Biofouling in fishing gears & vessels: assessment, impacts & prevention

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Introduction

Accumulation of materials or particles and living organisms on a surface is called fouling. Fouling is categorized into three such as inorganic fouling, organic fouling and biofouling. Inorganic fouling is formed by the physical and chemical effects like heat, pressure, and friction or by natural process through which the minerals in the water stacked on the surface of the materials were immersed in the water. The materials that accumulate on the fishing inputs may be non-living, comprising detritus and organic or inorganic compounds, but it may also include organisms that may range in size from microscopic viruses to giant kelps, which can grow on to form complex multi-species, multi-dimensional communities. Biofouling as a process means biological fouling and is a general term used to describe both the micro-biological and macro-biological growths that occur on the exposed exterior of materials.

Marine biofouling has been a major problem for man since the ancient maritime explorations and initial human engagement with the ocean through artificial structures. The attachment, growth and colonization of aquatic fouling organisms on the exterior of fishery engineered structures likes vessel hull, fuel lines, propeller blades, wooden poles of stake net, concrete/ wooden poles of Chinese dip net, and nets & frames of aquaculture cages, etc. causes adverse effects in the fisheries and economy.

The ever-expanding global population has the quest for sustainable nutrition sources has intensified, triggering a heightened demand for food production. Capture and culture fishery together provide food security, but amidst this quest, aquaculture has emerged as a pivotal solution that offers both economic prosperity and enhanced food security. Cage culture has gained substantial popularity in mariculture as well as aquaculture. However, the persistent challenge of biofouling, particularly in cage aquaculture within marine and inland settings, poses a formidable hurdle to achieving efficient and sustainable production. The enduring development of the aquaculture industry is a key factor in the strategy to guarantee global nutritional safety. Nano technological interventions in cage aquaculture refer to the application of nano-technology to improve various aspects of cage-based aquaculture systems. Nowadays, different types of nano-technology-based systems have been employed to increase aquaculture production, efficiency and sustainability, and also for the prevention and control of biofoulers on the fishing gears, & fishing vessels. The assessment of biofouling on fishery inputs was essential for understanding the impacts of biofoulers and for implementing effective prevention methods.

Biofouling and fouling organisms

Biofouling is a multi-stage process and it develops sequentially from an initial condition layer of absorbed organic and inorganic matter in the aquatic environment. Biofouling is defined as the undesirable accumulation of living organisms on exposed artificial surfaces in the aquatic ecosystem by adhesion, growth and reproduction. When it occurs in the marine environment it is called marine biofouling. Marine biofouling accumulates on surfaces in five succeeding stages such as initial attachment, irreversible attachment, initial growth, final growth, and dispersion. Most aquatic fouling organisms prefer hard substratum for settlement. It was estimated that about 127,000 aquatic species depend on hard surfaces for living while 30,000depends on soft surfaces (*Gizer et.al,* 2023). However, a wide range of micro and macro-organisms can contribute to marine bio-fouling and approximately 5,000 species of marine biofouling organisms occur in the world, of which 2,000 species are recorded (Tseng andHuang, 1987). Marine biofouling can be divided into two main categories based on the size of organisms that accumulate and attach to the water contacted surfaces such as microfouling and macrofouling. Microscopic organisms like bacteria, viruses, protozoa, diatoms, fungi, and micro algae form micro fouling. Macro fouling organisms directly depend on microfoulers. Micro-fouling is essential for the settlement of more complex macrofouling organisms. Macrofouling organisms are further classified into two based on the body structure of the colonizing organisms namely soft and hard macro fouling organisms. Macro-algae, soft corals, anemones, tunicates, and sponges-like organisms with no solid/calcareous supporting structure are considered soft macrofouling organisms and organisms with hard supporting structures are hard macrofouling organisms such as barnacles, tubeworms, bivalves, and polychaetes which are difficult to remove once established. Some organisms bore more deep to the submerged and fouled materials such organisms are called borers. Organisms bore either for shelter or for food. The boring behavior of organisms directly destroys the submerged woods, rock, and other materials.

