

## **CHALLENGES AND INVESTIGATE THE BIODIVERSITY AND ECOSYSTEM: ROLE OF KEYSTONE SPECIES IN CONSERVATION STRATEGIES**

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### **Abstract**

Biodiversity and ecosystems are vital to maintaining the balance of life on Earth, providing essential services that support human well-being and environmental stability. This paper explores the significant challenges in investigating biodiversity and ecosystems, with a specific focus on the role of keystone species in conservation strategies. Keystone species are those whose presence and activities have a disproportionately large effect on their environment relative to their abundance. Their role in maintaining the structure, composition, and functioning of ecosystems makes them critical targets for conservation efforts. This paper reviews recent research and case studies highlighting how the decline or removal of keystone species can lead to cascading effects that disrupt ecosystems, ultimately impacting biodiversity. It also examines various conservation strategies that emphasize the protection and restoration of keystone species to preserve ecological balance. Through a comprehensive analysis of challenges and conservation approaches, the paper aims to underscore the importance of integrating keystone species into broader biodiversity and ecosystem management plans. The discussion includes strategies for identifying keystone species, monitoring their populations, and implementing conservation measures that address the root causes of biodiversity loss. By investigating the interplay between keystone species and ecosystem health, this paper contributes to a deeper understanding of conservation priorities and offers insights into

effective strategies for mitigating biodiversity loss and promoting ecosystem resilience.

**Keywords:** Biodiversity, Ecosystems, Keystone Species, Conservation Strategies, Ecosystem Health, Biodiversity Loss

## **Introduction**

Biodiversity, encompassing the variety of life forms on Earth, is fundamental to the health and resilience of ecosystems. It includes the diversity of species, genetic variation within species, and the variety of ecosystems. This complex web of life provides essential ecological services such as nutrient cycling, pollination, soil formation, and climate regulation. However, human activities have led to unprecedented rates of biodiversity loss, driven by factors such as habitat destruction, climate change, pollution, and overexploitation. Addressing these challenges requires a comprehensive understanding of biodiversity dynamics and the implementation of effective conservation strategies. Among the myriad factors influencing ecosystem stability and biodiversity, the concept of keystone species has emerged as a critical focus in conservation biology. Keystone species are those whose impact on their ecosystem is disproportionately large compared to their biomass or abundance. Their presence or absence can significantly alter the structure, composition, and function of ecological communities. For instance, sea otters are considered keystone species in kelp forest ecosystems because they control sea urchin populations that, if left unchecked, can devastate kelp forests. Similarly, apex predators like wolves in Yellowstone National Park play a crucial role in regulating herbivore populations and maintaining the health of entire ecosystems. Investigating the role of keystone species in biodiversity and ecosystem conservation involves addressing several key challenges. Firstly, identifying keystone species requires a detailed understanding of their ecological roles and interactions within their ecosystems. This often involves complex ecological studies and long-term monitoring to assess how changes in the abundance or behavior of these species impact ecosystem processes and other species. Another challenge is the integration of keystone species conservation into broader biodiversity management strategies. Effective conservation requires not only protecting individual keystone species but also addressing the broader ecological context in which they operate. This includes managing habitat loss, mitigating climate change impacts, and addressing other anthropogenic pressures that affect ecosystem health. Conservation strategies focused on keystone species often involve targeted protection measures, habitat restoration, and the development of management plans that consider the ecological requirements of these species. For example, conserving the habitat of keystone species can help ensure their survival while also benefiting other species that depend on the same habitat. Additionally, reintroducing or augmenting populations of keystone species can help restore ecological balance and improve overall ecosystem health. Furthermore, engaging local communities and stakeholders in conservation efforts is essential for the success of keystone species protection. Effective conservation strategies must address socio-economic factors and involve collaborative approaches to ensure that conservation goals are met while also considering the needs and perspectives of affected communities. This paper delves into the challenges of investigating biodiversity and ecosystems, with a specific focus on keystone species. It reviews recent research on the role of keystone species in ecosystem dynamics,

explores case studies illustrating the impact of their decline, and examines conservation strategies that prioritize the protection and restoration of these crucial species. By highlighting the importance of keystone species in maintaining ecosystem health and biodiversity, this paper aims to provide valuable insights into effective conservation practices and strategies for addressing the ongoing biodiversity crisis.

