Biofouling of vessels - a challenge to the ship industry and the environment

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Why is biofouling a problem?

Biofouling (or simply fouling) of vessels leads to corrosion and increased water resistance and fuel consumption. Furthermore, vessels carrying biofouling constitute a risk for the spreading of non-indigenous, invasive aquatic species to ecosystems around the world. Biofouling begins when a surface without fouling-protection is exposed to water. Vessel hulls are therefore protected by antifouling coating with properties that reduce and prevent fouling.

Marine fouling starts with bacteria forming biofilm on the vessel hull or another submersed surface. The bacteria are followed by algae, especially diatoms, and, subsequently, other organisms like protists, macro algae and larvae of barnacles and bivalves attach to the surface. Microfouling is fouling stages that are invisible to the human eye, while macrofouling can be observed by the human eye (IMO, 2011). The presence of biofilm and microfouling increases the water resistance, and the water resistance markedly increases, when the vessel hull carries macrofouling.

The interest in avoiding excess fuel consumption is the main reason leading commercial vessel owners to keep the biofouling of the hull to a minimum. For container vessels, the fouling of the hull may increase the fuel consumption by up to 20% between docking intervals, and fouling of niche areas like propellers may lead to excess fuel consumption of up to 5% (FORCE). The elimination of biofouling of the vessel's surfaces leads to improved fuel efficiency, and it reduces the risk of spreading live organisms to new ecosystems, where they may reproduce and become invasive species. Invasive aquatic species may outmatch the indigenous species in the ecosystem, which may adversely affect the biodiversity of the ecosystem and impact economic interests such as local fishery. The spreading of non-indigenous, invasive aquatic species with biofouling of vessels or discharge of ballast water has received considerable international attention. Efficient management of the biofouling of vessels is therefore essential to protect the biodiversity of marine ecosystems.

Biofouling management

The main component in the biofouling management of commercial vessels is the use of protective antifouling coatings. Some antifouling coatings contain biocide which is slowly released and prevents fouling on the surface (Figure 1a + 1c). Several biocides are used, but especially copper and zinc have been applied after the ban of tributyltin in the beginning of this millennium. One of the most common coatings is based on a self-polishing co-polymer (SPC) paint (Figure 1c). Non-biocidal coatings or coatings with low biocide concentrations are also used, and the fouling-protection of these coatings is achieved by prevention of the attachment of microorganisms to the hull (Figure 1b + 1d). These antifouling coatings are usually made from silicone which prevents firm attachment of fouling-organisms to the hull and facilitates removal of the organisms by the force of water, when the vessel is moving at normal speed (Nurioglu et al., 2015). Finally, epoxy antifouling coatings provide a hard surface which enables regular mechanical cleaning (Lewis, 2020; Tamburri et al., 2020).

