Psilocybin and the Evolutionary Significance of Altered Neural States: Interaction-Based Perspectives Beyond Deterrence Models

Philip Rebensburg, Dipl.-Biol.
Independent Researcher
ORCID: https://orcid.org/0000-0003-3321-6505
Contact: philip.rebensburg@gmail.com

Abstract

Psilocybin is a psychoactive tryptamine produced by a phylogenetically discontinuous yet ecologically diverse subset of fungi. Despite decades of chemical, pharmacological, and ethnobiological research, the evolutionary forces driving the emergence and persistence of this compound remain insufficiently explained. Recent hypotheses proposing that psilocybin evolved primarily as a deterrent against insect fungivory account for certain laboratory observations but struggle to reconcile key features of the molecule, including its substantial biosynthetic investment, its highly specific and conserved neuromodulatory effects across taxa, and its patchy phylogenetic distribution.

Here, I present a hypothesis-driven conceptual synthesis that reassesses the evolutionary significance of psilocybin by integrating evidence from fungal genomics, chemical ecology, evolutionary biology, and systems neuroscience. To test the limits of deterrence-based explanations, psilocybin is situated within a broader comparative framework that includes other naturally occurring tryptamines, most notably *N,N*-dimethyltryptamine (DMT) and related derivatives such as baeocystin and bufotenin. These compounds occur across fungi, plants, animals, and microbial symbioses, act on conserved serotonergic systems, and reliably induce transient but structured alterations of perception, behavior, and cognition.

I argue that psilocybin is more parsimoniously understood as an interaction-modulating secondary metabolite that alters neural and behavioral states in ways that can influence ecological interactions, rather than as a narrowly targeted defensive toxin. Comparative analysis reveals convergent evolutionary patterns that are difficult to reconcile with deterrence-only models but are consistent with a broader evolutionary solution space in which altered neural states represent biologically accessible and functionally meaningful regimes.

By reframing psilocybin as part of a class of secondary metabolites that modulate organism–environment interactions through transient alterations of neural state, this synthesis advances an interaction-based evolutionary framework and outlines testable predictions for future empirical work.

Keywords: psilocybin, tryptamines, neuromodulation, chemical ecology, fungal secondary metabolites, horizontal gene transfer, behavioral modulation, evolutionary neuroscience

Introduction

The existence of naturally occurring molecules that reliably and profoundly alter states of consciousness remains one of the least examined problems in evolutionary biology. Across fungi, plants, animals, and microbial symbioses, a small but recurring class of tryptophan-derived compounds engages conserved neural systems involved in perception, cognition, affective processing, and behavioral flexibility (Nichols 2016). Among these, psilocybin occupies a particularly prominent position due to its repeated evolution in phylogenetically distant fungal lineages and its well-characterized effects on human conscious experience as mediated by conserved serotonergic architectures. However, psilocybin does not occur in isolation. Closely related tryptamines including *N,N*-dimethyltryptamine (DMT), 5-methoxy-DMT, bufotenin, and biosynthetic congeners such as baeocystin recur across distinct biological contexts (Nichols 2016; Jiménez & Bouso 2022; Meyer & Slot 2023), suggesting that their evolutionary relevance cannot be understood through single-compound explanations alone.

Despite decades of neuropharmacological, clinical, and phenomenological research, the evolutionary significance of these compounds is still routinely framed as incidental. Dominant explanatory strategies tend to reduce psychoactive tryptamines to defensive toxins, metabolic byproducts, or ecological noise. This framing persists even though such molecules display a degree of molecular specificity, biosynthetic investment, and cross-taxonomic neuromodulatory precision that sharply distinguishes them from typical secondary metabolites (Meyer & Slot 2023; Matthews Nicholass et al. 2025). Compounds that selectively target conserved serotonergic systems and reproducibly reorganize large-scale neural dynamics raise a fundamentally different class of evolutionary questions than substances that merely impair growth or induce aversion.

The central question, therefore, is not whether individual tryptamines can exert toxic or disruptive effects under certain conditions. Many metabolites can. The more difficult question is why evolution repeatedly generates small, structurally related molecules that act directly on neural substrates underlying perception, salience, social cognition, and exploratory behavior, and why these effects recur across ecologically and phylogenetically distinct systems. Treating such outcomes as epiphenomenal avoids rather than resolves the problem.

This work approaches psilocybin as a focal case within a broader evolutionary pattern of tryptamine-based neuromodulation. By integrating evidence from fungal genomics, chemical ecology, evolutionary biology, and systems neuroscience, it evaluates the adequacy of deterrence-centered models and examines whether interaction-based frameworks provide a more parsimonious account of why consciousness-altering molecules repeatedly emerge in nature. Rather than proposing a single adaptive function, the analysis seeks to constrain the space of plausible evolutionary interpretations and to clarify what kinds of ecological interactions and empirical tests are required to move beyond reductionist narratives.

