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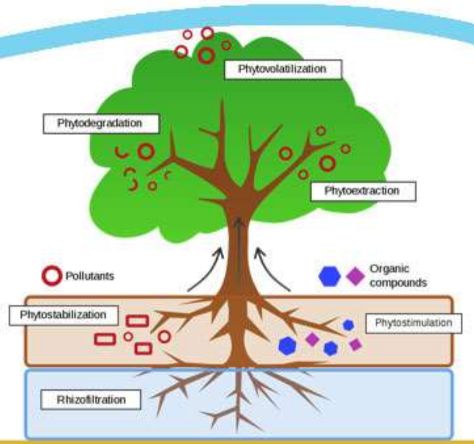

Paper No: 03 **Biodiversity and Conservation**

Module: 25 **Keystone Species**

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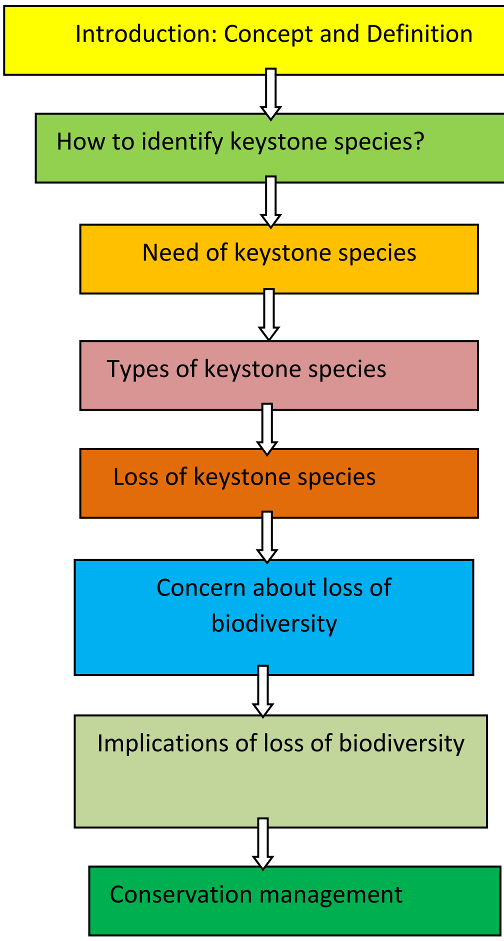
Description of Module	
Subject Name	**Environmental Sciences**
Paper Name	Biodiversity and Conservation
Module Name/Title	Keystone Species
Module Id	EVS/BC-III/25
Pre-requisites	
Objectives	a. To understand the concept of keystone species. b. to identify keystone species. c. To understand the need of keystone species. d. To understand the types of keystone species. e. To understand the impact of loss of keystone species and the associated loss of biodiversity. f. To understand the implications of loss of biodiversity. g. To understand the conservation of keystone species.
Keywords	

Module 25: Keystone Species

1. Objectives

h. **To understand the concept of keystone species.**
i. **To learn how to identify keystone species.**
j. **To understand the need of keystone species.**
k. **To understand the types of keystone species.**
l. **To understand the impact of loss of keystone species and the associated loss of biodiversity.**
m. **To understand the implications of loss of biodiversity.**
n. **To understand the conservation of keystone species.**

2. Content outline



Definitions:

Keystone species: The species that has a greater impact on its community than would be expected by the contribution of its overall numbers or biomass.

Umbrella Species: The species requiring large areas of natural habitat for their continued survival.

Iconic Species: The species having cultural significance and are involved in traditional activities and are broadly recognized for their existence and aesthetic values.

Flagship Species: The species selected to act as an ambassador, icon or symbol for a defined habitat, issue, campaign or environmental cause. By focusing on them, their habitat and other species which share the same habitat can also be conserved.

Guilds: A group of species with similar ecological features, similar requirements and play a similar role within a community.

Dominant Species: The species which influence community structure primarily by virtue of their great abundance or biomass. They are also called as foundation species.

3. Description (Keystone Species)

Concept and Definition:

Ecologically, "Keystone Species" concept is quite alluring. This term was originated in Robert Paine's study in 1966 on rocky shore community in California, where the entire species assemblage collapsed when the top predator (Carnivorous Starfish-*Pisaster ochracceus*) was removed.

