

## Commensal Relationships in Forests: The Ecological Role of Epiphytes

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International Journal of Molecular Ecology and Conservation, 2025, Vol.15, No.5 doi: [10.5376/ijmcec.2025.15.0023](https://doi.org/10.5376/ijmcec.2025.15.0023)

Received: 06 Aug., 2025

Accepted: 15 Sep., 2025

Published: 28 Sep., 2025

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### Preferred citation for this article:

Xu X.L., 2025, Commensal relationships in forests: the ecological Role of epiphytes, International Journal of Molecular Ecology and Conservation, 15(5): 229-239 (doi: [10.5376/ijmcec.2025.15.0023](https://doi.org/10.5376/ijmcec.2025.15.0023))

**Abstract** This study introduces the diversity pattern, functional adaptation and ecological role of epiphytes in forest ecosystems. Research has found that there are various symbiotic relationships in forest ecosystems, with epiphytes being typical representatives. It forms a symbiotic relationship with the host tree: Epiphytes utilize the support and space provided by the host tree, but generally do not directly absorb nutrients or water from the host. Epiphytic plants are rich in species, including ferns, mosses, lichens, orchids and bromeliads, etc., and are widely distributed in tropical, subtropical and even temperate forests. Epiphytes play a significant role in maintaining forest biodiversity, regulating the microclimate of the forest canopy, and participating in nutrient and water cycling. However, deforestation, climate change and air pollution pose threats to epiphytes, and the decline in their diversity will weaken the above-mentioned ecological functions. The recovery and conservation of epiphytic plants can be promoted through conservation strategies such as strengthening corridor connections and artificial breeding and reintroduction. Epiphytes, as a crucial yet easily overlooked component in forests, their research and protection are of vital importance for maintaining the integrity of forest ecosystems.

**Keywords** Epiphytic plants; Symbiotic relationship; Forest diversity; Functional adaptation; Ecological function

## 1 Introduction

In forest ecosystems, there exist complex interrelationships among organisms, and commensalism is one of the common types. In a symbiotic relationship, one party benefits while the other remains largely unaffected. In canopy ecosystems, epiphytes and the host trees to which they attach are usually regarded as symbiotic relationships (Garcia-Garcia et al., 2025). This kind of symbiotic relationship is very important in forests because it creates opportunities for many plants to survive in the vertical space of the forest, greatly enriching the structure and biodiversity of the forest (Kromer and Batke, 2025). For instance, in the canopy layer of tropical rainforests, a large number of epiphytic plants "live at high altitudes", together with the ground vegetation, forming a multi-level forest structure. Symbiotic relationships enable species in different niches to coexist, promoting energy flow and material cycling at multiple levels (Amici et al., 2020).

Epiphytes are generally defined as "plants that can germinate and grow on the surface of other plants (mainly trees) throughout their entire life cycle but do not obtain nutrients from their hosts" (Kromer and Batke, 2025). It is estimated that 20% to 39% of the vascular plants in the Tropical Plant Diversity Center are epiphytes, and in some specific tropical regions, the number of epiphyte species in the flora even exceeds half. The main epiphytic vascular plant groups include: Ferns (such as epiphytic ferns of the Polypodiaceae family), Orchidaceae (Orchidaceae, which accounts for a particularly prominent proportion of epiphytic flowering plants, approximately 75% of epiphytic angiosperms), and Bromeliaceae. It includes many epiphytic species such as the genus Airweed, plants of the Araceae family (such as some epiphytic plants of the genus Peperomia), and the genus Peperomia, etc. The non-vascular epiphytes are mainly mosses (including moss, lichen, etc.) and lichens. These groups each have their own adaptability, forming diverse epiphytic types.

Epiphytic plant groups are rich, and different groups occupy different positions in the vertical stratification of the forest, constituting unique and significant components of the forest ecosystem. Epiphytes also include some special life forms, such as hemiepiphytes, whose life cycle is in an epiphytic state for part of the time and extends long roots to penetrate the soil at another stage. For instance, some Ficus plants are epiphytic on trees when they

are young, and later grow aerial roots that droop into the soil, eventually becoming independent large trees. Such plants are sometimes called strangling plants, but in a broad sense, they can be regarded as a special epiphytic life form (Sundue and Maraia, 2024). In addition, nomadic vines and others are also associated with epiphytic habits and are regarded as "structural parasitism", but their ecological strategies are different.

This study will review the ecological roles of epiphytes in forest ecosystems, with a focus on their roles in maintaining forest diversity and participating in the material and energy cycles. The specific content is to explore the diversity and distribution pattern of epiphytes, discuss the ecological adaptation of epiphytes in terms of morphology and physiology, investigate the interaction between epiphytes and host trees, and summarize the functions of epiphytes in the ecosystem. This study aims to deepen the understanding of the ecological roles of epiphytes, emphasize their significant contributions to the ecological functions of forests, and provide references for the protection of epiphytes in the context of global change.