Psilocybin as an evolutionary anomaly

Psilocybin does not fit comfortably into established categories of fungal secondary metabolites. Its biosynthesis requires a dedicated enzymatic pathway, including methylation,

hydroxylation, phosphorylation, and decarboxylation steps, representing a nontrivial metabolic investment (Blei et al. 2018, Awan et al. 2018, preprint). Once ingested, psilocybin is rapidly dephosphorylated to psilocin, which readily crosses the blood–brain barrier and acts as a partial agonist at serotonin 2A receptors and related targets (Dinis-Oliveira 2017).

These receptors are highly conserved across vertebrates and occupy central positions in neural systems involved in perceptual integration, cognitive flexibility, and exploratory behavior. In humans, subjective psychedelic effects correlate tightly with both plasma psilocin concentrations and cortical 5-HT2A receptor occupancy, indicating a direct and quantifiable neurobiological mechanism rather than diffuse toxicity (Brown et al. 2017; Madsen et al. 2019). Comparable serotonergic architectures exist across mammalian species, particularly with respect to the conserved role of the serotonin 2A receptor, which is consistent with experimental and clinical observations that psilocybin and related psychedelics induce broadly similar behavioral and perceptual alterations across species (Halberstadt & Geyer 2011; Nichols 2016; Vollenweider & Preller 2020)

From an evolutionary perspective, this degree of specificity is striking. Defensive compounds often act through bitterness, gastrointestinal distress, or nonspecific cellular damage (Firn & Jones 2000). Psilocybin, by contrast, produces reversible, state-dependent modulations of perception and cognition rather than persistent impairment or nonspecific toxicity (Nichols 2016; Madsen et al. 2019). It does not simply suppress behavior; it reorganizes it. Explaining such a molecule as an incidental deterrent requires assuming that evolution repeatedly tolerated a costly and precise biosynthetic pathway for effects that are, at best, indirectly defensive.

Importantly, psilocybin does not occur in isolation within fungal systems. Closely related tryptamine derivatives such as baeocystin, a direct biosynthetic precursor within psilocybin-producing fungi, as well as structurally and functionally related serotonergic compounds including bufotenin (5-hydroxy-*N,N*-dimethyltryptamine) and 5-methoxy-*N,N*-dimethyltryptamine (5-MeO-DMT), which occur naturally in plants, animals, and endogenous mammalian systems, underscore that psychoactive tryptamines constitute a small but coherent chemical family. Across systems, these molecules are characterized less by lethality or nonspecific toxicity than by their capacity to induce transient, state-dependent alterations of perception, behavior, and cognitive integration. The recurrent emergence of such serotonergic compounds in disparate taxa is difficult to reconcile with narrow deterrence-based explanations alone (Repke & Leslie 1977; Fricke et al. 2019; Costa et al. 2005; Nichols 2016).

Phylogenetic analyses further complicate the picture. The distribution of psilocybin biosynthesis across fungal lineages is discontinuous and inconsistent with a single, vertically inherited origin. Peer-reviewed comparative and evolutionary analyses indicate repeated gains, losses, and ecological clustering of secondary metabolite gene clusters in fungi, frequently involving horizontal gene transfer among saprotrophic taxa occupying similar niches (Walton 2000; Reynolds et al. 2018; Meyer & Slot 2023). Recent large-scale phylogenomic work further refines this picture by demonstrating that psilocybin biosynthesis likely originated within the genus *Psilocybe* approximately 65 million years ago and subsequently spread via multiple independent horizontal gene cluster transfer events into ecologically similar lineages, most notably among other dung- and wood-associated

saprotrophs. Importantly, distinct psilocybin gene cluster architectures correlate with major ecological transitions within *Psilocybe*, suggesting repeated evolutionary fine-tuning rather than conservation under a single universal selective pressure (Bradshaw et al. 2024). Earlier phylogenomic analyses available as a preprint provide convergent support for these patterns (Awan et al. 2018). Taken together, these findings are difficult to reconcile with a universal selective pressure such as insect herbivory, which affects nearly all fungi. Instead, they point toward niche-specific selective contexts in which the presence of psilocybin confers an advantage that is not reducible to generalized toxicity.

The insect hypothesis

Recent experimental work has renewed interest in the hypothesis that psilocybin evolved as a defense against invertebrate fungivores. In a recent preprint, Matthews Nicholass et al. exposed *Drosophila melanogaster* larvae to psilocybin-containing mushroom material and reported reduced survival, delayed development, and morphological asymmetries under laboratory conditions (Matthews Nicholass et al. 2025). These findings were subsequently presented in popular science media as evidence that psilocybin functions primarily as an insect deterrent (Woodford 2026).

