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Chapter- 4

Reproductive Ecology of Plants: A Key Approach to Effective Conservation

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Abstract:

Pollination ecology, or reproductive ecology, represents one of the most fascinating and holistic interactions between plants and animals. Various animals, at least during a part of their lifecycle or livelihood, depend on plants for food, shelter, mating grounds, or breeding sites. In return, plants share their valuable resources with these animals, intentionally or unintentionally, as part of a reciprocal relationship. Plants entrust animals with the task of transferring pollen grains to suitable stigmas and seeds to appropriate germination beds (soil). To ensure the success of this interaction, plants have adapted and co-evolved to meet the animals' needs, making themselves inseparable from the ecological niche of these animals. This relationship builds an ecological equilibrium so strong that the entire ecosystem could collapse if a single element is removed. Therefore, studying and understanding the relationships between all organisms within the biosphere is crucial. Knowledge will guide the development of sustainable conservation strategies that, to some extent, can heal the environment and protect it from further harm.

Introduction:

Reproduction is one of the most significant characteristics that differentiate living entities from non-living ones. The perpetuation of life on Earth necessitates the creation of replicas of individuals, allowing the transmission of genetic material to the next generation. Therefore, reproduction can be defined as the multiplication of individuals within a species at a given time, ensuring the sustenance of that species. Angiosperms reproduce both sexually and vegetatively. In vegetative propagation, a clone of an individual is produced without any genetic variation. Genetic variation among individuals of a species is essential to maintain adaptability in response to a changing environment, ensuring the population's survival over time. This genetic variation is achieved only through sexual reproduction, as half of the genetic material of any plant is contributed by the female parent and the other half by the male counterpart. Regarding non-nuclear genes (mitochondrial and chloroplast genes), the contribution of females is slightly higher.

Angiosperms release two types of disseminules into nature during sexual reproduction: pollen grains, released before fertilization, and seeds, released after fertilization. The reproductive success of any plant depends on whether the disseminules released without control can reach their respective destinations. A pollen grain must reach the receptive surface of a

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compatible stigma, where it can germinate. Given the uncertainty in pollen transport, only a tiny fraction of the pollen grains produced by a flower successfully reach a compatible stigma. Additionally, each species has a fixed pollen longevity. A pollen grain that fails to reach a receptive stigma within its viability period is useless to the plant. Therefore, the primary requirement for successful sexual reproduction is the transfer of viable pollen grains from the anther to a receptive stigma, a process known as pollination. Successful pollination often requires the active involvement of biotic or abiotic agents, a process facilitated by the flower's intricate morphological and physiological characteristics (Mandal, 2020). In cases where animals are involved in pollination, flowers offer various attractants and rewards. These flowers are designed in such a way that their functional organs, the androecium and gynoecium, remain well protected.

Seeds carry the embryo of the future plant. Like pollen grains, the successful placement of a seed in a suitable environment is essential for germination and, ultimately, the development of a new individual. To disperse seeds over long distances, plants adopt several morphological modifications in seeds and seed-bearing organs and utilise biotic and abiotic agents.

Due to the increasing human population and resulting habitat destruction, along with other anthropogenic effects, the rate of plant species extinction is rising. According to the IUCN (1998), there are currently over 270,000 extant plant species; of these, approximately 34,000—or one in every eight—are endangered. Many have become regionally threatened, and it is estimated that nearly 25% of plant species are at risk of extinction within a few generations (Raven, 1987). Both in situ and ex-situ conservation of plant species is crucial to mitigate this loss. In situ conservation ensures the preservation of habitats, thus protecting both plants and their associated organisms, such as biotic vectors (Pence, 1999). In this chapter, the pollination ecology from the perspective of both plants and their pollinators will be discussed to formulate a possible holistic approach to biodiversity conservation.

Biotic Pollinators

According to Baker et al. (1971), pollinators can be classified into major and minor. Minor pollinators visit various types of flowers within their locality, feeding on nectar and pollen grains and occasionally conducting accidental pollination. They are not dependent on a specific plant or group of plants, nor are the plants dependent on them. For example, even a boy climbing a Jujube (Kul) tree may unintentionally pollinate some flowers simply by shaking the flowering branches together. Who would have thought that *Homo sapiens sapiens* could be a pollinator of *Ziziphus jujuba*? However, *Ziziphus jujuba* produces fleshy pulp and nectar as rewards, not only to attract its primary pollinators but also to engage other animals, including humans, in pollination without them realizing it.