Processes behind biofouling

The processes of biofouling consist of five elementary processes such as transport, settlement, attachment, development, and growth of fouling organisms. All these elementary processes replace each other sequentially during surface colonization by foulers. The colonization processes consist of two models such as probabilistic model and succession model or classic model. Prior to colonization, film formation is the crucial step. Organic conditioning film formation is an important process in marine biofouling. Marine biofilm formation is a highly dynamic combination of chemical, physical, and biological processes that occurs within seconds of the initial interaction between exposed material and an aquatic ecosystem. Once a new surface, whether biotic or abiotic immersed in seawater can quickly adsorb organic matter that forms a nutrient-rich layer within a minute, in other words, it is described as the organic conditioning film. The formation of organic conditioning film is the result of a simple physical reaction, and it is comprised of colloidal organic matter and molecules such as polysaccharides, proteoglycan and proteins. Organic conditioning film formation is the first step of marine biofouling and that result in the development of a stickier surface and which makes the exposed surface more favorable for the attachment of bacteria. The attachment of bacteria to the conditioning film results from the metabolism of organisms, as a result, they adhere to the surface faster and lead to the development of bacterial colonization. The sequence of colonization consists of bacteria, diatoms, autotrophic flagellates, heterotrophic flagellates, amoebae, heliozoans and ciliates. This sequential colonization process is known as succession or microfouling and the resulting layer is termed as microfilm/biofilm/marine biofilm. Diatoms are considered the major contributor to the primary colonizer. The reversible adsorption and irreversible adhesion are the two distinct steps involved in the microorganism colonization. The reversible adsorption is governed mainly by physical effects such as Brownian motion, electrostatic interaction, gravity, water flow and Vander Waals forces. The irreversible adhesion occurs mainly through biochemical effects such as the secretion of extra cellular polymeric substances. Within the biofilm, bacteria can coordinate their adhesion, biofilm maturation, swarming, luminescence and toxin production through a process known as quorum sensing. Quorum sensing is a process that involves producing releasing, detecting, and responding to small hormone-like molecules termed auto inducers that are released into the environment by bacteria. Some bacteria and marine organisms like algae can respond to the quorum sensing signals of other bacteria. The development of a biofilm on a substratum changes the attractiveness of the substratum to invertebrate larvae and algal spores through physical modification of surfaces or by production and release of chemical compounds. In the next stage of marine biofouling, propagules of macroorganisms, larvae of invertebrates, and spores of macroalgae will settle on the surface. Two or three weeks later, these will finally evolve into a complex biological community. Microfouling is the first stage of succession of hard-substrate community and it is also considered the second step in marine biofouling. The colonization process is broadly described as a biological succession. The rod-shaped chemo-heterotrophic bacteria (e.g.*Pseudomonas*) are considered primary colonizers on the submerged surfaces. They appear on the conditioning film within 1 or 2h or earlier and may prepare the microconditions for the development of filamentous and stalked bacteria at the final stage of bacterial succession. Bacteria stimulate the fouling and development of diatoms. Succession may be based on the facilitation by early-species by creating conditions favorable for the late succession species. So the primary colonizers create conditions for secondary colonizers (spores of macroalgae, protozoa) this process continues until the development of tertiary colonizers. The first stage of macrofouling succession is by fast-growing and the second stage is by slow-growing organisms and succession ends with a short-term climax stage. This classic succession model over simplifies the colonization process implying stage to stage. The absence of a stage does not impede the occurrence of another stage and such colonization process follows a more dynamic and probabilistic model. In probabilistic model, some species like acorn barnacle and bryozoan's species may settle on the surfaces without the presence of a conditioning film and biofilm. The colonization process is dependent on the number and type of organisms and the attachment of organisms on substratum are independent of one another. The absence of a surface may result in the aggregation of foulants and form marine snow and it remains in the seawater. That entrapped the propagules of macroorganisms, larvae of invertebrates, and spores of macroalgae and it may gradually settle to a substratum that will allow the growth after attachment.

