Mycoses of amphibians

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Article highlights:

- Fungal disease is a leading driver of the ongoing global amphibian extinction crisis.
- Chytridiomycosis (*Bd, Bsal*) remains the most consequential amphibian mycosis worldwide.
- Amphibians host a diverse spectrum of other mycoses, including mucormycosis, fusariosis, and infections by melanized fungi.
- *Mucor amphibiorum* causes a distinctive, often systemic mucormycosis in Australian amphibians, distinct from mammalian mucormycosis.
- Environmental management, biosecurity, and early molecular detection remain central to control and conservation efforts.

Keywords:
amphibia; ectotherm; mycoses; skin mycobiota; control; treatment; conservation

- Received 28 January 2026
- Revised 18 July 2026
- Accepted 26 July 2026
- Appeared online 29 July 2026
- One Health Mycology 3(2): 129-139, 2026
- doi.org/10.63049/OHM.26.32.2

Abstract

Fungal diseases have emerged as one of the most significant infectious threats contributing to the ongoing global decline of amphibian populations, acting synergistically with habitat destruction, climate change, pollution, and other anthropogenic stressors. This review provides an overview on mycosis reported in amphibia, including members of *Anura*, *Caudata*, and *Gymnophiona*. *Batrachochytrium dendrobatidis* and *B. salamandrivorans* are the causative agents of chytridiomycosis, a disease that has panzootic transmission and has been implicated in unprecedented population declines and species extinctions across multiple continents. Though less common, amphibians are susceptible to a broad range of fungal pathogens, including mucormycosis caused predominantly by the amphibian-specific pathogen *Mucor amphibiorum;* fusariosis, phaeohyphomycosis, and chromomycosis caused by melanized fungi such as *Exophiala* species; cryptococcosis, dermatophytosis, basidiobolomycosis, and rare cutaneous infections caused by basidiomycetes. Apart from these infections, the skin mycobiota of amphibians become pathogenic under stressful conditions as well. *Saprolegnia*, an oomycete, has also been found to pose a serious threat to amphibian populations. The present paper further discusses the current advances in diagnosis, treatment, biosecurity, and disease management. A comprehensive understanding of the expanding spectrum of amphibian mycoses is essential for strengthening conservation strategies, improving captive breeding and rehabilitation programs, and enhancing One Health surveillance, particularly in view of the zoonotic potential of several fungal pathogens.

Introduction

Amphibians (from Greek, amphi, 'both' and bios, 'life') are a class of tetrapod vertebrates that include frogs, toads, salamanders, newts, and caecilians (Helmenstine, 2025). The class comprises approximately 8,000 described species distributed across three orders: *Anura* (frogs and toads), *Caudata* (salamanders and newts), and *Gymnophiona* (caecilians) (Dinesh *et al.*, 2025). Amphibians are found on all continents except Antarctica, inhabiting diverse environments from tropical rainforests to temperate woodlands, though they are particularly abundant in moist habitats due to their permeable skin and complex life cycles involving aquatic and terrestrial phases (Pham & Tapley, 2025).

The unique physiology of amphibians, particularly their highly permeable skin that serves respiratory and osmoregulatory functions, makes them exceptionally vulnerable to fungal pathogens. Unlike mammals and birds, amphibians have thin keratinized skin and rely on cutaneous respiration, making their integument a critical interface with the environment (Akat Çömden *et al.*, 2023). This vulnerability has contributed to the current amphibian extinction crisis, with fungal diseases being identified as one of the primary drivers of global amphibian population declines (Luedtke *et al.*, 2023).

Major mycoses

Chytridiomycosis

Chytridiomycosis is an infectious disease in amphibians caused by the chytrid fungi *Batrachochytrium dendrobatidis* and *B. salamandrivorans* (Webb & Waddle, 2022). This disease

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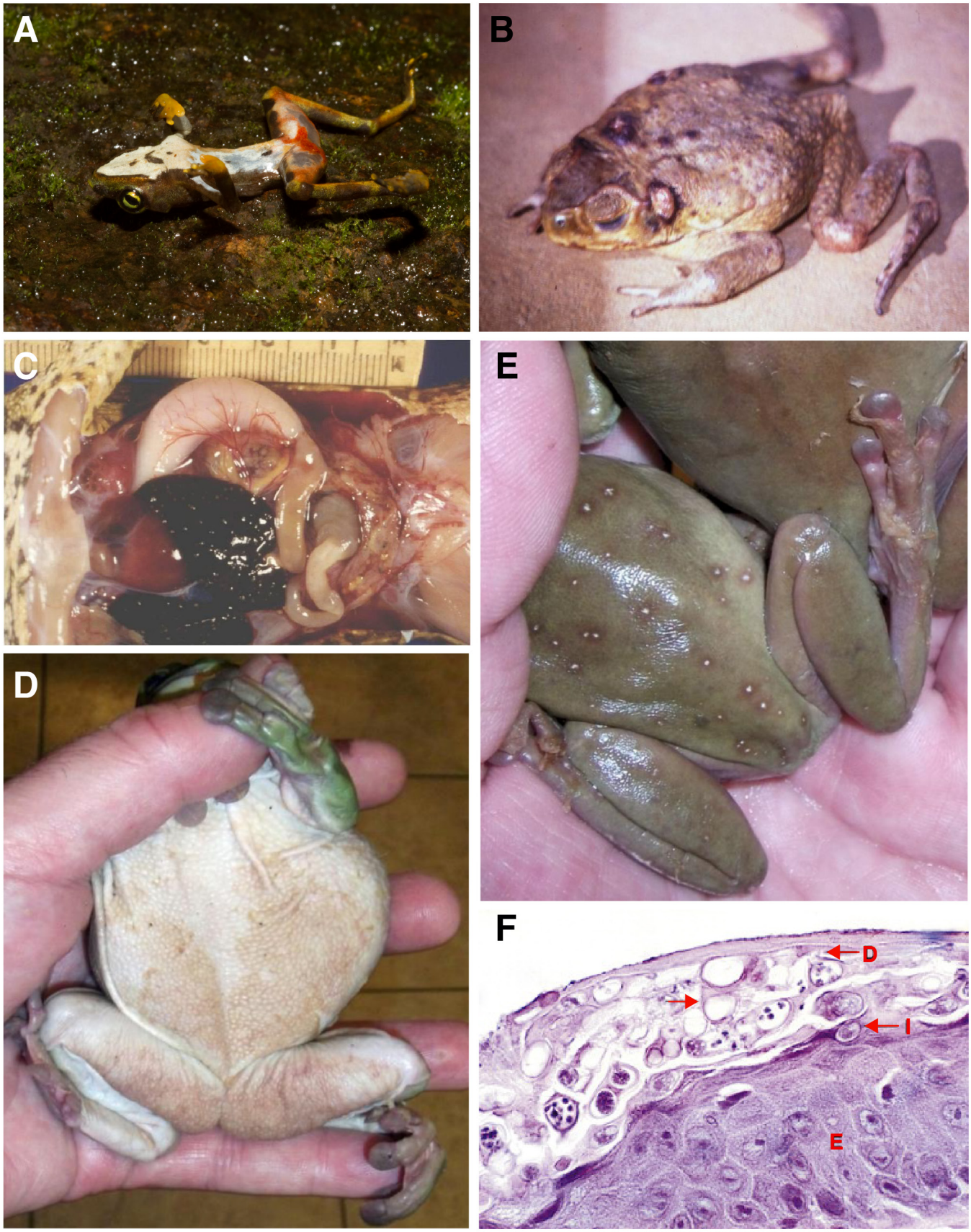

