IJAMSR
International Journal of
Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281

# Fragmentation and Diversity: Towards Advancing a Conceptual Framework

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## ABSTRACT

Habitat fragmentation, caused by human activities like urban development and agriculture, impacts biodiversity and ecological processes. It leads to isolated ecosystems, declining species populations, and genetic diversity loss. Ecological networks aim to address these challenges by preserving essential conditions for ecosystem and species survival in fragmented landscapes. However, public institutions often overlook ecologists' and wildlife managers' expertise in planning, resulting in strategies that inadequately tackle habitat fragmentation complexities. Current land use planning focuses on cartography and ecology but lacks species specific understanding, leading to ineffective conservation measures. This gap hinders biodiversity conservation efforts by failing to consider species' unique needs and behaviours in fragmented habitats. This paper introduces a conceptual framework designed for planners, integrating ecological principles with actionable strategies to tackle the challenges posed by habitat fragmentation. The framework is organized into three distinct levels: 1. Layout, which underscores the significance of landscape patterns in shaping ecological processes and species interactions. 2. Purpose, which examines the spatial distribution of species and the effects of habitat fragmentation on these species over time. 3. Drafting/Management, which emphasizes the necessity of establishing corridors and stepping stones to improve connectivity between fragmented habitats, thereby fostering biodiversity and enhancing ecosystem resilience.

***Keywords: Habitat Fragmentation, Connectivity, Landscape Management, Development of Conservation Areas, Focus Species.***

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**International Journal of Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281**

## INTRODUCTION

Anthropogenic habitat fragmentation poses a significant and multifaceted threat to global biodiversity, impacting not only individual species but also the intricate web of interactions that sustain ecosystems. This phenomenon arises from various human activities[i], including urban development, agriculture, and infrastructure expansion, which lead to the destruction, reduction, isolation, and transformation of natural habitats. Each of these components plays a critical role in altering the structure and dynamics of populations, communities, and ecosystems, ultimately disrupting essential ecological processes such as nutrient cycling, pollination, and seed dispersal.

The destruction of habitats often results in the complete loss of ecosystems, leading to the extinction of species that depend on those environments. Reduction refers to the diminishing size of habitats, which can lead to smaller, more vulnerable populations that are less resilient to environmental changes. Isolation occurs when habitats become fragmented into smaller patches, making it difficult for species to migrate, find mates, or access resources, thereby increasing the risk of inbreeding and genetic decline[ii]. Transformation involves changes in habitat quality and composition, which can alter the ecological balance and favour invasive species over native ones. In response to these challenges, researchers and conservationists have proposed a variety of strategies aimed at mitigating the impacts of habitat fragmentation through effective landscape planning and management. One particularly promising approach is the establishment of ecological networks[iii]. These networks are designed to create interconnected habitats that facilitate the movement of species and the flow of ecological processes across fragmented landscapes. By maintaining essential ecological conditions, these networks support the persistence of ecosystems and the viability of species populations, even in the face of ongoing habitat loss[iv]. The concept of ecological networks is deeply rooted in established theories of island biogeography and population dynamics, which emphasize the importance of habitat connectivity and the role of spatial arrangements in biodiversity conservation. This approach marks a significant shift from traditional conservation strategies that often focus solely on the protection of discrete areas, such as national parks or wildlife reserves. Instead, the "chorological" landscape approach advocates for a more comprehensive perspective that considers the entire territory, recognizing that the health of ecosystems is influenced by the broader landscape context in which they exist[v].

By integrating ecological networks into landscape planning, conservation efforts can become more effective and resilient. This holistic approach not only enhances the chances of species survival but also promotes the overall health of ecosystems, ensuring that they continue to provide vital services to human societies and the planet as a whole. Ultimately, addressing the challenges of anthropogenic habitat fragmentation[vi] requires a collaborative effort that brings together scientists, policymakers, land managers, and local communities to create sustainable solutions that benefit both biodiversity and human wellbeing. To effectively implement the theoretical principles derived from ecology, it is crucial that planning processes incorporate the complexities and nuances of the "real world." This necessitates a multidisciplinary approach that brings together various fields of expertise. Applied ecologists and wildlife managers must collaborate closely with landscape planners and policymakers,

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International Journal of
Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281

despite the differences in the specific language and terminologies used within their respective disciplines. While this collaborative strategy is essential, it often does not lead to a comprehensive understanding of the fundamental conservation challenges that need to be addressed. The focus on teamwork and integration can sometimes overshadow the need for a deeper exploration of the core issues that underpin ecological conservation.