Keystone species are those whose effect is large and disproportionately large relative to their abundance. Power et al. (1996) considered keystone species as dominants or the foundation stone species. Mills et al. (1993) determined the Community Importance Index (C.I.) as the strength of the effect of a species on a community per unit change in a measure of abundance (usually biomass) of the species. This change is measured in terms of a community trait such as productivity, species richness, etc. This effect can be positive or negative. Removal of the species entirely from the community and then measuring the resulting change with respect to a relevant community feature help in determining the Community Importance (C.I.) Index Generally, a species with an impact proportional to its abundance would have a C.I. of 1 whereas in case of keystone species, it would be greater than 1.

"Keystoneness" is not an intrinsic property of a species but it depends upon the functional role of a species in a particular community. In other words, keystone status of a particular species is entirely context-dependent or it may vary from one ecological situation to another. Menge et al. (1994) reported starfish (*Pisaster ochraceus*) as the keystone species due to its predation on mussels on wave-exposed rocky headlands. Another set of experiment by Navarrete and Menge (1996) described whelks as keystone species in the absence of starfish, but not in their presence. Thus, we can conclude that keystone role can be adopted by different organisms. Keystone role of a species cannot be really predicted on the basis of life history traits **but can be identified by identifying their role/function in specific communities**. For instance, Prairie dog (*Cynomys ludovicionus*) is an inhabitant of wide variety of grasslands but is reported as keystone species in North American Grasslands. Now the question is whether it acts as a keystone species in all of them. The answer to this question is that each type of grassland acts like a different "context" where separate assessment of the prairie dog's role is required to consider it as a keystone species.

Keystone species is known to maintain the structure of an ecological community. Due to its relative abundance, its impact is greater on the community. Their absence sometimes alters the native ecological community and disturbs many other species, as well, in a negative manner. Generally, keystone species are predators and even their small population has a great impact on the distribution, number and behavior of prey species. This interdependency among the different components of an ecosystem can be easily understood from this example-Elephant in Savannas act as keystone species. Their dependency on Acacia for food prevents Savannas from turning into woodlands and allows the grasses to flourish well. This benefits other animals such as wildebeets, zebras, antelopes, etc.

How to identify Keystone Species?

Identifying keystone species is a challenging task. A variety of approaches have been used, either singly or in combination. Comparative studies, natural experiments, natural history observations, and experimental manipulations have been used but no concrete methodologies have been developed so far.

The best way to demonstrate the keystone role of an individual species in a particular community is the experimental removal, but it is impractical due to ethical, social, technical and logistical reasons. In this complex scenario, Power et al. (1996) suggested the combination of manipulative experiments with modeling approaches such as path analysis (Wooton, 1994). Following this methodology, one or few strongly interacting species are experimentally reduced or removed and the following change is observed in a much wider range of species within the community. Generally, interpretation of removals does not indicate clear results. Moreover, in case of multiple removals, it is often not possible to determine whether the resultant changes are due to a single keystone species or the collective impacts of various members of a trophic level.

The consequences of experimental manipulations for other species in the community are time consuming and the spatial scales applied for results are extremely variable. Generally, the impact of species manipulations is observed more frequently in aquatic ecosystems. For instance, Paine (1971, 1974) reported significant changes after the removal of starfish from rocky shore communities within less than 12 months whereas the actual effects may not become apparent for decades or even centuries.

To overcome experimental manipulations, natural history observations or comparative studies using habitats with varying densities of putative keystone species are employed. Individually, both the approaches lack meticulous results because of the subjective nature in the former case and in the latter due to difference in two sites, since no two sites can be exactly the same. However, in combination both can be extremely useful for identifying hypothesis and for determining the genuineness of experimental results.

How to determine potential keystone role of species by natural experiments?

- ✓ Invasion of organisms in new environment ⟶ significant changes in species abundance
- ✓ Overharvesting of natural population
- ✓ Deliberate eradication of pest species

Drawbacks of natural experiments

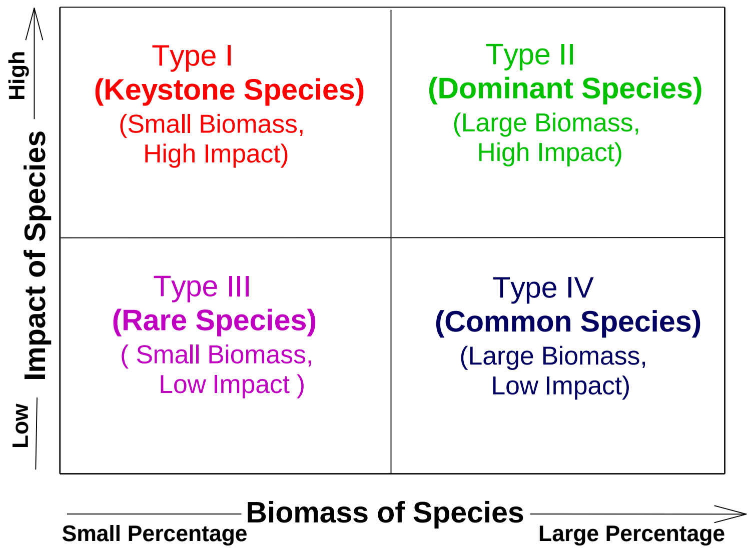
- ✓ Lack pretreatment baseline
- ✓ Inability to find comparable non-manipulated sites
- ✓ Replication of treatments is not feasible.