## 2 The Diversity and Distribution Pattern of Epiphytes

### 2.1 Distribution characteristics in tropical, subtropical and temperate forests

Epiphytic plants are distributed in forests of different climate zones, but there are significant differences in their abundance and community characteristics. Tropical forests, especially moist lowland rainforests and cloud forests, are the regions with the highest diversity of epiphytes. In the mountain cloud forests of the neotropical region (Central and South America), epiphytic plants often account for more than half of the local plant species. Studies have pointed out that the species richness of tropical epiphytes often peaks at medium altitudes, where high humidity and frequent clouds and mists occur throughout the year, providing favorable habitats (Suissa et al., 2021).

In contrast, the richness of epiphytes in subtropical forests is relatively low, but it is still considerable in humid monsoon evergreen broad-leaved forests and other environments. The subtropical mountain forests in Taiwan, China, southern Japan, etc. are rich in epiphytic orchids and ferns, mostly concentrated in the forest areas with high altitude and high humidity (Figure 1) (Hsu et al., 2024). Due to the relatively dry and cold climate in temperate forests, there are fewer epiphytic vascular plants, but there are still a large number of epiphytic mosses and lichens. Temperate rainforests (such as those along the northwestern coast of North America) are a special case: winters there are mild and rainy, with abundant epiphytic mosses and lichens that can cover tree trunks and branches, forming a thick "green carpet", accompanied by a small number of epiphytic angiosperms (Werner and Homeier, 2024).

### 2.2 Classification of major epiphytic plant groups and their life forms

Epiphytic plants can be classified according to systematic classification or ecological life form. In terms of systematic classification, epiphytes cover multiple categories. Among angiosperms, Orchidaceae and Bromeliaceae are particularly representative. In addition, Araceae and Piperaceae also have a considerable number of epiphytic species. Among ferns, the Dipterophyllaceae and Pteridaceae families contain a large number of epiphytic ferns. Among mosses and algae, hanging lichens and mosses are the main body of epiphytic communities in temperate forests (Ceballos et al., 2025).

In terms of ecological life forms, epiphytes can be classified into holo-epiphytes and hemi-epiphytes. All epiphytic plants remain unconnected to the soil throughout their lives, such as most epiphytic orchids and bromeliads. Semi-epiphytic plants, such as the aforementioned strangled plants, are epiphytic in the early stage and attached to the soil later (Sundue and Maraia, 2024). There are also some epiphytes (facultative epiphytes), which are usually terrestrial but can also epiphyte in suitable conditions, such as some ferns that can grow on the ground and climb tree trunks.

According to the location and morphology of epiphytes, they can be further classified into trunk epiphytes (large epiphytes at the base of the main trunk, such as staghorn ferns and epiphytic iron horn ferns, which often attach to the base of the main trunk) and crown epiphytes (small species that inhabit the end of the tree crown, such as many tiny orchids and bromeliaceae air plants). There are also morphological categories such as the hanging type

(such as fibrous lichen, long moss) and the bedding type (moss covering the bark to form a blanket) (Dias-Pereira et al., 2022).



Figure 1 *P. formosana* in the canopy of old-growth yellow cypress forest at Yuanyang Lake in northern Taiwan (Adopted from Hsu et al., 2024)

Based on functional features, it can also be classified as: "tank epiphytes" (such as some species of the Bromeliaceae family, where water accumulates in the leaf tubes to form water tanks) and "atmospheric epiphytes" (such as air bromeliads, which have no obvious water storage structure) Absorb moisture from the air entirely by scales, etc. (Gao et al., 2025). These classifications reflect the differences in the adaptation strategies of epiphytes to microhabitats. In addition, there is the coexistence relationship between epiphytes and other climbing plants. For instance, nomadic vines, which start as epiphytes and then move among the canopies, can be regarded as a life form that lies between vines and epiphytes.

### 2.3 Influencing factors of epiphytic plant diversity

The factors influencing the diversity and distribution of epiphytic plants can be classified into macroscopic climatic conditions and microscopic host and stand characteristics. Among climatic factors, moisture and humidity are the primary limiting factors. Epiphytes do not take root in the soil and rely on atmospheric moisture. Therefore, epiphytes thrive more in areas with high air humidity and abundant precipitation (Suissa et al., 2021). Temperature also has an impact. The tropical environment with high temperature and humidity is suitable for the growth of various epiphytic plants. However, in cold regions, many epiphytic angiosperms cannot tolerate low temperatures, so mainly cold-resistant mosses and lichens are used (Francisco et al., 2019).

The characteristics of host tree species are important influencing factors at the local scale. The bark properties, branch structures and chemical environments provided by different tree species vary, thereby affecting the colonization of epiphytes (Shen et al., 2022). In addition, the age and size of the host tree are also crucial: older and taller trees, having more time and more complex structures, can accumulate a richer epiphytic community (Wagner et al., 2021). In terms of stand structure, there are often significant differences in the diversity of epiphytic plants between primary forests and secondary forests. The primary forest has complex layers and stable microclimate, which is more conducive to the preservation of epiphytes (Kromer et al., 2025).

