How do mycorrhizal fungi get around?

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In a landmark review paper back in 2019 ("Taxi drivers: the role of animals in transporting mycorrhizal fungi;" *Mycorrhiza*; 29: 413–434; doi.org/10.1007/s00572-019-00906-1), Vašutová et al. assessed what was known at the time about the role of animals in dispersing fungi (termed "zoochory"). What did we know then, and what have we learned since? In this review, I will revisit the 2019 paper and then call attention to newer reports.

Animals play a crucial role in the dispersal of fungal spores, a process that ensures reproduction, genetic diversity, and the colonization of new habitats. While wind and water are often recognized as primary agents of dispersal, the involvement of animals adds a layer of complexity and resilience to fungal life cycles. Much like plants that rely on animals for seed dispersal, fungi benefit from similar interactions, and these relationships are central to forest ecology and evolution. The authors of the paper emphasize that fungi produce two main types of fruitbodies, epigeous and hypogeous, and that the strategies for dispersal differ significantly between them. Epigeous fungi fruit above ground, producing mushrooms, puffballs, and brackets that can release spores into the air. Although wind dispersal is common for these species, animals also contribute by grazing, trampling, or carrying spores externally. Hypogeous fungi, by contrast, fruit below ground and cannot rely on wind. They depend almost entirely on animals that consume their fruiting bodies and excrete viable spores, often at considerable distances from the original site. This obligate reliance on animals has shaped the evolution of truffle-like fungi, which produce aromatic compounds to attract mammals and ensure dispersal.

Different groups of animals contribute in distinct ways. Mammals such as rodents, squirrels, deer, and wild boar are particularly important, with rodents serving as efficient dispersers of truffles. Birds also play a role, either by consuming fungi directly or transporting spores externally on feathers and feet. Insects, including beetles, flies, and ants, interact with fungi through feeding, external carriage, or even cultivation in specialized structures. Reptiles, amphibians, and soil invertebrates like earthworms contribute incidentally, either through ingestion or disturbance of soil layers. Together, these groups form a multi-layered dispersal network that enhances fungal survival and ecosystem resilience. The authors highlight the concept of functional complementarity, noting that different animals disperse spores at different times, places, and scales. Nocturnal rodents spread spores in forest understories, diurnal birds cover open habitats, and large mammals transport spores over long distances. This complementarity ensures that fungi colonize diverse niches and recover after disturbances such as fire or logging.

The evolutionary implications of these interactions are profound. The repeated emergence of animal-fungus partnerships suggests strong selective pressures favoring these relationships. Fungi that produce attractive scents, colors, or nutritional compounds may have evolved specifically to entice animals, while animals gain dietary benefits in return. Hypogeous fungi demonstrate these evolutionary pressures and adaptations, sacrificing wind dispersal but gaining specialized animal partners. Conservation efforts must therefore account for these relationships, as declines in animal populations can disrupt fungal dispersal and, by extension, forest health.

Mycorrhizal fungi, which form symbiotic relationships with plants, depend on animal vectors to reach new hosts, and without dispersal, forest regeneration may falter. Recognizing animals as integral to fungal life cycles is vital for ecology, evolution, and conservation. The paper concludes that animals are not incidental but essential partners in fungal reproduction, and that understanding these interactions opens new avenues for forestry, agriculture, and biotechnology. By situating fungi within broader ecological networks and emphasizing the roles of epigeous and hypogeous fruitbodies, the authors provide a framework for appreciating the hidden but indispensable role of animals in spore dispersal.

Animal-mediated fungal spore dispersal: New findings since 2019

Animals remain pivotal partners in fungal reproduction, ecology, and forest resilience—and recent studies deepen and complicate that picture. Since 2019, research has emphasized how animal vectors complement wind and water, how their roles shift with disturbance and climate change, and how overlooked species can strongly influence forest health. Together, these findings refine our understanding of epigeous (above-ground) and hypogeous (below-ground) fungal strategies and the multi-species networks that keep mycorrhizal communities connected across space and time.

Complementary dispersal after disturbance

Following timber harvesting, mammal–fungal networks exhibit functional, temporal, and spatial complementarity: different mammals move distinct sets of fungal spores at different times and across different microhabitats, together sustaining both arbuscular mycorrhizal (AM) and ectomycorrhizal (ECM) communities. This complementarity enhances the re-seeding of disturbed patches from intact forest "source" communities, accelerating regeneration and supporting seedling establishment where mutualists are otherwise scarce. The core insight is practical: animal diversity isn't just nice to have; it's instrumental in bridging the mutualism gap created by disturbance. When epigeous fungi rely heavily on wind but lose canopy-mediated microclimates, mammals can "patch-connect" spores into newly exposed substrates; when hypogeous fungi (e.g., truffles) lack wind dispersal altogether, mammals remain indispensable across all phases of forest recovery (Stephens et al., 2021).

Wind and mammals as coequal, complementary vectors

Wind dispersal is often broad but shallow—effective at local persistence but limited in delivery to certain microsites. Small mammals, by contrast, move spores into seedbeds, down coarse woody debris, and across habitat boundaries, sometimes transporting viable hypogeous spores kilometers away via gut passage. New work highlights that the two modes work best together: wind maintains continuity near source stands, while mammals create spatial "leapfrogs" into disturbed or early-successional habitat where mutualist scarcity is most acute. This synergy is especially valuable for epigeous fungi whose wind-borne spores saturate immediate surroundings but require animal vectors to reach sheltered microsites with the right moisture, shade, and substrate (UNH, 2022; UNH 2023).

