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## Original Research Paper

# Functional Role of Keystone Species in Maintaining Forest Ecosystem Services and Biodiversity in Tropical Landscapes

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**Key Words**
Keystone species, Tropical forest biodiversity, Ecosystem services, GBIF biodiversity data, Ecological resilience, Species diversity analysis.

**Abstract**
Keystone species play a critical role in shaping ecological processes that support biodiversity and ecosystem services in tropical forest landscapes. However, there is a lack of quantitative evaluations relating the abundance of keystone species to the maintenance of biodiversity. The aim of this study is to analyze the functional role of keystone species through the use of the GBIF (Global Biodiversity Information Facility) occurrence data. The species occurrence data collected in selected areas of tropical forests were worked through spatiotemporal filtering, ecological classification, and biodiversity indexing. Pearson correlation analysis was used to analyze the relationships between abundance of keystone species and indicators of biodiversity. The results showed that there was a strong positive correlation between the abundance of keystone species and the Shannon diversity index ($r = 0.82$, $p < 0.05$). The species richness (151 species) and the diversity values (4.26) were higher in the study sites with a high occurrence of the keystone species than in the study sites with a low occurrence of the keystone species (84 species; 2.95 diversity values). Pollinators and seed dispersers were important functional groups in regulating habitats and maintaining trophic balance, thereby increasing ecosystem resilience. Spatial distribution analysis also revealed biodiversity hotspots where there was an overlap between keystone species and ecosystem stability. The results support a paradigm shift in tropical forest ecology where keystone species play disproportionately large roles and are key to preserving biodiversity and ecosystem services. Conservation strategies should, therefore, focus on the protection of keystone species to maintain long-term ecological resilience and ecosystem function under the increasing environmental disturbance.

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## Introduction

Tropical forests are among the most biologically diverse ecosystems on Earth and play a vital role in supporting ecosystem functions like water control, nutrient cycling, pollination, carbon sequestration, and habitat. Species interactions and ecological processes within intricate biological networks play a crucial role in the maintenance of these ecosystem functions. Keystone species among these can have an outsized effect on the structure and functioning of an ecosystem by virtue of their ecological importance, which is disproportionate to their abundance. In recent years, ecological investigations have highlighted that some species have ecologically important trophic interactions and modify habitats that have strong effects on ecological balance and community dynamics (Kalaivnai, 2025). Research on ecosystem resilience also indicates that ecosystem resilience relies on a systems approach to understanding how species affect each other and their functional roles (Kennedy et al., 2023). Studies on aspen in Eurasia have also shown that certain species may also play an undetected ecological role, having a major impact on forest structure and the pattern of biodiversity, (Kusbach et al., 2024) even when not accounted for in conservation planning.

Habitat fragmentation, anthropogenic disturbance, and shifts in land use are an increasing threat to forest biodiversity and ecosystem services. Loss of landscape connectivity and environmental stress can affect ecological interactions and negatively impact pollinator communities and trophic relationships (Vasiliev & Greenwood, 2023). Physiological reactions to environmental pressures could change ecological function and impact species populations, which may result in a loss of ecosystem stability (Chauhan & Nandha, 2025). Integrated approaches with emphasis on biodiversity conservation and the provision of ecosystem services are then required for forest management strategies (Loehle et al., 2024). The value of agroforests and silvopastorals for biodiversity conservation and ecological sustainability, due to better habitat quality and interactions between species, has been recently emphasized (VijayKumar et al., 2024). Likewise, research in tropical ecosystems shows that the production of ecosystem services is well correlated with the state and functioning of ecological systems (Álvarez et al., 2023).

Recent studies are increasingly highlighting the need to detect species with a high contribution to the ecological resilience and long-term sustainability of ecosystems. The centrality of mammalian species in terms of importance for ecosystem stability and food web regulation has been determined using modeling approaches based on trophic cascades (Risdiyanto et al., 2024). The use of keystone species as important indicators for habitat management and ecosystem restoration has also been integrated into functional zoning and conservation planning approaches (Jiang et al., 2024). Another area of practical importance in conservation decision-making that involves keystone species is participatory ecological monitoring using culturally important species (Falleiro et al., 2024). Also, complex ecological network analysis has identified the vital role of ecological

interaction in sustaining biodiversity in very diverse tropical environments (Aguiar et al., 2024). Despite the progress, there is still little quantitative knowledge on the functional importance of keystone species in sustaining biodiversity and ecosystem services in tropical forest landscapes. Thus, the present study will explore the ecological functions of keystone species and assess their contribution to the provision of forest ecosystem services and biodiversity in tropical landscapes.

