Biofouling

Dad: why do we have to scrape the bottom of our boat every year?

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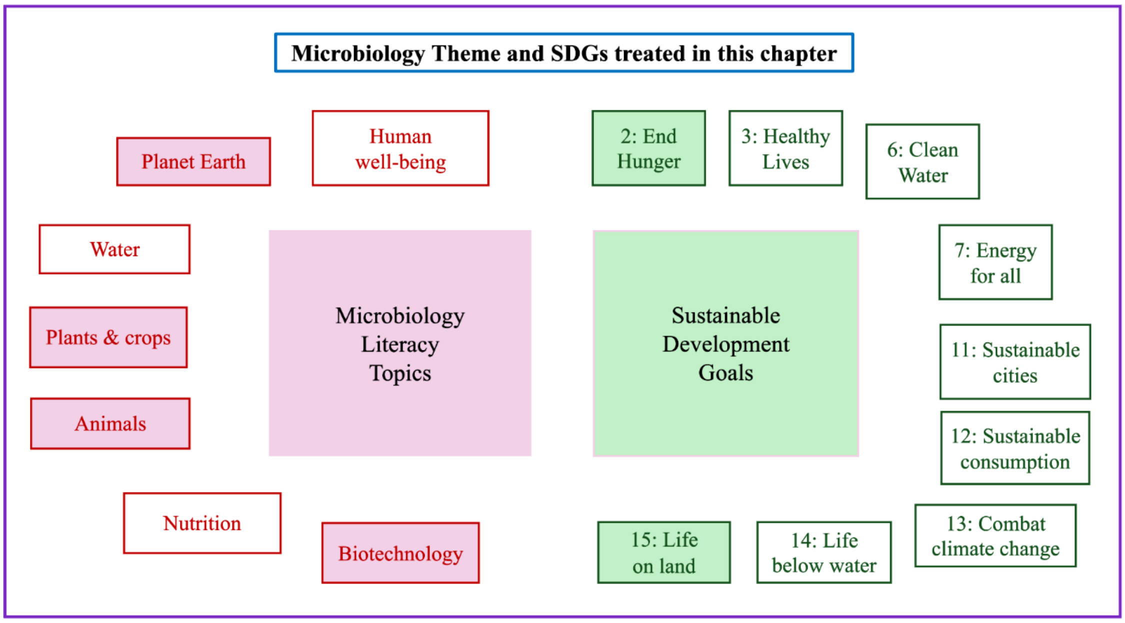
Storyline

Biofouling is a process by which microbes and ultimately larger invertebrate organisms settle into a surface submerged in water and begin to build encrustations on it. We see this in the marine environment on boats and marina pontoons. Additionally, we see biofouling in sewers and waterways, where the internal surfaces of these pipes slowly become blocked. To combat this biofouling, we historically employed biocidal coating that kills the fouling organism and/or mechanical cleaning. However, the environmental pollution impacts of the toxic coatings have become apparent, with some antifouling options being banned from use internationally. This is driving research to develop new biofouling prevention techniques that are more sustainable. This research in turn may lead to a better understanding of why organisms settle on these man-made surfaces, allowing us to use this knowledge to ameliorate various environments, such as kelp forests.

The Microbiology and Societal Context

Microbiological context: biofouling is a process in which microorganisms such as bacteria, algae, and other microbes colonize submerged surfaces and form biofilms. These microbial communities create the foundation for the attachment of larger organisms, leading to the accumulation of biological material on structures in marine and freshwater environments.
Social context: Biofouling has significant economic and environmental impacts on society. It affects boats, marina infrastructure, sewers, and waterways by reducing efficiency, increasing maintenance costs, and causing blockages. Traditional antifouling methods often rely on toxic biocidal coatings, which can pollute aquatic ecosystems and have led to regulatory restrictions in many countries. The research aims to develop safer and more sustainable antifouling technologies that protect infrastructure while minimizing environmental harm and supporting the health of aquatic ecosystems such as kelp forests.