The planning processes are predominantly conducted by public institutions, which often operate within constrained timelines that do not permit a thorough ecological assessment. This limitation can result in decisions that are made without a full understanding of the ecological implications, potentially undermining the effectiveness of conservation efforts. As a result, the establishment of ecological networks—critical for maintaining biodiversity and ecosystem health—often relies heavily on cartographic tools. While these tools can provide valuable spatial information, they may not offer a sufficiently detailed ecological or functional analysis. This oversight can lead to a failure to adequately consider essential indicators of ecological processes, which are vital for informed decision making. The methodologies employed in these planning efforts may not align with established theoretical frameworks, leading to inconsistencies and gaps in the application of ecological principles, it is imperative that planning processes are not only collaborative but also grounded in a thorough understanding of ecological dynamics. This requires a commitment to comprehensive assessments, the integration of diverse perspectives, and adherence to established ecological principles to ensure that conservation efforts are both effective and sustainable. This method could lead to the development of a strategy that ultimately argue ineffective in achieving the desired outcomes of conservation initiatives. When planners rely on approaches that do not align with established ecological principles, they risk implementing measures that fail to address the complexities of ecosystems and the needs of the species they aim to protect. Consequently, it becomes imperative to equip planners with appropriate methodologies that are not only practical but also grounded in the theoretical foundations of ecology and conservation science. By ensuring that these methodologies are informed by robust ecological theories, planners can create strategies that are more likely to succeed in preserving biodiversity and maintaining ecosystem health. The aim of this study is to contribute to this goal by developing a comprehensive conceptual framework for planning that is specifically rooted in theories related to habitat fragmentation. Habitat fragmentation is a critical issue in conservation biology, as it can lead to the isolation of wildlife populations, disrupt migration patterns, and reduce genetic diversity.

This framework will focus on understanding the impacts of habitat fragmentation on wildlife, taking into account various factors such as species behaviour, habitat connectivity, and landscape composition. By integrating these theoretical insights into the planning process, the study seeks to provide a structured approach that can guide conservation efforts more effectively. Ultimately, the goal is to enhance the ability of conservation planners to devise strategies that not only mitigate the adverse effects of habitat fragmentation but also promote the resilience and sustainability of wildlife populations in their natural habitats.

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**International Journal of
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## THEORETICAL BACKGROUND

*Breaks and fragmentation of habitats*

Biological communities exhibit a spatial distribution characterized by natural patchiness, a phenomenon that arises from a complex interplay of environmental factors. These factors can vary along gradients such as altitude, moisture, temperature, and nutrient availability or follow identifiable trends that manifest across different spatial and temporal scales. This natural patchiness is essential for maintaining biodiversity, as it creates a mosaic of habitats that support a wide range of species and ecological interactions. Human activities have introduced significant changes to these naturally occurring patterns through habitat fragmentation. This process involves the division of relatively uniform natural habitats into smaller, more isolated segments, which can disrupt the ecological integrity of these areas. Habitat fragmentation can be dissected into several key components: habitat loss, which refers to the outright reduction of habitat area; a decrease in fragment size, which can lead to smaller populations and reduced genetic diversity; isolation of habitat patches, which limits the movement of species between them; and an increased edge to interior habitat ratio, which can alter microclimatic conditions and increase vulnerability to invasive species.

The isolation of these habitat fragments bears resemblance to the dynamics observed in true islands, a concept that has led some ecologists to apply theories of insular biogeography to terrestrial ecosystems. However, a critical distinction exists between island ecosystems and fragmented habitats on land. The anthropogenic matrix that surrounds these fragments composed of urban areas, agricultural lands, and other human modified environments can significantly influence ecological dynamics. The characteristics of this matrix, such as its permeability, land use practices, and the presence of barriers, can either facilitate or hinder the movement of species, materials, and energy between habitat patches. The specific vulnerabilities of different species to habitat fragmentation can vary widely. Some species may be highly adaptable and capable of thriving in fragmented landscapes, while others may be more specialized and sensitive to changes in their environment. This variability can lead to shifts in community composition, altered predator prey dynamics, and changes in species interactions, ultimately affecting numerous ecological processes. The consequences of habitat fragmentation are profound and far reaching, contributing to declines in biodiversity and the disruption of ecosystem services. As species become isolated, they may face increased risks of extinction due to reduced genetic diversity, limited access to resources, and heightened susceptibility to environmental changes. This phenomenon is increasingly recognized as a major threat to biodiversity, prompting conservationists and ecologists to seek strategies for mitigating its impacts and promoting connectivity between fragmented habitats. By understanding the intricate relationships between natural patchiness, habitat fragmentation, and ecological dynamics, we can better inform conservation efforts aimed at preserving.