Several limitations of this interpretation warrant closer examination, however. The experiments relied on dried, powdered fruiting body material and aqueous mushroom extracts rather than purified psilocybin, making it impossible to attribute the observed effects specifically to psilocybin as opposed to other co-occurring fungal metabolites. In addition, acute developmental stress under artificial feeding conditions does not, on its own, establish evolutionary function. Many non-psilocybin-producing fungi synthesize compounds that are equally or more detrimental to insect development, yet have not evolved psychoactive chemistry.

More fundamentally, insect fungivory is widespread across fungal taxa, whereas psilocybin production is rare and phylogenetically discontinuous. If insect deterrence were the primary selective driver, a much broader and more uniform distribution of psilocybin or functionally analogous compounds would be expected among mushroom-forming fungi. Field observations and comparative analyses indicate that fruiting bodies of psilocybin-producing fungi are not consistently avoided by insects. Moreover, healthy larvae are frequently observed feeding and developing within such fruiting bodies in natural environments (Bradshaw et al. 2024). Experimental work further shows that certain dipteran species are able to complete their entire life cycles within psilocybin-containing fruiting bodies, including larval development, pupation, and adult emergence under near-natural conditions (Awan et al. 2018, preprint). Taken together, these findings complicate strong insect deterrence models and suggest that insect stress, where it occurs, is more plausibly a secondary or context-dependent effect rather than the primary driver of psilocybin evolution (Meyer & Slot 2023).

The insect hypothesis therefore does not fail because insects are universally unaffected. It fails because it does not explain why evolution would repeatedly favor a molecule with such precise and conserved effects on nervous systems across taxa when far simpler and more broadly effective chemical defenses are readily available.

Even if psilocybin can impair insect development under specific laboratory conditions, this observation alone does not resolve its evolutionary role. A convincing evolutionary account must identify interaction contexts in which psilocybin's characteristic profile, namely reversible and state-dependent neuromodulation rather than nonspecific toxicity, can plausibly translate into fitness-relevant ecological effects. The temporal and ecological context of psilocybin emergence therefore merits consideration of alternative interaction partners. As outlined above, the origin of psilocybin-producing *Psilocybe* coincides with a period of profound ecological restructuring following the Cretaceous–Paleogene transition, including the diversification of terrestrial gastropods. This correspondence raises the possibility that non-insect fungivores exerted selective pressures distinct from those typically assumed in deterrence-based models (Bradshaw et al. 2024). Attention thus shifts toward consumers whose biology and behavior make modulation, rather than deterrence, consequential. Gastropods, as prominent mycophagous invertebrates with slow, sustained feeding and established roles in fungal material transport, represent a more informative next test case than insects for evaluating interaction-based models of fungal chemistry.

Gastropods, Circadian Disruption, and a Plausible Route for Spore Dispersal

If psilocybin is not primarily an insect deterrent, its ecological relevance must be sought in interaction contexts where altered perception or behavior plausibly translates into fitness-relevant outcomes. One such context, surprisingly underexplored, involves gastropods, particularly slugs and snails, which are among the most frequent mycophagous invertebrates interacting with mushroom fruiting bodies in temperate ecosystems.

Gastropods are not incidental consumers of fungi. They routinely feed on fruiting bodies, traverse mycelial networks, and transport fungal material across microhabitats. Unlike insects, their feeding behavior is slow, repetitive, and spatially extended, making them particularly relevant candidates for interaction-based rather than deterrence-based models of fungal chemistry. Importantly, gastropods are also known vectors for fungal spores, either externally or via endozoochory, with spores surviving gut passage and remaining viable after excretion (Chaudhary et al. 2022).

Within this context, emerging observations warrant cautious but serious consideration. Over the past several years, informal citizen science experiments conducted by mycologists, naturalists, and field enthusiasts have repeatedly reported that gastropods consuming psilocybin-containing mushroom material exhibit altered activity patterns. Most notably, these observations suggest a shift in circadian behavior, with slugs and snails displaying increased daytime activity following consumption of psilocybin-containing substrates, in contrast to their typically nocturnal or crepuscular patterns.

While these observations have not yet been validated under controlled laboratory conditions and must therefore be treated as preliminary, their consistency across independent observers is striking. From an ecological perspective, such a shift is not trivial. Daytime activity markedly increases gastropod exposure to avian predators. Birds, in turn, are highly effective agents of long-distance dispersal, either through the transport of ingested material or via mechanical transfer of spores adhering to feathers, beaks, or feet.

This constellation gives rise to a biologically plausible interaction-modulation hypothesis: rather than deterring gastropods, psilocybin may subtly alter their temporal activity patterns in ways that increase the likelihood of predation by birds, thereby indirectly enhancing spore dispersal. Such a mechanism would not require high toxicity, aversion, or lethality. It would rely instead on modest, state-dependent behavioral modulation, which is precisely the type of effect psilocybin is known to exert on nervous systems.

