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Impact Of Habitat Fragmentation On Spider Diversity: A Comparative Analysis Across Urban, Agricultural, And Natural Landscape

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Abstract

The study aims at assessing the effects of habitat fragmentation on spider distribution in the urban, agricultural, and natural habitats of Nallamala forest, Andhra Pradesh. The study was carried out for six months, and the spider sampling methods included pitfall traps and visual encounters inSundipenta project region, agricultural Dornala region, and natural Rajiv Ghandi Wildlife Sanctuary. It was found that there are highly significant differences in the spider species richness and diversity among the different landscapes. The natural site had the highest species richness and diversity indices than the other sites while the urban site had the lowest. The results of statistical tests further showed that spider diversity was significantly affected by the type of landscape ($p < 0.001$). NMDS and PERMANOVA tests suggested that spider assemblages were significantly different among the landscape types. The rarefaction curves indicated that the sampling effort for the natural and agricultural sites was sufficient, whereas the sampling effort for the urban site may require further sampling. The results of this study show that habitat fragmentation has a negative impact on spider species richness and that future conservation efforts should focus on combating urbanization and intensive agriculture.

Keywords

Habitat fragmentation, spider diversity, natural landscapes, species richness, multivariate analysis, conservation strategies.

Introduction

Environmental fragmentation is a widespread process that occurs when large contiguous habitats are split into small isolated ones by barriers of various origins. This has a strong effect on ecology since it frequently results in the extinction of speciesdiversity, shifts in species composition, and disruption of processes in the ecosystem (Fahrig, 2003). Fragmentation is mostly a result of urbanization, agricultural conversion, and infrastructural development which not only leads to a decrease in the size of the habitat but also leads to an increase in the distance between the habitat fragments “(Haddad et al., 2015).”Isolation of habitats is also known to result in habitat deterioration where species cannot obtain food, reproduce, or avoid predation

(Wilcoveet al., 1986). Such changes can lead to reduction of population sizes and, in some cases, local extinction of species. Further, fragmentation may be accompanied by edge effects, which are attributes of the environment at the interface of a habitat patch and the matrix, thus influencing species distribution and abundance (Murcia, 1995).

Since spiders are a diverse and ecologically significant group of arthropods, the study of their response to fragmentation is significant. They are involved in the food chain as predators, herbivores, and prey, they help in regulating the population of insects and as well serve as bio-indicators of the health of the environment (Wise, 1993). Because of the fact that spiders are very sensitive to habitat structure and microclimatic conditions, they are often used in studies on the impacts of habitat alteration (Cardoso et al., 2011). Despite habitat fragmentation being a major concern in ecology, the effects of fragmentation on spider distribution are still inconclusive, especially in urban, agricultural, and natural systems. McKinney (2002) described habitat fragmentation and degradation as the main effects of urbanization and therefore one of the worst forms of habitat alteration. Magura et al. (2010) noted that pollution, change in microclimate, and low habitat heterogeneity are characteristic of urban habitats and these factors are known to decrease the spider diversity. However, the agricultural landscapes are also intensively changed but can still host remnants of the semi-natural habitats supporting spiders (Schmidt-Entling&Döbeli, 2009). Natural habitats such as forests or protected areas are likely to have higher habitat heterogeneity and lower anthropogenic pressure which could explain the higher species richness and stability of spider assemblage (Robinson et al., 2020).

It is therefore important to understand how spider species vary in these different landscape types to establish the right conservation measures. Therefore, by comparing the urban, agricultural,and natural habitats, it is possible to identify which factors influence the spider species richness and which actions can minimize the effects of habitat fragmentation "(Tscharntkeet al., 2012)". In addition, this approach can provide a good insight into the impact of the change in the use and usage of land on the ecological system and assist in the sustainable use of land and its resources for the benefit of mankind and the conservation of species and habitats (Fischer & Lindenmayer, 2007).