Need of keystone species

1. Keystone species influence species diversity. Sometimes, keystone species also act as umbrella species which provide protection to many other species. Their health determines the condition of other smaller species as well. Removal of keystone species from a community initiates a chain reaction and disturbs other species, where some species become abundant while others decline.
2. They stabilize the community structure. Their health determines the condition of other smaller species and stabilizes the entire community structure.

These two factors have proved elusive for the ecological conservationists in order to focus their conservation efforts.

Fig.1. Typology of group of species with similar ecological functions within a biological community with respect to their biomass and impact on the ecosystem.



Types of Keystone Species

Keystone Species not only control potential dominants but also provide critical resource. They work as mutualists to modify the environment. They can be classified as following on the basis of their functional role in an ecosystem

1. **Organisms regulating dominant species:**

The best example of keystone species is the one who regulates the population of a potentially dominant species. This reduces competition amongst other species for a limiting resource and promotes coexistence. For instance, in Paine's rocky shore community (Paine 1966, 1974) the primary resource is space and the dominating species "mussel" tends to occupy the entire rock surface. Here the keystone species is starfish which tends to keep the population of mussels in check. Another top predator like Triton gastropod "Charonia" controls species diversity by eating starfish, thus preventing over consumption of corals by the starfish. Removal of Triton will not only reduce coral population but also community degradation at the subsequent levels.

Darwin noticed that the activities of Cats affect the population of red clover. There was a sequence in the food chain where cats fed on mice which damage the nests of bumble bees, which in turn pollinate the clover flowers. These are relatively simple food chains which exist without strong collateral connections and the keystone effects of this type are probably most frequent.

In some cases, pathogens also function as keystone when they affect predator or herbivore populations which further have flow-on effects for rest of the community. Well-documented example includes rinderpest virus and anthrax bacterium, which affected grazing mammal population in Africa. This had a flow-on effect, where reduction in the pressure of the grazing land facilitated regeneration of woody species and displaced the grassland communities.

The elimination of even a small number of individual predators (although they constitute a minute amount of community biomass) may result in dramatic changes in vegetation and a great loss in biodiversity, called as "**trophic cascade**".

2. Resource Suppliers

Another type of keystone species is the one that provides a vital resource to a range of organisms at times of paucity, although it occurs seasonally. Sometimes, the resource provider itself may not be an abundant species but in case of its removal, the dependent organisms are not able to meet the supplies. Sometimes, keystone plant resources such as fruits are not available in abundance and animals have to feed on alternative sources of nourishment during seasonal shortages.

Ficus acts as a keystone resource provider in many tropical forests. Due to its continuous seasonal fruiting, specialized wasp pollinators rely on *Ficus*. Further, 29 *Ficus* species in a

Malaysian forest acted as keystone resource provider for a variety of frugivores. However, in some forests, *Ficus* trees are scanty in their distribution and act as keystone resource providers for highly mobile species with large home ranges. In some of the tropical forests, like Gabon, *Ficus* is not available in plenty to be a keystone resource provider. Rather, the need is fulfilled with two species of Myristicaceae and one of Annonaceae for frugivorous birds and monkeys.

Additionally, presence of microorganisms sometimes enhances a limiting nutritional resource. For instance, after volcanism, nitrogen-limited forest communities develop with the help of invasive symbiotic nitrogen fixer, which acts as a keystone resource provider. Enhanced nitrogen availability has subsequent effects in terms of litter accumulation, nutrient cycling, earthworm population and cause major changes to the formerly open canopied forests.

3. Mutualists

In this case, the two species are mutually dependent on each other or in other words, they act as keystone for each other. Mutualism can also occur in groups, like fruit producers, seed-dispersing frugivores, pollinators and groups of plants, all are mutually dependent on each other. It is a risky strategy and is rarely found in most of the communities. However, it is common in case of orchids and their specialist pollinators. According to Darwin, it is a good example of plant-pollinator co-evolution.

