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Climate Change and Threat of Indoor Mold Diversity

I. Introduction

Climate change is no longer just a story of extreme weather or melting glaciers; it has permeated every layer of the microscopic world. Rising temperatures, altered humidity cycles, and the increasing frequency of extreme weather events are redefining the survival boundaries of molds and other fungi. These organisms, invisible to the naked eye, were long regarded as localized issues of buildings, food, and health. Today, however, they have become some of the most active ecological responders to climate change.

The distribution and activity of fungi are extremely sensitive to climatic variations: global warming drives them to migrate toward higher latitudes, while changes in humidity and material composition reshape both indoor and outdoor fungal communities. Meanwhile, extreme rainfall and flooding act as catalysts for massive mold outbreaks. Yet, compared with studies on plants, insects, or marine ecosystems, research on fungal responses to climate change remains fragmented and insufficient. The expansion and reorganization of molds not only alter the flow of energy within ecosystems but also threaten building durability, indoor air quality, and human health.

This article examines how climate change is rewriting the ecological boundaries of molds through three dimensions: geographic expansion, diversity restructuring, and the accelerating impact of extreme events. Together, these perspectives reveal how molds are transforming from overlooked contaminants into crucial sentinels—and amplifiers—of climate change.

II. Literature Review

(i) Mold Migration Toward Higher Latitudes

Under the overarching influence of climate change, the geographic distribution of molds and other fungal groups is showing a clear poleward shift—a tendency to expand toward higher latitudes. This phenomenon has been observed not only in the fields of medicine and public health but also in studies of plant pathogenic fungi and ecosystem-level fungal community adjustments (Waheed *et al.*, 2023).

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Long-term records spanning 56 years have revealed that many large fruiting-body fungi now begin fruiting earlier, finish later, and in some cases even produce two fruiting periods per year. Such shifts indicate that global warming is shortening winters and extending the active season, thereby facilitating the northward spread of molds (Gange et al., 2007).

According to *Financial Times* (2023), in the context of pathogenic fungi, projections suggest that if current warming trends continue, the habitable range of *Aspergillus fumigatus* in Europe could expand by approximately 77% by the year 2100, spreading from southern Europe into higher-latitude temperate regions. Similarly, *Cryptococcus gattii*—once limited to tropical and subtropical zones—began causing outbreaks in the temperate Pacific Northwest of North America in the late 1990s, making it a well-documented case of high-latitude expansion (Ngamskulrungroj et al., 2024).

The poleward migration of molds and other fungi signifies more than just a shift in geographic range—it represents a reorganization of the ecological interaction networks that sustain life. As temperature barriers gradually weaken, fungi are entering formerly inhospitable cold regions, where new fungal communities begin competing and coexisting with local plants, wood, and microbial populations, forming novel ecological equilibria. At the same time, warming and drought are reducing the defensive capacity of host plants and organic materials, creating "windows of opportunity" for fungal invasion and symbiosis. Some fungi, through rapid genetic adaptation, have developed enhanced tolerance to heat or cold, further transforming their ecological functions.

Together, these developments illustrate that climate change is triggering a cascade of interconnected effects—from microscopic genetic adaptations to large-scale ecological transformations—redefining global fungal diversity and its roles in material cycling, host interactions, and environmental stability.

(ii) Reorganization of Mold Diversity Under Climate Change

Climate change not only alters the geographic range of molds but is also

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reshaping their ecological functions and community structures. As humidity levels, material composition, and airflow dynamics shift, fungal communities display an unprecedented degree of adaptive flexibility. In damp or flooded built environments, increased material moisture content drives significant community reorganization. Studies have shown that when building materials remain under prolonged high-humidity conditions, fungal diversity tends to increase, and material-associated species such as *Aspergillus*, *Penicillium*, and *Stachybotrys* become more prevalent. These genera possess high enzymatic activity and moisture tolerance, enabling them to rapidly decompose organic substrates and release spores, leading to notable rises in total microbial biomass and the expression of functional genes (Lax et al., 2019).

Recent empirical research on fungal diversity confirms that climatic factors are already shaping community structure. Elevated CO_2 concentrations and rising temperatures have been shown to alter the community composition of arbuscular mycorrhizal fungi associated with maize and wheat roots. Although overall diversity did not change significantly, clear shifts in species dominance occurred, indicating that climate change is reshaping ecological hierarchies and interspecific interactions among fungi (Liu et al., 2023).

Similarly, a two-year monitoring study across nine museum storage facilities found a strong correlation between microclimate fluctuations—particularly variations in temperature and relative humidity—and changes in fungal abundance and community composition (Derksen et al., 2025). These results confirm that indoor fungal assemblages are highly sensitive to climate variability, responding primarily through species turnover and structural reorganization.