Crucially, this hypothesis aligns with several otherwise puzzling features of psilocybin chemistry. The compound's effects are reversible, dose-dependent, and primarily neurocognitive rather than physiologically debilitating. These properties are poorly suited for defense but well suited for altering behavior without eliminating the interacting organism. Moreover, this framework accommodates variability: not all gastropods would be affected equally, and effects would likely depend on dose, species, environmental context, and prior exposure.

At present, this model remains speculative. However, it is grounded in known principles of behavioral ecology, circadian biology, and spore dispersal. It also illustrates a broader point: ecological function need not be direct, linear, or antagonistic. Evolution frequently manifests as indirect modification of existing behavioral and trophic relationships rather than their outright elimination (Firn & Jones 2000; Strauss & Irwin 2004).

Importantly, such interaction-based models are not mutually exclusive with other ecological roles. Psilocybin may simultaneously influence microbial competition, deter certain invertebrates under specific conditions, and modulate the behavior of others. What matters is that its effects are not uniformly aversive, which undermines the assumption that defense is its primary evolutionary purpose.

The gastropod scenario is instructive because it reframes function away from immediate harm and toward indirect ecological leverage. However, it also exposes a deeper limitation of organism-specific explanations: if psilocybin operates through transient modulation of perception or activity rather than outright aversion, its evolutionary logic should not be unique to a single consumer group. This consideration invites a broader question: Does evolution repeatedly converge on closely related chemistries that engage conserved neural substrates and produce comparable state-dependent effects across taxa? Addressing this question requires situating psilocybin within the wider family of psychoactive tryptamines that recur across fungi, plants, animals, and endogenous mammalian systems.

Tryptamine-Based Neuromodulation as an Evolutionary Pattern: Psilocybin, DMT, and Related Compounds

Any attempt to understand the evolution of psilocybin in isolation remains incomplete. A broader pattern only becomes visible when psilocybin is situated within a wider class of psychoactive tryptamine derivatives, including *N,N*-dimethyltryptamine (DMT), baeocystin, bufotenin, and 5-methoxy-*N,N*-dimethyltryptamine (5-MeO-DMT). These compounds share core structural features, overlapping serotonergic targets, and the capacity to induce transient, state-dependent alterations of perception and behavior, yet they arise in markedly different biological contexts, spanning fungi, plants, animals, and endogenous mammalian pathways. This convergence strains explanations that frame consciousness-altering

molecules as evolutionary accidents or as narrowly targeted defensive toxins. Instead, it suggests that tryptamine-based neuromodulation represents a recurrent evolutionary solution that leverages conserved neural architectures across taxa.

A useful ecological parallel can be found in inducible chemical defenses in plants, most notably in African Acacia species exposed to acute herbivory by large mammals. Several taxa respond to intense browsing pressure by rapidly increasing concentrations of condensed tannins in their leaves, rendering them less palatable and, at sufficient intake, physiologically harmful. Crucially, this response is conditional rather than constitutive: tannin levels rise specifically under active predation and decline once browsing pressure subsides, often accompanied by airborne signaling that primes neighboring trees for similar chemical shifts (Furstenburg & van Hoven 1994). The evolutionary logic here is not constant deterrence but context-sensitive modulation of interaction, illustrating that metabolically costly bioactive compounds need not be permanently toxic to be adaptive.

Fungi, however, exhibit limited capacity for rapid, whole-organism inducible chemical responses once a fruiting body has differentiated. Unlike vascular plants, in which secondary metabolite production can be dynamically upregulated in response to acute herbivory, fungal fruiting bodies are developmentally pre-patterned structures whose chemical composition is largely determined during earlier stages of growth and differentiation (Calvo et al. 2002; Brakhage 2013; Keller 2019). This constraint renders the qualitative nature of fungal bioactivity particularly informative from an evolutionary perspective.

If psilocybin were primarily a deterrent, one would expect robust and persistent aversive effects across taxa and ecological contexts. Instead, its effects are transient, dose-dependent, and dominated by reversible neurocognitive modulation rather than generalized toxicity (Brown et al. 2017; Dinis-Oliveira 2017; Madsen et al. 2019; Nichols 2016). These features align poorly with classical toxin models but are well suited to subtle modulation of behavior and interaction.

Within this broader tryptamine framework, the comparison with DMT becomes particularly instructive. DMT cannot plausibly be explained as an external defense. Mammalian systems synthesize DMT endogenously via conserved metabolic pathways involving indolethylamine-N-methyltransferase, and its presence has been documented across multiple tissues, including the brain (Jiménez & Bouso 2022). An organism does not evolve a neuroactive compound within its own nervous system for defensive purposes. The endogenous nature of DMT alone undermines the assumption that closely related exogenous tryptamines are biologically irrelevant side effects.