On the other hand, significant pollinators are more focused and effective than minor ones. These pollinators, mainly insects, depend on the flowers for food, shelter, breeding places, or a combination. The relationship between plants and insects is dynamic in evolutionary terms. It is rare to find a one-blossom-one-pollinator relationship. The relationship should be viewed from both the plant's and the pollinator's perspectives, schematically represented below, for better understanding (Faegri and Van Der Pijl, 1979).

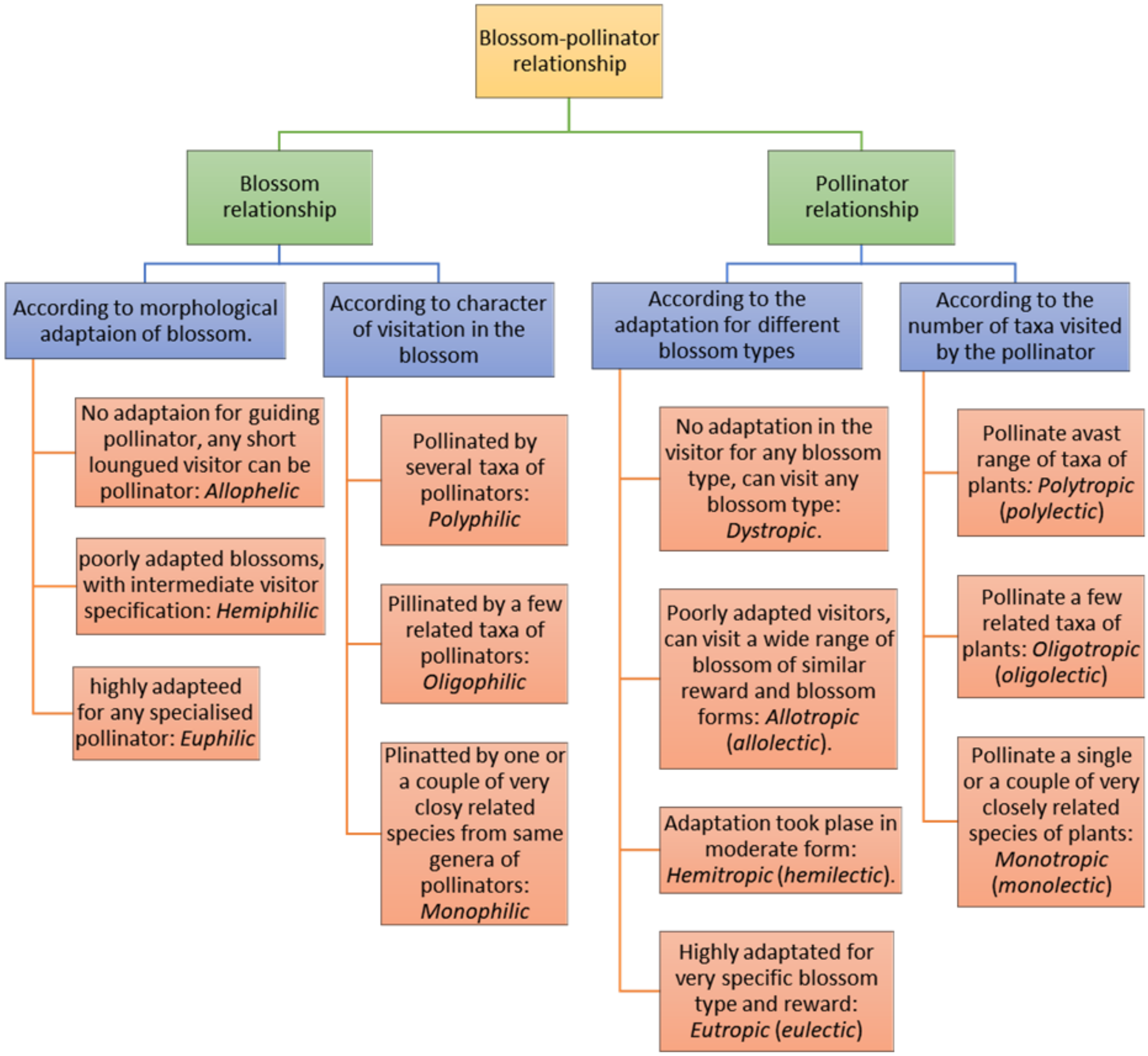

Figure 1. The schematic representation of blossom *vis-à-vis* pollinator relationship.