Biofouling is related to SDG 6 – Clean Water and Sanitation: Reduces biofouling-related blockages and supports healthier aquatic systems. SDG 9 – Industry, Innovation and Infrastructure: Promotes innovative, sustainable antifouling technologies for marine and water infrastructure. DG 14 – Life Below Water: Minimizes the use of toxic antifouling chemicals, helping protect marine biodiversity and ecosystems.

Biofouling: The Microbiology

1. ***Biofilms are everywhere and have a role to play in the biogeochemical cycles we can observe all over the world.*** The roles biofilms play are just as diverse as the locations in which they are found, yet not all are desirable. One such unwanted biofilm grows on a surface and thereby changes its characteristics such that the structure providing the surface, like a boat, functions less well. We call this *biofouling*, and it can be observed on the hulls of ships, the insides of aquarium pipes or even the surfaces of immersed scientific probes. Essentially any biological growth on a surface on which the organisms are unwanted, is considered to constitute biofouling.

2. ***The biofouling of ships' hulls.*** Ships are the most well-known example of biofouling, and have been for hundreds of years. The encrustations on the ship's hull created by biofouling organisms distort its hydrodynamic shape and create drag on the vessel. The ship then has to exert a greater amount of energy to achieve the same velocity that it previously had, when the hull was smooth before it became encrusted with a biofilm.

To mitigate this inefficiency, ships have historically been taken to dry dock and had the biofouling organisms removed. More recently we have taken to simply coating the ship's hull surfaces with paints and other coatings in which the biofouling organisms cannot survive or do not to settle on. Though we still see ships in dry dock for cleaning, even with these modern anti-fouling coatings, the frequency of dry-dock cleaning is substantially less. Therefore, less time in dock is less time the ships are not actively working, meaning increases in productivity.

3. ***Biofouling of pipes and tubes***. While external surfaces can serve as supports for biofilms and biofouling, internal surfaces of pipes, tubes and containers used to hold and transfer liquids are also subject to biofouling. One such example is the aquarium water pipe. As organisms build up on the internal surface of the pipe, they reduce its actual internal diameter. This means that the pump used to circulate water in the aquarium must exert more force to ensure the same flow is maintained. In the most extreme situation, biofouling can block the pipe, either through growth and build-up of biofilm material, or through debris getting caught in the material.

As a result of the reduction in pipe diameter, sections of the system upstream of the biofouled sections of pipe will experience back-pressure and a buildup of hydrostatic pressure will occur. This is all together a bad scenario to have when dealing with hundreds of gallons of water.

The blocked pipe scenario can occur in a variety of systems, such as aquaria, wastewater treatment and drinking water delivery pipes. While all experience biofouling of the internal piping, the solutions are not always the same. One such solution when not delivering water to living systems, for example, when simply disposing of the fluid carried in the pipe, is to coat the internal diameter in a biocidal coating to kill anything that comes into contact with the pipe's internal walls. This will slow biofilm growth considerably, but eventually the pipes will become coated in other materials, such as mineral deposits or debris, and eventually experience a blockage. This means that the biocidal coatings can mitigate but are not a permanent solution to biofilm blocked pipes.

For systems in which the use of harmful biocidal chemical is not recommended, such as animal husbandry or drinking water supplies, we must foster other mitigation strategies. Typically, in this situation, we do not see anti-fouling coating on the internal surfaces of the pipe as this may affect the health of humans or animals downstream of the treatment. Here we could simply see the pipe as a disposable item and replace once the biofouling reaches a non-viable stage. Obviously, this differs with the cost/size/material of the pipework. Another solution would be to use non-toxic methods for the prevention of biofouling. An example of this would be to reduce the ability of any organisms to bind to the internal surfaces by altering the surface to render it less attractive or have reduced efficacy for adhesion (e.g., rough surfaces, slow-shedding of surface layers). While the aim of the biocidal and the non-biocidal anti-fouling coatings is the same, the methods used are very different.

However, it is important to remember that biofouling is simply the term for unwanted biofilms in the environment. The same type of biofilms may be beneficial to other stakeholders and then we refer to these simply as 'biofilms'. Examples of this differentiation will be discussed below.