However, increases in diversity are not universal. In urban heat islands or poorly ventilated environments, increased rainfall and reduced airflow can limit the influx of outdoor microorganisms, potentially lowering overall indoor fungal diversity. Yet, dominant mold species in damp corners and material crevices often become more concentrated and resilient. These molds typically exhibit enhanced heat and moisture tolerance, form stable biofilms, or secrete sticky extracellular

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metabolites that reinforce their dominance within microenvironments (Aguilar-Marcelino et al., 2021).

In extremely humid or water-damaged environments, community diversity and dominance generally shift in favor of mold species. In contrast, in enclosed or poorly ventilated settings without visible water intrusion, species diversity may decline, but the functional and adaptive capacity of specific mold communities becomes stronger. Climate change is thus driving a restructuring of fungal ecosystems—blurring the boundary between indoor and outdoor microbiomes—and amplifying the ecological influence of molds as active participants in environmental dynamics.

(iii) Extreme Rainfall and Flooding as Accelerators of Mold Outbreaks

Climate change is driving a continuous increase in the frequency and intensity of extreme weather events. According to the *IPCC Sixth Assessment Report (AR6)*, every 0.5 °C rise in the global average temperature is associated with a significant increase in both the occurrence and severity of extreme rainfall events (high confidence). This means more frequent heavy rain, leaks, and prolonged flooding—conditions that create persistently humid environments ideal for mold growth. In urban and building contexts, such moisture not only raises the water content of construction materials but also extends the duration during which walls and floors remain damp, allowing fungi to proliferate deep within structures.

Following Hurricane Katrina in 2005, visible mold contamination was found in 46% of residential buildings in New Orleans, with airborne spore concentrations in some areas soaring from 82,000 spores/m³ to 630,000 spores/m³ (*Chew et al., 2006*). These values far exceed the World Health Organization's recommended safety limits, illustrating how extreme flooding can trigger community-wide mold outbreaks within mere weeks.

Similarly, after Hurricane Harvey (2017), the U.S. Centers for Disease Control and Prevention (CDC) reported cases of invasive mold infections among immunocompromised individuals, underscoring the serious environmental and health risks associated with post-flood fungal exposure. Together, these

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events confirm a clear causal chain: more extreme rainfall → increased indoor moisture and material dampness → mold proliferation.

Environmental monitoring and clinical research have continued to reinforce this conclusion. Multiple post-disaster studies have shown strong positive correlations between flood depth, building dampness indices, and indoor mold concentrations. When buildings remain at relative humidity levels above 75% or material moisture content above 15% for extended periods, mold growth rates can increase by two to five times. High-moisture indicator species such as *Stachybotrys chartarum*, *Aspergillus niger*, and *Cladosporium cladosporioides* are most frequently detected under these conditions. Their spores can form dense colonies on damaged surfaces and rapidly reactivate even after drying, utilizing residual moisture for renewed growth.

Extreme rainfall and flooding, therefore, are not merely structural hazards—they also reshape local fungal communities, often turning previously rare aquatic or moisture-loving species into dominant players. As climate change continues to amplify the frequency of such extreme events, these "climate-driven mold outbreaks" are becoming the new normal, compelling a paradigm shift in environmental and architectural mold prevention—from short-term remediation toward long-term climate adaptation.

III. Conclusion

The ecological responses of molds reveal another dimension of climate change—a microbial-scale crisis. As global warming intensifies, humidity fluctuates, and extreme weather events become more frequent, molds are evolving from local environmental nuisances into global ecological and public health threats. Geographic warming drives fungi to expand toward higher latitudes; fluctuations in temperature and moisture are reshaping community structures; and extreme climate events are accelerating mold outbreaks. Collectively, these trends demonstrate that molds are no longer passive environmental organisms, but among the most sensitive and rapidly responding indicators of climate change.

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Projections suggest that if global temperatures rise by more than 1.5 °C, the suitable habitats of common molds such as *Aspergillus*, *Cladosporium* could expand by 60–80%, while fungal concentrations in post-disaster regions may surge dozens of times within a short period. Such changes will make mold-related problems increasingly chronic and systemic—accelerating the deterioration of building materials, complicating the preservation of cultural heritage, and worsening indoor air quality and allergy-related diseases.

Thus, the threat of molds will grow ever more severe under a changing climate, unconstrained by season or geography. Future strategies for mold prevention and environmental management must shift from reactive responses to proactive climate adaptation, integrating fungal monitoring, material innovation, and resilient urban design. Ultimately, molds are not merely by-products of climate change—they are biological indicators of environmental stability and human habitability in an increasingly unstable world.

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