In the fynbos vegetation, number of plants is exclusively pollinated by a sparse fauna of long-tongued flies, oil collecting beetles, monkey beetles, carpenter bees and butterflies. This illustrates good example of pollination mutualism.

Sometimes, the mutualism is disproportionate. For instance, in Malaysia certain fig eating specialist birds depend exclusively on fig whereas fig does not depend exclusively on these birds for seed dispersal. Further, there are cases when several species depend upon a single mutualist. In case of guild of eight plant species with long tubular flowers depending exclusively on single species of long-proboscis fly for pollination clearly demonstrate keystone role of the long-proboscis fly, acting as a single mutualist.

Many-a-times, one-to-one-mutualism could act in a keystone community if any one of the partner had strong interactions with other species in the community. For example, *Ficus* trees and fig wasps are mutually dependent. The *Ficus* trees are keystone resource providers for frugivores and these frugivores, in turn, are the essential seed dispersal agents for a wide range of plants. Fig flowers are pollinated by small, highly specialized fig wasp, which mature inside the developing fruit. The fig wasps are one of the best examples of keystone mutualist. In this case, the health of fig tree population depends upon the health of their wasp pollinators and in turn fig wasps rely on them for food and for their development. The mutualistic relationship between trees and the wasps forms the foundation of the entire community's health.

4. Ecosystem Engineers

Organisms modify the physical environment, thereby, providing resources to other species; organisms provide habitats to some species which would not have been available otherwise due to disturbance in physical habitat-the organisms bringing out such structural alterations, have been referred to as ecosystem engineers. They can be called as keystone species if their effects are large and disproportionate to their abundance.

This function of ecosystem engineer is best illustrated by dam building beavers, nest building by ants and termites, vegetation destruction by elephants and hole drilling by woodpeckers, wallow creation by alligators, burrowing by rabbits, moles, rats, earthworm action in soil, etc. Normally, the provision of habitat and other resource is incidental of engineering activity of keystone species. The benefiting organism gets adapted to exploit the resource and is considered as "opportunist". For incidence, the Red-naped sapsucker's abandoned nesting holes are occupied by two species of swallow. Not only this, its feeding holes in willows provide sap flows for a variety of birds, mammals and insects. Thus, its engineering activities prove a good example of "incidental" provider of both food and habitat, that too of disproportionate importance.

Termites, one of the true ecosystem engineers exhibit a keystone status in Brazilian cerrado community. Apart from termites, many other occupants such as ants, beetles, flies, wasps, bees, scorpion, centipedes, spiders, lizards, snake, mice and birds were recorded in termite mounds. This shows a high degree of adaptation in the benefiting species. The elimination of termites from this community would affect drastically community structure and species diversity.

Sometimes, it is difficult to distinguish the keystone role of an organism as a predator or an engineer. It is best illustrated by large grazers who act as ecosystem engineers as well as herbivores. By grazing, they suppressed the invasion of woody species and helped in maintaining open grassland vegetation. They exhibit a classical example where they profoundly alter the physical structure of the community.

In assessing the keystone role of an organism as an ecosystem engineer, it is necessary to explore how profound the physical effect is, what is the ratio of disproportion, how many other species benefit out of it and what is the rate of their dependence on the alteration?