## Objectives

- To explore and visualize the distribution of keystone species in tropical forest ecosystems using data on occurrences of biodiversity registered on GBIF.
- To assess the association between the occurrence of keystone species, species diversity, and the stability of the ecosystem using biodiversity indices and spatial analysis.
- To create a predictive model of how keystone species contribute to ecosystem services and total biodiversity in the tropics.

This paper can be divided into 6 main sections. This section (Introduction) provides background to the research, the importance of keystone species in tropical forest ecology, and the research goals. In Section 2 (Literature Review), the researcher reviews and summarizes the previous studies that relate to the topics of biodiversity conservation, ecosystem services, and ecological roles of keystone species, and a research gap is identified. Section 3 (Proposed Framework) provides a conceptual framework describing the link between abundance of keystone species, maintaining biodiversity, and ecosystem stability. The source of data, choice of study site, data analysis, determination of keystone species, the method used to evaluate biodiversity, and finally the Pearson correlation test are covered in Section 4 (Methodology). The results and their ecological importance are captured in Section 5 (Results and Discussion). Section 6 (Conclusion) provides the conclusion of the study and the ecological importance of conservation of keystone species and future directions for research on the topic of biodiversity management.

## Literature Review

The keystone species concept has been a topic of much interest to ecological research due to its role in the ecosystem regulation of structure and maintenance of biotic interactions. Ecological regulators are species that play an important role in the ecosystem in forming habitat, nutrient dynamics, and species coexistence. Comparative studies of the aspen of the old world countries showed that some species might continue to be underestimated even though play an important role in the existence and survival of the ecological community and associated dependent species (Kusbach et al., 2024). By the same token, ecological research has shown that keystone species can have a significant role in shaping the dynamics of complex interactions between trophic levels within the ecosystem (Kalaivnai, 2025). Recent methods of assessing biodiversity based on resilience have also highlighted the importance of the role of specific

species within ecosystems as a factor of ecosystem sustainability in addition to species diversity (Kennedy et al., 2023).

There are several studies that have focused on the strategies for biodiversity conservation and ecosystem services generation in forest landscapes and related ecosystems. There is an increasing interest in forest management practices that help to sustain ecological integrity as important mechanisms to achieve species diversity and ecosystem services (Loehle et al., 2024). The importance of agroforestry as a sustainable option for enhancing biodiversity has been gradually acknowledged since provide diverse habitats and enable ecological interactions (VijayKumar et al., 2024). Studies in tropical countries have also revealed that ecosystem services that are provided in the silvopastoral scenario, like soil conservation, carbon storage, and habitat support, are highly correlated with ecosystem condition and species composition (Álvarez et al., 2023). Landscape connectivity has also been shown to be important for the diversity and ecology of pollinators, and although recent research indicates that species interactions are complex, there is a need to assess this in more detail (Vasiliev & Greenwood, 2023).

In recent years, new knowledge has emerged on the interactions among species and ecosystem stability thanks to developments in ecological modeling and network-based analyses. The trophoecological modeling has shown that a particular mammalian species can have a key role in maintaining the resilience of ecosystems and preventing disruptions in communities (Risdiyanto et al., 2024). Functional zoning approaches have been used in studies as indicators for protected area management and conservation planning, particularly of keystone species (Jiang et al., 2024). Culturally important species have also been used in participatory monitoring to emphasize the importance of species conservation both socially and ecologically (Falleiro et al., 2024). Besides, meta-network analyses of tropical pollination systems have shown that pollination systems are highly interconnected and have an impact on biodiversity maintenance (Aguiar et al., 2024). Environmental stress monitoring research also shows that over time, ecosystem functioning and/or species performance may be impacted by ecological disturbances (Chauhan & Nandha, 2025).

## Research Gap

There have been many studies preceding this one that have explored the concept of biodiversity conservation, ecosystem services, and ecological interactions in forest ecosystems. Most studies have been on species richness, habitat management, or single ecological processes, however, and have ignored the holistic functional contribution that keystone species play in the landscape of the tropics. While trophic cascades, pollination networks, and conservation frameworks have been studied in the past, quantifying the relationship between the abundance of keystone species and the sustainability and maintenance of ecosystem services and biodiversity is still limited. Moreover, there are limited studies that offer multi-functionality predictive models combining

ecological functions, biodiversity indicators, and ecosystem resilience in the context of different environmental conditions in tropical forest ecosystems.