Fig. 1. A. Chytridiomycosis in amphibians (*Batrachochytrium dendrobatidis*). Dead *Atelopus limosus* (Limosa harlequin frog) naturally infected with *Batrachochytrium dendrobatidis*, showing severe cutaneous involvement. (courtesy Brian Gratwicke). **B.** Ulcerative nodular lesions in a moribund *Bufo marinus* from the Northern Territory, Australia; **C**. Numerous small pale nodules (~ 5 mm) on liver, kidney, mesentery, urinary bladder, and subcutaneous sinuses. The nodules bear the microscopic fungi. Courtesy Rick Speare James (B, C); **D.** Gross lesions of chytridiomycosis in Green tree frog. Thickened ventral skin in *Dryopsophus caeruleus* associated with chytridiomycosis; **E.** excessive epidermal shedding on the feet of a chytrid-infected frog. Courtesy K. Wright (D, E). **F.** Ultrastructural and epidermal changes in chytridiomycosis. Histological section of infected epidermis in adult *Litoria caerulea*, showing immature stages (red I), multinucleate zoosporangia, discharge tubes containing zoospores (red D), and empty zoosporangia (red arrow) following discharge; red E = epidermis (H&E).

represents one of the most significant threats to global amphibian biodiversity and has been implicated in dramatic population declines and extinctions worldwide (Fisher & Garner, 2020; Kolby & Daszak, 2016).

Batrachochytrium dendrobatidis (*Bd*) is significantly impacting amphibian populations across the globe and has caused the decline or complete extinction of over 200 species of frogs (Cornell Wildlife Health Lab, 2025). The pathogen primarily affects the keratinized structures of amphibian skin, including the mouthparts of tadpoles and the superficial skin layers of post-metamorphic individuals (Li *et al.*, 2021). The skin disease affects the vital function of amphibian skin, and not all amphibians respond equally to infection with host responses ranging from resistant, over tolerant to susceptible (Sun *et al.*, 2023).

Clinical signs of *Bd* infection include lethargy, abnormal posture, excessive skin shedding, and cutaneous hyperkeratosis (Fig 1A, E–D; Australian Government, 2020). In tadpoles, infection typically manifests as abnormal mouthpart development, feeding difficulties, and growth retardation (Northeast Wildlife, 2025). Post-metamorphic amphibians may exhibit skin discoloration, ulceration, and behavioural changes such as reduced activity and aberrant posture. The pathogen disrupts normal skin function, leading to electrolyte imbalances and eventual cardiac arrest in severe cases (Fig. 2; Voyles *et al.*, 2011). Pathological changes in chytridiomycosis are classically confined to the epidermis, with no significant involvement of internal organs generally observed (Voyles *et al.*, 2011).

Transmission occurs through direct contact with infected individuals, contaminated water, or infected environmental substrates. The pathogen can persist in aquatic environments and on moist surfaces, facilitating horizontal transmission between individuals and populations (Sasso *et al.*, 2021). Zoospores are released from infected skin and can actively swim to new hosts or survive in suitable environmental conditions (Fig. 1F; Voyles *et al.*, 2011; Zipkin & DiRenzo, 2022).

The global emergence of *Bd* is now understood to reflect the recent, human-mediated spread of a single, hypervirulent panzootic lineage rather than a uniformly ancient host association, which explains why previously unaffected, immunologically naive populations have suffered the most catastrophic declines following first contact with the pathogen (Fisher & Garner, 2020). International trade in amphibians, particularly for the pet, food, and laboratory-animal markets, has been repeatedly implicated as the principal pathway by which *Bd* lineages have been translocated between continents, seeding new epidemics in regions with no prior exposure (Kolby & Daszak, 2016). Once established, the trajectory of an outbreak is shaped by an interplay of pathogen load, host density, temperature, and community susceptibility, with some populations undergoing rapid epizootic die-offs while others settle into an enzootic state in which *Bd* persists at lower prevalence without further mass mortality (Fisher & Garner, 2020).

