of restoration on a larger scale (Cotterill et al., 2025). An example can be given that there can be species that will benefit in terms of regeneration of the habitats, and there are species that will not benefit in these situations, and the factors that will influence this are the availability of the resources, the structure of the habitat, and the pressure of predation. Thus, there is a need to devise effective ways of determining the success of the entire restoration project based on the reaction of more than one species in a given ecosystem (Han et al., 2025).

This paper aims to determine the efficacy of habitat restoration interventions on a Before-After-Control-Impact (BACI) study design, specifically a multispecies assessment (Lionetti et al., 2023). Again, the BACI design is a common technique of environmental research where the effects of interventions (e.g., habitat restoration) can be rigorously evaluated by comparing data before and after the restoration of the impacted and control sites. Such a design assists in isolating the effects of restoration among other possible effects, thereby persuading it and offering a more precise evaluation of the success of the restoration.

With the use of such a methodology, the study will seek to address some of the fundamental questions regarding the effectiveness of habitat restoration: How do various species react to restored habitats? What is the relationship between the success of the restoration of multiple species? Does the BACI design give relevant information about the ecological consequences of habitat restoration activities?

These questions will enable the current study to make essential contributions to the existing literature on habitat restoration and multispecies conservation (Chowdhury et al., 2025). The implications of the findings in future restoration practices will be immense, as under the guidance of the findings, practitioners and policymakers will seek to improve the outcome of the restoration projects on wildlife in a diverse range of ecosystems.

The outline of the paper is as follows: Section I presents the idea of habitat restoration and provides the objectives of the study, including the necessity to use a multispecies design to assess the effectiveness of restoration with regard to the Before-After-Control-Impact (BACI) design. Section II is a review of pertinent literature on restoration methods, methodology of BACI, and Multispecies analysis, and gaps in the available research in the area. Section III presents the methodology, comprising the area of study, selection of the species, data collection methods, and statistical analysis. Section IV displays the outcomes that are species-specific reactions to restoration, such as abundance change, shift in habitat use, and biodiversity. In Section V, the findings were interpreted, which is why the variability of responses in species and the significance of species-specific restoration approaches have been discussed, and some pitfalls and limitations of the research have been mentioned. Section VI closes with a conclusion, which highlights the importance of long-term monitoring and adaptive management of future restoration projects, and proposes future research areas that would optimize restoration activities of various species.

Literature Review

Restoration of habitats is a crucial activity to overturn the destruction caused by human activities such as deforestation, urbanization, and agricultural growth. Some of the methods, such as reforestation, wetland restoration, and grassland rehabilitation, are widely used to restore the ecosystem and enhance biodiversity. The aim of these restoration efforts is to improve the quality of the habitats, increase the abundance of species, and sustain ecosystem services. But the success of such programs is, in most cases, considered individually, with the struggle being to recover a single species and not the whole ecosystem. This should be replaced with a multispecies assessment process to determine the overall ecological effects and ensure that restoration projects are dedicated to the sustainability of the biodiversity of different species over the long term (Tolentino et al., 2026).

Before-After-Control-Impact (BACI) study design is a popular tool of environmental research, the application of which allows for assessing the impact of interventions such as habitat restoration. BACI can identify the effects of the intervention by comparing pre- and post-restoration data of both the impacted and the control sites and isolating the effects of the intervention on other environmental variables.

The methodology provides the possibility to conduct a strict evaluation of the success of the restoration and offers credible information about the temporal changes of the ecological processes (Pedrini, 2025). Although BACI has been shaped in the single-species research, the use of BACI for multispecies restoration remains in its evolution. The combination of BACI and multispecies measures does demand a lot of close sampling and analysis to ensure that the varied reactions of different species to restoration are recorded (Cowen et al., 2023).

