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Biofoulers in Cage: A Hazardous Phenomenon in Aquafarming

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Biofouling in cage aquaculture involves the accumulation of organisms like algae, mussels, and bacteria on submerged surfaces, posing serious operational, economic, and ecological challenges. It begins with microscopic biofilm formation and progresses to complex communities of macro-organisms, reducing water flow and oxygen availability. This process stresses fish, increases disease risk, and adds maintenance costs due to net clogging and structural damage. Biofouling is classified into microfouling, macrofouling, chemical, sediment, and corrosion-associated types. Effective control strategies such as antifouling coatings, mechanical cleaning, and site selection are essential for sustainable aquaculture operations. It reduces water flow, oxygen levels, and fish health, ultimately affecting growth and survival. It increases disease risks as fouling organisms harbor pathogens and parasites. Structural damage to cages and high maintenance costs further strain operations. Chemical control methods risk environmental harm, while integrated approaches offer more sustainable management. Effective biofouling control is essential to ensure fish welfare, economic viability, and ecological balance in aquaculture systems.

Keywords: Cage, Biofoulers, Barnacle, Mussel, Seaweeds

Introduction

Biofoulers are organisms such as algae, barnacles, mussels, tunicates, and bryozoans that attach themselves to submerged surfaces in aquatic environments, including fish cages. In cage aquaculture, biofouling poses significant operational, economic, and ecological challenges. These organisms colonize cage nets and structures, reducing water exchange, limiting oxygen supply, and leading to the accumulation of waste, which can stress the cultured fish and impair growth and health. Fouling also increases the weight of cages, risking structural damage and requiring frequent maintenance and cleaning, which adds to operational costs. Additionally, biofoulers may act as vectors for pathogens and parasites, increasing the risk of disease outbreaks. Effective biofouling management through regular cleaning, antifouling coatings, and strategic site selection is crucial to maintain optimal water quality, fish health, and overall productivity in cage aquaculture systems.

Fig. 1. Fouling effect on fish cage

Types of Biofoulings

Categorized based on the nature of the fouling organisms or materials.

1. Microfouling (Primary Biofouling): Involves microscopic organisms that form a biofilm. Examples: Bacteria, diatoms, and protozoa.

2. Macrofouling (Secondary Biofouling): Involves the colonization of larger, visible organisms. Example: Algae, seaweeds, sponges, barnacles, Mussels etc.

3. Chemical Fouling: Accumulation of unwanted chemical substances that support or enhance biological fouling. Examples: Organic matter, nutrients, and pollutants that promote microbial growth.

4. Sediment Fouling: Deposition of inorganic particles that may encourage biological colonization. Example: silt, clay, or sand

5. Corrosion-Associated Fouling: Occurs when fouling accelerates corrosion (called microbiologically influenced corrosion). Example: Sulphate-reducing bacteria (SRB) and iron-oxidizing bacteria.

Fouling Process

Biofouling in fish cage aquaculture is a natural but problematic process that involves the unwanted accumulation of aquatic organisms on submerged surfaces of fish cages and related equipment. This process begins with the initial conditioning of the surface, where dissolved organic matter and microscopic organisms such as bacteria and diatoms form a thin biofilm, creating a sticky layer that facilitates the attachment of larger organisms. Over time, more complex organisms like algae, barnacles, mussels, tunicates, hydroids, and sponges colonize the surface. This biological accumulation affects the structural integrity and functionality of the cage system by clogging nets, reducing water flow, and impeding oxygen exchange. The fouling layer increases the drag force on cages, making them more susceptible to damage from currents and storms. It also leads to higher maintenance costs due to the frequent need for cleaning and net replacement. Moreover, biofouling can harbor pathogens and parasites, posing a health risk to cultured fish and potentially impacting growth, feed conversion, and overall productivity. If not managed properly, it can severely reduce the efficiency and sustainability of cage-based aquaculture systems. Preventive and control measures such as mechanical cleaning, antifouling coatings, regular net exchange, and the use of environmentally friendly biocides are essential to minimize the adverse impacts of biofouling in fish cages.