Recent work at the molecular level has begun to dissect the developmental and pathogenic biology of *Bd* more directly. Brody *et al.* (2025) reported a homology-mediated genetic transformation system for *Bd*, providing a long-sought tool for functionally interrogating chytrid developmental biology and the mechanisms underlying its pathogenicity, an advance expected to accelerate the identification of virulence factors and potential intervention targets.

Batrachochytrium salamandrivorans (*Bsal*) is a fungal pathogen closely related to *Bd* that particularly threatens salamanders and is currently sweeping across Europe, threatening three species of salamanders (Castro-Monzon *et al.*, 2022). The species was formally described by Martel *et al.* (2013), who isolated and characterized the fungus from fire salamanders (*Salamandra salamandra*) undergoing a steep, previously unexplained population decline in The Netherlands, demonstrating that it causes erosive skin disease and rapid mortality in experimentally infected animals. *Bsal* causes severe skin lesions and mortality in susceptible salamander species (Grear *et al.*, 2021). The pathogen appears to have emerged in Asia and was subsequently introduced to Europe through the international pet trade (Gray *et al.*, 2023; Farrer, 2019).

Clinical presentations include skin ulceration, excessive shedding, and necrotic lesions that can cover large portions of the body surface (Fig. 4; Areces-Berazain, 2024). Unlike *Bd*, which primarily affects the superficial skin layers, *Bsal* can cause deeper tissue destruction and more severe lesions (Castro-Monzon *et al.*, 2022). The disease progression is typically rapid, with mortality occurring within weeks of infection in susceptible species (Castro-Monzon *et al.*, 2022).

European salamanders show varying degrees of susceptibility, with fire salamanders (*Salamandra salamandra*) being particularly vulnerable (Fitzpatrick *et al.*, 2018). The pathogen has caused dramatic population declines in affected regions and poses a significant threat to naive salamander populations in North America and other regions where it has not yet been detected (Basanta *et al.*, 2022).

Chytridiomycosis in caecilians (Gymnophiona)

Until 2013, *Bd* had been confirmed only in anurans and caudates, with caecilians presumed refractory to infection despite their close, fossorial association with moist soil and leaf litter. The largest qPCR survey of *Bd* in caecilians to date, comprising over 200 field-swabbed specimens spanning five countries in Africa and South America and representing approximately 20 species, first demonstrated that caecilians can carry the pathogen, with positive individuals recovered from Tanzania and Cameroon; the same study reported the first evidence of lethal chytridiomycosis in the order, in captive, wild-caught *Geotrypetes seraphini* (Gower *et al.*, 2013).

Subsequent work has documented *Bd* infection in additional wild African caecilian populations (Doherty-Bone *et al.*, 2013) and reported the first case in a wild Neotropical caecilian, alongside successful itraconazole immersion treatment of *Bd* infection in captive terrestrial and aquatic caecilian species (Rendle *et al.*, 2015). Beyond chytridiomycosis, other mycoses remain essentially undocumented in *Gymnophiona*, reflecting both the cryptic, fossorial habits of this order and the comparatively limited research attention it has received relative to *Anura* and *Caudata*.