*Impacts on diversity*

<u>Individual level</u> - The reduction in habitat size and increased isolation of landscape fragments can significantly affect ecological dynamics. Smaller and more fragmented habitats limit resources like

**International Journal of Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281**

food and shelter, altering dispersal patterns as organisms seek essential needs. Isolation can hinder movement, making mate-finding and territory establishment more difficult, which may lead to reduced genetic diversity through inbreeding. Behavioural changes may arise, with animals displaying increased aggression or caution, directly influencing survival rates. The impact of habitat fragmentation varies based on age, sex, fitness, and body size, with younger and less fit individuals being particularly vulnerable. Males and females may exhibit different behaviours, affecting their survival in fragmented environments. Larger animals may require more resources and territories, making them more susceptible to fragmentation effects. Understanding these dynamics is vital for conservation strategies aimed at addressing the challenges posed by habitat fragmentation on wildlife populations.

<u>Population level</u> - Habitat fragmentation can lead to local extinction, reduced populations, and changes in the social structures of sensitive species. It affects dispersal rates and gene flow, which can threaten species viability and increase extinction risks on a larger scale. There is a critical threshold of fragmentation beyond which species show reduced abundance due to smaller and more isolated habitats. Additionally, deterministic factors can directly or indirectly impact populations, while diminished numbers may lead to stochastic factors that hinder adaptability to environmental changes. Some species may exhibit delayed responses to fragmentation, complicating assessments of its effects. As habitat availability declines, certain populations may experience increased density within remaining fragments, which act as refuges.

<u>Local community level</u> - The attributes of habitat fragments, such as their dimensions, degree of isolation, configuration, and overall quality, play a crucial role in determining species composition and diversity. These elements interact with broader landscape processes, influencing ecological results. Typically, smaller fragments support a reduced number of species due to limited resources, while isolation hinders species movement and genetic interchange. The configuration of a fragment can produce edge effects that benefit specific species, and the quality of the habitat determines which species can thrive. Generalist species may experience an increase in diversity as they adapt to modified environments, often flourishing at the edges of fragments[vii]. Conversely, sensitive species face challenges due to competition and habitat degradation[viii], resulting in alterations in community structure. Such shifts can disrupt essential ecological interactions, including pollination, thereby impacting overall biodiversity and the functioning of ecosystems. Grasping these dynamics is essential for implementing effective conservation strategies in fragmented habitats.

<u>Level of landscape</u> - The spatial configuration of an ecosystem is crucial for the movement of energy and matter within it. This configuration includes the size, distribution, and quality of landscape fragments, which are distinct patches of habitat within a broader ecological context. Variations in these characteristics can significantly impact the functionality of the eco-mosaic, the complex interplay of different ecological patches and their surrounding environments[ix]. The matrix can influence edge effects, which are changes in population or community structures at the boundary between two ecosystems. For example, a well-connected matrix can provide alternative habitats for generalist species, allowing them to thrive and potentially disperse into adjacent fragments.

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**International Journal of**
**Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281**

Conversely, a fragmented or inhospitable matrix can impede movement, leading to isolated populations that may be more vulnerable to extinction. In fragmented landscapes, the matrix governs the flows of energy and matter, such as nutrients, water, and organic material. It can dictate how these flows occur, influencing processes such as nutrient cycling, water retention, and energy transfer between different parts of the ecosystem. Understanding the role of the matrix and its interactions with landscape fragments is essential for effective conservation and management strategies aimed at maintaining ecological integrity and resilience in fragmented environments[x]. Recognizing the importance of spatial configuration and the surrounding matrix can help us appreciate the complexities of ecological dynamics and work towards healthier, more interconnected landscapes.

Specificity to species - The survival and survival of a species in a fragmented landscape is a complex phenomenon influenced by intrinsic traits, external environmental conditions, and the nature of the fragmentation process itself. Intrinsic traits, such as the size of a species' home range, dispersal behaviour, and ecological requirements, play a crucial role in how a species interacts with its environment. Larger home ranges may be better equipped to navigate through fragmented habitats, while smaller species may find themselves isolated in insufficient patches. Dispersal behaviour is also critical, with species that can easily move between habitat patches being more resilient to fragmentation. External environmental conditions, such as climate, resource availability, and barriers like roads or urban development, also significantly influence a species' capacity to endure fragmentation. For example, a species that thrives in moist, dense forests may find it challenging to adapt to a fragmented landscape altered by drought or human activity. The impact of fragmentation is not uniform and is contingent upon several factors related to the fragmentation process itself. The nature of the fragmentation, the extent of habitat loss, the modality of fragmentation, the scale of fragmentation, and the temporal phase of fragmentation also play a significant role in species responses. Overall, the complexity of the fragmentation process and the factors that influence species survival in fragmented landscapes are essential considerations for understanding and managing the effects of fragmentation.