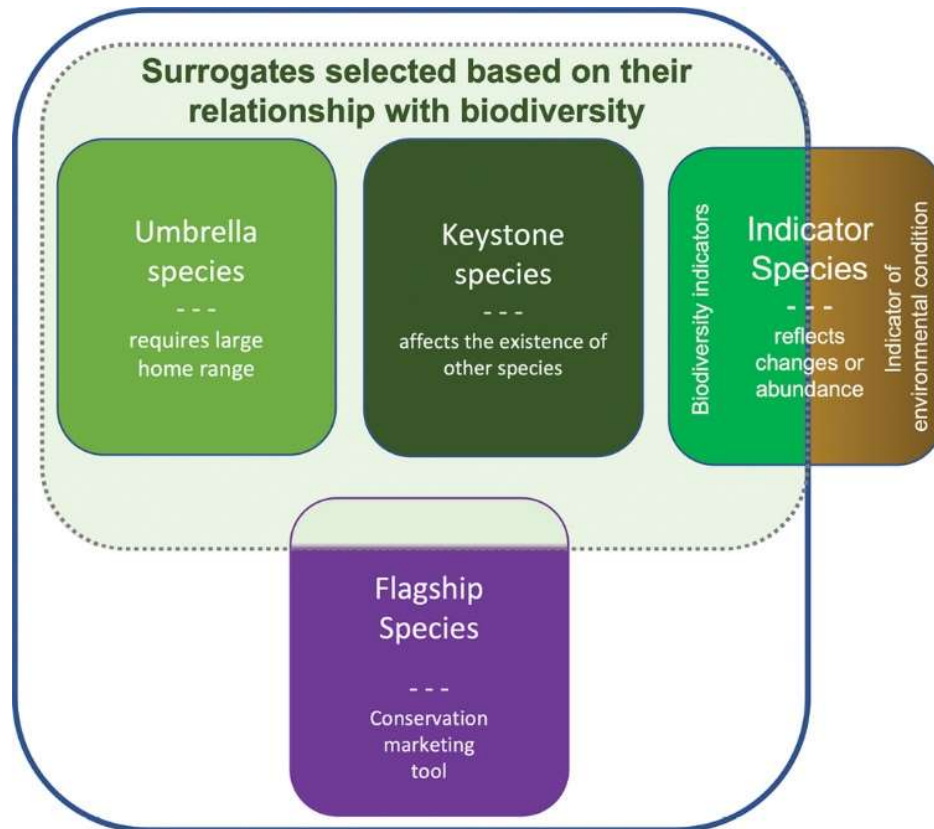


Fig.1: Examples of the most common surrogate types in conservation literature

## 1.1. Literature Review

The role of keystone species in ecosystems is pivotal for maintaining biodiversity and ecological balance, and recent literature highlights their importance in conservation strategies. This review synthesizes findings from recent research on keystone species, biodiversity, and ecosystem management.

### 1. *Keystone Species and Ecosystem Dynamics*

**Estes and Palmisano (2023)** explore the role of sea otters in kelp forest ecosystems. Sea otters are considered keystone species because they control sea urchin populations, which, if unchecked, can decimate kelp forests. The study emphasizes how the removal of sea otters leads to cascading effects, resulting in degraded kelp forests and a loss of biodiversity. This work underscores the critical role of keystone species in maintaining ecosystem structure and function.

**Paine (2022)** provides a comprehensive review of keystone species and their ecological roles. The paper discusses how keystone species, despite their relatively low abundance, have a disproportionate impact on ecosystem dynamics. Paine's review highlights various examples from marine and terrestrial ecosystems, demonstrating how the presence or absence of keystone species can drastically alter ecological communities.