The microbiology and societal context

One key ethical question to ask is if biocidal anti-fouling coatings can affect the biology of the aquaria and therefore are not used, does it not also affect the biology of the oceans in which the ships sail? The short answer is, yes it does. The longer answer is that there is a level of environmental impact we are willing to accept and until recently, biocidal anti-fouling paints were considered within the levels of acceptable impact. However, this is changing as governments are looking to regulate anti-fouling compounds, especially those that bio-accumulate through trophic levels. How they are regulated will be dictated by specific governments, but overall, the result should be a major reduction in the use of biocidal products in the natural environment.

If we cannot kill the biofilms, what can we do to prevent biofouling? This is something researchers are currently looking into. One method is to simply prevent biofouling organisms being able to maintain a stable hold on the surfaces. By altering the surfaces to make them 'slippy', the simple act of a vessel moving through the water, or of water passing through a pipe, will dislodge any organisms inhabiting the surface. The water passing over the surface will generate shear stress which in turn will dislodge the organism bound to the surface. At no point does the coating primarily exhibit any toxic effects to the local environment, including the recently ejected stow-away. This is ethically more acceptable but overall a more costly and less well-developed technology than its biocidal predecessors.

Until now we have discussed biofilms as a generic entity, however size matters when discussing biofilms and biofouling. The reason for this is the succession of organisms taking up residence on any surface is generally seen to be initially microbial and subsequently larger multicellular organisms. Typically, we see a sticky matrix of exopolymeric substances (EPS) exuded by bacteria and micro-algae. This sticky EPS envelopes the cells it originated from as well as other cells it may have collided with in the water column. Once any surface, be it a boat, a pipe, or a beach pier, is submerged in water, it has a chance of coming in contact with the sticky EPS agglomerate. If it does make contact, then the EPS will hold it in place and the cells will start to produce more EPS. This is the mechanism by which biofilm formation starts. Once we have a large and stable microbial biofilm established on the surface, we can start to see larger organisms, such as invertebrate larvae, settle on the biofilm and become established on the surface.

Interaction between microbiology and invertebrate settlement

Once a microbial community is formed on the surface of a submerged structure, we generally start to see the settlement of invertebrates on the structures. However, microbiology plays a key role in controlling or influencing larval settlement. We have seen that biofilms densely inhabited with bacteria promote enhanced invertebrate settlement. However, the mechanisms responsible for controlling settlement are not well understood. What we do know is that many microbes increase larval settlement rates when the microbes are abundant, but not all microbes have this ability. The larvae sense the biofilms prior to initiation of metamorphosis (beginning the non-reversible settlement process), however, this can require the larvae to be in contact with the biofilm to detect the signals being emitted, which quickly become diluted away from the surface. The majority of this type of work has been achieved through model organisms, such as tubeworms (*Hydroides* spp) and barnacles (*Cirripedia* spp) and these different types of invertebrates react to different settlement stimuli, making the process very complex to model.

It is at this point of larger invertebrate colonization that we start to see inefficiency creep into our marine and aquatic structural systems, as the flow of water over the invertebrate surfaces is impeded to such an extend as to be measurable. Once the biofilms are impacting the system a decision to remediate is normally made based on whether the foundation biofilms promote biofouling or not.

Biofilms that serve a purpose

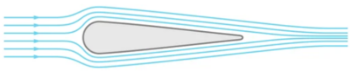
Can we use this order of organism settlement succession to our advantage? As was discussed, biofouling is simply the settlement of organisms that are unwanted. What if we did want them? We have seen that altering the bacterial community of a marine biofilm can enhance or reduce the settlement efficacy of many invertebrates. Therefore, if we can manipulate the surface of any object to dictate what can grow at the microbial level, can we reduce or even eliminate the invertebrate biofouling. In the case of stationary objects, such as piers or seawalls, might we influence the surfaces to promote coral settlement or act as the foundation to a new kelp forest? This is work currently ongoing in various institutes throughout the world to reestablish and promote resilient and sustainable coastal ecosystems that have been impacted by coastal development and maritime activity. This process can have the added advantage of providing habitats for other marine or aquatic organisms that would otherwise be unable to flourish in negatively impacted waters. The main point to remember is that unless we are willing to employ biocidal products, we must learn to adapt and promote biofilms that are sought after and hence no longer considered biofouling.