A monotropic visitor (Figure 1) typically does not visit any other plant species except for its preferred ones. Cruden (1972) suggested that oligolectic bees switch their pollen sources only without their preferred pollen. Suppose a specific population of bees thrives on and adapts to alternative pollen sources. In that case, there must be a genetic factor at play, potentially leading to the development of a new strain. However, in addition to absolute monotropy, there may be instances of geographically induced monotropy, where only one species of the desired pollen flora of an oligolectic visitor is present (e.g., the monotropic relationship between Cucurbitaceae and specialized bees, as described by Hurd et al. in 1971).

On the other hand, from the perspective of the blossom, monophily represents a more advanced trait. Polyphilic or oligophilic species are less specialized in floral architecture, allowing a more comprehensive range of visitors to access the flower, as all of them may serve as potential pollinators. However, these blossoms have less protection against nectar and pollen theft, which can result in no pollination. This is considered a primitive characteristic, typically adopted by a species when it is establishing itself in a new environment.

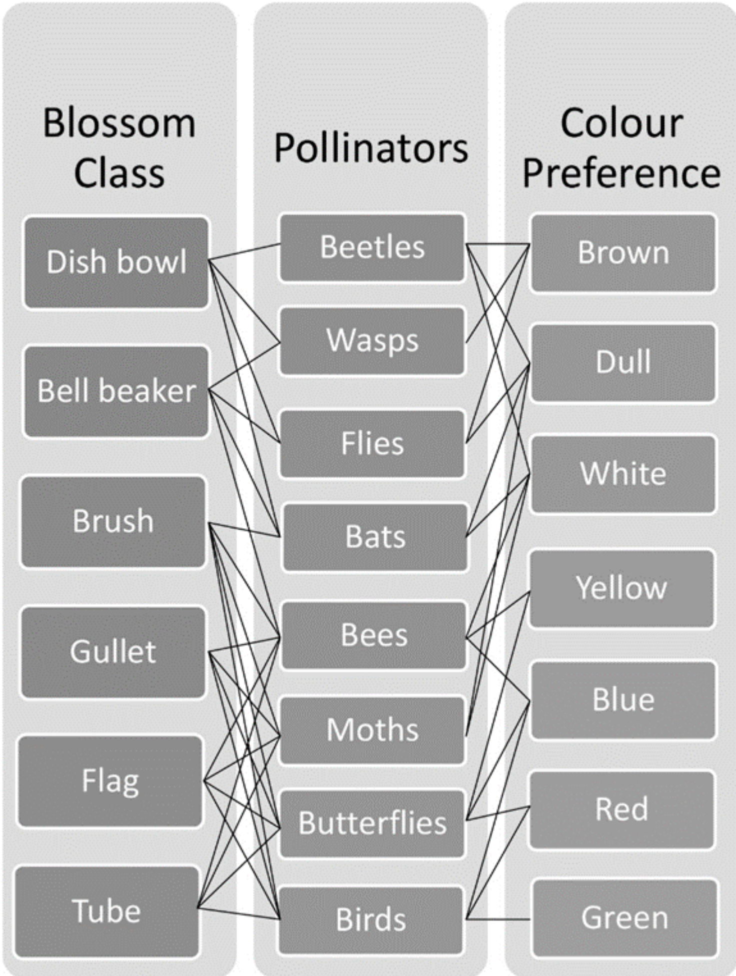

Figure 2. The pollinators and their preferred blossom class and colour.

Pollination Syndrome:

Beetle Pollination or Cantharophily

Beetles are mostly dystrophic or sometimes allotropic. Their mouthparts are short and brutal, adapted for crushing. In some groups, the mouthparts are prognathic (aligned parallel to the body's axis) (Olberg, 1951). Beetles generally need better precision when landing on blossoms, and they can handle only flowers with the most straightforward floral structures. In short, beetles are considered primitive pollinators among all insects. As a result, the blossoms they pollinate must be both olfactory and pollyphilous. Recent studies suggest that nine angiosperm families—Arecaceae, Annonaceae, Arecaceae, Cyclanthaceae, Dipterocarpaceae, Proteaceae, Magnoliaceae, Myristicaceae, and Sterculiaceae—are frequently pollinated by members of at least twenty-eight beetle families (Ulyshen et al., 2023; Muinde and Katumo, 2024).