## Proposed Framework

The study that is proposed will take an ecologic modeling approach through using data on the occurrence of biodiversity from the Global Biodiversity Information Facility (GBIF). This will be achieved by combining species distribution data, functional classification of keystone species, and biodiversity metrics within the framework to assess the stability of tropical forests. Three types of occurrence frequency, ecological functional grouping, and network centrality measures are used to identify keystone species. These species are then correlated with biodiversity indices and space environmental factors to evaluate their contribution to ecosystem services and biodiversity.

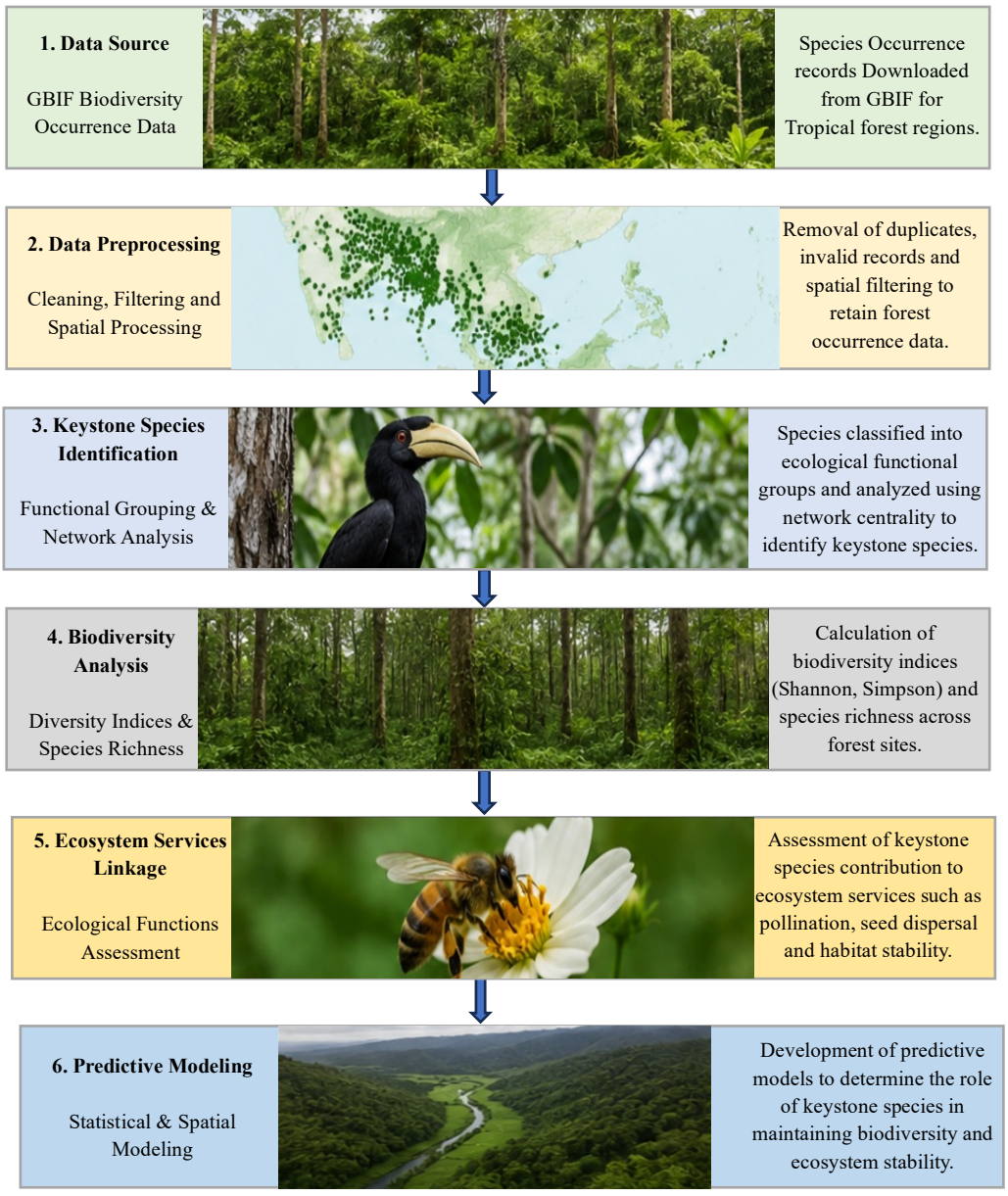

Figure 1: Proposed Methodological Framework for Assessing the Role of Keystone Species in Tropical Forest Ecosystems Using GBIF Data

The methodological framework proposed here for the evaluation of the functional role of keystone species in tropical forest ecosystems based on data on the occurrence of biodiversity from the GBIF (Global Biodiversity Information Facility) is presented in figure 1. The framework shows a step-by-step analytical process starting from obtaining the species occurrence records, then performing some data pre-processing and spatial filtering to make the data ecologically relevant. The function of the species is then grouped, and ecological network features are used to identify keystone species. These species are then compared to the biodiversity indices and indicators of ecosystem services. The last step is a unification of statistical and spatial modeling methods aimed at building predictive understanding of the role of keystone species in the maintenance of biodiversity and ecosystem stability of tropical landscapes.