Geographical factors such as altitude gradient and slope orientation also have an impact. Generally speaking, epiphytic plants are most abundant in the moist area at medium altitude. Low temperature at too high altitude and strong competition at too low altitude may both reduce the abundance of epiphytic plants (Suissa et al., 2021). In addition, the spatial pattern of forest landscapes also determines the spread and colonization of epiphytic plants. The spores or seeds of epiphytes need to spread from the source to new hosts. Over-isolated woodlands may lack epiphyte propagule sources, thereby reducing diversity (Paoli et al., 2020).

### **3 Ecological Adaptation and Functional Morphology of Epiphytes**

#### **3.1 Root system and water utilization strategies**

The epiphytic living environment determines that epiphytic plants develop unique strategies in water acquisition and storage. Because they are suspended in the tree canopy, epiphytes cannot directly draw water from the soil and can only rely on rain and fog precipitation as well as air humidity. The root system and water strategy of epiphytic plants embody the principle of "quick absorption and quick storage, slow consumption and water retention": limited water is quickly intercepted and stored through special root coverings, leaf tubes and water storage tissues, while unnecessary water loss is reduced through stomatal regulation and structural isolation. These adaptations ensure that epiphytes can survive in the canopy environment with intermittent and unstable water supply. The morphological diversity of different groups is precisely the result of their long-term adaptation to the water conditions of their respective microhabitats. For example, epiphytic ferns usually rely on curled leaves for rapid water absorption and cuticle for reduced transpiration, while epiphytic orchids rely on fleshy tissue and root cover (Garcia-Garcia et al., 2025). This diversity in functional morphology ensures that there are always epiphytes that can adapt to the local water conditions in the gradient from humid tropical cloud forests to seasonal arid forests (Hsu et al., 2024; Slate et al., 2024; Gao et al., 2025).

#### **3.2 Nutrient acquisition mechanism**

Another major challenge for epiphytes is the source of nutrients. Because they are suspended in the air, epiphytes cannot absorb mineral nutrients from the soil. They must obtain limited elements such as nitrogen and phosphorus through multiple channels. The interception of rainwater and fog water is an important channel for nutrient input. Rainfall in the forest canopy brings trace amounts of dissolved nutrients. The accumulation and decomposition of fallen leaves are important sources of nutrients for epiphytic plants. Many epiphytic plants can capture the fallen leaves, branch shavings of the host tree, or their own withered organs, and accumulate them at the branches to form "canopy soil". This canopy soil is rich in organic matter and provides nutrients for epiphytes after decomposition by microorganisms (Victoriano-Romero et al., 2020). The special symbiotic relationship helps epiphytic plants obtain nutrients. The seeds of many epiphytic orchids are extremely small and lack endosperm, requiring symbiosis with mycorrhizal fungi for germination and nutrient absorption. Among them, the photosynthesis of algae and partial nitrogen fixation make lichenoid appendage a nitrogen source producer in the canopy (Slate et al., 2024). In addition, some epiphytic plants can obtain mineral elements from fallen dust.

#### **3.3 Adaptation of epiphytic life types to light, temperature and humidity gradients**

There is a significant vertical environmental gradient within the forest: from the undergrowth to the canopy, the light gradually intensifies, the temperature rises and the air humidity decreases. Epiphytes, as users of the "vertical ecological gradient", exhibit diversity and functional differentiation that conform to this gradient (Dias-Pereira et al., 2022). Near the base of tree trunks and the lower branches under the forest, the light is weak but the humidity is high. Here, mosses, lichens and shade-tolerant epiphytic ferns thrive. The middle part of the trunk and the higher branches, with moderate light and humidity, are often the "territory" of epiphytic ferns and some orchids. Epiphytic ferns such as the *Adiantum* family thrive in semi-shaded environments. The topmost outer canopy is exposed to strong light, high temperature and relatively dry air. This is the stage for another set of epiphytes, including a large number of bromeliaceae, cactus epiphytes, and some sun-resistant orchids (Suissa et al., 2021).

The temperature in the vertical gradient also affects the distribution of epiphytes: the upper part of the tree crown has a large temperature difference between day and night and a high daytime temperature. Epiphytes that adapt to this environment often have higher heat tolerance and resistance to sudden temperature changes. In terms of

humidity gradient, the humidity at the top layer of the tree canopy varies greatly, and most epiphytic plants have water-retaining structures and dormancy during the dry season and other adaptations. When the humidity in the lower part of the tree canopy is persistently high, epiphytes tend to maintain active growth and rely on stable humidity. For example, many mosses remain in a water-absorbing state for 24 hours and are quite sensitive to dryness (Murakami et al., 2022; Landeros-Lopez et al., 2025).