Ecological systems - Drawing from a thorough understanding of this issue, it is important to highlight that: the traditional focus on protecting individual sites and species needs to shift towards a more holistic, spatially integrated approach; habitats must be large enough and interconnected to enable the landscape to function effectively from an ecological standpoint. These principles have been outlined in recent international agreements, pan-European strategies, and national policies. The main goals of ecological network planning are to: safeguard natural ecosystems by expanding their size and increasing the number of protected areas; improve connectivity by taking into account species-specific dispersal patterns, reducing habitat isolation, and facilitating gene flow among populations that are vulnerable to fragmentation, thus ensuring their survival and enhancing the permeability of the surrounding landscape for the movement of at-risk species; integrate conservation principles into landscape planning initiatives.

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International Journal of
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**A STRUCTURE FOR CONCEPTUAL PLANNING**

The planning of ecological networks presents a complex challenge due to the diverse array of contexts, spatial dimensions, species-specific reactions to fragmentation, and the various ecological and anthropogenic factors present in the real world. Consequently, it is not feasible to establish a universal guideline. A methodological approach must take into account not only the study context but also the ecological tiers, objectives, and scales of analysis.

Context - The consequences of habitat fragmentation are contingent upon the specific characteristics of the landscape, influenced by local ecological and anthropogenic factors. Consequently, planners possess limited generalizations to guide their efforts. Each strategy, tailored to address particular local issues, should be viewed as a unique experiment from which both ecology and landscape planning can derive new insights.

Ecological levels - Conservation strategies and ecological planning will rely on the prior identification of sensitive targets, which may include species, communities, ecosystems, or processes. Generally, populations of individual species are more straightforward to study than higher levels of ecological organization and can serve as effective indicators for assessing the success of corridors and ecological networks.

Scale - Connectivity is associated with a scale that is appropriate for the ecology and dynamics of sensitive populations, as well as those that are ecologically linked. The effective scale for ecological network strategies seems to be at the landscape level. Consequently, it is recommended to implement strategies across multiple spatial scales, thereby encompassing a broad interspecific range of ecological needs and enhancing their effectiveness.

Framework level -The structural level serves as the foundation for the development of an ecological network. The use of thematic maps and remote sensing techniques enables the analysis of spatial structures and patterns within landscape mosaics, facilitating the identification of sensitive ecosystems, regions affected by human-induced fragmentation, as well as gaps and corridors. The remaining fragments can be classified based on various criteria, including type, size, shape, quality, isolation, spatial articulation, and their functional relationships with the surrounding matrix. Furthermore, the matrix itself can be examined according to its type, origin, extent of anthropogenic influence, along with ecological and spatial variables.

Active operational level–The arrangement of the landscape can influence the movement of energy and matter, as well as the dynamics of biological systems. Through structural analysis, certain functional characteristics can be identified: landscape ecology offers methodologies for an initial assessment of the cause-and-effect relationships between structure and function. Nevertheless, the preliminary structural analysis of the landscape may not necessarily align with an understanding of its connective functionality for sensitive species. For instance, certain species might struggle to disperse across areas that appear continuous from a structural perspective, potentially due to factors such as the edge effect.

Vol 6, Issue 5, 2023 **Impact Factor: 5.099** DOI: https://doi.org/10.31426/ijamsr.2023.6.5.6321

**International Journal of Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281**

Connectivity arises from both a structural-cartographic aspect and an eco-ethological, species-specific dimension. The varying roles that landscape elements play whether connective, neutral, or obstructive will depend on these two components for each species. Therefore, the design of a functional ecological network must incorporate a species-specific perspective regarding the structural patterns present in the landscape. Several models have been developed to incorporate the ecological significance of landscape elements in the dynamics of sensitive species, theoretically assessing the relationships between distribution/abundance patterns and landscape patterns. The functionality of structural patterns can be examined in terms of their roles as habitats and/or corridors, as well as the minimal specific requirements necessary for maintaining viable populations. However, discrepancies exist between the outcomes of these models and real-world scenarios: individuals do not disperse randomly across space, and their directional choices may be influenced by prior experiences with the landscape, conspecific attraction, and other ecological and ethological factors that are challenging to model. Consequently, it would be prudent to concurrently investigate populations within actual landscapes.