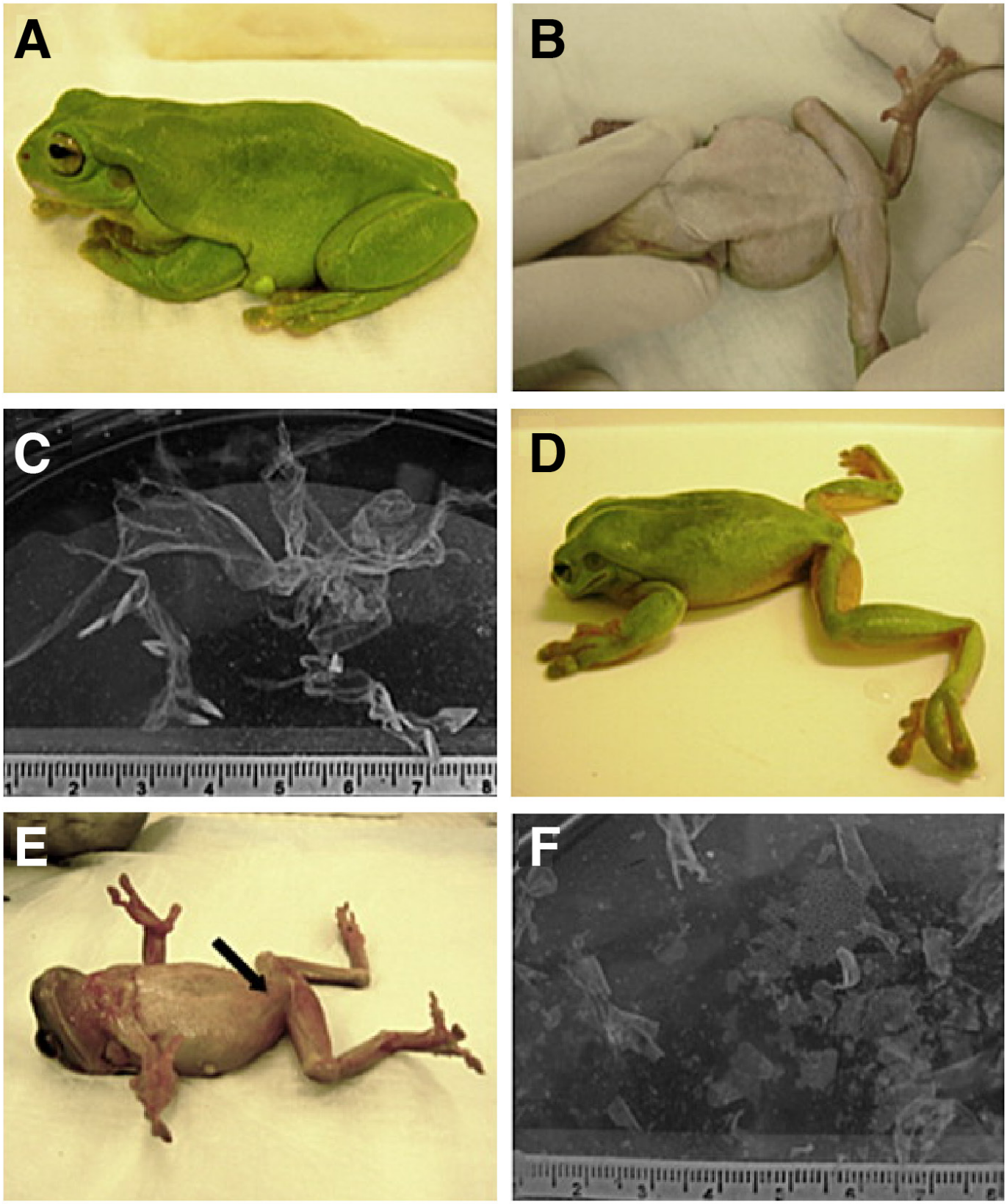

Fig. 2. Clinical and behavioral alterations in chytridiomycosis. **A, B.** Lateral and ventral views of a clinically healthy *Litoria caerulea*; **C.** single intact skin slough from a healthy frog; **D.** frog with severe chytridiomycosis showing abnormal posture with head lowered and hind limbs abducted. **E.** frog in dorsal recumbency, impaired postural recovery, with ventral cutaneous erythema (arrow); **F.** multiple fragmented skin sloughs collected from the container of a frog with severe chytridiomycosis. Courtesy Jamie Voyles A–F).

Less common mycoses

Mucormycosis

Mucormycosis is an invasive mycosis caused by fungi belonging to the order *Mucorales*, including species of *Mucor*, *Rhizopus*, and *Lichtheimia*. While mucormycosis is classically regarded as an opportunistic infection in mammals, particularly affecting immunocompromised hosts, a distinct and well-characterized form occurs in amphibians, primarily caused by *Mucor amphibiorum* (Speare, 2021). Unlike many opportunistic fungal infections, amphibian mucormycosis may occur in apparently healthy individuals, indicating a capacity for primary pathogenicity in this host group.

Mucor amphibiorum has been reported predominantly from Australia, affecting both captive and free-ranging amphibians, including frogs and toads. The infection is typically systemic, with widespread dissemination involving the liver, kidneys, lungs, mesentery, urinary bladder, subcutaneous tissues, and dermis. Gross lesions consist of multiple small, pale to white nodules distributed throughout affected organs. Cutaneous involvement may present as subcutaneous swellings or sinus tracts, although external lesions are not always apparent (Fig. 1B–C). The first Australian descriptions documented mucormycosis in a free-ranging green tree frog (*Litoria caerulea*; Berger *et al.*, 1997) and characterized the histopathology and gross lesions of the disease in cane toads (*Rhinella marina*, previously *Bufo marinus*) from Townsville (Speare *et al.*, 1997), building on the original identification of *M. amphibiorum* as the causative agent in this host (Speare *et al.*, 1994).

The host range for *M. amphibiorum* extends beyond Australian native and introduced anurans: isolates held in culture collections include one recovered in 1977 from a captive dendrobatid frog (*Dendrobates* sp.), alongside an isolate of determined (positive) mating type obtained from an ulcer on a Tasmanian platypus, indicating that the fungus is not restricted to a single host species or geographic origin (Webb *et al.*, 2012). Notably, *M. amphibiorum* is also the only agent known to cause significant morbidity and mortality in free-living platypuses (*Ornithorhynchus anatinus*) in Tasmania, where it produces a severe granulomatous and often ulcerative dermatitis that may extend into underlying muscle and, occasionally, disseminate to internal organs, particularly the lungs, leading to death (Connolly, 2015). The amphibian and platypus diseases share the same causative species but differ in isolate biology: essentially all *M. amphibiorum* isolates recovered from diseased platypuses have been of the positive mating type, and platypus-derived and positive-*MAT* isolates have proven to be more pathogenic in experimental studies than negative *MAT*-strains or anuran-derived isolates (Connolly, 2015). Multifocal red discolored cutaneous lesions and nodules on the lips, and nodules along with hemorrhage, erosion, and ulceration on chest and limbs has been reported in a female captive Japanese common toad (*Bufo japonicus*; Fig. 3A–C). *Protoellisomyces batrachophilus*, a member of the *Mucor circinelloides* complex, has been identified as the causative agent (Tamukai *et al.*, 2026).

Histopathologically, mucormycosis caused by *M. amphibiorum* (and, similarly, by the related fungus *Protoellisomyces batrachophilus*) is characterized by the