Figure 3. A beetle visiting a *Rhododendron* flower.

Fly pollination or Myophily

Flies are generally polytropic or allotropic and sometimes dystropic. Due to their short proboscis and small size, they tend to visit flat, dish-bowl-shaped blossoms with exposed nectar and pollen, such as those of the Asteraceae and Umbelliferae, considered primitive flower traits. Dipteran pollinators are unable to carry large pollen loads (Figure 4). Larger flowers often miss the stigma and, in the case of nectar eaters, even the anthers. However, in tiny blossoms, they can be highly effective. Their large populations compensate for their low pollen-carrying capacity and limited flight range.

Additionally, flies are present almost every season throughout the year, making them reliable pollinators (Toivonen et al., 2022). As a result, fly-pollinated flowers are typically simple, regular, flat, pale, and dull-coloured (Figure 2), with prominent nectar guides and fully exposed reproductive organs, facilitating easy access to nectar. Some species develop oligo- or monophyletic relationships with flies by evolving specific rewards or trap mechanisms.

Another variation in fly pollination is sapromyophily, in which blossoms mimic the scent of decaying protein to attract carrion flies. The long-distance attractant is often paired with traps, such as a hairy interior guiding the flies toward the reproductive organs, a slippery inclined tube, or liver-like petals designed to provide landing spots for the flies. Orchids commonly exhibit sapromyophily (Lipińska et al., 2022).

Figure 4. A small amount of pollen grains adhered to the body of a Fly.

Ant-pollination or Myrmecophily

Ants are dystrophic visitors if not pollinators. They are omnipresent on almost every plant part and are often found in large numbers wherever something sweet or starchy is present. Ants primarily act as nectar thieves since they carry little to no pollen (Figure 5). However, in some cases, an entire population of ants can function as pollinators for a specific flower, facilitating vector-mediated autogamy or, to some extent, geitonogamy. For instance, *Conospermum undulatum* has adapted its pollen so that its germination rate is enhanced when carried by ants (Delnevo et al., 2020).

Figure 5. A minimal amount of pollen grains adhere to the body of an Ant.

Bee pollination or Melittophily

Bees are the most specialized pollinators, and plants are highly adapted to utilize bees for pollination. The diet of bees consists mainly of nectar and pollen. As a result, they actively collect pollen and have evolved to carry it on their bodies. There are primarily two modes of pollen carriage in bees: i) Sternotribic, where bees carry pollen on the dorsal surface of their bodies, and ii) Nototribic, where bees carry pollen on the ventral surface (Figure 6). Before entering the hive, bees brush off all the pollen using their forelegs and deposit it into the baskets on their hind legs (Faegri and Van Der Pijl, 1979). The hairs on their bodies are very dense, and these hairs develop static electricity due to air friction caused by their high-speed wing movements, becoming positively charged.

On the other hand, plants develop negative charges in their anthers and pollen grains. This charge is transferred from the roots to the flowers through the movement of electrolytes from the soil to every part of the plant. These opposite charges enable the pollen grains to adhere firmly to the bees. Witherell (1972) and Kendall and Solomon (1973) estimated that at least 15,000 pollen grains must attach to a moderate-sized bee (Kendall and Solomon, 1973). After adhering, the pollen grains become neutral or slightly positively charged. When a bee visits another flower, the positively charged pollen sticks to the negatively charged stigmatic surface.

Most bees are polytropic. Social bees, particularly worker bees, visit various flowers, ranging from tubular flowers to disc-shaped bowl flowers. They require landing spaces that match their body sizes. After landing, they crawl down into the flower toward the nectar, feed on it, and then crawl through the filaments to collect pollen. In many cases, the style of the carpel mimics the staminal filaments.

Consequently, bees sometimes (almost every alternate time) crawl up to the stigma through the style instead of the filaments (Figure 6). Giant solitary bees, such as bumblebees, are stronger than other bees and can access various types of flowers that smaller bees and other insects cannot. They can press through most floral barriers to collect nectar and pollen.