Determining target species –In the field of conservation biology, certain species can serve as surrogates to assess the integrity, diversity, and vulnerability of ecosystems. When planning conservation efforts, it is essential to identify species that are sensitive to fragmentation and may benefit from particular landscape features, such as habitats and connectivity areas, as they can serve as indicators of ecological processes. Given the varied responses of different species to fragmentation, it is prudent to simplify the approach by designating "umbrella" species for specific ecosystems. The selection of these target species can be conducted using a local checklist, guided by conservation, bio geographical, and ecological criteria.

The application of rarity criteria for the selection of species has been suggested in the context of nature conservation. Additionally, species that exhibit a sensitivity to fragmentation will also be chosen, even if they remain relatively widespread and abundant. Typically, these species are stenoecious, interior-dwelling, and sensitive to their habitat area; they may have experienced local extinction in isolated patches or may still exist in diminished numbers, yet they are not prevalent in human-altered environments. Large carnivores represent a group that is inherently sensitive to fragmentation and can serve as target, umbrella, or flagship species. A substantial amount of data is available regarding sensitive bird species. One may also choose to identify species that are tolerant to fragmentation, such as introduced, invasive, or generalist species, for which it is more advantageous to manage their dispersal.

The examination of distribution, abundance, and dispersal patterns of target species or guilds is a critical step in the development of a functional ecological network. This network is designed to include various essential components such as core areas, which serve as the primary habitats for these species; buffer zones that provide a protective barrier around these core areas; corridors that facilitate movement and gene flow between populations; stepping stones that offer additional habitat patches for species to utilize during their dispersal; and restoration sites aimed at rehabilitating degraded habitats to support biodiversity. To effectively create this ecological network, it is vital to

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**Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281**

incorporate ecological data and potential distribution models for vertebrate fauna. Recently, such data has become available on a national scale, providing a comprehensive overview of where these species are likely to occur based on environmental variables and habitat preferences. This information can significantly enhance our understanding of species distributions and inform conservation strategies. However, it is crucial to compare this potential distribution data with actual distribution data obtained from field surveys. These field surveys must be conducted over appropriate spatial and temporal dimensions to capture the full range of variability in species presence and abundance.

Relying solely on limited study areas and short timeframes can lead to misleading conclusions about the status, patterns, and dynamics of the target species. Such an approach may overlook critical seasonal variations, migratory behaviors, or local population fluctuations that are essential for understanding the ecological needs of these species. Therefore, a comprehensive assessment that integrates both potential and actual distribution data, gathered over extensive areas and time periods, is necessary to accurately inform the design and implementation of an effective ecological network. This holistic approach will ultimately support the conservation of biodiversity and the resilience of ecosystems in the face of environmental change.

Strategic and management level – The distribution and abundance patterns, derived from a functional analysis utilizing a target-species approach, can be assessed in relation to the presence and spatial configuration of the protected area system. The identification and design of nature reserves are influenced by both political considerations and conservation criteria; consequently, they may not align spatially with the habitats and corridors identified within the functional ecological network. By comparing various thematic layers, it becomes possible to assess the effectiveness of the protected area system, with a particular emphasis on identifying conservation gaps. The stratification of structural and functional data, in conjunction with information pertaining to the anthropic system, will facilitate the identification of critical areas, thereby enabling the selection of defragmentation and restoration measures.

## CONCLUSION

Incorporating ecological priorities into landscape planning is a strategic approach. The examination of ecological networks and the assessment of habitat fragmentation's effects on biodiversity and ecological processes indicate various mitigation strategies through a spatial and dynamic framework that encompasses the entire territory. To ensure the effectiveness of this strategy, it is essential to develop a comprehensive and scientifically grounded planning process that merges urban planning with ecological sciences. While ecological networks may not serve as a complete solution due to the intricate factors associated with fragmentation and the irreversibility of certain processes, they provide valuable concepts and conservation criteria that can be integrated into conventional planning, where anthropogenic and natural systems have typically been evaluated separately. Ultimately, this area of research offers the potential to enhance our understanding of both natural and planning sciences, paving the way for further investigations in theoretical aspects, such as species-specific sensitivity to area, isolation, and edge effects and applied ecology, including the design of nature reserves and the use of fragmentation-sensitive species as indicators.

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International Journal of
Advanced Multidisciplinary Scientific Research (IJAMSR) ISSN:2581-4281

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