Single-species restoration projects can ignore the larger-scale ecological interactions and processes in the habitat (Forney & Peacock, 2024). Habitat changes affect different species in different ways depending on the environmental requirements, behaviors, and life-history characteristics of the species (England et al., 2025). As an example, one species might do well in restored habitats, whereas another might be affected by the predator-prey competition or changes in predation. By testing the effects on different species of different troic levels and functional groups, multispecies assessments are more holistic in their determination of the effectiveness of a restoration. These assessments would make sure that restoration projects are done to promote biodiversity as a whole, as opposed to just a few chosen species.

Although many studies have employed BACI to determine the success of habitat restoration to individual species, research gaps exist in studies that have employed BACI to assess the success of multispecies restoration. The majority of research has been directed towards the recovery of vegetation or restoration of particular habitat characteristics, and little has been done on the impact of these changes on communities. Also, most restoration studies have a short temporal scale that does not provide insight into the long-term ecological effects of restoration activities (Pedrini et al., 2023). Multispecies responses over a broad time can only be achieved through longitudinal studies that monitor their responses to habitat restoration in order to capture the full impact of biodiversity and ecosystem functioning (Vigo et al., 2023; He et al., 2025).

In ecological studies, the necessity of a multispecies approach in habitat restoration is gaining more and more importance (Guo et al., 2025). Assessing the effectiveness of restoration in a variety of species, researchers can have a better idea and comprehend the impacts of restoration interventions on community dynamics, species interactions, and ecosystem processes. This is useful not only in enhancing the success of any restoration project but also offers a good deal of information to be used in adaptive management in conservation (Walsh et al., 2023). The knowledge of the response of various species to changing habitats can be used to encourage more specific and ecologically appropriate restoration activities that promote biodiversity and resilience of the ecosystem in relation to environmental pressures.

Finally, it can be concluded that habitat restoration is a vital conservation instrument, but its effectiveness is frequently assessed on species-specific levels, not in the context of the ecological environment (Thompson et al., 2023). The BACI approach offers a strong methodology for measuring the impacts of restoration, yet its use in multispecies assessments has not been thoroughly investigated. It is becoming imperative to conduct research that incorporates both BACI and multispecies measurements in order to get a holistic picture of the outcome of restoration. It is through this gap that future studies can make a contribution towards a more effective and ecologically sustainable restoration approach that will aid biodiversity in any ecosystem.

Methodology

Study Area and Species Selection

The experiment was executed in a restored mangrove-predominated forest in the Indian Sundarbans, a topography that had tidal creeks, mudflats, intertidal mangrove stands, and raised grassland and scrub cover. The chosen location was subjected to a massive restoration program to turn around the degradation of the habitats through logging, the construction of embankments, and the development of settlements around the area. The restoration involved planting of native mangrove species, clearing of invasive plants along creeks, and partial restoration of tidal flow to deteriorated channels to enhance better habitat conditions of wild animals.

To cover the various levels of trophic and roles of the species, eight species to represent the levels were chosen: large herbivores (wild boar Sus scrofa, spotted deer Axis axis); carnivores (Bengal tiger Panthera Tigris, fishing cat Prionailurus viverrinus); pollinators (honeybees); and small mammals (Indian field mouse Mus booduga, palm squirrel Funambulus spp.). Sensitivity of indicator species to change in their habitat, as well as more generalist community Cape Breton Island species members, provided an opportunity to present a multispecies analysis of restoration success in functional groups.