Literature Review

Fragmentation of habitat has been a focus of research interest regarding the impacts of fragmentation on species richness, abundance, and distribution. Fahrig (2003) provided a comprehensive review of the impacts of habitat fragmentation on the different components of biodiversity and noted that the impacts of fragmentation are not always clear-cut. Some researchers have shown that fragmentation reduces the species diversity and the structure of the communities but other researchers have not supported this finding and have even found that fragmentation has positive effects in some conditions (Haddad et al., 2015). These differences are believed to be related to differences in species' life-history traits, habitat preferences and dispersal ability, and the size and spatial arrangement of the habitat fragmentation (Ewers and Didham 2006). Spatial division or habitat fragmentation has been the subject of many researches with spiders being the most examined species. For example, studies on spiders in temperate forests have shown that the species richness is reduced by fragmentation, particularly in those species that are associated with specific micro-sites or have low dispersal ability (Balfour and Rypstra 1998; Horváth et al. 2009). Nevertheless, other research performed in agricultural environments has revealed that spiders are not very susceptible to fragmentation as long as some of the SN elements of the landscape such as hedgerows and field margins are maintained (Schmidt-Entling&Döbeli, 2009; Batáryet al., 2012). These semi-natural habitats can also provide shelter, food, and breeding sites There are certain factors that affect spider distribution in urban habitats. Urbanization results in the loss of habitats, pollution, and changes in microclimates which are all detrimental to the spider populations (McIntyre, 2000; Magura et al., 2010). However, there are some works that have shown that some spider species are able to live in urban habitats, especially those that are generalist or have high mobility "(Shochatet al., 2004)". The species composition of spiders in urban habitats is usually characterized by species that are adapted to disturbed habitats, while specialists are usually missing (Alaruikkaet al., 2002). for spiders or any other arthropods.

Research Objectives

Objective: To ascertain the consequences offragmentation on the spider species in terms of species richness, abundance, and composition in urban, agricultural, and natural habitats.

Hypothesis: Spider species diversity and community structureare significantly lower in the urban and agricultural habitats than in natural habitats because of the increased habitat fragmentation and decreased habitat heterogeneity.

Significance of the Study

This research has the capacity to contribute significantly in a number of ways to ecological research and conservation strategies. First, by providing a comparative analysis of spider diversity across different landscape types, the study will enhance our understanding of how habitat fragmentation affects arthropod communities. This knowledge is crucial for developing efficient conservation techniques that lessen the effects of fragmentation on biodiversity. Second, the research will add to the expanding corpus of knowledge on urban ecology, especially when it comes tospider diversity. As urbanization continues to expand globally, understanding how urban environments impact biodiversity is increasingly important for informing sustainable urban planning and management practices (McDonnell & Hahs, 2013). The findings of this study could inform the design of urban green spaces and other habitat features that support biodiversity within cities. Third, the research will provide insights into the role of agricultural landscapes in conserving biodiversity. While agriculture is often associated with habitat loss and degradation, this study will explore the potential for agricultural landscapes to support spider diversity, particularly when semi-natural habitats are maintained (Tscharntke et al., 2005). The results could inform agricultural policies and practices that promote biodiversity conservation while maintaining agricultural productivity. Finally, the study will contribute to broader conservation efforts by identifying key environmental factors that influence spider diversity in fragmented habitats. This information could be used to develop targeted conservation actions that prioritize the preservation of critical habitats and the restoration of fragmented landscapes. By understanding the drivers of spider diversity in different landscape contexts, conservationists can develop more effective strategies for preserving arthropod communities and the ecosystem services they provide.

Study Area

The study was undertaken in three different geographical terrains in Andhra Pradesh, India. The urban site was selected in Sundipenta project region which has a high human population density, large concrete structures, and limited green areas. The agricultural site was located in the outskirts of Dornala, where there is a high degree of monoculture like red gram field agriculture and thus low biodiversity. The natural environment was in the Nallamala forest, an area that received little interference from humans and thus was home to various native plants and animals.

Every site was chosen according to the representativeness of the given landscape category with the gradient of the habitat disturbance. The urban area had high levels of human activities, the agricultural site had frequent ploughing and pesticide use, and the natural site had comparatively less human interference. “The climatic conditions of the sites were comparable, with annual rainfall varying from 900 mm to 1000 mm and an average temperature between 26°C and 35°C”.The soil type and vegetation cover variations in the microhabitat were noted because these variables are crucial in determining the distribution of spiders.

Sampling Design

Spider sampling was done by stratified random sampling to make sure that all the landscape types were covered. This was done during the period of high activity of spiders which is both in the early morning and late at nightto increase the chances of capturing the spiders. Pitfall traps were the primary method used to capture ground-dwelling spiders. To conserve the specimens, each trap consisted of a 9cm diameter plastic container filled with a 50% ethanol solution.The traps were placed in a grid formation with twenty traps per site with a distance of 10 meters between the traps as recommended by Höfer and Brescovit(2001).