## 4 The Interaction Relationship Between Epiphytes and Their Hosts

### 4.1 Positive effects

Although epiphytes mainly utilize their hosts to provide space and support, an increasing number of studies have shown that epiphytes can also have a positive impact on host trees and the entire canopy environment. Epiphytes promote the nutrient cycling of their hosts by intercepting and accumulating nutrients. Sometimes, host trees even directly benefit from the nutrients accumulated by epiphytes. Epiphytic plants also provide physical protection. The dense epiphytic moss covering the tree trunks and branches helps to reduce direct exposure of the bark to strong light and sudden temperature changes, and reduces the heat stress and sunburn risk of the host bark (Santos-Escamilla et al., 2024). In addition, some epiphytic plants can secrete compounds that inhibit pathogenic microorganisms, which may have indirect benefits for the host.

From the perspective of biodiversity, the existence of epiphytes can also increase the overall environmental capacity of the host tree, attract beneficial insects and birds to stay, and thereby indirectly help the host control pests and spread seeds, etc. Experimental studies also support the positive effects of epiphytes: Garcia-Garcia et al. (2025) found through greenhouse experiments that when the dead leaves of the common epiphytic *Tillandsia recurvata* were added to the host soil, the survival and growth of the host seedlings could be significantly improved. This indicates that epiphytic plants enrich the soil through their litter and have a positive impact on the host. Epiphytic plant communities can also buffer the impact of acid rain or pollution on the host.

### 4.2 Neutral and negative effects

Although in most cases, epiphytes do not pose obvious harm to the host tree, in some situations, a large number of epiphytes may cause certain stress or even negative effects on the host. Mechanical load is the main potential problem. When epiphytes accumulate and grow to a considerable biomass on the host tree, they will increase the load-bearing capacity of the host's branches. Epiphytes may compete with their hosts for space and light. When epiphytes completely cover the branches, especially when epiphytic vines spread rapidly, they will block the light from the host's leaves or cover the treetops, thereby hindering the growth of some branches of the host (Ceballos et al., 2025).

Under natural conditions, epiphytes usually do not directly draw resources from their hosts, but indirect competition may occur, such as for rainwater. Dense epiphytic lichen traps a large amount of precipitation, and host branches may reduce the chance of water absorption through bark (Murakami et al., 2022). Another potential negative effect is the risk of host infection. Epiphytes themselves are not pathogenic, but their presence may alter the microbial community and humidity on the surface of the host tree, thereby affecting the development of pathogenic fungi and mosses (Mitchell et al., 2021). For instance, the bark of the host is more prone to mold growth in an overly humid environment. Epiphytic moss that remains saturated with water for a long time and adheres closely to the bark may lead to poor ventilation of the bark, which in turn can cause some fungal infections.

### 4.3 The preference mechanism of epiphytes for host selection

The colonization of epiphytes does not occur randomly in any tree species and location. They have certain "preferences" or selection mechanisms for the host (Shen et al., 2022). This preference is related to the physical and chemical properties of the host tree on the one hand, and is also influenced by the propagation process on the other. The bark properties of different host trees are very crucial for epiphytes. Epiphytic plants often prefer tree species with rough bark and wrinkles and cracks, as rough surfaces are more likely to retain seeds, spores, water and nutrients. The *Prosthechea karwinskii* orchid mainly grows on the trunks and branches of *Quercus* plants, presenting a drooping epiphytic form. It has a high dependence on microclimatic conditions (such as humidity and

shading), and at the same time has a strong adaptability to arid environments (Figure 2) (Mitchell et al., 2021). The water retention capacity of the bark is also very important: tree species with spongy bark (such as cotton trees and mahogany) often have a higher coverage of epiphytic moss and mosses. The chemical composition of bark can affect the distribution of lichens, mosses and mycorrhizal appendages.



Figure 2 Ecological characteristics of the epiphytic orchid *Prosthechea karwinskii* in mountain dry forests (Adopted from Santos-Escamilla et al., 2021)

Image caption: (A) Habitat of *Prosthechea karwinskii*, an oak forest in San Pedro y San Pablo Teposcolula, Oaxaca. (B) *Prosthechea karwinskii* growing in situ as a hanging epiphyte on *Quercus* sp. in Santo Domingo Yanhuitlan, Oaxaca. Photographs by R. Solano (Adopted from Santos-Escamilla et al., 2021)

The chemical composition of bark can affect the distribution of lichens, mosses and mycorrhizal appendages. Some barks are rich in tannins, resins and other substances, which may inhibit the germination of certain epiphytic lichen spores, resulting in fewer epiphytic lichen species of this tree species (Paoli et al., 2020). The age and size of the host tree affect the space and time occupied by epiphytes. Studies have shown that the several old trees with the largest diameters at breast height in a forest often carry a much greater diversity of epiphytes than other trees and are called "key hosts" (Shen et al., 2022; Siaz Torres et al., 2024).