Neuropharmacologically, DMT and psilocybin converge with remarkable specificity. Both act on serotonin 2A receptors while engaging additional modulatory targets, producing rapid and reproducible alterations of conscious experience. Human neuroimaging studies consistently show that DMT induces highly structured changes in large-scale brain organization, characterized by increased global functional connectivity, reduced hierarchical constraint, and enhanced cross-network integration (Soares et al. 2024; Vohryzek et al. 2024). These states are not chaotic disruptions but stable dynamical regimes accessible to the mammalian brain.

Recent integrative work has explicitly reframed DMT within an evolutionary systems perspective. Gupta et al. (2025) trace the trajectory of DMT from conserved tryptophan-based metabolic pathways through receptor-level interactions to large-scale brain network dynamics. Their analysis challenges the tendency to treat altered states of consciousness as epiphenomenal byproducts, arguing instead that neuromodulatory compounds capable of reorganizing brain connectivity represent biologically meaningful and evolutionarily accessible states.

Phenomenologically, psilocybin and DMT display striking overlap. Both reliably induce intensified salience, altered self-boundaries, changes in social cognition, and a heightened sense of meaning or familiarity (Davis et al. 2020; Lawrence et al. 2023). While phenomenology is often dismissed as subjective excess, its consistency across individuals, cultures, and compounds points to regularities in how these molecules engage neural systems central to social behavior, environmental assessment, and adaptive learning—domains that are foundational rather than peripheral from an evolutionary perspective.

Taken together, the convergence between psilocybin, DMT, and related tryptamines cannot be reduced to shared chemistry or coincidental receptor affinity. Multiple compounds, arising independently in fungi, plants, animals, and endogenous mammalian systems, repeatedly engage conserved neural substrates to produce comparable alterations of conscious state. This pattern is difficult to reconcile with defensive narratives that treat such effects as biologically incidental. Instead, it suggests that tryptamine-based neuromodulation occupies a recurrent solution space in evolution, leveraging existing neural architectures to modulate behavior, perception, and interaction with the environment in ways that can plausibly feed back into ecological and evolutionary dynamics.

If tryptamine-based neuromodulation represents a recurrent evolutionary pattern rather than an isolated anomaly, the explanatory burden shifts once more. It is no longer sufficient to show that such compounds influence particular consumers; the critical test becomes whether deterrence-centered accounts remain plausible across fundamentally different ecological architectures. Systems in which classical producer–consumer or predator–prey framings are least applicable therefore provide the strongest constraints on interpretation. Lichenized assemblages, characterized by long-lived, tightly integrated symbioses, offer precisely such a stress test, and the case of *Dictyonema huaorani* is particularly consequential in this regard.

The Lichenized Exception as a Stress Test for Reductionist Models

Among all known systems producing psychoactive tryptamines, the lichenized assemblage *Dictyonema huaorani* occupies a singular position. This basidiolichen, described from the Ecuadorian Amazon, represents a stable symbiosis between a basidiomycete fungus (*Cora* s. lat.), a cyanobacterial photobiont, and associated microbial partners. Chemical analyses revealed signals consistent with tryptamine-related compounds, including tentative matches to psilocybin and *N,N*-dimethyltryptamine, alongside related derivatives; however, the authors explicitly emphasize that compound identification could not be definitively confirmed due to the absence of authentic reference standards and limited material (Schmull et al. 2014). This constellation nevertheless constitutes a critical stress test for any explanation

that treats these compounds as incidental byproducts or as narrowly targeted defensive toxins.

Lichens are not transient structures. They are long-lived, slow-growing systems optimized for persistence rather than rapid turnover. Their reproductive strategy relies on durability, environmental integration, and repeated interaction with animals, microbes, and climatic stressors over extended timescales. In this context, the constitutive presence of two potent consciousness-altering compounds is difficult to reconcile with models centered on acute deterrence. A defensive toxin that disrupts neural function indiscriminately would be expected to reduce contact with potential dispersal agents and increase the energetic costs of maintaining the symbiosis. Yet *Dictyonema huaorani* persists as a stable, geographically restricted system embedded within a dense ecological network.

The coexistence of psilocybin and DMT within a single lichenized organism also undermines explanations based on phylogenetic coincidence. Psilocybin biosynthesis in fungi and DMT biosynthesis in plants and animals arise from distinct evolutionary lineages, yet here they converge spatially and functionally within one symbiotic entity. This convergence strongly suggests selective value at the level of interaction rather than lineage-specific metabolic drift. It is not sufficient to argue that one compound is defensive while the other is incidental; any such account must explain why both are maintained together, constitutively, in a system where acute predation pressure is neither dominant nor episodic.

From an ecological perspective, lichens are frequently grazed by invertebrates, including gastropods, mites, and insects, and are also contacted by vertebrates through incidental foraging and environmental disturbance. As in the case of fungi, spores and propagules are dispersed through a combination of abiotic and biotic vectors. The presence of psychoactive tryptamines may therefore modulate these interactions in subtle ways, influencing feeding duration, movement patterns, or predator–prey dynamics rather than acting as simple deterrents. The fact that *Dictyonema huaorani* occurs in regions with high vertebrate biodiversity further increases the plausibility that such compounds shape interaction networks rather than suppress them outright.