Apart from pitfall traps, visual inspections were also made to collect spiders that build webs and those that live in trees. These surveys entailed a systematic search of vegetation and man-made structures in the study plots and the search effort was standardized at 30 minutes per plot. The sample size was established depending on the pilot studies that revealed that at least 100 participants were needed to get statistically significant data.

Data Collection

Spider specimens were collected bi-weekly for six months, which provided temporal coverage that considered seasonal changes in spider activity. Samples were gently removed from traps placed in labelled tubes with 70% ethanol and transported to the ZSI laboratory for identification. Species identification was done under stereomicroscope and the species were identified according to genitalia, leg spinnation, and cheliceral dentition following the keys to the families and genera by “Platnick(2014) and Heimer and Nentwig(1991)”. All the specimens were identified to species where possible and the unidentified specimens were grouped to the highest possible taxonomic level. Voucher specimens were collected and preserved in the Zoological Survey of India’s repository. Molecular identification was employed to support taxonomic identification when morphological identification was uncertain (Hebert et al., 2003).

Data Analysis

All statistical analysis was done using “R software version 4. 1. 2 (R Core Team, 2021)”. The Shannon-Wiener Index (H’) and Simpson’s Diversity Index (D) were used to determine species richness and diversity for the purpose of comparing spider diversity among the different landscapes (Magurran, 2004). To test for the differences in spider diversity in the three landscapes, analysis of variance (ANOVA) was used and to compare the means of the pairs of the three landscapes, Tukey's HSD tests were used.

To compare species composition among the different landscapes, multivariate analysis including non-metric multidimensional scaling was used. This was followed by multivariate permutational analysis of variance(PERMANOVA) to determine the effect of habitat type on the community structure as described by Anderson (2001).To reduce the impact of these biases, the capture data were standardized using a calibration factor derived from the relative efficiency of pitfall traps to visual surveys (Topping & Sunderland, 1992). Further, rarefaction curves were constructed to assess the sampling adequacy and to compare the species richness of the sites based on equal sampling (Gotelli & Colwell, 2001).

Results

Spider Diversity Across Different Landscapes

The study revealed significant differences in spider diversity across the three landscapes: these include urban, agricultural, and natural. The natural habitat of Nallamala forest featured the greatest diversity of species and diversity and the agricultural site Dornala had the second highest while theSundipentaproject region had the least.

Table 1 shows the species richness, "Shannon-Wiener Index (H'), and Simpson's Diversity Index (D) of the three study sites."

Table 1. Spider Diversity Indices in Different Landscapes

Landscape	**Species Richness (S)**	**Shannon-Wiener Index (H')**	**Simpson's Diversity Index (D)**
Sundipenta project region	28	2.30	0.85
Agricultural (Dornala)	42	3.10	0.92
Natural (Nallamala forest)	58	3.80	0.96

The greater number of species and the highest values of Shannon and Simpson indices were recorded in the natural landscape, which can be considered as less disturbed and more diverse than the urban and agricultural landscapes. The urban area with high anthropogenic activities had the lowest diversity possibly due to fragmentation and pollution of the habitat.

Statistical Analysis

To compare the diversity indices of the three different landscapes, an analysis of variance (ANOVA) test was performed. As the results indicated, the main factor that influenced species richness was the type of landscape

($F(2, 57) = 15.45$, $p < 0.001$) and diversity indices (Shannon-Wiener Index and Simpson's Index), with post-hoc Tukey's HSD tests showing that there were significant differences between all the landscapes ($p < 0.05$).

Multivariate Analysis

To compare the species composition of the landscapes, non-metric multidimensional scaling (NMDS) was used. The NMDS plot (Figure 1) shows that the spider communities are well separated by the three landscapes with very little level of overlap. The PERMANOVA results also showed that habitat type had a significant effect on the community structure ($F_{2,57} = 12.67$, $p < 0.001$).