The transmission mechanism also shapes the "selection" of hosts by epiphytes. The vectors (wind, birds, etc.) and behaviors of many epiphytic plant seeds can cause them to tend to land on certain tree species. In addition, the requirements of epiphytes themselves for the microenvironment lead to their rooting in specific forest structures. For instance, some epiphytes require a shaded environment. Their spores germinate on the trunks of relatively shady tree species and do not survive on tree species with sparse canopies and direct sunlight (Dias-Pereira et al., 2022).

## 5 Ecological Functions of Epiphytes

### 5.1 Promoting role of biodiversity

Epiphytic plants have significantly enhanced the biodiversity and ecological complexity of forests with their unique lifestyles. The presence of epiphytes effectively expands the forest ecological space, creating vertical habitats beyond the two-dimensional ground, thereby increasing  $\beta$  diversity (inter-habitat heterogeneity) (Svahnstrom et al., 2025). Just as some people refer to epiphytes as "the aerial gardens of the forest", this garden attracts and nourishes a host of flora and fauna residents in the forest canopy (Kromer and Batke, 2025). The significant contribution of epiphytes to the biodiversity of forests is also reflected in species conservation: many endangered plants such as orchids and ferns are epiphytes. Protecting epiphytes in forests is protecting these endemic species (Santos-Escamilla et al., 2024). In addition, at the landscape scale, different forest lands have enhanced regional diversity due to the diversity of epiphytic plant communities. For instance, in landscapes with remnants of primary forests and those with only secondary forests, the primary forests significantly increase the regional plant list due to the greater number of epiphytic species (Werner and Homeier, 2024).

## 5.2 The cycle of matter and energy

Epiphytic plants play an important role in the material and energy cycles of forest ecosystems. Epiphytes profoundly affect the forest water cycle by intercepting rainfall and conserving water (Hembre et al., 2021). Epiphytes play the role of "accumulators and converters" in the forest canopy during the nutrient cycle. Epiphytes intercept nutrients and fallen tree debris from atmospheric deposition and temporarily store them in the canopy (Victoriano-Romero et al., 2020). The process by which epiphytic plants participate in the carbon cycle. Epiphytes fix CO<sub>2</sub> through photosynthesis and store carbon in the forest canopy in the form of their own biomass. In addition, epiphytes change the path of energy flow. Many epiphytic plants' leaves, flowers and fruits are fed by predators such as insects and birds. This is a food chain independent of the ground vegetation, which transports the energy of the primary producers in the forest canopy to a group of specialized consumers.

## 5.3 Potential contribution to forest carbon sink function

Forests, as global carbon sinks, play a key role in mitigating climate change. Although epiphytes have a relatively small biomass compared to trees, they also make certain contributions to forest carbon storage and the carbon cycle. Epiphytic plants net accumulate carbon through their growth. Although individual epiphytes are light in weight, the total carbon content per unit area of forest land in high-density epiphytic communities cannot be ignored. The presence of epiphytes may enhance the net carbon fixation efficiency of the host tree. The reason lies in that epiphytes improve the canopy microclimate, thereby alleviating the adverse effects of extreme heat and drought on the photosynthesis of the host (Amici et al., 2020).

The canopy soil and organic matter pads composed of epiphytes are also part of the carbon stock and may reduce the rate of carbon leakage to the outside. From another perspective, epiphytes promote soil carbon accumulation. When they fall to the ground, they provide high C/N litter rich in lignin and polysaccharides, which is difficult to decompose and can increase the soil organic carbon pool (Furtado and Menini Neto, 2021). Meanwhile, certain epiphytic plants such as lichens can fix exogenous carbon (through photosynthesis by symbiotic algae) and eventually convert it into soil humus, which increases the carbon input to the ecosystem from the source. Furthermore, in the context of global climate change, the feedback effect of epiphytic plants on the carbon cycle deserves attention.

## 6 Threats and Protection Strategies Faced by Epiphytes

### 6.1 The impact of deforestation, climate change and air pollution on epiphytes

Although epiphytes play a crucial role in ecosystems, they are highly sensitive to environmental changes and human disturbances. Habitat loss, climate change and pollution load caused by human activities all exert multiple pressures on epiphytes. Many epiphytic plants are endemic species of small populations and have poor adaptability to environmental changes. Once the habitat is destroyed or the climate exceeds its tolerance range, it may die out rapidly. For instance, epiphytic orchids and ferns with narrow distribution tend to become extinct first with deforestation (Kromer et al., 2025). The loss of large trees led to the direct extinction of many plant populations that were originally epiphytic to them, and the young trees in the secondary forest failed to carry the same epiphytic species again, indicating that the aftereffects of the destruction of stand structure are serious (Cruz et al., 2022).