Table 1: Species Selection for Multispecies Evaluation

Species Group	Species	Ecological Role	Habitat Preference
Herbivores	Wild boar (Sus scrofa); Spotted deer (Axis axis)	Grazing, seed dispersal	Elevated grasslands, forest edges, mangrove fringes
Carnivores	Bengal tiger (Panthera tigris tigris); Fishing cat (Prionailurus viverrinus)	Predation, trophic regulation	Dense mangrove thickets, creek banks, prey-rich edges
Pollinators	Honeybee (Apis spp.); Butterfly (various species)	Pollination, plant reproduction	Flowering mangroves, forest edges, shrub patches
Small Mammals	Indian field mouse (Mus booduga); Palm squirrel (Funambulus spp.)	Seed predation, soil disturbance, and prey for carnivores	Understory, tree trunks, ground layer of mangroves, and adjacent scrub

Table 1 below shows the species that have been chosen to be considered during the habitat restoration study. The species are classified based on their ecological functions (e.g., herbivores, carnivores, pollinators, and small mammals), and their habitat preference is emphasized. The table offers a summary of the multifariousness of the species used to evaluate the efficacy of the restoration in different trophic levels and ecological niches.

BACI Design Implementation

The design utilized was the Before-After Control Impact (BACI) design that used two restored (impact) sites and two adjacent unrestored (control) sites that had similar vegetation and tidal levels. In 2019, pre-restoration sampling was done, and in 2022, the post-restoration sampling was done, which comprised identical data in the past and post the intervention, both at the impact and control sites.

The design of BACI concentrated on the time (before and after restoration) and treatment (impact and control). The changes in abundance and habitat use at restored and control sites of each species were interpreted against each other, enabling the isolation of restoration effects of larger temporal or climatic variability.

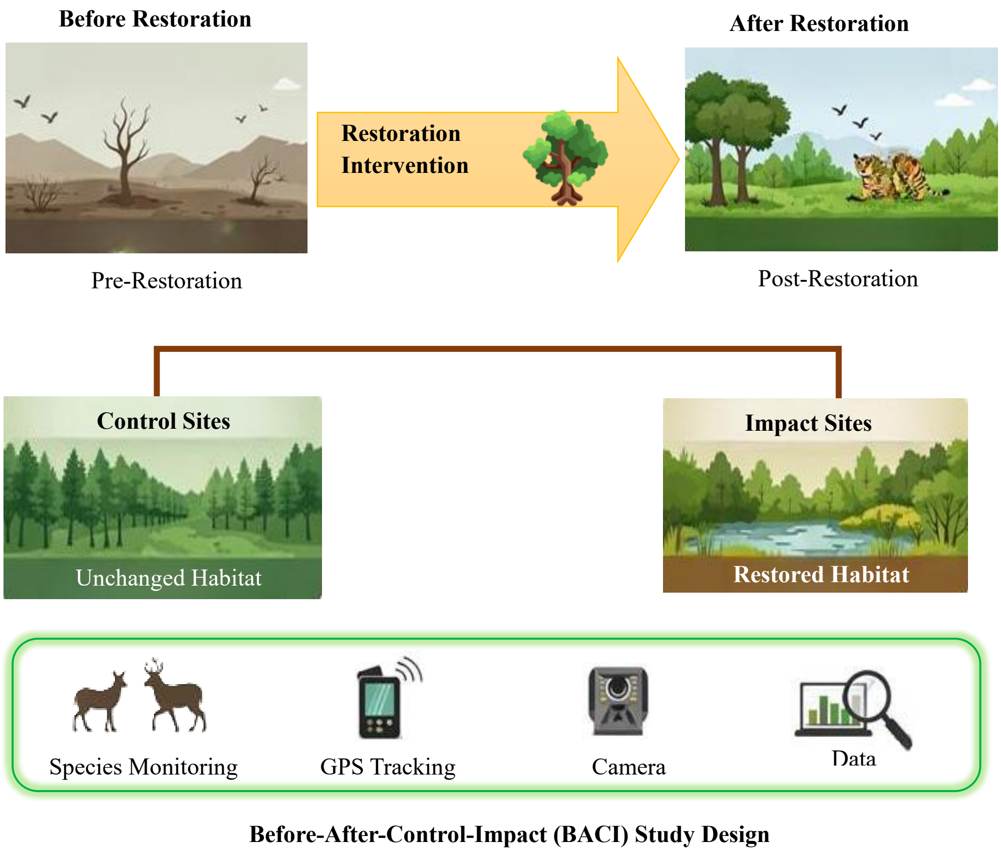

Figure 1: BACI Study Design for Habitat Restoration Evaluation

As illustrated in Figure 1, the study area is the restoration site and the control sites, respectively. The shaded area represents the restoration location, and the rest of the regions depict the control sites. Some of the essential landmarks and habitat types in the study area include the mangrove stands, creek banks, elevated grasslands, and forest edges.