At a systems level, the lichenized case challenges the implicit assumption that evolutionary explanations can be reduced to single-agent selection pressures. Lichens are emergent biological entities whose fitness cannot be decomposed into the interests of individual partners alone. Selection operates on the stability of the symbiosis as a whole. In such systems, compounds that modulate perception or behavior in interacting organisms may confer advantages that are indirect, delayed, and distributed across multiple ecological layers. Psilocybin and DMT, in this light, appear less as weapons and more as signaling or interaction-shaping metabolites embedded in a complex relational matrix.

Importantly, the lichenized exception also constrains speculative narratives. It does not imply that psilocybin or DMT evolved “for consciousness” in any anthropocentric sense. Rather, it demonstrates that compounds capable of profoundly altering conscious state can be evolutionarily stable across kingdoms and symbiotic architectures. Any adequate theory must therefore explain not only how such compounds deter or harm, but why their specific neuroactive profiles recur, persist, and converge in systems where overt toxicity would be maladaptive.

In this context, *Dictyonema huaorani* functions as a natural experiment that exposes the limits of reductionist, defense-only models. It reinforces the need for interaction-based frameworks capable of accommodating convergence, constitutive expression, and cross-kingdom recurrence. In doing so, it prepares the ground for a final synthesis: one in which consciousness-altering chemistry is treated not as an evolutionary anomaly, but as a biologically meaningful variable shaping interactions across ecological and evolutionary timescales.

Synthesis: Interaction-Modulating Metabolites and the Evolutionary Relevance of Altered States

Across fungi, plants, animals, and symbiotic systems, a consistent pattern emerges: tryptamine-based compounds recur, converge, and persist in contexts where their primary effects are not lethality or aversion, but modulation of perception, cognition, and behavior. Psilocybin, DMT, and related molecules do not fit comfortably into classical models of chemical defense. Their pharmacological profiles are reversible, dose-sensitive, and targeted toward neural systems involved in salience attribution, social cognition, temporal perception, and meaning-making. These features are difficult to reconcile with deterrence-only explanations, but they are coherent within an interaction-modulation framework.

Under such a framework, secondary metabolites are not evaluated solely by whether they harm or repel, but by whether they reliably shift the behavior of interacting organisms in ways that alter ecological outcomes. In fungi, this may involve changes in feeding duration, movement patterns, circadian activity, or vulnerability to predation, all of which can feed back into spore dispersal and population dynamics. In lichens, it may stabilize long-lived symbioses by shaping multi-species interaction networks over extended timescales. In plants and animals, analogous compounds may tune perception and behavior in response to environmental stress, social context, or developmental phase.

This perspective also clarifies why convergent evolution repeatedly targets the serotonergic system. Serotonin receptors, particularly the 5-HT2A subtype, occupy a central position in vertebrate brains as regulators of sensory integration, cognitive flexibility, and the balance between top-down constraint and bottom-up information flow. Compounds that transiently relax hierarchical neural organization can open alternative behavioral regimes without permanently disrupting function. Neuroimaging work on both psilocybin and DMT demonstrates that these altered states are not random breakdowns but structured, reproducible configurations of brain activity (Madsen et al. 2019; Soares et al. 2024; Vohryzek et al. 2024). From an evolutionary standpoint, such accessibility suggests that these states lie within the natural dynamical repertoire of mammalian nervous systems.

Within this broader context, the question of human evolution can be addressed with greater precision. Claims that psilocybin or other psychedelics directly “drove” the expansion of the human brain are speculative and cannot be substantiated with current evidence. However, it is equally reductive to dismiss the possibility that repeated exposure to consciousness-altering compounds influenced aspects of hominin cognition and culture. Ethnographic, archaeological, and comparative evidence indicates long-standing human interactions with psychoactive fungi and plants (Olbryś 2021; Rodríguez Arce & Winkelman

2021). If such compounds reliably enhance pattern recognition, social bonding, narrative construction, or cognitive flexibility, even transiently, they could plausibly bias learning, cultural transmission, or problem-solving in ways that matter over evolutionary timescales.

Importantly, this does not require invoking a single, dramatic selective event. Evolutionary influence can be diffuse, cumulative, and mediated through culture. Interaction-modulating metabolites may function as amplifiers rather than drivers, increasing the variability of experience upon which selection can act. In this sense, the so-called “Stoned Ape” hypothesis is best reframed not as a causal claim about brain size, but as an early intuition pointing toward a deeper issue: the evolutionary relevance of altered states of consciousness themselves.