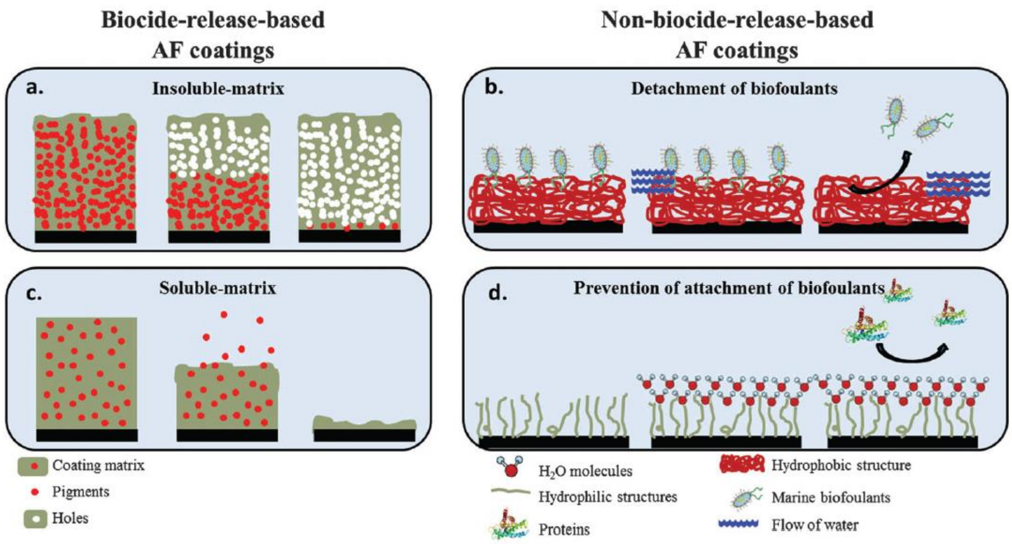

Figure 1 Illustrations of different antifouling technologies. Insoluble matrix with a high concentration of biocide from which the biocide is released with time (a.). Soluble matrix with biocide, usually also known as self-polishing co-polymer (SPC), which is slowly dissolved whereby the biocide is released (c.). Non-biocide coating (or coating with low biocide concentration), usually silicone-based, which prevents firm attachment of fouling-organisms (biofoulants) and facilitates detachment of biofoulants, when the vessel is travelling (b.). Non-biocide coating with active substances that prevent attachment of biofoulants (d.) (Nurioglu et al., 2015).

Antifouling coating is essential to reduce biofouling, and it usually provides efficient protection, when the product is used in accordance with the instructions from the manufacturer, and the coating is suitable for the activity of the vessel. When first applied on the surface, the antifouling coating has an expected durability, and the antifouling properties decrease with time. Despite the effects of antifouling coatings, biofouling may sometimes occur when the vessel is at quay or anchored for longer time, especially in waters with high biological activity. Mechanical hull cleaning is therefore typically performed during docking with intervals of 3-5 years. Underwater hull cleaning, or in-water cleaning, is an alternative method which is performed by divers or robots (e.g., remotely operated vehicles, ROVs).

Large container vessels are normally docking every five years, but in-water cleaning of the hull or niche areas may be necessary between the docking intervals. Different methods are applied for cleaning of the large hull surfaces and cleaning of niche areas such as the sea chest, propeller, thruster tunnel, or bilge keel. Cleaning the hull is relatively easy, and the hull is affected by the mechanical effects of water during travelling that reduce biofouling. The niche areas are to a lesser extent affected by mechanical stress, and, thereby, they are more exposed to biofouling. Biofouling of some niche areas, like the sea chest and the thruster tunnel, has a lesser effect on the fuel consumption, and, thus, the economic incentives for cleaning of these areas are lower than for the hull.

A questionnaire targeting commercial vessel owners in the Baltic nations showed that 72% of the participants used some form of in-water cleaning (COMPLETE, 2021). In-water cleaning leads to questions concerning the cleaning procedure and whether it takes relevant precautions to protect the local water environment from exposure to hazardous chemicals or non-indigenous invasive aquatic species.

Proactive and reactive biofouling management

Biofouling management may be either proactive or reactive. *Proactive cleaning* is performed frequently and before biofouling is established without using vessel performance or risk assessments as triggers. Proactive cleaning reduces the biofouling risk, as the fouling is easy to remove in its initial stages. Proactive cleaning removes the biofilm layer and, thus, prevents the growth of macrofouling. Softer procedures in proactive cleaning lead to less abrasion and promote optimal durability of the antifouling coating. Remotely operated vehicles (ROVs) are used for in-water cleaning of microfouling and possibly macrofouling in its initial stage. ROVs typically make use of high pressure flushing and exert their best performance on large hull surfaces.