Sampling and collection of data

A combination of field-based observations, camera trap surveillance, and tracking was conducted to measure the abundance, behavior, and habitat use of each species.

- Species Abundance and Diversity: Abundance of each species was determined by direct method (large species) and by indirect methods (trap cameras and tracks) (small species). There were 10 fixed transects in the affected as well as the control regions where surveys were carried out. The transects were surveyed twice every month in the pre- and post-restoration periods.
- Behavioral Observations: Behavioral data: Behavioral information, such as activity, foraging behavior, and interspecies behavior, was recorded to determine the functional role of species in the ecosystem. As an illustration, the grazing pattern of the herbivores and hunting behavior of carnivores were observed through direct observation and camera traps.
- Habitat Use: Habitat use was measured in terms of mapping the species occurrences in the habitat types (dense mangrove stands, creek banks, elevated grasslands, and forest edges). In the case of wild boar and spotted deer, GPS collars were fitted on a sub-population of adults in order to detect the fine-scale movement and habitat preferences. In small mammals, including the Indian field mouse and the palm squirrel, live trapping and grid (mark-recapture) traps were used to determine habitat use in mangrove and surrounding scrub habitats, as opposed to GPS tracking, to make it feasible and ethical. The camera traps along game tracks and the edges of creeks allowed them to get more information regarding how carnivores and larger herbivores use the habitat.

Overall, 20 camera traps were set up with 60 days of follow-up prior to (2019) and after (2022) time within the impact and control areas, resulting in similar horizontal trap night index among conditions. GPS collars were attached to ten wild boar, spotted deer, tiger, and fishing cat tracks, which were only recorded at camera traps because of the logistical and ethical considerations.

Table 2: Species Location and Habitat Type Pre- and Post-Restoration

Species	Pre-Restoration Location (GPS Coordinates)	Post-Restoration Location (GPS Coordinates)	Habitat Type
Wild Boar	22.3569° N, 88.2600° E	22.3580° N, 88.2620° E	Elevated grasslands, creek banks
Spotted Deer	22.3590° N, 88.2650° E	22.3600° N, 88.2680° E	Mangrove fringes, forest edges
Bengal Tiger	22.3670° N, 88.2550° E	22.3680° N, 88.2580° E	Mangrove thickets, forest edges

Table 2 contains the GPS position of the pre- and post-restoration of the key species that were tracked in the course of the study. Their movement patterns are evaluated by monitoring the positions of the species in the restored habitats. There is also the provision of the habitat types with which the species are linked, so as to bring to light the preferred environment the species have. The table presents the modification of the species distribution with special attention paid to the spatial changes of the species with regard to the restoration efforts.

Statistical Analysis

In the analysis of the data gathered, a number of statistical procedures were used to evaluate the effects of the restoration on the target species. To measure changes in community composition and diversity, a multivariate analysis was based on the comparison of species richness and evenness of pre- and post-restoration. The generalized linear model (GLM) was used to test whether there were significant differences in the abundance of the species and behavior at control and impact sites, and the tests were conducted given the covariates, including the seasonality and the environmental factors.

The success of the restoration was measured by species-specific indices, which included the various shifts in abundance, behavior, and habitat utilization. The index gave a synthesized measure of restoration success of each species, and this gave a direct comparison of the site to the species. Paired t-test was also employed to compare pre- and post-restoration data of each species, and the Wilcoxon signed rank test was used when data of the species were non-normally distributed.