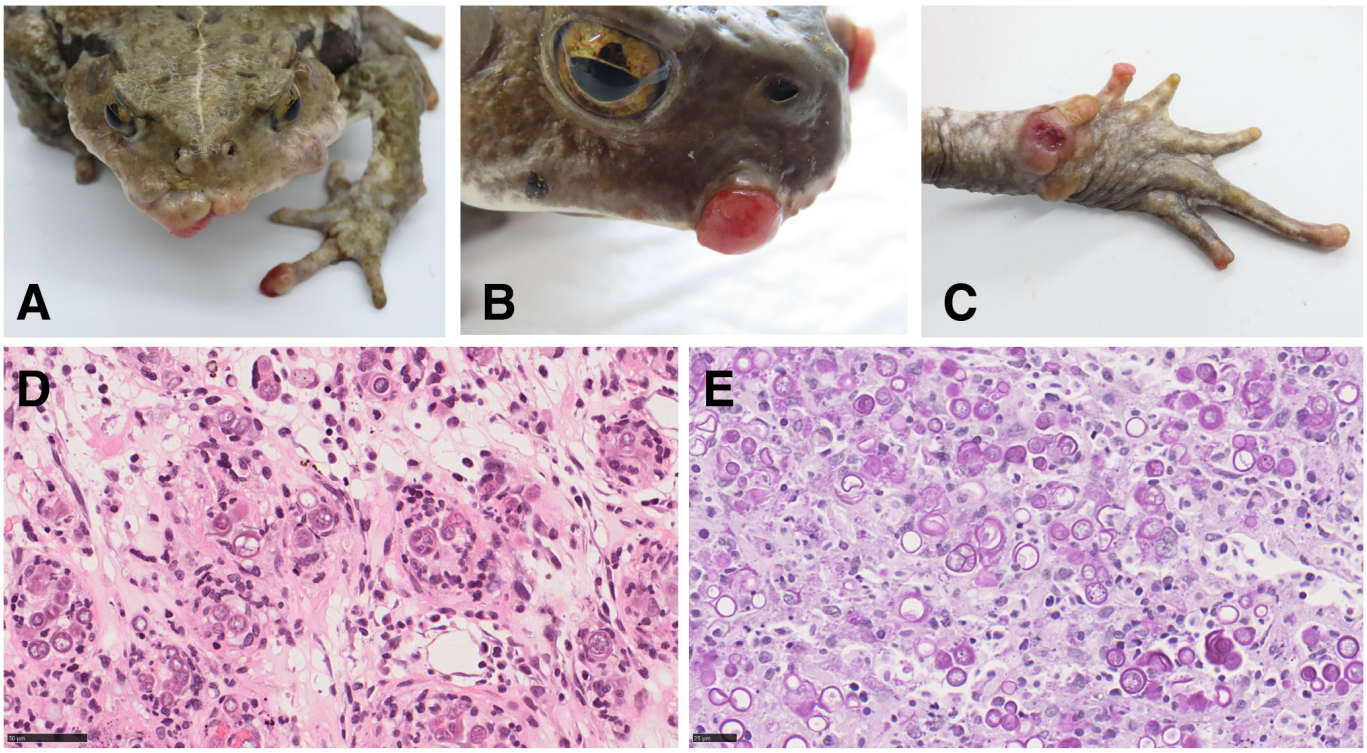

Fig. 3. Mucormycosis in a captive Japanese common toad (*Bufo japonicus*) caused by *Protoellisomyces batrachophilus*. **A.** Macroscopic presentation showing multiple nodules of varying number and size on the lip and the tip of the right hind limb; **B.** higher-magnification view of the lip nodule; **C.** higher-magnification view of the hind-limb nodule; **D.** Histopathology showing granulomas containing numerous sporangia, foamy cytoplasmic cells, histiocytes, and neutrophils. Sporangia have an eosinophilic wall, some containing sporangiospores. Hematoxylin and eosin stain; scale bar = 25 µm; **E.** thick eosinophilic sporangial walls and septa separating the sporangiospores stain positively with periodic acid-Schiff; scale bar = 25 µm. Courtesy Ken-ichi Tamukai (A–C), Sho Kadekaru (D, E).

presence of distinctive spherical fungal structures (spherules), ranging from approximately 5 to 35 µm in diameter, often containing internal daughter spherules. These structures elicit granulomas to pyogranulomas inflammatory responses containing numerous sporangia, foamy cytoplasmic cells, histiocytes, and neutrophils (Fig. 3D–E; Tamukai *et al.*, 2026). Unlike the filamentous hyphae typically observed in mammalian mucormycosis, the spherule-dominated tissue morphology of *M. amphibiorum* is considered a distinguishing diagnostic feature in amphibians (Speare, 2021).

Clinical signs in affected amphibians are frequently non-specific and may include lethargy, weight loss, dehydration, and reduced activity. A proportion of infected animals may remain asymptomatic, with infection detected only at necropsy. In captive settings, outbreaks with significant morbidity and mortality have been reported, whereas prevalence in wild populations appears low, suggesting environmental or husbandry-related factors may influence disease expression.

Comparative insights from mammalian mucormycosis indicate that members of the *Mucorales* possess several conserved pathogenic traits, including rapid growth, tissue invasion, and the ability to evade or overwhelm host immune defences (Alqarihi *et al.*, 2023). Unlike mammalian mucormycosis, the role of angioinvasion and extensive vascular thrombosis in amphibian infections remains incompletely understood. Nevertheless, the systemic distribution of lesions in amphibians suggests efficient tissue dissemination.

Amphibian mucormycosis must be distinguished from chytridiomycosis and other cutaneous mycoses through histopathology, fungal culture, and, where available, molecular identification. Given the potential for subclinical infection and systemic involvement, mucormycosis represents an important, though comparatively rare, component of the spectrum of mycoses affecting amphibians.

Fusariosis

Fusariosis in amphibians is an opportunistic mycosis caused by filamentous fungi of the genus *Fusarium*, widely distributed in soil, decaying vegetation, and water. Although *Fusarium* species are ubiquitous saprophytes, they can act as opportunistic pathogens under conditions of environmental stress, poor husbandry, or compromised skin integrity. The disease has been primarily documented in captive amphibians and is often associated with high morbidity and mortality.