Steps involved in biofouling process

Step 1: Initial Conditioning (Surface Film Formation)

When a fish cage is submerged in water, its surface (nets, frames, ropes) gets immediately covered by a thin layer of organic molecules (like proteins, lipids, and polysaccharides). This layer, called a conditioning film, alters the surface properties and makes it attractive for microorganisms to settle.

Fig. 2. Biofilm development in fish cage

Step 2: Microbial Colonization (Microfouling)

Within hours to days, bacteria, diatoms, and microalgae begin to attach to the conditioned surface. These microorganisms form a biofilm, which is a slimy and

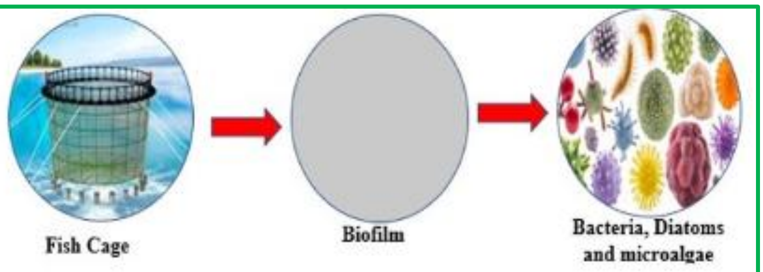

Fig. 3. Microbial colonization in fish cage

sticky layer that further facilitates attachment of larger organisms.

Step 3: Larval Settlement (Initial Macrofouling)

The biofilm attracts the larvae of larger fouling organisms such as barnacles, mussels, tubeworms, and tunicates. These larvae settle on the surface and begin to grow, forming the early stages of macrofouling.

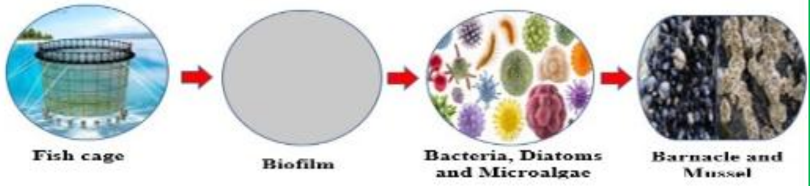

Fig. 4. Initial Microfouling in fish cage

Step 4: Growth and Maturation of Biofoulers

Over time, the settled organisms grow in size and number, creating a complex community of macro-organisms including: Seaweeds (macroalgae), Bivalves (mussels, oysters), Sponges, Barnacles etc.

Fig. 5. Advance Microfouling in fish cage

The structure becomes more stable and layered, leading to dense biofouling.

Step 5: Ecological Succession and Stabilization

As the biofouling community matures, there is a succession of species, with dominant species often replacing earlier settlers.

The fouling layer becomes more complex and resilient, making it difficult to remove and increasing its impact on the cage structure and water flow.

Impact of biofouling

Biofouling in fish cages has significant and multifaceted impacts on aquaculture operations, particularly affecting the health of farmed fish, operational efficiency, and overall economic viability. Biofouling refers to the accumulation of unwanted biological material—such as algae, barnacles, mussels, and other marine organisms—on submerged structures like nets, cages, and mooring systems. Over time, these organisms form dense layers that reduce water flow through the cages, leading to decreased oxygen exchange and build-up of waste products like ammonia. This creates a suboptimal environment for fish, potentially stressing them and increasing their susceptibility to disease. In addition, biofouling can physically damage cage infrastructure, causing wear and tear on nets, increasing the risk of escape or collapse. Maintenance costs rise significantly, as regular cleaning and net replacement are required to manage fouling, sometimes necessitating the use of antifouling coatings or mechanical cleaning systems. These methods, while helpful, can be labour-intensive and environmentally challenging due to the release of toxic substances into the surrounding waters. Furthermore, biofouling organisms can serve as vectors or reservoirs for pathogens and parasites, amplifying the risk of infections within and around fish farms. Ultimately, biofouling not only compromises fish welfare and growth rates but also diminishes the profitability and sustainability of aquaculture operations, making it a critical concern for the industry.