Cryptic animal vectors and climate-linked forest health

A 2025 mini-review foregrounds "cryptic" animal vectors (species not typically monitored in forest health programs but capable of substantial fungal transport) found mites, squirrels, and woodpeckers, alongside the usual bark beetles and moths, operate across different spatial and temporal scales to move both mutualists and pathogens. As warming intensifies, these vectors are accelerating the redistribution of fungal communities, with humidity and precipitation patterns shaping dispersal windows and pathogen pressure. The review urges managers to anticipate and incorporate these overlooked vectors into surveillance and restoration strategies, especially where hypogeous mutualists and climate-sensitive pathogens overlap in shifting ranges. Practically, this means that monitoring should extend beyond charismatic mammals to include micro-arthropods and foraging birds that bridge canopy, bark, and soil interfaces (Korkmaz et al., 2025).

Climate adaptation in forest pathogens

Landscape genomics now shows climate—especially humidity and precipitation—as a primary driver of adaptation in major forest pathogens (e.g., agents of Dutch elm disease, *Dothistroma* needle blight, and Swiss needle cast). As these pathogens evolve toward local climates, animal vectors can amplify spread by bridging ecological edges and dispersal gaps. The result is a more dynamic pathogen landscape where animal movement, microclimate refugia, and host stress interact tightly with fungal evolution. These insights sharpen risk models and suggest that managing animal corridors, edge habitats, and disturbance regimes may indirectly modulate pathogen dispersal and establishment. The take away message? That even when wind propagates spores broadly, animals can determine where—and in what ecological context—those spores are actually deposited, germinate, and become epidemiologically relevant (Hessenauer et al., 2025).

Epigeous vs. hypogeous strategies in the 2020s

The epigeous-hypogeous distinction continues to structure dispersal ecology. Epigeous fungi combine wind with animal-mediated delivery, benefiting from both. And probably a failsafe if one doesn't happen. Hypogeous fungi remain obligate on animals for both distance and placement—food rewards, scent cues, and fruiting phenology match the foraging patterns of rodents and other mammals. Post-harvest landscapes magnify these differences: epigeous species can ride wind to colonize exposed substrates, but hypogeous fungi depend entirely on animals to recolonize soils and root zones, sustaining ECM linkages critical for seedling nutrition and stress tolerance. By designing management around these contrasting strategies—e.g., retaining downed wood, encouraging small mammal habitat, and maintaining heterogeneous stand structure—forests can regain mutualist connectivity faster.

Management implications, research gaps, and future priorities

As far as management, all authors say it's important to maintain or restore animal diversity as a functional asset, not just a biodiversity value. Mammals, birds, and microfauna together ensure the continuity of AM and ECM networks, particularly after harvest or fire. And don't count out those "cryptic" vectors in monitoring (mites, woodpeckers, squirrels), given their outsized role in pathogen and mutualist movement under climate change! Management needs to couple wind-aware strategies (e.g., leave-tree placement, canopy gaps) with animal habitat features (edge complexity, coarse woody debris) to harness dual dispersal modes. And finally, use climate-informed risk models that incorporate animal corridors and microhabitat deposition dynamics to forecast pathogen expansion and target early interventions. These steps reconceive animals as active infrastructure for fungal metacommunities, with measurable impacts on regeneration, resilience, and disease dynamics.

What about gaps in our understanding and future priorities? Three fronts stand out. First, quantifying multi-vector deposition at microsite scales—how wind and different animals co-deliver spores to root zones, bark fissures, and litter layers—will refine mechanistic models for colonization success. Second, expanding surveillance of cryptic vectors, with trait-based approaches (movement range, foraging strata, grooming behavior) can predict which species are most influential for particular fungal guilds under shifting climates. Third, integrating landscape genomics of pathogens with animal movement data will illuminate where adaptive fungal genotypes are most likely to establish and spread, enabling proactive management of high-risk edges and corridors (Hessenauer et al., 2025).

Across these priorities, the epigeous–hypogeous framework remains central: epigeous fungi gain resilience from multi-modal dispersal, while hypogeous fungi demand deliberate conservation of animal partners and their habitats. The post-2019 literature clarifies that neither wind nor animals alone can sustain fungal community connectivity under disturbance and climate change; it is their complementarity—scaled across species, seasons, and microhabitats—that keeps forests functionally knit together.

Conclusions

When I was a student, animals were hardly even considered as vectors of fungi. Since 2019, the evidence base has shifted from “animals are helpful” to where we are now, thinking that “animals are essential and complementary.” And climate change further raises the stakes. Mammals and other vectors now look less like incidental carriers and more like the connective tissue of fungal metacommunities, especially for hypogeous mutualists and climate-adapting pathogens. Managing forests for fungal health must therefore include explicit strategies for animal-mediated dispersal, wind–animal synergy, and the monitoring of cryptic vectors. Doing so turns a hidden ecological process into a tangible lever for resilience—supporting regeneration, buffering disease, and sustaining the mycorrhizal relationships that underwrite forest function.

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