Loss of Keystone Species

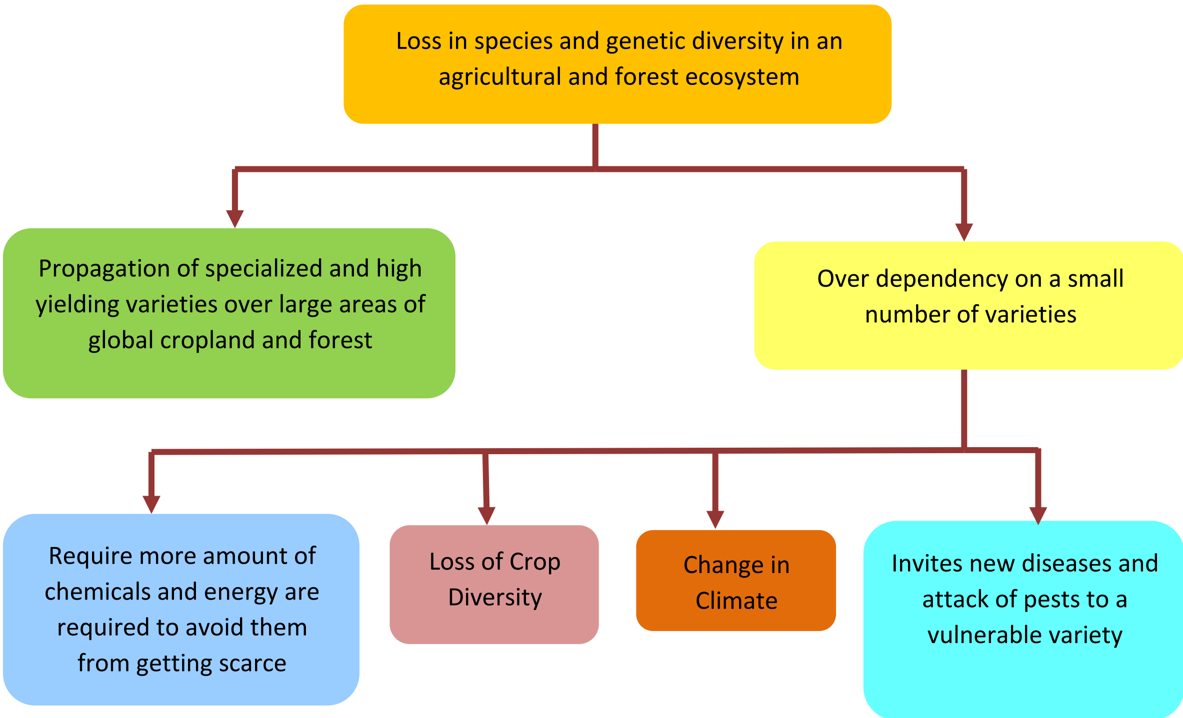
This can lead to series of extinction effects, known as "**extinction cascade**". This reduces the biodiversity at all trophic levels. For example, overharvesting in tropical forests has significantly reduced the populations of birds and mammals that act as seed dispersers, predators and herbivores. Such type of forest looks green and healthy superficially but actually it is an "**empty forest**" where all the ecological processes have been irreversibly altered, thereby eliminating various plant and animal species over the succeeding decades or centuries. Thus, keystone species not only maintain the ecosystem structure and function but also the persistence of many other species.

Concern about loss of biodiversity

Biodiversity is defined as the variety of life forms, the ecological roles they play and the genetic diversity they contain. Their habitat and landscape diversity is also considered. To maintain redundancy in an ecosystem, a single species or group of species carry out major functions and provide links in the food web. While analyzing the impacts of removal or addition of species, it is necessary to explore whether it is a keystone species or not. Since, their loss will alter the community structure and disturb the ecosystem functioning. However, invasive species often become a keystone species that reduces diversity.

Implications of loss of biodiversity

Reduction in species and genetic diversity, particularly in agricultural and forest ecosystem results in some short term benefits, such as, propagation of specialized and high yielding varieties in large areas of cropland and forests. However, over dependency on small number of varieties reduce crop diversity (for instance, out of 537 varieties of rice only 78 are cultivated in India); require more amount of chemicals and energy to prevent them from getting scarce (like ruthless use of insecticides has resulted in the loss of natural enemies of the pests and now reinvestment is required to reinstate them in the food chain in order to maintain natural biological control and stabilize the natural ecosystem); result in change of climate (for example, increase in rice cultivation area contributes methane by approximately 1.5% of total greenhouse gas emissions, which cause global warming and climate change); and invites new diseases and attack of pests to a vulnerable variety (illustrated by the pure lines of wheat cultivated in ancient past which were more susceptible to diseases and attack of pests).



Conservation Management

- Bewildering array of species, communities and ecosystems are subjected to variety of internal and external influences which impose challenges for conservation managers.
- Due to this complexity and the ever increasing demands for limited resources-the issue is how to maintain indigenous biodiversity and retain functional natural ecosystems?

- It has been difficult to monitor and manage all aspects of biodiversity which has further paved the way to focus on either single species or whole ecosystem.

Conflict between single species approaches and whole ecosystem Paradigm

Single Species Approach	**Ecosystem or Landscape Paradigm**
Indicators create disagreement over what they indicate.	It emphasizes on ecological processes and habitat in order to maintain healthy ecosystem and preserve the biological diversity in a best manner.
Umbrella species raise questions over the range of biological diversity, they shelter.	With proper scientific knowledge, existing biodiversity can be preserved.
Iconic species are often difficult to maintain and they might require orderly arrangement procedure that clash with other elements of the natural biota.	Targeting a single species will not only exhaust the financial resources but will also lead to wastage of time. Many-a-times not much significant change is observed in the key processes due to disappearance of threatened species.

Thus, keystone species can be conserved easily by emphasizing on ecological processes and their habitat in order to maintain ecosystem diversity and to stabilize the community structure.

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