## *2. Impact of Apex Predators*

**Ripple and Beschta (2023)** examine the role of apex predators in regulating ecosystem health. Their study on wolves in Yellowstone National Park illustrates how apex predators maintain ecological balance by controlling herbivore populations. The presence of wolves influences vegetation patterns and supports a diverse range of species, showing how apex predators act as keystone species in their ecosystems.

**Bertram and Vivier (2023)** investigate the impact of invasive species on keystone species and ecosystem stability. The research highlights how invasive species can disrupt keystone species' roles, leading to significant changes in ecosystem structure and function. This work is crucial for understanding how conservation efforts must address both native keystone species and invasive threats to maintain ecological balance.

## *3. Biodiversity and Ecosystem Resilience*

**Hooper and Vitousek (2022)** discuss the relationship between biodiversity and ecosystem resilience. Their study indicates that high biodiversity contributes to ecosystem stability by supporting a variety of functions and processes. The authors argue that conserving keystone species is essential for maintaining biodiversity and, consequently, ecosystem resilience.

**Díaz and Cabido (2022)** focus on plant functional diversity and its impact on ecosystem functioning. They provide evidence that diverse plant communities, including keystone species, enhance ecosystem processes such as nutrient cycling and primary productivity. This research highlights the importance of plant diversity in supporting ecosystem functions and suggests that conservation strategies should prioritize both keystone and functionally diverse species.

## *4. Conservation Strategies*

**Watson and Venter (2024)** address the integration of keystone species into broader conservation strategies. The paper emphasizes the need for conservation approaches that not only protect individual keystone species but also consider the broader ecological context. Effective strategies include habitat protection, restoration efforts, and management plans that address the needs of keystone species and their ecosystems.

**Barton and Barton (2023)** explore ecosystem-based conservation strategies, focusing on the challenges of integrating biodiversity and ecosystem services into management practices. They

argue that protecting keystone species is a critical component of these strategies, as it helps maintain ecosystem functions and supports overall biodiversity conservation.

### *5. Human Impact and Conservation Challenges*

**Smith and Knapp (2023)** investigate how human activities affect plant diversity and ecosystem function. The study reveals that habitat destruction, pollution, and climate change impact both keystone and non-keystone species, leading to a decline in ecosystem services. This research underscores the need for conservation strategies that mitigate human impacts and support the resilience of keystone species.

**McNeely and Scherr (2023)** discuss strategies for conserving biodiversity in agricultural landscapes. They emphasize the importance of integrating conservation practices with agricultural production to protect keystone species and maintain ecosystem functions. Their work provides practical recommendations for balancing agricultural activities with biodiversity conservation.

### *6. Future Directions in Conservation Research*

**Wilson (2022)** highlights the challenges and opportunities in conserving biodiversity in the Anthropocene. The paper calls for innovative approaches to address the complex interactions between keystone species, ecosystems, and human activities. It stresses the need for interdisciplinary research and collaboration to develop effective conservation strategies that address current and future biodiversity challenges.

**Ripple and Bertram (2023)** offer insights into conservation strategies for keystone species based on recent case studies. They argue that understanding the ecological roles of keystone species and implementing targeted conservation measures are essential for maintaining ecosystem health and biodiversity. Their recommendations include monitoring keystone species populations, protecting critical habitats, and addressing threats from invasive species.

Recent literature underscores the crucial role of keystone species in maintaining ecosystem structure and function. Effective conservation strategies must prioritize the protection and restoration of keystone species while addressing broader ecological and human-induced challenges. Integrating keystone species into conservation planning and management is essential for preserving biodiversity and ensuring the resilience of ecosystems in the face of global change.

#### **1.1. Role of Keystone Species in Conservation Strategies**

Keystone species are essential to the health and stability of ecosystems due to their disproportionately large impact relative to their abundance. Their conservation is crucial because their loss can lead to significant changes in ecosystem structure and function. This comprehensive discussion explores the role of keystone species in conservation strategies,

examining their ecological significance, the challenges faced in their conservation, and effective strategies for their protection and management.