Climate warming may force epiphytes to migrate to higher altitudes, but it is a problem whether the distribution of suitable host trees can keep up. Many epiphytes may fall into the predicament of "nowhere to go" (Suissa et al., 2021). Air pollution mainly affects the epiphytic layer of moss and lichen, and its decline will cause negative feedback on the water and nutrient cycle of the forest canopy (because moss and lichen are the main force in intercepting water and nutrients) (Phoenix and Khafsha, 2023). In summary, when the forest environment deteriorates, epiphytes are usually regarded as "ecologically sensitive indicators" : their decline often occurs earlier than large-scale changes in trees and is an early warning signal of impaired ecological health (Mitchell et al., 2021)

## 6.2 Ecological consequences of loss of epiphytic plant diversity

The loss of epiphytic plant diversity will lead to a decline in the service functions of forest ecosystems. Services such as water conservation, microclimate regulation, and provision of biological habitats may all be compromised. Especially in mountainous cloud forests, epiphytic mosses are important "water towers", and their decline will directly affect the stability of water supply in the basin (Werner and Homeier, 2024). The disappearance of epiphytes as indicators also means that the environment has deteriorated to a point where it is difficult to support sensitive species. This not only has an impact on the natural ecosystem, but is also related to human well-being: for instance, the disappearance of lichens means a deterioration in air quality, which may endanger human health. Therefore, although the loss of epiphytes often occurs in the high parts of the forest canopy that are not easily noticed by us, its ecological consequences will gradually spread to the entire forest and even the external environment along the material and energy transfer pathways.

It should be emphasized here that the lag in the loss of epiphytic plant diversity may mask its severity (Kromer et al., 2025). When the forest is disturbed, large life forms such as trees may still survive for a while, but the population of epiphytic plants may have already shrunk. In such "empty shell forests", the trees are still there, but their ecological functions have significantly weakened. It is only after a relatively long period of time that we will observe obvious consequences such as soil degradation and deteriorating water quality, but by then epiphytes have long disappeared. Therefore, the disappearance of epiphytes can be regarded as a precursor to the decline of forest ecological functions. This also gives us a warning: when the diversity of epiphytic plants drops sharply, it is the moment when ecological management needs urgent intervention.

## 6.3 Protection and recovery strategies

Given the significant ecological importance and threats faced by epiphytes, it is imperative to enhance their protection. The protection of epiphytic plants cannot be carried out in isolation but should be integrated into the overall protection and restoration of forest ecosystems. The protection of primary forests is fundamental. Without healthy forests, epiphytic plants are out of the question. But paying attention to these hidden little lives at the same time can make forest protection more complete and in-depth (Koster et al., 2009).

Fortunately, some regions have begun to pay attention to epiphytes: for instance, Mexico has taken measures to protect ancient oak trees to preserve their epiphytic lichen communities, and Costa Rica has developed the "Orchid Route" ecotourism to enhance community conservation enthusiasm, etc. These explorations indicate that by integrating scientific research, community and policy, it is possible to protect epiphytes while taking into account human interests (Richards, 2020).

In addition, public education should be strengthened to enhance the awareness of the value of epiphytic plants and avoid behaviors such as artificial picking and collection (Santos-Escamilla et al., 2024). Many people lack understanding of epiphytes and even mistakenly think they are harmful and remove them (for example, some people think that moss on trees is harmful to trees and scrape it off). Education can correct these misunderstandings and make the public realize that epiphytes are the "hanging gardens" of the forest and deserve to be cared for.

## 7 Concluding Remarks

Epiphytes are a key but long-neglected component of forest ecosystems. Although they "reside" on high branches, they profoundly influence the structure and function of the forest in various ways. Epiphytic plants highly enrich the biodiversity of the forest: from large ferns to small mosses, they form a unique life community in the forest canopy. They provide micro-habitats, nourish numerous invertebrates and amphibians, form a "forest aerial ecological network", and offer essential conditions for the reproduction of some endemic species. In terms of material circulation, epiphytes promote nutrient cycling and regulate water balance by intercepting rain and mist and accumulating fallen debris, effectively serving as soil and water conservators and nutrient accumulators in the forest canopy. To a certain extent, they also contribute to the carbon sink function of forests, enabling them to fix and store more carbon and smooth out fluctuations during the carbon cycle.

In the face of global changes and human interference, epiphytes, as sensitive and delicate factors in ecosystems, have shown signs of decline. Deforestation has destroyed their habitats, and warming climates and extreme weather make it difficult for them to adapt. Air pollution, especially nitrogen deposition, has changed the appearance of epiphytic moss and lichen communities, and problems such as eutrophication and species monotony have emerged. The reduction of epiphytic plants will inevitably lead to the weakening of forest ecosystem functions, which deserves high attention. Based on the understanding of the ecological role of epiphytic plants, practical measures need to be taken in the future to strengthen their protection and restoration. This includes: strictly guarding the primary forests and building ecological corridors to maintain the sources and transmission routes of epiphytic plants; Artificial breeding and reintroduction of endangered epiphytic species, and strengthening local conservation; And macro efforts such as comprehensive governance of air pollution and mitigation of global warming.