A well-characterized outbreak occurred in captive populations of the endangered Wyoming toad (*Bufo baxteri*), maintained at the Henry Doorly Zoo, Omaha, U.S.A. In this outbreak, approximately 60 % of the toads exhibited clinical signs including ventral erythema, lethargy, inappetence, and impaired righting reflexes (Densmore *et al.*, 2010; Perpiñán *et al.*, 2010). Histopathological examination revealed fungal dermatitis characterized by epidermal hyperplasia, superficial ulceration, and fungal hyphae (1–3 µm in diameter, septate) infiltrating the epidermis and dermis. *Fusarium proliferatum, F. oxysporum, F. solani,* and *F. verticillioides* were repeatedly isolated from skin, kidneys, feces, and even feeder crickets, suggesting both environmental and dietary sources of infection (MSD Veterinary Manual, 2023).

Grossly, affected toads exhibited reddening of the ventral skin and, in severe cases, focal erosions. The disease course was acute to subacute, often culminating in death within days to weeks. Despite therapeutic intervention with antifungal agents and antibiotics, the outcome was uniformly poor. There was no evidence of systemic dissemination in most cases, indicating that *Fusarium* infections in amphibians are typically localized to the skin.

Environmental factors play a crucial role in the development of fusariosis. Suboptimal water quality, excessive humidity, organic debris, and contaminated substrates facilitate fungal growth and sporulation. Traumatic skin injuries further predispose amphibians to infection, as the permeable epidermis serves as the primary defence barrier. *Fusarium* pathogenicity extends well beyond amphibians among other ectothermic vertebrates. In marine and freshwater turtles, members of the *Fusarium solani* species complex cause sea turtle egg fusariosis (STEF) and the analogous freshwater turtle egg fusariosis (FTEF), both linked to high embryo mortality and of significant conservation concern (Saenz *et*

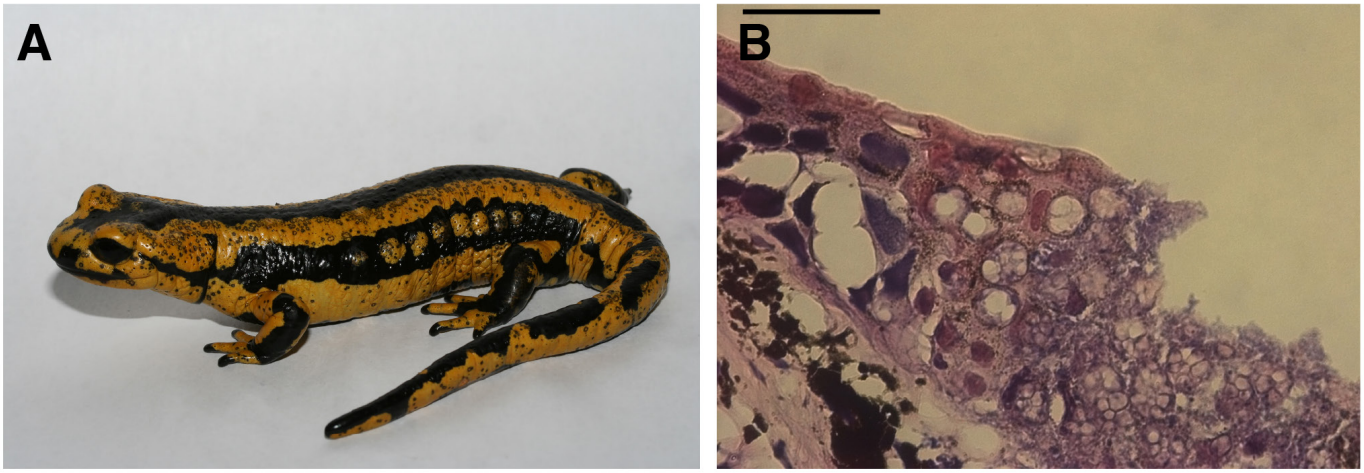

Fig. 4. *Batrachochytrium salamandrivorans* (*Bsal*) infection in fire salamander (*Salamandra salamandra*) (Gray *et al.*, 2015). **A.** Fire salamander showing extensive *Bsal*-associated ulceration, visible as black spots across the skin surface (image courtesy F. Pasmans); **B.** histopathology of *Bsal*-infected skin showing extensive epidermal necrosis, high numbers of intra-epithelial colonial chytrid thalli, and loss of epithelial integrity. Hematoxylin and eosin stain; scale bar = 50 µm. Courtsey Frank Pasmans (A), Ann Martel, Frank Pasmans and Mathew J. Gray (B).

al., 2024). In cartilaginous fish, by contrast, *Fusarium* and related *Hypocreales* are the near-exclusive fungal pathogens, in marked contrast to bony fish, which are predominantly affected by melanized fungi (Janse *et al*., 2024).

Diagnosis involves identification of characteristic septate hyphae in histological sections (stained with PAS or Grocott's methenamine silver), supported by culture and molecular confirmation of *Fusarium* spp. Effective management requires strict environmental hygiene, periodic substrate replacement, and improved water quality, as pharmacological treatment alone has shown limited efficacy.

Infections by melanized fungi

Waterborne species of the black yeast genus *Exophiala* (order *Chaetothyriales*) are recognized as opportunistic pathogens of amphibians, where they primarily cause cutaneous and, less frequently, disseminated infections. Susceptibility in amphibians is closely linked to their aquatic or semi-aquatic life cycle and the presence of smooth, moist, mucus-covered skin, which provides a favourable niche for fungal colonization. Infected amphibians, particularly frogs and toads, may develop chronic skin lesions that can progress under conditions of environmental stress or immunosuppression. Amphibian tissue responses to *Exophiala* infection are often poorly granulomatous, reflecting limited inflammatory containment. Virulence in amphibian infections has been associated with melanin production and metabolic versatility, while species-specific thermotolerance influences environmental persistence and host adaptation, with most amphibian-associated *Exophiala* species showing optimal growth at mesophilic temperatures below 30°C (de Hoog *et al*., 2011). A novel *Exophiala* species (not formally named at the time of description; reported as *Exophiala* sp. 1, isolate UTHSCSA R-5437) has also been associated with disseminated granulomatous inflammation in a captive Eastern hellbender (*Cryptobranchus alleganiensis alleganiensis*), extending the recognized host range of this genus to a caudate species (Hopf *et al*., 2020).