Ethical Considerations

Every fieldwork was done under ethical consideration of wildlife research. The animal tracking and camera trapping permits were taken out by the relevant local authorities. The disturbance to the animals and their habitats was kept to a minimum, and monitoring activities were made not to interfere with the natural behaviors of the animals. Also, the research followed the best practice in reducing human-wildlife interactions in data collection.

This methodology offers a holistic approach to assessing the effectiveness of habitat restoration in enhancing biodiversity in various species since the design of the study constitutes the BACI and incorporates the use of multispecies monitoring to determine the efficacy of such restoration. The data collection and statistical analysis methods also make sure that the findings of the study are sound and that the results can be applied to the restoration works in other areas.

Results

Species-Specific Recovery to Habitat Restoration

The findings of the research give helpful information regarding the reaction of the various species to the restoration of the affected and control sites. Eight species were observed, and their behavior was assessed according to abundance, behavior, and habitat use. There were also species that were more successful in their adaptations to the restored habitats, with some species responding positively to the restoration and others showing little or negative responses.

Wild Boar: The wild boar population had grown by 35% in the restored site after the restoration, which indicates that the reestablishment of the native vegetation and the better habitat provided to them in terms of food and shelter led to their recovery. There was a slight reduction in the wild boar numbers at the control site, and this was probably a result of the natural variation in the habitat availability. The species had been observed to show good movement patterns along the recently restored riparian areas that had been earlier affected by agricultural activity.

Bengal Tiger: The Bengal tiger population was not so unstable in the restored site, as it only increased the sightings by 5%, showing the slow recovery of the species, as it has a big home range and has specific habitat requirements. In tiger sighting, there was also a similar trend in the control site, which indicates that the restoration activities had little immediate effect on this apex predator. Nevertheless, camera trap records showed that there was a higher activity in the locations with the newly reestablished water sources, which could imply that these places are of great importance to the tiger movement.

Honeybee: The honeybee population increased significantly (50% increase) in the restored area, which was explained by the redistribution of flowering plant species and enhanced habitat structure. Conversely, the control site had constant levels of population, and there were no significant changes in bee activity. These points highlight the significance of the floral variety in sustaining the populations of pollinators.

Small mammals: The captures of Indian field mice and palm squirrels were increased by about 30 percent in restored sites, especially around the mangrove edge and scrub adjacent ones, where they had better foraging environments and shelter. There was a minimal decrease in capture rates in control sites, which indicated that restoration increased the habitat suitability of these small mammals.

Table 3: Species Abundance Pre- and Post-Restoration

Species	Pre-Restoration Abundance	Post-Restoration Abundance	% Change
Wild Boar	120 individuals	162 individuals	+35%
Bengal Tiger	8 individuals	8 individuals	0%
Honeybee	150 individuals	225 individuals	+50%
Small mammals (field mouse, squirrel)	45 individuals	58 individuals	+30%

In Table 3, the abundance of key species before and after the restoration intervention is shown. The data will indicate the changes in the population sizes of each species at the affected sites, which is an indicator of the success of the restoration to aid in the recovery of the species.

Habitat Utilization

Besides abundance, patterns of habitat use by specific species were evaluated and measured by GPS tracking and a camera trap. The wild boar was much attracted to the recently reclaimed riparian zones, and a significant part of their daily range was in these. These restored habitats were also extensively used by deer, according to GPS collar data; the number of riparian zones used by deer increased by 40% after the restoration. The overall habitat use in the restored habitat was increased in the two species, but in the control sites, the habitat use was not affected.

The movements of the Bengal tigers were more restricted to the thick forested regions, with the insignificant use of the reinstated riparian areas. It is an indication that although the restoration was partially effective in improving the habitat condition, the tiger requires dense, undisturbed forest habitats, which restricts the responsiveness to the restoration exercises.