The social and economy impacts of biofouling

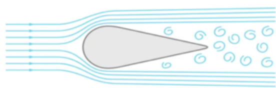
The key question many researchers are asking is in regards to the availability of sustainable technologies to combat biofouling. For ship-based biofouling, we have discussed the need to dry dock and clean ships as well as the increased energy required to travel through the water in the presence of biofouling-associated drag on the hull. This will result in a substantial increase in fuel costs as the systems or ships lose efficiency over time. Indeed, increased fuel consumption provides a means for measuring inefficiency, and hence the need to remove the build-up of fouling organisms. The United States of America Navy reports that biofouling costs more than US$1 billion per year in extra fuel and dry dock cleaning. For the former, a biofouled hull with increased fuel usage/costs also emits proportionally more greenhouse gases.

The process of drydock cleaning a vessel is labor intensive and expensive. However, it is essential currently to maintain a laminar flow over the ship's hull when travelling.

Laminar Flow



Turbulent flow



How does this rise in fuel, energy and greenhouse gas emissions compare to the solution? We can mitigate these issues by impregnating the pipes or vessel hulls with highly toxic substances. But then we risk the solution becoming more environmental damaging than the initial problems. Currently there is no solution to biofouling that does not have its own impacts; meaning we are still striving for a truly sustainable option to control the growth of microorganisms and invertebrates in the marine environment.

Pupil participation

Exercises

a) By reducing biofouling on boats we reduce the fuel usage. Can you think of another method to reduce the fuel usage of these vessels?

b) As stated, we can reduce fuel usage and this will lower the greenhouse gases emitted by the vessels. Other than lowering the volume of fuel, is there any other way we can limit greenhouse gas emission?

c) The interior of sewerage pipes have thick layers of biofilm that have grown over time. Knowing that bacteria and other organisms require a food source and other optimal conditions to grow, suggest methods by which we could 'sustainably' slow/stop the biofouling of a typical sewer, which transports nutrient rich sewage.

d) Removing biofouling from a vessel will make it more sustainable and efficient to operate. However, what other aspects might be affected by dry-docking a vessel for cleaning, both positive and negative. (e.g., more vessels results in more ballast water transfer; faster transport of essential items such as medicine/food distribution)

Further reading:

Callow and Callow 2002. "Marine biofouling: a sticky problem" Biologist 49 (1)

Flemming 2002. "Biofouling in water systems – cases, causes and countermeasures" Applied Microbiology and Biotechnology 59: 629 – 640

Bixler and Bhushan 2012. "Biofouling: lessons from nature" Philosophical Transactions of the Royal Society A, 370: 2381-2417.

Glossary

Antifouling. Methods or coatings used to prevent biofouling.
Biocide. A substance that kills living organisms to reduce biological growth.
Biofilm. A community of microorganisms attached to a surface and surrounded by a protective matrix.
Biofouling. The accumulation of microorganisms and larger organisms on submerged surfaces where they are unwanted.
Coastal Ecosystem. A community of organisms and their environment in coastal marine areas.
Colonization. The establishment and growth of organisms on a surface.
Encrustation. A layer of organisms that builds up on a surface over time.
EPS (Extracellular Polymeric Substances). Sticky materials produced by microorganisms that help them adhere to surfaces.
Hydrodynamic Drag. Resistance to movement through water caused by surface irregularities.
Hydrostatic Pressure. The pressure exerted by a liquid within a confined system.
Larva. An early developmental stage of an invertebrate that can settle on biofilms.
Microorganism. A microscopic living organism, such as bacteria or microalgae.
Pipe. A tube that transports liquids and may become blocked by biofouling.
Ship Hull. The outer body of a ship where biofouling commonly occurs.
Sustainability. The use of practices that minimize environmental impact and conserve resources.