Biofouling assessment

The most commonly used assessment method for biofouling is Physical and biological assessment. The establishment of both physical and biological assessments forms the fundamental techniques in assessing biofouling problems

Physical assessment

This method focuses on detecting and analyzing any physical changes that take place due to the presence of biofouling growth and deposition on exposed surfaces. The first method uses a heat transfer monitoring (HTM) device for determining the thickness of micro fouling that is appeared as a thin layer of biofilm on the surface of the pipeline wall. Based on the concept of heat transfer measurement, the thickness of biofilm that acts as heat transfer resistance is measured by measuring the temperature difference between the heated section of fluid inside the pipeline and the reference temperature, in this case at ambient temperature. The apparatus consists of two thick-walled sections of copper cylinders, one section that acts as ambient temperature measurement and another section is a heated wall surrounded by a nichrome heater. The presence of biofilm is detected through changes of measured temperature difference.

Biological assessment

Scanning electron microscopy (SEM) is used to analyze biofouling growth and deposition profile on the contacted surface, providing crucial information of the type of organisms or materials involved, a rough estimation of biofilm thickness and the nature of its growth. Before this visual inspection, the accumulated biofouling sample on a set of attached coupons to the surface was extracted by scrapping manually or using a special tool to scrape any deposit on the surface of fishing inputs. These coupons were subjected to accumulate biofouling deposition over a period of time. It was done within six months up to one year before the samples were extracted. The extracted samples formed a biofilm layer comprised of entrapped diatoms and portions of differentiated algae and other organisms. Apart from determining the species present on extracted substrates, this technique evaluates the effectiveness of mechanical cleaning techniques by observing any residual that remains after the physical cleaning process. The availability of various biochemical assessments provides a comprehensive biological and chemical characterization of the extracted biofouling. There are a few biochemical assessments such as adenosine triphosphate (ATP) total organic carbon (TOC), carbohydrate analyses, chlorophyll contents, and total dissolved iron content, combustible organic matters. The various biochemical assessments provide quantitative measurement of biofouling. Several biofouling monitoring systems reported from other water treatment industries.

Impacts of biofouling

The adverse effect of marine fouling on vessel hulls still exists and it occurs on the vessel hull, propeller blades, fuel lines, etc. Macro-biofouling makes the vessel heavier and the hull rougher which leads to an increase in frictional resistance which results in a loss of the speed of the vessel which may decrease by 40% or more. The fuel consumption increases by about 40%. A layer of microbial slime of 1mm thickness can increase hull friction by 80% and cause a 15% loss in vessel speed. Frictional resistance increases with sufficient strong fouling of the hull by both micro and macro biofouling. While in some cases, the biofouling on the propeller blades is a more important cause of fuel waste. Biofouling indirectly influences the carbon footprint of vessels and greenhouse gases in the atmosphere, that is a 5 per cent increase in biofouling causes 17 percent increase in fuel consumption by ships which leads to 14 percent increase in greenhouse gases (CO_2, NO_x, and SO_2) emission. On the other hand, heavy biofouling of fuel lines causes engine failure and a greater danger is observed by the fouling of heat exchangers. Biofouling accelerates the corrosion of metal walls. Docking frequency and other prevention methods such as antifouling coating are the widely used method for controlling biofouling. Up to200-400 tons of fouling biomass may be removed in one docking. Dry docking operation is more expensive and time-consuming moreover it generates a large number of toxic substances that are discharged into the ocean. While fouling on the poles of stake nets and Chinese dip net will reduces the service life of the both gears.

Submerged aquaculture cage nets are highly susceptible to biofouling especially during summer months due to favorable and nutrient-rich aquatic environments around the cages which attract micro and macro foulers, and also attract invasive species like Mytella strata. Biofouling in aquaculture cages develops either through a succession model or a probabilistic model. Biofouling in aquaculture cage nets causes several problems such as occlusion of mesh openings, thereby increasing weight and drag, deformation of cages due to the ensuing stress, reduction of volume, thereby decreased stocking density per area, anoxic condition due to disruption of dissolved oxygen flow, blocking of food waste diffusion, restriction of water exchange, increased hydrodynamic force, all of which makes an unfavorable environment for fish and which adversely impacted fish health. In addition, cnidarians' biofouling can be harmful to the fish; biofouling can facilitate and amplify the presence of pathogens by harboring viral, bacterial, and parasitic organisms that cause various diseases. This leads to economic loss and also makes that area not suitable for further aquaculture activities. Earlier the fouling in aquaculture cages was controlled by cleaning by means of brushing and scrubbing of cage nets. While for commercial farmers such cleaning and scrubbing on particular intervals were not practically possible because of more time consuming in addition to that high labor charge.