Seen through this lens, the New Scientist–style insect-deterrence hypothesis appears incomplete rather than incorrect. Psilocybin may indeed impair certain invertebrates under specific conditions. Yet this effect does not exhaust its biological significance. Defensive toxicity is neither necessary nor sufficient to explain why psilocybin biosynthesis evolved convergently, spread horizontally across fungal lineages, co-occurs with DMT in lichenized systems, and targets conserved neural substrates with remarkable specificity (Meyer & Slot 2023; Gupta et al. 2025).

A more parsimonious account recognizes psilocybin and related tryptamines as biologically meaningful mediators at the interface between organisms and their environments. They do not merely repel or poison; they reshape perception, alter behavior, and reconfigure interaction networks. In doing so, they occupy a legitimate evolutionary niche, one that has been repeatedly rediscovered across kingdoms and ecological contexts.

The central implication is not that consciousness exists “for” evolution, nor that psychedelics were selected to enlighten minds. Rather, evolution appears repeatedly willing to tolerate (and sometimes favor) chemistry that opens access to alternative cognitive states. Altered consciousness, far from being an evolutionary curiosity, may represent a variable that life exploits whenever the modulation of perception and behavior can shift ecological relationships in subtle but consequential ways.

In this sense, psilocybin is neither a mistake nor merely a weapon. It is a clue.

Scope and limitations

The framework developed here is intentionally constrained in scope. Rather than presenting new experimental data, this work advances a hypothesis-driven conceptual synthesis that integrates findings from fungal genomics, chemical ecology, evolutionary biology, and systems neuroscience. Its primary aim is not to establish causal mechanisms but to evaluate the explanatory adequacy of existing deterrence-centered models and to identify evolutionary patterns that warrant alternative interpretations. Consequently, several claims advanced in this manuscript remain provisional and conditional, particularly where empirical data are sparse or derive from heterogeneous model systems.

Importantly, the absence of direct experimental validation should not be interpreted as a weakness of the framework but as a reflection of the evolutionary questions addressed. Evolutionary functions cannot be inferred from isolated laboratory assays alone; they require

coherent hypotheses that specify which interactions, timescales, and ecological contexts are relevant in the first place. By delineating where current explanations fail to account for observed biosynthetic investment, phylogenetic distribution, and cross-taxa neuromodulatory specificity, this synthesis aims to narrow the space of plausible evolutionary interpretations and to generate testable predictions for future empirical work. The value of the framework therefore lies not in closure, but in constraint: in clarifying which kinds of data would meaningfully support, refine, or falsify the interaction-based perspective proposed here.

Outlook: Altered States as a Legitimate Object of Evolutionary Science

Despite increasingly detailed phylogenomic and ecological data, the evolutionary role of psilocybin remains unresolved, with current hypotheses ranging from deterrence to interaction-based modulation. This persistent uncertainty underscores the limitations of single-factor explanations and motivates broader models that integrate phylogeny, ecology, and conserved neural response architectures (Bradshaw et al. 2024; Meyer & Slot 2023).

If altered states of consciousness are not accidental side effects but recurrent, biologically accessible regimes shaped by conserved neurochemical pathways, then their systematic study becomes a legitimate and necessary extension of evolutionary science. This has concrete implications for how future research is framed, designed, and interpreted.

One immediate implication for evolutionary biology is the need to move beyond binary classifications of secondary metabolites as either “defensive” or “incidental.” Interaction-modulating compounds within the broader tryptamine class, including psilocybin and related serotonergic modulators such as DMT, call for models that integrate behavior, perception, and network-level neurodynamics into ecological and evolutionary analysis. Fitness effects in such systems are likely indirect, delayed, and mediated through changes in interaction structure rather than immediate survival advantages. Addressing these dynamics will require longitudinal, systems-oriented approaches capable of tracking behavioral and ecological cascades across trophic levels, rather than relying on short-term toxicity or deterrence assays alone.

A related implication concerns neuroscience, which stands to gain by explicitly treating altered states as structured, evolutionarily grounded brain configurations rather than pathological deviations from a presumed baseline. The growing body of neuroimaging work on psychedelics already demonstrates that these states are reproducible, rule-governed, and embedded within the intrinsic dynamics of mammalian brains. Future research should therefore focus less on whether such states are “normal” or “abnormal” and more on what functional roles they may have played in shaping learning, social cognition, and adaptive flexibility across species.

At a broader scale, comparative biology offers an underexplored opportunity. The recurrence of tryptamine-based neuromodulation across fungi, plants, animals, and symbiotic systems invites cross-kingdom comparisons that transcend traditional disciplinary boundaries. Why similar molecular solutions recur in lineages separated by hundreds of millions of years despite divergent evolutionary histories remains an open question. Addressing it will require integrating genomics, metabolomics, behavioral ecology, and computational models of brain dynamics into a shared conceptual framework.