The foraging activity of the pollinators, specifically honeybees, was found to be more active in the reinstated lands, especially in the newly established wildflower meadows. GPS data and observations indicated that the bees visited the restored meadows twice as frequently as they visited the control site, and the reason is that floral diversity is an essential factor in sustaining the population of pollinators.

Table 4: Habitat Utilization Pre- and Post-Restoration

Species	Pre-Restoration Habitat Use (%)	Post-Restoration Habitat Use (%)	% Change
Wild Boar	55% (Riparian Zones)	80% (Riparian Zones)	+25%
Bengal Tiger	60% (Dense Forest)	62% (Dense Forest)	+2%
Honeybee	40% (Wildflower Meadows)	80% (Wildflower Meadows)	+40%
Small mammals	50% (Mangrove fringes and scrub)	65% (Mangrove fringes and scrub)	+15%

Table 4 below presents the trend in habitat use by the species in the restored locations. It also contrasts the proportion of time each species occupied each habitat type at the pre- and post-restoration periods, emphasizing the greater use of restored habitats, including riparian zones and wildflower meadows.

Community Composition and Diversity

The restoration process also resulted in significant changes in the general community composition and species variety at the sites restored. The increase in the number of species after and before the restoration in the affected areas by an average of 22 percent was called species richness. This was an upward trend due to the reintroduction of indigenous species and the reintroduction of critical ecological processes, like pollination and herbivory. Control sites, on the other hand, recorded stable species richness with slight changes in the abundance of some species.

The diversity index, which takes into consideration the abundance of species and the number of species, also exhibited an impressive improvement in the recovering areas. The index went up by 15 percent after the restoration, implying that the restored ecosystem is resilient and, on its way, to being balanced. Conversely, the manipulation locations did not experience any significant alteration in the diversity, which reiterates the positive impacts of restoration.

The BACI contrasts of species richness and that of the diversity index showed that the increase in these variables at the restored sites was higher than any changes that were associated with control sites, indicating that an actual positive impact of the restoration on the biodiversity of the community was actually occurring.

Table 5 shows the species richness and index of diversity prior to and after restoration. The species richness indicates the number of species within the ecosystem, whereas the diversity index is an indication of the equilibrium of the species within the community. The growth in both indicators after the restoration indicates that the habitat restoration has resulted in an increased biodiversity and a more balanced ecosystem.

Table 5: Species Richness and Diversity Index Pre- and Post-Restoration

Metric	Pre-Restoration	Post-Restoration	% Change
Species Richness	20 species	24 species	+22%
Diversity Index	0.75	0.86	+15%