Chromoblastomycosis (chromomycosis), as used here for amphibians, is not strictly comparable to human chromoblastomycosis[1]. Clinically, chromomycosis presents as nodular lesions, grey to darkly pigmented papules, or ulcerative skin lesions. The disease may remain localized initially but frequently progresses to systemic involvement, characterized by multiple granulomatous lesions in internal organs. Histologically, lesions contain pigmented fungal elements, reflecting the melanin content of the cell wall, which contributes to persistence and pathogenicity, and muriform (sclerotic) bodies are considered a histological hallmark of the group. Some causative agents of chromomycosis are potentially zoonotic, highlighting the need for appropriate biosafety measures during handling and diagnosis (Schmidt, 1984; Queiroz-Telles *et al*., 2017).

Historically, chromomycosis and related phaeohyphomycoses have been reported repeatedly in captive toads of the marine toad/cane toad group (*Rhinella marina*, previously *Bufo marinus*): *Fonsecaea pedrosoi* was both observed spontaneously and experimentally transmitted in this species (Cicmanec *et al*., 1973), *Bufo marinus* has also served as a comparative model for chromomycosis caused by agents shared with human disease (Velasquez & Restrepo, 1975), and a further spontaneous case of chromomycosis has been documented in the same host (Bube *et al*., 1992). An early report of a *Phialophora*-like fungus causing mycotic infection in frogs (Elkan & Philpot, 1973) is of historical interest, though the causative isolate has subsequently been reidentified and should be cited with that caveat rather than as a confirmed *Phialophora* case. More recently, *Fonsecaea* sp. has been reported from the skin of the edible frog complex (*Pelophylax kl. esculentus*) in Serbia (Stupar *et al*., 2017), and a lethal, disseminated infection by a fungus reported as *Cladosporium allicinum* has been described in a captive African bullfrog (*Pyxicephalus adspersus*) in Europe, presenting as a cutaneous nodule that progressed to fatal multi-organ granulomatous disease with muriform bodies despite antifungal treatment (Grassi *et al*., 2023). Of note, this fungal species is otherwise known as a host-specific plant pathogen on onions; the identification of this organism might be inaccurate

Cryptococcosis

Cryptococcosis in amphibians is caused by *Cryptococcus neoformans* and related species. The infection typically affects the central nervous system but can also involve the skin and other organs. The disease is more commonly reported in captive amphibians than in wild populations (Seixas *et al*., 2008). Across wildlife and free-living mammals more broadly, cryptococcosis is now recognized as a sporadic but globally distributed disease whose clinical presentation is shaped by host anatomy, behaviour, and environmental exposure, a framework that offers useful comparative context for interpreting the sporadic amphibian case reports available (Danesi *et al*., 2021).

Although cryptococcosis is rare in amphibians, a notable case has been documented: Seixas *et al*. (2008) reported pulmonary cryptococcosis in a free-living common toad (*Bufo bufo*) in Portugal. In that case, both lungs harboured yeast-like organisms that were positive by PAS and Grocott silver staining; mucicarmine staining showed capsule positivity; immunohistochemistry with anti-*Cryptococcus neoformans* antibodies and PCR amplification confirmed *C. neoformans* as the etiologic agent (Seixas *et al*., 2008).

Dermatophytosis

Although less common than in mammals, dermatophytosis has been reported in amphibians, particularly in captive collections (Moskaluk & VandeWoude, 2022). The primary causative agents include *Trichophyton* and *Microsporum* species. The infection typically manifests as scaling, hyperkeratosis, and localized skin lesions (Paré, 2003). Clinical signs include keratin alterations or localized lesions (Chitty, 2009).

[1]Chromoblastomycosis (chromomycosis), as used here for amphibians, is not strictly comparable to human chromoblastomycosis, which is defined narrowly by muriform cells and agents restricted to the order *Chaetothyriales*. Because the term chromomycosis was abandoned in human medicine as too vague, we repurpose it here as an operationally defined designation for muriform-cell disease in amphibians, which is caused by a heterogeneous group of dematiaceous (melanized) fungi and occurs as an opportunistic infection in frogs, toads, and salamanders. Infection usually follows cutaneous injury or immunosuppression.

Basidiobolomycosis

Basidiobolomycosis in amphibians is caused by *Basidiobolus ranarum*, a member of the order *Entomophthorales*. The disease primarily affects frogs and toads and is typically associated with disruption of the cutaneous barrier, through which the fungus gains entry. *Basidiobolus ranarum* may occur as a commensal organism in the amphibian gastrointestinal tract, and recent molecular surveys confirm that *Basidiobolus* is a widespread, cross-domain component of the amphibian gut mycobiome, present across host species spanning conservation, urban, and rural habitats and implicated in supporting gut microbiome homeostasis rather than acting solely as a pathogen (Ghotbi *et al*., 2025; Hincher *et al*., 2025). Clinical presentation includes behavioural changes, with affected individuals exhibiting altered posture including back arching. Behavioural changes are common, with aquatic species leaving water and semi-terrestrial species showing increased water contact. Mortality is typically high following onset of clinical signs. *Basidiobolus ranarum* is zoonotic and has been associated with subcutaneous granulomatous infections in humans (Chitty, 2009).