Biofouling in fish cages causes a range of negative impacts that affect both aquaculture operations and the health of cultured fish. These impacts can be categorized into several key areas:

Reduced Water Flow and Oxygen Exchange: The accumulation of fouling organisms such as algae, barnacles, mussels, and tunicates on the mesh and nets reduces the porosity of cage structures. This hinders water circulation, leading to poor oxygen exchange and accumulation of waste metabolites, which can stress fish and impair growth.

Increased Disease Risk: Biofouling can harbor and promote the proliferation of pathogenic microorganisms, including bacteria, viruses, and parasites. These organisms can infect cultured fish, increasing the likelihood of disease outbreaks, higher mortality rates, and greater reliance on medications or treatments.

Higher Operational and Maintenance Costs: Regular cleaning, maintenance, and replacement of fouled nets are labour-intensive and expensive. The need for anti-fouling treatments, such as copper-based paints or mechanical cleaning, adds to operational costs.

Structural Damage: Some biofouling organisms, especially burrowing species like certain worms or bivalves, can weaken cage materials over time. This can compromise the structural integrity of the cages, increasing the risk of fish escapes and requiring more frequent repairs.

Reduced Growth and Feed Efficiency: Poor water quality and increased stress caused by fouling reduce fish appetite and growth rates. The feed conversion ratio (FCR) worsens, meaning more feed is required per unit of fish biomass produced, thus reducing profitability.

Environmental Impact: Frequent use of chemical antifouling agents to control biofouling can pollute surrounding waters, harming non-target marine organisms and disrupting local ecosystems.

Market Quality and Perception: Biofouling can affect the visual appearance of cage infrastructure, which may influence the perception of farm hygiene and product quality among consumers and regulators.

Control Methods

The main methods of controlling biofouling in fish cages include:

1. Mechanical Cleaning

Manual Scrubbing: Regular manual removal of fouling organisms using brushes or high-pressure water jets.

Automated Cleaners: Use of underwater remotely operated vehicles (ROVs) or cage-cleaning robots to reduce labour and improve efficiency.

Net Changing: Periodic replacement of fouled nets with clean ones while fouled nets are cleaned and dried.

2. Antifouling Coatings

Copper-Based Paints: Application of copper or copper alloy-based coatings on cage nets to inhibit biofoulers attachment.

Silicone or Non-toxic Coatings: These smooth coatings make it harder for organisms to attach and easier to clean the nets.

Biocide-free Paints: Environmentally friendly options that reduce ecological impact while still preventing attachment.

3. Biological Control

Cleaner Fish: Introduction of species like wrasse or lumpfish that feed on fouling organisms (mostly in marine cages).

Biomanipulation: Promoting the presence of natural predators or grazers that help control fouler populations.

4. Environmental and Management Practices

Site Selection: Choosing locations with optimal water currents, depth, and salinity that are less favourable to biofouling.

Proper Cage Design: Using materials and designs that reduce fouling potential and improve flow.

Fallowing: Temporarily removing cages from a site to disrupt the fouling organism lifecycle.

Rotation and Resting: Moving cages between different locations or resting areas to reduce biofoulers build-up.

5. Thermal and Chemical Treatments

Hot Water Immersion: Briefly immersing nets in hot water (around 60–70°C) to kill fouling organisms.

Chemical Dips: Using hydrogen peroxide, acetic acid, or other mild chemicals to treat nets, although environmental regulations limit their use.

6. Use of Advanced Materials

Copper Alloy Mesh: These are inherently antifouling and do not require frequent cleaning.

Polymer Composites: Materials resistant to fouling that are more durable and easier to maintain.

7. Integrated Pest Management (IPM)

Combining multiple strategies, such as scheduled cleaning, selective site management, and biological controls, for a holistic and sustainable approach.

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