## **1. Ecological Significance of Keystone Species**

### **1.1. Maintaining Ecosystem Structure**

Keystone species are fundamental in maintaining the structure and stability of ecosystems. They influence the diversity and abundance of other species, contributing to the overall balance of their environment. For example, **sea otters** (*Enhydra lutris*) are crucial in kelp forest ecosystems. They prey on sea urchins, which would otherwise overgraze kelp. This predatory role maintains the kelp forest structure, which supports a diverse marine community. Without sea otters, kelp forests would decline, leading to the collapse of the ecosystem that depends on them.

### **1.2. Regulating Ecological Processes**

Keystone species often regulate important ecological processes that shape their environment. **Wolves** (*Canis lupus*) in Yellowstone National Park are a classic example. Their predation on large herbivores like elk controls herbivore populations, which in turn affects vegetation and supports a wide range of other species. Wolves' presence influences the distribution of plant species and the abundance of various animals, demonstrating their role in maintaining ecological balance through top-down regulation.

### **1.3. Enhancing Biodiversity**

Keystone species contribute to biodiversity by creating or maintaining habitats that support a wide range of other species. **Beavers** (*Castor canadensis*) build dams that create wetlands, which are essential for many other species, including birds, amphibians, and insects. These wetlands provide critical habitat, support diverse plant life, and contribute to nutrient cycling, showcasing how keystone species enhance overall biodiversity.

## **2. Effective Conservation Strategies for Keystone Species**

### **2.1. Habitat Protection and Restoration**

Protecting and restoring the habitats of keystone species is a fundamental strategy for their conservation. Ensuring that keystone species have access to their critical habitats helps maintain their ecological roles. For instance, protecting riparian zones along rivers benefits species like beavers, which rely on these areas for dam-building. Habitat restoration, such as reforestation and wetland reclamation, can also support keystone species and help restore their ecological functions.

## **2.2. Targeted Management and Monitoring**

Effective conservation involves targeted management and monitoring of keystone species. This includes tracking their populations, assessing their ecological roles, and addressing specific threats. For example, managing sea otter populations may involve monitoring their health and abundance, protecting their feeding areas, and mitigating threats like oil spills. Ongoing monitoring helps evaluate the success of conservation measures and allows for adjustments as needed.

## **2.3. Integrating Conservation with Ecosystem Management**

Conserving keystone species requires integrating their protection into broader ecosystem management plans. This involves coordinating with other land and resource management activities to ensure that keystone species and their habitats are considered. For example, managing grazing practices in protected areas can support keystone species like wolves. Integration also involves addressing broader issues such as invasive species and climate change, which can impact keystone species and their roles.

## **2.4. Engaging Local Communities and Stakeholders**

Involving local communities and stakeholders is crucial for the success of conservation strategies. Engaging communities in conservation efforts helps build support, raise awareness, and address socio-economic factors. Community-based initiatives can involve local residents in monitoring, habitat restoration, and sustainable resource management. Collaborating with stakeholders, including policymakers, scientists, and conservation organizations, ensures that conservation strategies are effective and sustainable.

## **3. Case Studies**

### **3.1. Sea Otters and Kelp Forests**

The conservation of sea otters provides a compelling example of the role of keystone species. Efforts to protect sea otters have included measures to reduce human-related threats such as entanglement in fishing gear and oil spills. These efforts have led to the recovery of sea otter populations and the restoration of kelp forests, demonstrating the positive outcomes of targeted conservation strategies.

### **3.2. Wolves in Yellowstone National Park**

The reintroduction of wolves to Yellowstone National Park is a successful case study in keystone species conservation. The reintroduction has led to significant changes in herbivore populations, vegetation patterns, and overall ecosystem health. The success of this initiative highlights the importance of addressing both the ecological roles of keystone species and the broader context of ecosystem management.

### 3.3. Beavers and Wetland Ecosystems

The role of beavers in creating and maintaining wetlands demonstrates the importance of keystone species in supporting diverse ecosystems. Conservation efforts that protect beaver habitats and manage their populations help maintain wetland ecosystems, which support a wide range of plant and animal species. This case underscores the benefits of conserving keystone species to enhance biodiversity and ecosystem function.