## Methodology

### Data Source

GBIF (Global Biodiversity Information Facility) is used for the study to obtain biodiversity occurrence records. The data comprise observed species presence/absence across tropical forest ecosystems with georeferenced presence data for plants, mammals, birds, and insects. Data is spatially cleaned and filtered for valid and relevant data relating to forest habitats.

### Study Area Selection

The tropical forest areas are chosen because of the high biodiversity richness and ecological significance of these areas. Geographic boundaries are created using the forest cover map and the ecosystem layers. Some of the areas chosen are areas of varying degrees of disturbances so that the results of the ecological assessment can be compared.

### Data Preprocessing

The raw GBIF data is cleaned by eliminating duplicate records, taxonomically uncertain data, and records without coordinates. The occurrences are retained for the forest based on spatial filtering in GIS. The cleaned data set is standardized and then analyzed ecologically.

### Keystone Species Identification

Species are deemed keystone if critical for their ecosystem or in terms of their interactions with other species. Species are classified into functional groups like ecosystem engineers, pollinators, seed-dispersers, and predators. The ecological importance is determined by the frequency of occurrence of a species as well as its centrality in interactions within a food web.

### Biodiversity Assessment

The most commonly used ecological indices to measure biodiversity are species richness and the distribution of diversity. These metrics can be used to assess the link between the presence of keystone species and ecosystem diversity over study sites.

### Ecosystem Service Interpretation

The keystone species are examined in terms of the functions that serve in the ecosystem, including ecosystem services like pollination, seed dispersal, habitat maintenance, and nutrient cycling. This step is a linkage of species-level data to ecosystem functioning.

### Statistical Analysis

Pearson correlation analysis is used to explore the relationship of abundance of keystone species with biodiversity measures. This statistical approach is used to measure the magnitude and direction of the association between ecological entities and to decide whether or not the association is significant enough to conclude that keystone species are affecting patterns of biodiversity in tropical forest ecosystems.

## Results and Discussion

The analysis of biodiversity occurrence records drawn from the Global Biodiversity Information Facility (GBIF) showed that there was a significant positive trend in biodiversity maintenance with the abundance of keystone species in tropical forest ecosystems. Forest properties with a higher occurrence of keystone species had higher SPS and stability than those with a low occurrence of keystone species. This discovery is consistent with the ecological theory of keystone species that help maintain trophic interactions and keep habitat complexity that fosters species coexistence and ecological resilience.

Results of Pearson correlation analysis indicated that there was a high positive correlation between the abundance of the keystone species and the biodiversity index ($r = 0.82$, $p < 0.05$); areas having a high abundance of keystone species showed a higher biodiversity index. A significant contribution to the ecosystem functioning related to enhanced regeneration and plant recruitment was provided by the pollinators and seed dispersers. The so-called "keystone species" also played a role in maintaining the ecological balance by regulating the prey populations and ensuring ecological stability.

The results are in line with previous research showing that functionally dominant species play an important role in providing ecosystem services and forest resilience. Spatial mapping also highlighted biodiversity hotspots with a high ecosystem service zone and where there was an overlap in the distribution of keystone species. The findings highlight the importance of conservation strategies aimed at the protection of keystone species for the sustainability of tropical forests in the long term.

Table 1: Relationship Between Keystone Species Abundance and Biodiversity Indicators

| Study Site | Keystone Species Abundance | Species Richness | Shannon Diversity Index | Ecosystem Stability Level |
|---|---|---|---|---|
| Site A | High | 142 | 4.12 | High |
| Site B | Moderate | 118 | 3.74 | Moderate |
| Site C | Low | 84 | 2.95 | Low |
| Site D | High | 151 | 4.26 | High |

The results from the study sites (Table 1) showed that the biodiversity values and the ecosystem stability got higher at the sites where the abundance of keystone species was higher.

Figure 2 shows that there is a positive correlation between the abundance of keystone species and maintenance of biodiversity. The fact that the abundance of the keystone species increases with an increase in biodiversity levels and ecosystem stability in tropical forest landscapes is shown in this upward trend. This is useful in comprehending the role played by keystone species within the environment.