Basidiomycete skin infections

A distinct skin mycosis caused by a basidiomycete rather than an ascomycete or zygomycete has been documented in the edible frog (*Pelophylax esculentus*) in South Banat, Serbia, where *Quambalaria cyanescens* – a fungus otherwise best known as a pathogen of eucalypts – was recovered from the skin, representing a new host record and expanding the known mycobiota of European amphibians beyond the more frequently reported ascomycete and mucoralean agents (Stupar *et al.,* 2022).

Amphibian skin mycobiota and environmental fungal flora

Although confirmed cases of aspergillosis have not been documented in amphibians, *Aspergillus* species are frequently recovered as environmental or cutaneous isolates from amphibian habitats and are best regarded as components of the skin mycobiome or environmental flora rather than established pathogens. A study on the bullfrog (*Hoplobatrachus tigerinus*) in Pakistan reported the isolation of several *Aspergillus* species, including *A. niger*, *A. fumigatus*, and *A. terreus*, from the skin of apparently healthy individuals (Fatima *et al.*, 2025). A subsequent survey of *Hoplobatrachus occipitalis* across three marshy sites in Man, Côte d'Ivoire, similarly found *Aspergillus*, *Rhizopus*, and *Mucor* species on the skin of wild-caught frogs, with *Aspergillus* the most frequently recovered genus (82.3 % of animals), and *A. niger*, *A. terreus*, and *A. fumigatus* individually detected in 51.6 %, 35 %, and 21.6 % of frogs respectively (Ble *et al.*, 2025). Similarly broad, largely commensal fungal communities – including numerous *Penicillium*, *Cladosporium*, and other genera alongside occasional pathogens such as *Exophiala castellanii* and *Mucor* spp. – have been characterized from the skin of the blind cave salamander (*Proteus anguinus*, the olm) across multiple cave systems in Slovenia, again illustrating that amphibian skin normally hosts a diverse fungal community from which only a minority of taxa behave as opportunistic pathogens under the right conditions (Zalar *et al*., 2022). Under conditions of immunosuppression, environmental stress, or suboptimal husbandry, some of these normally commensal or environmental fungi may possess the potential to cause infection (Fatima *et al.*, 2025).

Pseudofungal infections

Saprolegniosis

Saprolegniosis is caused by *Oomycetes* of the genus *Saprolegnia*, which are aquatic pathogens that primarily affect fish but can also infect amphibians, particularly during their aquatic larval stages (Costa & Lopes, 2022). These organisms are not true fungi but are functionally similar and cause comparable diseases (Costa & Lopes, 2022). The infection typically manifests as cotton-like growth on the skin surface, particularly around wounds or areas of compromised integument (Lock, 2017).

In amphibians, saprolegniosis commonly affects eggs, larvae, and recently metamorphosed individuals (O'Rourke & Rosenbaum, 2015). The pathogen can cause significant mortality in breeding populations and is often associated with environmental stressors such as poor water quality, overcrowding, or temperature fluctuations (Costa & Lopes, 2022). Clinical signs include white or gray fungal growth on the skin surface, lethargy, and secondary bacterial infections (Houston, 2025).

Control of mycoses in amphibians

Treatment of fungal diseases in amphibians is often challenging due to the physiological constraints of amphibian skin and the potential toxicity of antifungal agents. Topical treatments with antifungal solutions may be effective for localized infections, while systemic antifungal therapy may be required for disseminated disease.

Environmental management is crucial for prevention and control of fungal diseases. This includes maintaining appropriate temperature and humidity levels, ensuring good ventilation, and implementing proper hygiene protocols. Quarantine procedures are essential for preventing the introduction of pathogens into naive populations.

Treatment and control of chytridiomycosis

Treatment of amphibian chytridiomycosis is essential to reduce morbidity and mortality in captive populations, mitigate die-offs in wild amphibians, prevent pathogen spread to new locations, and establish chytrid-free assurance or breeding populations. *Batrachochytrium dendrobatidis* (*Bd*) exhibits low host specificity and infects a wide range of amphibian taxa, although susceptibility to disease varies markedly among species and life stages. Subclinical infections are common and can serve as reservoirs of infection, necessitating treatment even in the absence of clinical signs when *Bd* is detected by PCR.

Although several treatment approaches have proven effective, no single method is universally successful. Most

protocols are empirically derived, species-specific, and may vary in efficacy, tolerance, and safety. Topical bath treatments are commonly employed due to the superficial localization of *Bd* in the skin, but strict hygiene, environmental decontamination, and housing in *Bd*-free enclosures are critical to prevent reinfection. Post-treatment PCR testing is strongly recommended to confirm clearance, and multiple treatment cycles may be required. Disinfectants effective against *Bd* have also proven effective *in vitro* against *Mucor amphibiorum*, offering a shared decontamination strategy for facilities managing both chytridiomycosis and mucormycosis risks (Webb *et al*., 2012).

Treatment outcomes are influenced by species, developmental stage, infection burden, and adherence to biosecurity protocols. Supportive care, including electrolyte supplementation and antibiotics, may improve survival in clinically affected animals. Continued documentation and comparative evaluation of treatment protocols across species are essential to refine best practices for *Bd* management and conservation efforts (Amphibian Ark, 2010).

Conservation implications

Fungal diseases, particularly chytridiomycosis, have had devastating impacts on global amphibian populations. The emergence of these pathogens highlights the importance of disease surveillance, early detection, and rapid response protocols in amphibian conservation efforts. International cooperation is essential for preventing the spread of emerging pathogens and protecting vulnerable amphibian species.

Research into host-pathogen interactions, environmental factors influencing disease susceptibility, and potential treatment strategies continues to be a priority for amphibian conservation biology. The development of probiotics, antifungal treatments, and genetic resistance mechanisms offers hope for mitigating the impacts of fungal diseases on amphibian populations (University of Veterinary Medicine Budapest, 2025).

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