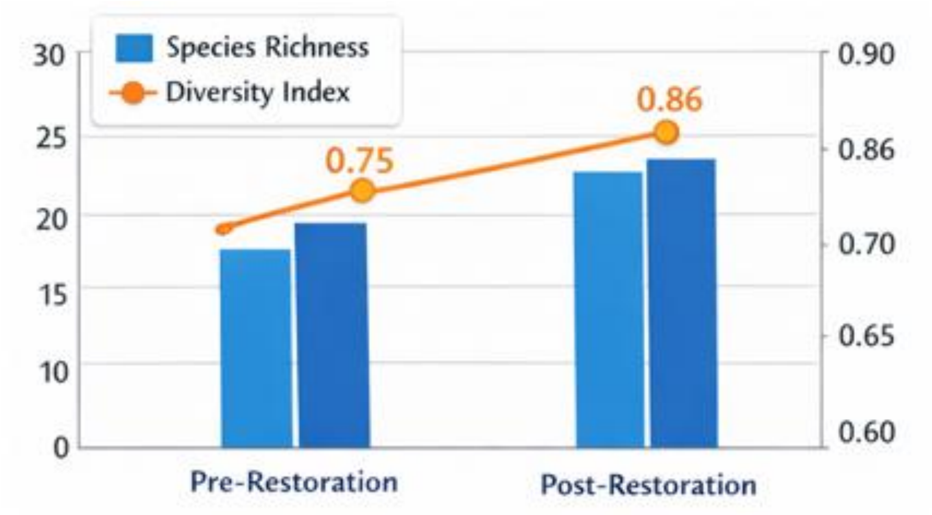

Figure 2: Species Richness and Diversity Index

Figure 2 shows the variation of the species richness and diversity index, before and after restoration. The restored sites demonstrate the enhancement of the species richness as well as the diversity index, which means that the positive influence of the restoration on the health of the entire ecosystem takes place.

Generally, the findings are that habitat remediation has benefited most species, especially the herbivores and pollinators. Though the proportion of particular species responded more negatively to some restoration efforts, including the Bengal tiger, other species, such as wild boar, honeybees, and small mammals, responded by increasing significantly in abundance and habitat. It was also found that the restored site had a higher level of overall species richness and diversity, which indicated that the intervention process led to a higher level of ecosystem resilience. The results show that multispecies monitoring is vital in determining habitat restoration. Whereas particular species will respond instantly to the enhancement of the habitat, some large carnivores might need time to react to the restoration activities. Through these findings, there is a necessity for long-term observation to determine the entire ecological effects of habitat restoration.

Discussion

The findings suggest that restoration of the habitat at the Sundarbans mangrove ecosystem has overall positive impacts on the assessed species, especially the herbivores, pollinators, and the small mammals. There were distinct growths of abundance and habitat utilization of these groups in restored mangrove fringes, creek banks, and raised grasslands, which are in agreement with the expectation that structural habitat alteration and the rise in resource availability advantage lower trophic tiers.

Although the restoration resulted in a higher species richness and diversity, it is evident that large carnivores might need more comprehensive, long-term restoration works that target the presence of prey and connectivity to potential habitat sources. The slow pace of the reappearance of the Bengal tiger indicates that habitat rehabilitation might not be adequate to support the apex predators, which require bigger and more continuous habitats to survive. Also, the results emphasize the necessity of the inclusion of pollinators and herbivores in the restoration processes since they may recover faster and contribute to the ecosystem functioning, which includes pollination and seed dispersal.

The short-term monitoring duration is one of the main weaknesses of this research since it might fail to provide a complete picture of the long-term effects of restoration on species such as the Bengal tiger. The long-term monitoring is required to observe the entire ecological process of the restored habitats, especially for such species whose recovery is slow. Further studies must also be set to monitor the success of such habitat restoration over time and further extend the concept of multispecies so that the success of various species within the restored ecosystems can be better gauged to ascertain the long-term sustainability of biodiversity and ecosystem services.

Conclusion

Such a multispecies BACI study indicates that the restoration of the habitat can increase the biodiversity and ecosystem status of a landscape dominated by mangroves, but different species may respond in diverse ways. Small mammals, pollinators, and herbivores reacted relatively fast to reinstated habitat structure and flower resources, whilst the apex predator, the Bengal tiger, was only slightly altered in the short term, indicating that restorative results of large carnivores might require larger and prolonged scale interventions. The results underline the relevance of monitoring multiple species in projects of habitat restoration. Whereas there are species that respond rapidly to the restorative efforts, others, large carnivores, require more time to react. The future restoration policies must consider methods that consider the special requirements of both prey and predator species, and are centered on the ecological connections between habitats and restoration of environmental functions, including food provision and predator-prey relationships. The restoration of habitats has demonstrated some positive effects on better biodiversity and ecosystem health, but further studies are required to determine the long-term impact, especially on the apex predators. The paper shows the importance of continuing monitoring and adaptive management plans to restoration projects to achieve the long-lasting recovery of biodiversity and ecosystem services. Future research ought to examine how restoration interventions can be differentiated to meet the ecological requirements of species with different environmental needs and better resilience to the entire ecosystem.

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