The Fungal Frontier: Mycelium as a building material for Sustainable Aquaculture

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Introduction: Redesigning Aquaculture with Fungal Materials Aquaculture has become a critical player in global food production, supplying over 50% of seafood consumed worldwide. As the industry grows, so too does the infrastructure needed to support it—buoys, cages, floating platforms, and support frames built predominantly from plastics, polymers, and treated metals. These materials, while durable, contribute heavily to marine pollution, microplastic contamination, and long-term ecological degradation. A growing body of research suggests that mycelium-based biocomposites, derived from the root-like structures of fungi, may offer a promising alternative. These materials are biodegradable, renewable, and can be locally sourced and manufactured, making them a compelling option for reimagining sustainable aquaculture infrastructure (MycoBuoys, 2024).

Understanding Mycelium: A Natural Bio-Composite

Mycelium is the vegetative part of fungi, consisting of a dense network of hyphae that binds together organic substrates such as sawdust, straw, or agricultural waste. When grown under controlled conditions, this network creates a lightweight, foam-like material that can be molded into specific shapes. The resulting composite is biodegradable, naturally fire-resistant, and capable of being engineered for various applications. In recent years, mycelium has been explored in packaging, architecture, and insulation, but its application in aquatic environments remains largely experimental (Jones *et al.*, 2018). The material's potential stems from its low embodied energy, capacity to upcycle agricultural byproducts, and end-of-life biodegradability, which is especially advantageous in marine settings where pollution from plastics is a growing crisis (Appels *et al.*, 2019).

Early Experiments in Aquaculture Applications

One of the first known applications of mycelium in aquaculture infrastructure comes from the MycoBuoys project in the United States. These biodegradable buoys, grown from hemp fiber and mycelium, were tested in oyster farming environments along the northeast U.S. coast. Uncoated mycelium buoys degraded rapidly in marine conditions, but those coated with non-toxic, plant-based sealants performed well for several months sufficient for seasonal aquaculture operations. Their buoyancy, low weight, and biodegradable nature allowed them to serve as temporary infrastructure without contributing to long-term marine debris. This prototype demonstrated the viability of mycelium as a floatation component in lower-stress environments such as protected bays and estuaries (MycoBuoys, 2024).

Material Science and Structural Potential

Scientific research has delved into the physical properties of mycelium-based composites. Jones *et al.* (2018) and Elsacker *et al.* (2019) examined how fungal species, substrate types, and processing techniques affect water absorption, density, and compressive strength. For instance, heat-pressing mycelium panels significantly increases their density and reduces porosity, resulting in enhanced mechanical strength and moisture resistance. Straw and sawdust substrates combined with fungi like Pleurotus ostreatus produce composites with higher rigidity, while cotton-based substrates offer flexibility but lower resistance to water uptake. However, even optimized composites still absorb significant moisture when uncoated, which can reduce structural integrity over time—an obstacle that must be addressed for marine deployment (Elsacker *et al.*, 2019).

Water Resistance: A Critical Challenge

Water resistance remains the greatest limitation to the broader application of mycelium in aquaculture. Studies show that uncoated mycelium composites can absorb between 50% and 300% of their dry weight in water after submersion for just 48 hours, leading to swelling, microbial decay, and structural collapse (Appels *et al.,* 2019). To mitigate this, researchers have tested various coatings beeswax, plant-based oils, chitosan, and biodegradable polymers with varying degrees of success. A study by van den Bosch *et al.* (2021) explored bacterial cellulose reinforced mycelium composites, revealing moderate gains in water resistance and tensile strength, though still not on par with conventional marine-grade plastics. For successful real-world deployment, further innovations in hydrophobic treatments that preserve biodegradability will be essential.

Durability and Performance in Marine Environments

Apart from water absorption, other environmental stressors such as UV exposure, wave action, and biofouling can accelerate degradation of mycelium-based structures. A comprehensive review by Curto *et al.* (2021) on biocomposite materials in marine settings found that constant immersion, saltwater corrosion, and colonization by algae or invertebrates significantly affect longevity. While some degradation is desirable for environmental sustainability, premature breakdown could pose operational risks or increase maintenance costs for aquaculture operators. Additionally, coatings used to enhance durability must be carefully chosen to avoid ecotoxic effects, as even biodegradable coatings can leach chemicals that harm marine life (Curto *et al.,* 2021).

Sustainability and Carbon Impact

Despite durability concerns, the environmental benefits of mycelium composites are clear. Life-cycle assessments (LCAs) of mycelium materials used in building and packaging industries demonstrate low embodied energy, carbon-negative potential, and minimal chemical processing. One study showed that fungal composites grown on agricultural waste can act as net carbon sinks, storing more carbon than they emit during their lifecycle especially when grown locally with minimal energy input (Sustainable Materials Lab, 2022). When compared to expanded polystyrene or polyvinyl-based floatation devices, mycelium's carbon footprint is orders of lower magnitude. For an industry like aquaculture, which relies more on sustainability, switching to biodegradable infrastructure could further reduce ecological impact while improving public perception.