Reactive cleaning is performed after observed biofouling or fouling-related effects on the vessel fuel consumption or the driving shaft (BIMCO, 2021a). Both the hull and niche areas may be cleaned during docking or in water by divers using rotating brushes. Initial biofouling stages may sometimes be removed by ROVs using high pressure cleaning. Brushes of different hardness are used, and especially metal brushes make it possible to remove hard, calcareous macrofouling like barnacles, bivalves, and tube worms, but this treatment involves a higher risk of damage to the coating and spills of coating materials during the cleaning. During in-water cleaning, the capture of the released materials requires particular attention, as these materials typically contain live organisms and coating materials. How effective is the capture? What treatment is applied for the seawater effluent produced during the cleaning? What are the levels of live organisms and coating materials in the released seawater effluent? These questions are relevant to evaluate whether the in-water cleaning presents a risk to the local water environment. Table 1 presents a survey of different cleaning methods and their effectiveness for fouling removal and capture of released materials.

Tabel 1 Survey of different cleaning methods and their properties and limitations. Based on dialogues with manufacturers and port authorities, and information in publications (COMPLETE, 2021; Floerl et al., 2010; Morrisey & Woods, 2015; Salminen et al., 2016; Scianni & Georgiades, 2019).

	Type	Fouling rate, FR [0-100] [1)]	Effective on niche areas	Applied force	Cleaning efficiency [%]	Capture efficiency			Risk of invasive aquatic species (IAS[2)])	
						Live organisms	Biocides			
							Dissolved in water	Particles	IAS risk[3)]	Remarks
ROV	Brushes (proactive cleaning)	10	No	Low	90	No capture	Medium	Low	Low	The risk of IAS is low, although no capture is applied, as cleaning is performed at a low fouling rate. The risk increases if the cleaning is performed at higher fouling rates.
	Hydrojet (proactive and reactive cleaning)	30	No	Low	90	High	Medium	Low	Low	The risk of IAS is low even at a higher fouling rate due to the efficient capture of live organisms.
Dock	Dry-dock (reactive cleaning)	100	Yes	Medium	100	Medium	Low	Low	Low to medium	During docking it is possible to clean niche areas with heavy fouling. The handling of the cleaning effluent varies between countries. Good risk management measures with capture may markedly reduce the risk of IAS[4)].
	Floating dock	100	Yes	Medium	100	Medium	Medium	Medium	Low to medium	The remarks for dry-docks also apply for floating docks. In addition, floating docks can

	(reactive cleaning)									be without cover, whereby the risk of over-flow of water and the release of IAS (and particles) increase, unless risk mitigating measures are implemented.
Diver	Brushcart (reactive cleaning)	70	Yes	High	95	No capture	High	High	High	The diver can clean niche areas with heavy fouling. The risk of IAS is high when no capture is applied. Good risk management measures (with capture) will markedly reduce the risk of IAS[4)].

1) Fouling rate (FR) describes the fouling of a surface (area with fouling in percent of total surface); FR covers a range from 0 to 100. The data indicate the maximum FR at which a high cleaning efficiency can be achieved by using the various methods.

2) Non-indigenous, invasive aquatic species (IAS)

3) The IAS risk is evaluated from the fouling rate, the cleaning efficiency, and the capture efficiency

4) Docking facilities in Denmark shall comply with Order on surface treatment of vessels, BEK No. 1188 of 12 December 2011, and all discharge effluent water must be treated (Salminen et al., 2016). Det er dog forskelligt hvordan lovgivning og praksis er i andre lande og der kan være større risiko for udledning af ubehandlet vand.

Because biofouling is highly variable dependent on many parameters, such as the activity of the vessel and the sailing route, it is important to define a biofouling management plan for each vessel. Furthermore, the vessel shall maintain an updated biofouling record book as prescribed in the International Maritime Organization (IMO) biofouling guidelines (IMO, 2011).

A study of commercial vessels with sailing routes in the Baltic Sea indicated that almost all vessels had a biofouling management plan, but this plan was too generic to maintain sufficient biofouling control for 60% of the vessels (COMPLETE, 2021). New digital solutions make it easier for vessel owners and authorities to use and access the biofouling management plan and the record book and obtain an overview of the risk assessment connected to the biofouling status of a specific vessel. Such facilities are, e.g., available in the biosecurity management tool Vessel Check® (Strydom et al., 2020). Furthermore, a decision support tool (COMPLETE, 2021) is being developed in the *Baltic COMPLETE Project* with the aim to assist vessel owners selecting the best antifouling system based on a broad range of parameters that affect the biofouling of vessels. These are two examples of decision support tools that may help vessel owners to achieve good biofouling management in accordance with the IMO biofouling guidelines and national regulations.