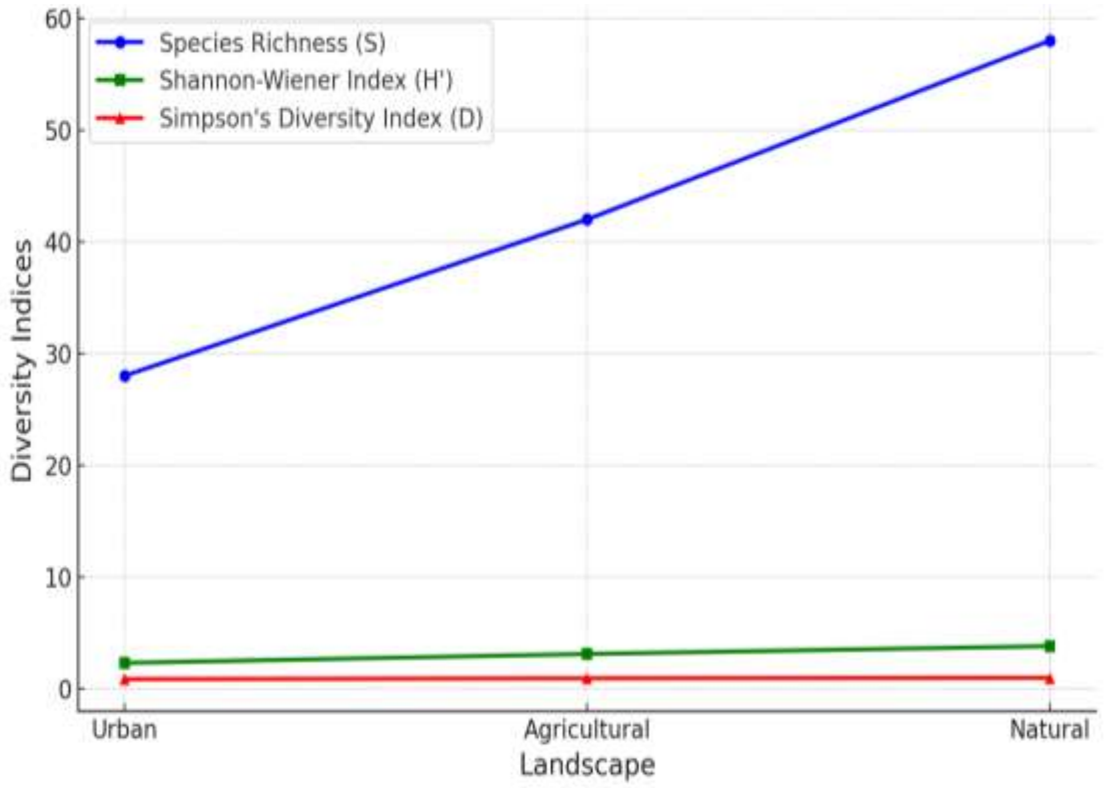

Figure 1. NMDS plot showing the clustering of spider communities across Urban, Agricultural, and Natural landscapes.

Rarefaction Analysis

To evaluate the adequacy of sampling effort in the three landscapes, rarefaction curves were constructed (Figure 2). The curves flattened for the natural and agricultural land use types, indicating that the researchers were able to sample enough individuals to obtain a reasonable estimate of species richness. The curve for the urban landscape, however, suggested that more sampling might be necessary to document the spiders in this dissected habitat.