Mycelium's Role in Bio-Remediation and Water Quality Enhancement

One fascinating, yet underexplored aspect of using mycelium-based materials in aquaculture is their potential to contribute actively to water purification and bio-remediation. Certain fungal species possess enzymatic systems capable of breaking down organic pollutants, heavy metals, and even microplastics in aquatic environments (Kuppusamy *et al.,* 2017). Incorporating mycelium composites into aquaculture infrastructure could, therefore, serve dual purposes: structural support and passive filtration or detoxification. For example, mycelium's natural absorption capabilities and enzymatic degradation pathways might help reduce eutrophication and harmful algal blooms by processing excess nutrients or degrading organic waste products within enclosed farming systems (Gadd, 2020). This symbiotic use of infrastructure and ecosystem service could revolutionize how farms maintain water quality and mitigate environmental impacts without chemical inputs.

Integration with Aquaponics and Circular Nutrient Systems

The integration of mycelium-based structures with aquaponic systems offers an innovative avenue for enhancing resource efficiency. Aquaponics combines aquaculture with hydroponic plant production, creating a closed-loop where fish waste fertilizes plants, and plants help filter water. Mycelium composites could act as biodegradable supports or planting substrates in these systems, providing a natural interface between fish and plants (Stamets, 2020). Moreover, as mycelium breaks down organic waste, it could help recycle nutrients within the system more effectively. This integrated approach not only improves material sustainability but also enhances system resilience and productivity by fostering beneficial microbial communities critical for nutrient cycling.

Socio-Economic Impact and Local Community Engagement

A promising, often overlooked benefit of mycelium materials lies in their potential to empower local communities economically. Mycelium production can be decentralized, using locally available agricultural residues and minimal infrastructure, thus creating new livelihood opportunities in rural and coastal regions (Jones *et al.*, 2020). Training aquaculture communities to cultivate and process mycelium composites could reduce dependence on imported, fossil-fuel-based materials, lower operational costs, and stimulate circular economies. This democratization of material production aligns with sustainable development goals (SDGs) related to poverty alleviation, responsible consumption, and climate action. Furthermore, community-led production may increase acceptance and adaptation of sustainable infrastructure innovations, bridging gaps between research and real-world application.

Potential For Customizable, Smart Mycelium Materials

Emerging biotechnology advances now enable the engineering of mycelium composites with functional properties customized for specific aquaculture needs. Genetic modification and selective breeding of fungal strains could enhance resistance to saltwater, improve mechanical strength, or imbue materials with antimicrobial properties to reduce biofouling (Haneef *et al.,* 2017). Additionally, embedding natural pigments or biosensors within mycelium matrices could allow for real-time monitoring of environmental parameters such as pH, temperature, or pollutant levels, providing aquaculture operators with vital data to optimize farm management (Lee *et al.,* 2022). These “smart” biostructures represent the next frontier in combining sustainable materials with digital aquaculture technologies.

Lifecycle Economics and Cost-Benefit Analysis

Although environmental benefits are clear, the economic feasibility of mycelium-based aquaculture infrastructure requires further scrutiny. Initial production costs can be higher compared to conventional plastics due to scale limitations and current technology readiness levels (El-sacker *et al.,* 2021). However, when accounting for end-of-life disposal costs, environmental remediation, and potential regulatory penalties on plastic pollution, mycelium composites could prove cost-competitive over the medium to long term (Sari *et al.,* 2020). Furthermore, investments in local production facilities and circular supply chains could reduce transportation emissions and expenses. Comprehensive techno-economic assessments and pilot-scale commercial trials are essential to validate these claims and attract investor confidence.

Policy Implications and Regulatory Frameworks

To accelerate adoption of mycelium in aquaculture, robust policy frameworks are necessary. Currently, regulations for aquaculture materials focus largely on durability, food safety, and environmental toxicity, with limited provisions for bio-based alternatives (FAO, 2023). Developing standards for biodegradability in marine conditions, certification schemes for sustainable material sourcing, and incentives for innovation could facilitate market entry for mycelium composites. Collaboration between regulatory agencies, research institutions, and industry stakeholders will be crucial to ensure that policies both protect marine ecosystems and encourage sustainable material adoption. International cooperation might also be needed given the transboundary nature of marine pollution and seafood markets.

Research Gaps and Innovation Opportunities

Though proof-of-concept projects like MycoBuoys show promise, significant research is needed to bridge the gap between lab-scale materials and field-ready solutions. Studies should focus on improving hydrophobicity without compromising biodegradability, testing hybrid composites that blend mycelium with natural fibers or bioplastics, and evaluating long-term degradation under varied marine conditions. There is also a need for regulatory clarity standards for biodegradability, toxicity, and performance must be developed for any bio-based material used in food-producing marine environments. Moreover, field trials across diverse aquaculture types (e.g., freshwater cages, offshore mussel rafts, kelp lines) are needed to build confidence among producers and investors (Curto *et al.*, 2021; van den Bosch *et al.*, 2021).

Conclusion: A New Paradigm in Blue Infrastructure

Mycelium-based biostructures hold transformative potential for aquaculture infrastructure, aligning ecological responsibility with material innovation. While challenges remain particularly in water durability and mechanical strength the early-stage data is encouraging. With appropriate research and pilot testing, fungal composites could offer a local, renewable, and biodegradable alternative to petroleum-based marine hardware. As climate concerns intensify and the need for regenerative solutions grows, the fungal frontier may well offer the aquaculture industry a path toward true sustainability—growing not only the fish we eat but also the structures that support them.

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