Epiphytes, though located on high branches, are closely related to the entire forest and human beings: they are the indicator lights of forest health, the reservoir of biodiversity, and one of the invisible pillars of ecological functions. Strengthening the research and protection of epiphytes can not only save many strange and beautiful species, but also is crucial for maintaining the ecological balance of forests and enhancing the ability to respond to global changes. Looking ahead, it is necessary to unite the efforts of all parties to incorporate epiphytes into the scope and policies of forest protection. Under the guidance of science, through community participation and public education, the concept of comprehensively protecting all life in the forest "above and below ground, above and under trees" has been established. In this sense, paying attention to epiphytes is to pay attention to the most minute yet indispensable link of the forest ecosystem. Only by protecting these "air fairies" well can the forest truly thrive and flourish.

### Acknowledgments

Thanks to the anonymous peer review for providing targeted revision suggestions for the manuscript.

### Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

### References

- Amici A.A., Nadkarni N.M., Williams C.B., and Gotsch S.G., 2020, Differences in epiphyte biomass and community composition along landscape and within-crown spatial scales, *Biotropica*, 52(1): 46-58.  
<https://doi.org/10.1111/btp.12725>
- Ceballos S.J., Aráoz E., and Rojas T.N., 2025, Exploring co-occurrence patterns to understand epiphyte-liana interactions, *Plants*, 14(1): 140.  
<https://doi.org/10.3390/plants14010140>
- Cruz A.C.R., de Medeiros Corrêa N., da Silva Murakami M.M., de Azevedo Amorim T., Nunes-Freitas A.F., and da Silva Sylvestre L., 2022, Importance of the vertical gradient in the variation of epiphyte community structure in the Brazilian Atlantic Forest, *Flora*, 295: 152137.  
<https://doi.org/10.1016/j.flora.2022.152137>
- Dias-Pereira J., Andrade G.C., da Silva L.C., Ferrari F.B., Ribas R.F., Neto L.M., and Azevedo A.A., 2022, Leaf structural adaptations in vascular epiphytes from the Atlantic rainforest along phorophyte vertical stratification, *Flora*, 288: 152022.  
<https://doi.org/10.1016/j.flora.2022.152022>
- Furtado S.G., and Menini Neto L., 2021, What is the role of topographic heterogeneity and climate on the distribution and conservation of vascular epiphytes in the Brazilian Atlantic Forest?, *Biodiversity and Conservation*, 30(5): 1415-1431.  
<https://doi.org/10.1007/s10531-021-02150-6>
- Francisco T.M., Couto D.R., Garbin M.L., Muylaert R.L., and Ruiz-Miranda C.R., 2019, Low modularity and specialization in a commensalistic epiphyte-phorophyte network in a tropical cloud forest, *Biotropica*, 51(4): 509-518.  
<https://doi.org/10.1111/btp.12670>
- Gao T.Y., Zhang W., and Zhang S.B., 2025, Differentiation in water adaptation strategy between epiphytic and terrestrial species of *Cymbidium* (Orchidaceae), *AoB Plants*, 17(4): plaf030.  
<https://doi.org/10.1093/aobpla/plaf030>
- García-García N.V., Valencia-Díaz S., Vergara-Torres C.A., Rios M.Y., Morales-Linares J., and Flores-Palacios A., 2025, Direct and indirect effects of the epiphyte *Tillandsia recurvata* (Bromeliaceae) on the growth of three of its phorophytes: A greenhouse experiment, *Plant Biology*, 27(4): 622-629.  
<https://doi.org/10.1111/plb.70028>