The most prominent features of bee-pollinated flowers are:

i. Zygomorphic and tubular flowers with semi-closed, intricate floral architecture.
ii. Strong and adequate landing space (e.g., horizontal petals or labellum).
iii. Bright colours, primarily white, blue, and yellow, occasionally greenish (bees can perceive wavelengths from approximately 400 to 600 nm in the visible spectrum) (Figure 2).
iv. Prominent nectar guides often appear as coloured spots or a step-like pathway leading toward the nectar.
v. A moderately strong, fresh Odor.
vi. A moderate amount of nectar is hidden inside the flower.
vii. Sex organs are either concealed or located along the path to the nectar.
viii. A large quantity of pollen in the anthers and multiple ovules per carpel.

Butterfly pollination or Psychophily

Butterflies are primarily dystrophic pollinators. Due to their long proboscis, they can access almost all blossoms to collect nectar (Figure 7). They are diurnal insects; thus, most of the flowers they visit remain open during the day. The flowers butterflies frequently visit are generally erect, tubular with flat openings, brightly coloured, and rich in nectar, although the nectar is often deeply hidden. The sex organs of these flowers are prominently displayed, allowing butterflies to mechanically assist in pollination, as they do not carry pollen themselves. Butterflies are not attracted to the scent, so these flowers usually produce a faint odouror nonexistent odour.

Figure 6. A Bee is pollinating a flower. The huge pollen load is visible on the pollen basket and the belly of the insect.

Figure 7. A butterfly is collecting nectar from a flower using its long proboscis.

Moth pollination or Phalaenophily

The pollination activity of moths is quite similar to that of butterflies, with the primary difference being that moths are nocturnal. Night-blooming species primarily rely on moths for pollination. To attract moths, these blossoms produce solid and sweet fragrances and often contain more nectar than butterflies pollinate. Such flowers are typically horizontal or pendulous, white or greyish, with well-lobed petals and deeply hidden nectar. Due to their diurnal and nocturnal habits, Lepidopterans play a significant role in pollination.

Bird pollination or Ornithophily

To be bird-pollinated, flowers must have well-displayed sex organs, a high amount of nectar hidden in a moderately sized tube, a wide mouth, and a mechanical labellum. Mostly, hummingbirds and sometimes sparrows participate in pollination. However, they mainly perform vector-mediated autogamy and geitonogamy, often accidentally, by brushing the anthers against the stigmatic surface. For example, hummingbirds are regularly found to pollinate *Costus* sp. throughout America (Kay and Grossenbacher, 2022). However, in this case, the relationship is important for the bird, not as much for the plants.

Bat pollination or Chiropterophily

Primarily nocturnal or diurnal, creamish white or drab-coloured, strong-mouthed, well-displayed big flowers with a strong sweet and fermented scent and a large amount of nectar are suitable for bat pollination. Flower bats are widespread in India and worldwide; at least 18 families have been identified as flower bat families (Fleming et al. 2009). It has been found that the crop yield of *Stenocereus queretaroensis* has improved in Mexico due to bat pollination (Tremlett et al. 2020). Apart from these, several other minor pollination syndromes exist, such as pollination by snails (Malacophily) and pollination by elephants (Elephophily) etc.

Conclusions:

Pollinators and blossoms are co-adapted for their mutual benefit and are related in several ways. For example, a dystropic, as well as a polytropic pollinator, is associated with those blossoms that are allophylic or polyphylic. The hemipterous insects are generally oligotrophic, while eutrophic species are monotropic due to their specific adaptations. These insects are typically related to hemiphylic (which, by virtue, will be oligophylic) and/or euphylic (which, by virtue, will be monophylic) (Figure 1). The relationship becomes more pronounced when a monotropic insect depends on a monophylic plant. These organisms should be considered the most advanced or evolved forms regarding their reproduction and livelihood. Therefore, these organisms are members of the climax community and become vulnerable here. If we want to conserve or protect any of them, we must protect all the other organisms linked to them. However, every organism is ultimately connected like a jigsaw puzzle. The only exception is we human beings, who began to disconnect from the ecosystem the day we discovered fire. Suppose we view evolution as auto-upgrading every living organism according to its habit, habitat, and niche by analysing data over billions of years. In that case, humans are like viruses that shut down several vital systems (read: cause the extinction of several organisms) and damage the equilibrium of the biosphere. For example, the pollinator of *Trichosanthes dioica* went extinct long ago. If farmers had not adopted a mechanical pollination process by brushing the anthers of male flowers on the stigma with their hands, parwal would not have been found on our plates.

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