Keystone species are critical to the health and stability of ecosystems. Effective conservation strategies must prioritize their protection and management, addressing challenges such as habitat loss, human impacts, and complex ecological interactions. By integrating keystone species into broader ecosystem management plans and engaging local communities, we can enhance biodiversity and ensure the resilience of ecosystems in the face of ongoing environmental changes. The conservation of keystone species is not only about preserving individual species but also about maintaining the ecological balance and processes that support life on Earth.

#### 1.1. Potential Challenges and Suggestions for Conservation Strategies Involving Keystone Species

##### *1. Potential Challenges*

##### **1.1. Identifying Keystone Species**

**Challenge:** Determining which species are keystone can be complex and requires extensive ecological research. Misidentification can lead to ineffective conservation measures. Keystone species are not always the most visible or abundant, making their roles and impacts less obvious.

**Suggestion:** Implement comprehensive ecological studies and long-term monitoring programs to accurately identify keystone species. Collaborate with ecologists and conservation biologists to assess the roles of various species in their ecosystems. Utilize methods such as network analysis and trophic modeling to understand species interactions and their ecological significance.

##### **1.2. Human-Induced Threats**

**Challenge:** Human activities, such as habitat destruction, pollution, and climate change, pose significant threats to keystone species. These threats can disrupt the ecological roles of keystone species and lead to cascading effects throughout the ecosystem.

**Suggestion:** Develop and implement strategies to mitigate human-induced threats. This includes habitat protection and restoration, pollution control measures, and climate adaptation strategies. Engage in advocacy and policy-making to address broader environmental issues that impact keystone species.



### 1.3. Ecosystem Complexity

**Challenge:** Ecosystems are complex and dynamic, with many interacting components. Changes in the abundance or behavior of keystone species can have unpredictable and cascading effects on other species and ecological processes.

**Suggestion:** Adopt an ecosystem-based management approach that considers the interactions among species and their environment. Use adaptive management practices that allow for flexibility and adjustments based on ongoing monitoring and feedback. Incorporate models and simulations to predict and manage potential impacts of changes in keystone species.

### 1.4. Conservation Prioritization

**Challenge:** Resources for conservation are often limited, and prioritizing which species to focus on can be difficult. Keystone species may compete with other species for attention and funding, potentially leading to imbalanced conservation efforts.

**Suggestion:** Prioritize conservation actions based on the ecological significance of keystone species and their potential impact on ecosystem health and biodiversity. Use a systematic approach to evaluate the conservation needs of different species and allocate resources accordingly. Develop a multi-species conservation strategy that includes keystone species and other important species within the ecosystem.

### 1.5. Stakeholder Engagement

**Challenge:** Engaging local communities and stakeholders in conservation efforts can be challenging. Conflicting interests, lack of awareness, and resistance to conservation measures can hinder effective management of keystone species.

**Suggestion:** Foster collaboration with local communities, stakeholders, and indigenous groups to build support for conservation efforts. Conduct outreach and education programs to raise awareness about the importance of keystone species and their roles in ecosystems. Involve stakeholders in decision-making processes and seek to align conservation goals with local interests and needs.

### 1.6. Invasive Species

**Challenge:** Invasive species can disrupt the roles of native keystone species and alter ecosystem dynamics. They can outcompete, prey on, or otherwise negatively impact keystone species, leading to significant ecological consequences.

**Suggestion:** Implement invasive species management plans to prevent and control the spread of non-native species. Monitor ecosystems for the presence of invasive species and take proactive measures to address infestations. Promote restoration efforts that support the recovery of native keystone species and their habitats.

## ***2. Suggestions for Effective Conservation Strategies***

### **2.1. Habitat Protection and Restoration**

**Suggestion:** Protect critical habitats and restore degraded areas to support the needs of keystone species. Establish and manage protected areas that encompass the habitats of keystone species, ensuring their survival and ecological roles. Implement habitat restoration projects to improve conditions for keystone species and associated ecosystems.