- Hembre K., Meyer A., Route T., Glauser A., and Stanton D.E., 2021, Stand-level variation drives canopy water storage by non-vascular epiphytes across a temperate–boreal ecotone, *Frontiers in Forests and Global Change*, 4: 704190.  
<https://doi.org/10.3389/ffgc.2021.704190>
- Hsu R.C.C., Chen Y.C., and Lin C., 2024, The impact of changing climate on an endangered epiphytic orchid (*Pleione formosana*) in a montane cloud forest and the conservation challenge ahead, *Plants*, 13(17): 2414.  
<https://doi.org/10.3390/plants13172414>
- Köster N., Friedrich K., Nieder J., and Barthlott W., 2009, Conservation of epiphyte diversity in an Andean landscape transformed by human land use, *Conservation Biology*, 23(4): 911-919.  
<https://doi.org/10.1111/j.1523-1739.2008.01164.x>
- Krömer T., and Batke S.P., 2025, Epiphytic plants: Perspective on their diversity, distribution, systematics and conservation in the changing environment, *Plants*, 14(15): 2265.  
<https://doi.org/10.3390/plants14152265>
- Krömer T., Einzmann H.J., Mendieta-Leiva G., and Zotz G., 2025, Impact of land-use change on vascular epiphytes: A review, *Plants*, 14(8): 1188.  
<https://doi.org/10.3390/plants14081188>
- Landeros-López J.G., Krömer T., Gómez-Díaz J.A., Velázquez-Rosas N., and Carvajal-Hernández C.I., 2025, Influence of microclimatic variations on morphological traits of ferns in urban forests of central Veracruz, Mexico, *Plants*, 14(11): 1732.  
<https://doi.org/10.3390/plants14111732>
- Mitchell R.J., Hewison R.L., Beaton J., and Douglass J.R., 2021, Identifying substitute host tree species for epiphytes: The relative importance of tree size and species, bark and site characteristics, *Applied Vegetation Science*, 24(2): e12569.  
<https://doi.org/10.1111/avsc.12569>
- Murakami M., Nunes Ramos F., Durand M., Ashton R., and Batke S.P., 2022, Quantification and variation of microclimatic variables within tree canopies—considerations for epiphyte research, *Frontiers in Forests and Global Change*, 5: 828725.  
<https://doi.org/10.3389/ffgc.2022.828725>
- Paoli L., Guttová A., Sorbo S., Lackovičová A., Ravera S., Landi S., Landi M., Basile A., Di Toppi S., Vannini A., Loppi S., and Fačková Z., 2020, Does air pollution influence the success of species translocation? Trace elements, ultrastructure and photosynthetic performances in transplants of a threatened forest macrolichen, *Ecological Indicators*, 117: 106666.  
<https://doi.org/10.1016/j.ecolind.2020.106666>
- Phoenix G., and Khafsha A., 2023, Untangling the influences of air quality and climate change on biodiversity in space and time, *Global Change Biology*, 29: 5115-5116.  
<https://doi.org/10.1111/gcb.16858>
- Richards J., 2020, Assessing the strength of climate and land-use influences on montane epiphyte communities, *Conservation Biology*, 35(5): 1496–1506.  
<https://doi.org/10.1111/cobi.13679>
- Santos-Escamilla M.H., Cruz-Lustre G., Cuéllar-Martínez M., Lagunez-Rivera L., and Solano R., 2024, Variation in the floral morphology of *Prosthechea karwinskii* (Orchidaceae), a Mexican endemic orchid at risk, *Plants*, 13(14): 1984.  
<https://doi.org/10.3390/plants13141984>
- Siaz Torres S.S., de la Rosa-Manzano E., Arellano-Méndez L.U., Aguilar-Dorantes K.M., Martínez Ávalos J.G., and Juárez Aragón M.C., 2024, Species richness, abundance and vertical distribution of epiphytic bromeliads in primary forest and disturbed forest, *Plants*, 13(19): 2754.  
<https://doi.org/10.3390/plants13192754>
- Shen T., Song L., Collart F., Guisan A., Su Y., Hu H.X., Wu Y., Dong J., and Vanderpoorten A., 2022, What makes a good phorophyte? Predicting occupancy, species richness and abundance of vascular epiphytes in a lowland seasonal tropical forest, *Frontiers in Forests and Global Change*, 5: 1007473.  
<https://doi.org/10.3389/ffgc.2022.1007473>
- Slate M.L., Antoninka A., Bailey L., Berdugo M.B., Callaghan D.A., Cárdenas M., Chmielewski M., et al., 2024, Impact of changing climate on bryophyte contributions to terrestrial water, carbon, and nitrogen cycles, *New Phytologist*, 242(6): 2411-2429.  
<https://doi.org/10.1111/nph.19772>
- Suisa J.S., Sundue M.A., and Testo W.L., 2021, Mountains, climate and niche heterogeneity explain global patterns of fern diversity, *Journal of Biogeography*, 48(6): 1296-1306.  
<https://doi.org/10.1111/jbi.14076>
- Sundue M., and Maraia H., 2024, Field work in Papua New Guinea documents seven new records of a hemiepiphytic habit in ferns, *Plants*, 13(8): 1104.  
<https://doi.org/10.3390/plants13081104>
- Svahnström V.J., Nie Lughadha E., Forest F., and Leão T.C., 2025, Geographic range size and rarity of epiphytic flowering plants, *Nature Plants*, 2025: 1-10.  
<https://doi.org/10.1038/s41477-025-02022-9>
- Victoriano-Romero E., García-Franco J.G., Mehlreter K., Valencia-Díaz S., Toledo-Hernández V.H., and Flores-Palacios A., 2020, Epiphyte associations and canopy soil volume: nutrient capital and factors influencing soil retention in the canopy, *Plant Biology*, 22(3): 541-552.  
<https://doi.org/10.1111/plb.13080>

- Werner F.A., and Homeier J., 2024, Diverging elevational patterns of tree vs. epiphyte species density, beta diversity, and biomass in a tropical dry forest, *Plants*, 13(18): 2555.  
<https://doi.org/10.3390/plants13182555>
- Wagner K., Wanek W., and Zotz G., 2021, Functional traits of a rainforest vascular epiphyte community: trait covariation and indications for host specificity, *Diversity*, 13(2): 97.  
<https://doi.org/10.3390/d13020097>

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