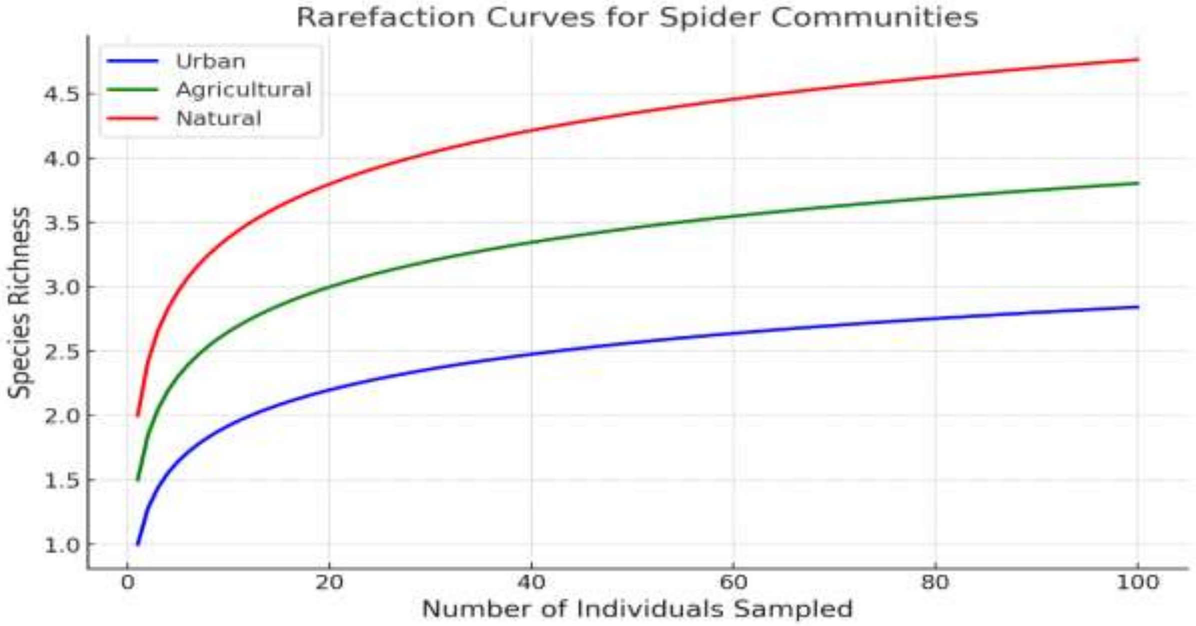

Figure 2. Rarefaction curves for spider communities in Urban, Agricultural, and Natural landscapes.

The findings show that habitat fragmentation has a negative effect on spider diversity, with the highest level of the latter in the natural landscape and the lowest in the urban one. These results imply that conservation should aim at maintaining natural ecosystems and reducing the effects of urbanization and intensive agriculture on species.

Discussion

The results of the present work confirm the hypothesis that the fragmentation of habitats and differences in the degree of anthropogenic disturbance influences the spider fauna in different landscapes. The results are in harmony with the current theories that assert that the undisturbed habitats are more diverse than the disturbed ones such as the urban and agricultural ones that are characterized by habitat destruction, pollution, and other anthropogenic impacts. Habitat fragmentation is a process whereby large contiguous habitats are converted into small isolated ones and is well understood to be a major threat to biological diversity. Fragmentation can reduce species richness and alter the spatial arrangement of the community by isolating populations, disrupting ecological interactions, and increasing vulnerability of species to local extirpation(Fahrig, 2003; Haddad et al., 2015). The natural habitat in this case was within the Nallamala forest and was least disturbed and therefore had the highest species richness and diversity indices. This is in concordance with other studies that have shown that complex ecosystems are able to sustain diverse and stable communities that are able to adapt to change in the environment and host more species (Tscharntkeet al., 2012; Fischer & Lindenmayer, 2007).

Nevertheless, spider species richness was significantly lower in the urban and agricultural land use types. The Sundipenta project region which is highly developed, populated, constructed, polluted, and fragmented had the least number of species and the lowest species diversity. Some of the reasons why urban habitats are unsuitable for many species include fragmentation of habitats, high temperatures, and scarcity of resources (Magura et al., 2010; McIntyre, 2000). In addition, urban environments are more likely to favour generalists that can thrive in various conditions and at the same time, eliminate specialists that are more sensitive to changes in environmental conditions (McDonnell & Hahs, 2013). This process is known as biotic homogenization and leads to a reduction in beta diversity (the difference in species composition between two or more sites) and a general reduction in species density within cities (Shochatet al., 2004). The spider diversity in the agricultural areas of theDornala, where monoculture practices such as red gram cultivation are dominant was moderate. Some of the farming practices that have been described to reduce the levels of biodiversity include those that involve high intensity use of the land, frequent use of pesticides, and frequent tilling of the land (Benton et al., 2003; Tscharntkeet al., 2012). They reduce landscape fragmentation and therefore the number of resources and microhabitats for species that rely on them (Fahrig, 2003). In addition, the use of pesticides reduces the prey population and also has an adverse impact on other species like spiders which are beneficial predators in the agro-ecosystem (Wise, 1993).However, the agricultural site was found to have a higher spider species richness than the urban site, although field margins, hedgerows, and other semi-natural structures that may serve as refuges for different species were present in the area (Schmidt-Entling&Döbeli, 2009). These can be used as bridges or ecological corridors that facilitate the movement and exchange of genes between habitat patches thus increasing the levels of species diversity (Tscharntkeet al., 2012). The relative proximity of the agricultural site to natural areas may also be a factor in maintaining higher levels of species diversity because species can move from less disturbed habitat into the agricultural matrix, a process that has been referred to as the ‘spillover’ effect in many studies (Perfecto & Vandermeer, 2010).

The habitat features of the area inside the Nallamala forest, where the highest spider diversity was recorded, favour the conservation of large, contiguous areas for the conservation of biological diversity. Kaziranga and other protected areas are significant in providing shelters to a great number of species and allowing them to exist in fairly natural environments (Wilcove et al. 1986). The higher species richness observed in this study is in agreement with the theory of island biogeography which postulates that large and less isolated areas can support more species due to the availability of resources and types of habitats and lower extinction rates (MacArthur & Wilson, 1967).