Strategies for biofouling prevention

Protection of technical and biological objects from biofouling includes a range of existing and emerging approaches. The protection can be based on physical and chemical factors or jointly. The process of biofouling occurs by both physical and chemical reactions. The protection can be easier by successful inhibition of the physical reactions which would constrain the later biochemical reactions. The different methods used for controlling biofouling include scrubbing off the fouling (docking), Autoclaving and plasma pulse technology, UV Radiations, use of remotely operated marine robotics for removal of biofilm and macrofouling from vessel hull, continuous bubble streams, high-frequency vibration, and biological control. The existing chemical, physical, and biological antifouling methods have not successfully tackled biofouling problems effectively and sustainably. Therefore, new surface technologies in combination with current methods should be developed by considering ecological effects.

Frequent visual inspections of cage nets can catch early signs of biofouling. Gently scrubbing or brushing the net surface can remove accumulated organisms before they become a problem.

In situ, net cleaning is one of the most common methods employed by farmers. This proactive approach prevents excessive buildup and maintains optimal water flow. Introducing natural predators like certain fish species and invertebrates into the cage ecosystem can help control biofouling organisms. These natural grazers feed on unwanted growth, reducing the need for manual cleaning. This method encourages a balanced ecosystem within the cage. Periodically moving aquaculture cages to new locations can disrupt the settlement of biofouling organisms. This method prevents attachment and growth on cage surfaces, reducing the overall impact of biofouling. Applying non-toxic anti-fouling coatings to cage nets can deter the attachment of biofouling organisms. These coatings create a slippery surface or release compounds that discourage settlement, making it easier to clean the cages when necessary. Using UV light systems can inhibit the growth of biofouling organisms on cage surfaces. UV treatment disrupts their reproductive cycles and prevents excessive accumulation. This method is environmentally friendly and helps maintain clean cages. Simple mechanical devices, such as rotating brushes or water jets, can be installed on cages to continuously clean the net surfaces. These devices help prevent biofouling build up and ensure consistent water flow.

The existing In-situ cleaning, rotational movement, and biological control methods have not successfully tackled biofouling problems effectively and sustainably. Therefore, new surface technologies in combination with current methods like the use of nano-engineered particles should be developed by considering ecological effects. Nanotechnology has enormous potential to provide innovative improvements to aquaculture systems to reduce costs, increase efficiency and reduce our impact on the environment. The non-polar nature of polyethylene aquaculture cage net causes difficulties in antifouling strategies over. For minimizing this problem in antifouling coating CIFT introduced copper oxide (CuO) nanoparticles coating over the modified surface of polyethylene by using polyaniline. The small size and high surface activity of nanoparticles rendered them a potential material that can use in cage nets. Nano copper oxide has the efficiency to avoid incrustation of microorganisms and hence prevent biofilm formation. The nano CuO-treated cage net exhibited excellent biofouling resistance in the marine environment and the percentage of occlusion of the mesh by foulers was 56.77% more efficient than the untreated cage net. Nano-materials improve the durability and strength of cage materials by improving the adhesiveness and rheological parameters such as viscosity, elasticity, mechanical strength and plasticity that increases the resistance to corrosion and wear and tear in harsh aquatic environment. In addition, Nano-material coating reduces the maneuverability and cost of cleaning cage frames and cage nets. The continuously flowing water may carry the leached nano-particles so the probability of accumulation of nano-particles (CuO) on cultured species in the cage is very less. While, nano metal oxide–polymer composites as it exhibits hydrophilicity, large surface area, and high toxicity towards microorganisms all these properties make it an suitable option for managing biofouling in cages.

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