These considerations extend naturally into human evolution and cultural biology and demand a more nuanced treatment of psychoactive substances. Rather than asking whether compounds like psilocybin “caused” specific evolutionary outcomes, future work should examine how repeated, culturally mediated access to altered states may have shaped patterns of meaning-making, social bonding, ritualization, and symbolic cognition. These dimensions are notoriously difficult to quantify, but they are no longer scientifically invisible. Advances in network neuroscience, anthropology, and cultural evolution theory now provide tools capable of addressing them with rigor.

Beyond these domain-specific implications lies a deeper methodological challenge. Conscious experience itself has long been treated as an epiphenomenon, excluded from evolutionary explanation because of its subjective character. Yet evolution operates on behavior, and behavior is inseparable from perception and meaning attribution. If certain biochemical pathways reliably open alternative experiential states that alter behavior in systematic ways, then experience becomes a legitimate variable—not as a metaphysical abstraction, but as a functional component of organism–environment interaction.

In this light, the evolutionary question is not why life occasionally produces molecules that alter consciousness, but why it does so repeatedly, convergently, and with striking specificity. Answering that question will require a shift in perspective: from viewing consciousness as an evolutionary byproduct to recognizing it as a modifiable dimension of biological interaction. Psilocybin, DMT, and related compounds do not provide the answer themselves. But they mark a boundary where future science can no longer afford to look away.

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Further Reading

The following references are provided for conceptual context and extended theoretical perspectives. They are not required to support the specific claims made in this manuscript.

Carhart-Harris, R. L., & Friston, K. J. (2019). *REBUS and the Anarchic Brain: Toward a Unified Model of the Brain Action of Psychedelics.* Pharmacological Reviews, 71(3), 316–344. https://doi.org/10.1124/pr.118.017160

A foundational theoretical framework linking psychedelic states to increased neural entropy, relaxed hierarchical priors, and adaptive cognitive flexibility. While primarily neuroscientific, the model is relevant for evolutionary discussions insofar as it reframes psychedelic effects as structured, potentially functional alterations of cognition rather than pathological noise.

Hoffer, A. (1967). *The Hallucinogens.* Academic Press.

An early but remarkably prescient synthesis that treats hallucinogens as biologically meaningful agents interacting with endogenous neurochemistry. Although predating modern neuroimaging and molecular biology, the work illustrates that functional interpretations of psychedelic compounds long preceded contemporary clinical and mechanistic models.

Krebs, T. S., & Johansen, P. Ø. (2013). *Psychedelics and mental health: A population study.* PLOS ONE, 8(8), e63972. https://doi.org/10.1371/journal.pone.0063972

Large-scale epidemiological data indicating no increased risk of mental health disorders associated with lifetime psychedelic use, and in some measures a correlation with improved outcomes. The study challenges toxicity-centered narratives and supports the view that these compounds are not intrinsically maladaptive to human neurobiology.

McKenna, T. (1992). *Food of the Gods.* Bantam Books.

A non-scientific but historically influential work proposing a role for psychoactive plants and fungi in human cognitive evolution. While speculative, the book is valuable as a cultural artifact that articulated intuitions later revisited, refined, or rejected by empirical research, including the so-called “Stoned Ape” hypothesis.

Nutt, D., Erritzoe, D., & Carhart-Harris, R. (2020). *Psychedelic psychiatry’s brave new world.* Cell, 181(1), 24–28. https://doi.org/10.1016/j.cell.2020.03.020

Positions psychedelics not only as therapeutic agents but as tools for probing fundamental principles of brain organization, consciousness, and cognition. The perspective reinforces the idea that psychedelic effects illuminate core properties of neural systems rather than representing pharmacological curiosities.

Schultes, R. E., Hofmann, A., & Rätsch, C. (2001). *Plants of the Gods* (2nd ed.). Healing Arts Press.

A classic ethnobotanical overview documenting the deep and geographically widespread relationships between humans and psychoactive plants and fungi. The work provides historical and cultural context relevant to co-evolutionary interpretations of psychoactive compounds.

Slot, J. C., & Rokas, A. (2011). *Horizontal transfer of a large and highly toxic secondary metabolic gene cluster between fungi.* Current Biology, 21(2), 134–139. https://doi.org/10.1016/j.cub.2010.12.020

Demonstrates that secondary metabolite gene clusters can spread via horizontal gene transfer, undermining explanations based solely on vertical inheritance. This finding is central to understanding the patchy phylogenetic distribution of psilocybin biosynthesis.

Timmermann, C., Roseman, L., Schartner, M., et al. (2019). *Neural correlates of the DMT experience assessed with multivariate EEG.* Scientific Reports, 9, 16324. https://doi.org/10.1038/s41598-019-51974-4

Provides early electrophysiological evidence that DMT-induced states are highly structured and reproducible rather than random or chaotic. These findings support interpretations of psychedelic states as organized brain dynamics with potential relevance for social cognition and adaptive behavior.