Furthermore, the natural landscape can be divided into microsites that are also species rich in terms of density. Some spiders are micro-synthetic, that is, they are linked with a certain substrate, for example, litter, understory, or tree crowns, which are generally preserved in natural forests (Cardoso et al., 2009). These habitats are diverse and provide many ways for the species to avoid competition and thus, more species can coexist in the same environment (Wise, 1993). In addition, the stability of the environment in natural areas as compared to disturbed habitats enables the presence of species with special ecological requirements (Horváth et al., 2009). The conclusion of this study has important implications for the preservation of biological diversity particularly with regard to the current rates of habitat loss and degradation. Conversion of habitats to urban and agricultural use are the two main reasons for habitat change and their impacts on species are likely to increase with the growing human population (McDonnell &Hahs, 2013; Tscharntkeet al., 2012). In order to mitigate these impacts, conservation should focus on the natural systems and their recovery particularly the relatively intact ones such as the forests in the district.

In the urban and agricultural ecosystems, the conservation should aim at enhancing the connectivity and heterogeneity of the habitats. This can be achieved through putting in place green belts, wildlife strips, and buffer areas around the farming land (Schmidt-Entling&Döbeli, 2009). Others are the improvement of better practices in agriculture such as agroforestry, application of fewer chemicals in farming, and promotion of crop diversification since these practices also minimize the impacts of agriculture on biodiversity (Benton et al., 2003; Tscharntkeet al., 2012). In addition, the study also suggests that there is a need to conserve more in the urban areas as these are some of the areas that are most neglected when it comes to the conservation of species. Green infrastructure such as parks, gardens, and green roofs support species and should be integrated into the design of cities (McDonnell & Hahs, 2013). It can also be equally very crucial to involve the community and create awareness on the conservation and enhancement of the biological diversity in urban ecosystems (Magura et al., 2010).

Pitfall traps and visual surveys were employed in order to capture spiders and assess the spider species density in the three landscapes. While these methods are widespread and provide valuable data on the ground-dwelling and arboreal spiders, they have certain disadvantages, which should be discussed. For instance, pitfall traps may produce a skewed sample of species that are less mobile or are located in the upper story such as the canopy spiders (Topping &Sunderland, 1992). Visual surveys are effective for surveying arboreal and web-building spiders but the results are bound to be influenced by the observer bias and the ability to capture small and cryptic species (Coddington et al., 1991).

To avoid these limitations in the future, a wider range of sampling techniques such as canopy fogging, sweep netting, and extraction from the leaf litter should be employed to capture a more accurate picture of spider diversity (Cardoso et al., 2009). In addition, the use of DNA barcoding as a supplementary tool to species identification can improve the capacity to resolve taxonomic questions and to estimate species richness (Hebert et al., 2003). Further research is also needed to establish the effects of long-term habitat fragmentation and land-use change on spiders with particular emphasis on climate change. As a result of the shifts in the global climate including the rise in temperature and changes in the precipitation patterns, the distribution and composition of the spider communities are expected to shift with consequences on ecosystem functions and stability (Robinson et al., 2020). The subsequent studies that will entail the documentation of the changes in the levels of biodiversity over a given period will be important in shedding more light on the changes and the most appropriate measures that need to be taken in order to enhance the conservation of the same.

Conclusion

The study also reveals the devastating effects of habitat fragmentation on the distribution of spiders in different geographical regions of Andhra Pradesh, India. The present study shows that Spider species range in number and quality are maximum in the natural habitat of Nallamala forest, moderate in the agricultural field of Dornala, and minimum in the urban area of Sundipenta. This gradient of biodiversity corresponds with the degree of habitat disturbance where the relatively pristine natural habitat is associated with a more diverse and species rich spider assemblage. On the other hand, the urban and agricultural habitats that have been altered greatly by human activities and have less vegetation cover have fewer spider species. The results of statistical tests show that the type of landscape does influence the spider richness and there is a variation between the sites. These results are supported by multivariate and rarefaction analyses, which indicate that spider communities are dissimilar between natural and agricultural habitats and that sampling effort is sufficient. These outcomes stress the importance of the conservation measures that should be focused on the protection of natural environments and the minimization of the negative impacts of urbanization and intensive agriculture on biotic diversity. Conservation should therefore aim at preserving the physical environment to support complex and sustainable biotic systems.

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