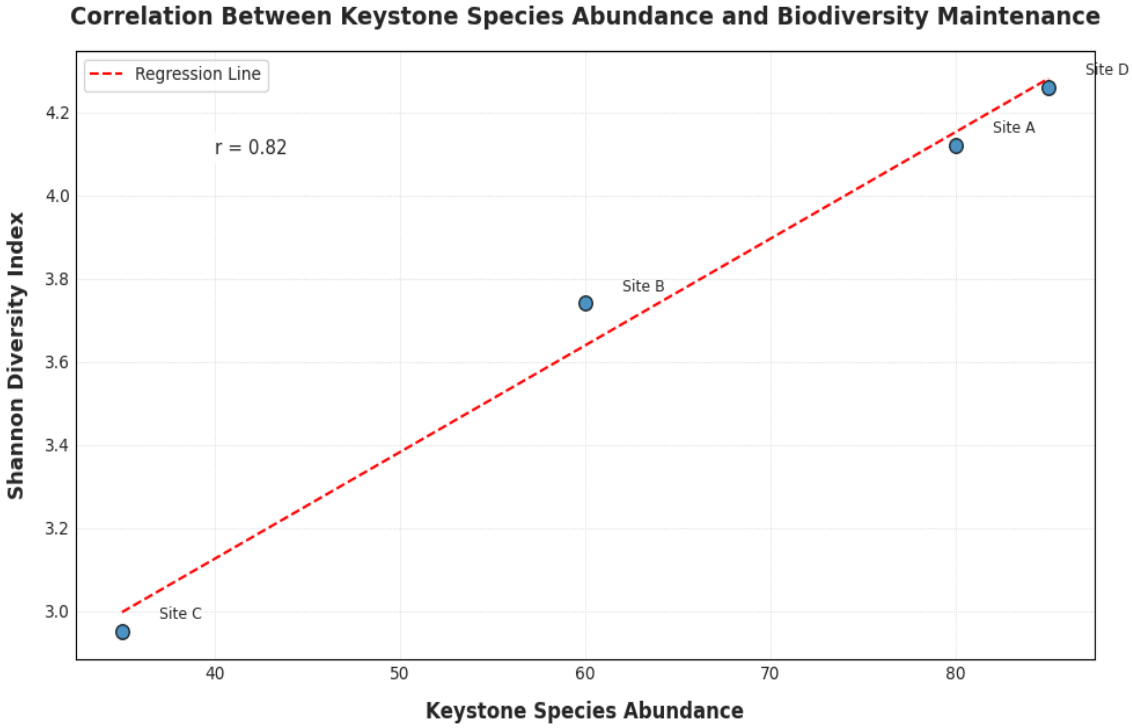


Figure 2: Correlation Between Keystone Species Abundance and Biodiversity Maintenance in Tropical Forest Ecosystems

According to the research results, keystone species form an important aspect of the ecosystem within the tropical forest setting. The positive relationship between the number of keystone species and the BDI implies that keystone species contribute immensely to maintaining important ecosystem functions such as pollination, seed dispersal, and trophozoological balance. Forest sites that had higher percentages of occurrence of keystone species were also more species-rich and structurally more stable, indicating a disproportionate impact of these species. The results are in line with previous ecological research that has shown that the decline of keystone species can lead to cascading effects in biological communities. Accordingly, conservation strategies need to focus on the identification and protection of the keystone species to guarantee the sustainability of ecosystem services and maintain biodiversity in tropical forests in the long term.

## Conclusion

This study is the first quantitative evidence of the important ecological role played by these keystone species as components of tropical forest landscapes and their ability to maintain biodiversity and ecosystem stability. GBIF biodiversity occurrence data analysis showed a strong positive correlation ($r = 0.82$, $p < 0.05$) between keystone species abundance and biodiversity indices, suggesting that more abundance of keystone species leads to improved ecological resilience. The species richness (151 species) and Shannon diversity value (4.26) also were significantly higher for forest sites with higher keystone abundance than for lower abundance forest sites (84 species, 2.95, respectively). These statistical results demonstrate that keystone species are involved in the control of key ecosystem processes such as trophic stability, pollination, seed dispersal, and habitat maintenance.

The results highlight the ecological aspects of keystone species and their importance to conservation planning and ecosystem management, despite the fact that make up a small proportion of the biomass. It was also found that biodiversity hotspots were always congruent with areas of high occurrence of keystone species, meaning that important in the maintenance of ecosystem services when analyzed in space. The study gives evidence that the loss or decline of keystone species could lead to cascading ecological consequences that could damage forests' resilience and long-term sustainability of biodiversity.

Future studies should include temporal biodiversity monitoring, ecological network modeling, and climate-induced disturbance modeling for better prediction of keystone species dynamics under changing environmental conditions.

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