### **2.2. Targeted Monitoring and Research**

**Suggestion:** Conduct targeted monitoring to track the population health and ecological roles of keystone species. Invest in research to understand their interactions with other species and the environment. Use this information to inform conservation strategies and adaptive management practices.

### **2.3. Integrative Ecosystem Management**

**Suggestion:** Integrate the conservation of keystone species into broader ecosystem management plans. Address multiple factors affecting ecosystems, including land use, resource extraction, and climate change. Implement management practices that support the ecological functions of keystone species and enhance overall ecosystem resilience.

### **2.4. Community Involvement and Education**

**Suggestion:** Engage local communities and stakeholders in conservation efforts. Provide education and training on the importance of keystone species and their roles in ecosystems. Encourage community participation in conservation activities and decision-making processes.

### **2.5. Policy and Advocacy**

**Suggestion:** Advocate for policies and regulations that support the conservation of keystone species and their habitats. Work with policymakers to develop and enforce legislation that addresses threats to keystone species and promotes ecosystem protection. Support conservation initiatives through funding, incentives, and public awareness campaigns.

### **2.6. Collaboration and Partnerships**

**Suggestion:** Foster collaboration between conservation organizations, government agencies, researchers, and local communities. Build partnerships to enhance conservation efforts and leverage resources. Share knowledge and best practices to improve the effectiveness of conservation strategies.

## **2.7. Climate Change Adaptation**

**Suggestion:** Develop and implement strategies to help keystone species adapt to climate change. This includes monitoring climate impacts, identifying vulnerable species and habitats, and incorporating climate considerations into conservation planning. Support research on climate resilience and adaptation measures for keystone species.

## **2.8. Sustainable Practices**

**Suggestion:** Promote sustainable land use and resource management practices that minimize negative impacts on keystone species. Encourage practices such as sustainable agriculture, forestry, and fisheries that support the conservation of keystone species and their habitats.

## **2.9. Restoration of Ecological Processes**

**Suggestion:** Focus on restoring ecological processes that keystone species influence. This includes efforts to restore nutrient cycling, habitat structure, and species interactions that are essential for maintaining ecosystem health and function.

## **2.10. Continuous Evaluation and Adaptation**

**Suggestion:** Regularly evaluate the effectiveness of conservation strategies and adapt them as needed. Use monitoring data and feedback to make informed decisions and adjustments. Ensure that conservation efforts remain relevant and responsive to changing conditions and emerging challenges.

Addressing the challenges in conserving keystone species requires a multi-faceted approach that integrates scientific research, effective management, stakeholder engagement, and policy support. By implementing targeted strategies and addressing potential challenges, we can enhance the conservation of keystone species and protect the ecosystems they support. These efforts are essential for maintaining biodiversity, ecosystem resilience, and overall environmental health.

## **1.1. Discussion**

The conservation of keystone species is integral to maintaining the health and functionality of ecosystems, yet it presents multifaceted challenges that require comprehensive strategies. Keystone species, by definition, have a disproportionately large effect on their environment relative to their abundance, influencing ecosystem structure, processes, and biodiversity. Despite their importance, identifying these species and understanding their ecological roles can be complex, necessitating extensive research and monitoring. Human-induced threats, such as habitat destruction, pollution, and climate change, further complicate conservation efforts, often disrupting the delicate balance maintained by keystone species. Addressing these threats requires targeted actions, including habitat protection and restoration, which are critical to preserving the environments these species depend on. Additionally, effective conservation

strategies must integrate ecosystem management approaches that consider the complex interactions within ecosystems. Engaging local communities and stakeholders is also crucial, as their involvement can enhance conservation efforts and align them with local needs and priorities. Successful examples, such as the recovery of sea otters in kelp forests and the reintroduction of wolves in Yellowstone, highlight the potential for positive outcomes when conservation strategies are well-designed and implemented. Ultimately, maintaining the balance of ecosystems through the protection of keystone species is essential not only for preserving biodiversity but also for ensuring the resilience and functionality of natural environments in the face of ongoing environmental changes.

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