International standards

In-water cleaning has led to concern that the biocides (e.g., cobber and zinc) released during the cleaning may result in biocide concentrations exceeding the local water quality standards (US Environmental Protection Agency, 1999). In response to the concern, new procedures for in-water cleaning with capture have been developed during the last decade. Increased focus on biosecurity and water quality has driven the development of methods for capture of coating materials, chemicals, and potentially invasive species in the cleaning water.

A Correspondence Group under the International Maritime Organization (IMO) has initiated a revision of the biofouling guidelines (IMO, 2011) and is drafting *Revised guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species* (IMO, 2021). Furthermore, an *Approval procedure* (BIMCO, 2021a) and an *Industry standard* (BIMCO 2021b) intended for in-water cleaning companies were issued by the international shipping industry organization BIMCO (Baltic and International Maritime Council) together with ICS (the International Chamber of Shipping).

BIMCO industry standard

The *Approval procedure* (BIMCO, 2021a) is intended for in-water cleaning service providers that remove and capture macrofouling organisms that have colonized the immersed surfaces of ships. The approval is granted by an independent Approval Body that verifies the cleaning system based on test results and documentation form an independent Testing Organisation.

The cleaning company shall have procedures in place that describe the handling of material as well as the capture, separation and/or treatment of seawater. The BIMCO industry standard (BIMCO 2021b) prescribes that the performance of three different tests that shall meet the following four criteria:

1. The in-water cleaning process removes at least 90% of macrofouling (i.e., individuals or colonies visible to the human eye)
2. The separation and/or treatment of captured materials during in-water cleaning both: (1) removes at least 90% (by mass) of material from seawater influent and (2) at least

95% of particulate material in effluent water is ≤10 µm in equivalent spherical diameter (ESD)

3. Local water quality parameters of total suspended solids (TSS) are not elevated above ambient levels during the same time period

4. Local water quality parameters of dissolved and particulate biocides found in AFC are not elevated significantly above ambient levels during the same time period.

The fourth criterion is not mandatory for the approval of a cleaning system, but compliance with this criterion may be required, if the system is used in harbours with local requirements to discharge of effluents from the cleaning process, e.g., to comply with local water quality standards.

The BIMCO industry standard applies particle size and total suspended solids as proxy for organisms, coating materials and other materials that are removed during the cleaning. The requirement that at least 95% of the particulate material in the effluent water shall be equal to or less than 10 µm makes use of the assumption that effective capture of small particles will ensure effective capture of microplankton (e.g., algae). When the particles in the effluent water are not identified (e.g., to quantify microplankton), and solely particle sizes are determined, it is of utmost importance that the size of the particles is correctly measured. Here the possible formation of aggregates composed of small particles that bind to each other may pose a challenge for correct measurements of particle sizes. A pre-treatment of the samples with a dispersion agent can minimize the risk, but it may be difficult to confirm that maximum 5% the particulates are larger than 10 µm, because the particle size analysis does not distinguish between aggregates and single particles.

The current draft revised IMO biofouling guidelines (IMO, 2021) include updated recommendations for risk assessment, inspection, and cleaning and maintenance. The revised guidelines will, when issued, provide a common global approach for management and control of biofouling that may be useful for reducing the risks related to invasive aquatic species.

References

BIMCO. 2021a. *Approval procedure for in-water cleaning companies*. BIMCO and International Chamber of Shipping.

BIMCO. 2021b. *Industry standard on in-water cleaning with capture. Version 1.0*. BIMCO and International Chamber of Shipping.

COMPLETE. 2021. Proposal for a regional baltic biofouling management roadmap. *Baltic COMPLETE Project*. https://balticcomplete.com/publications/project-reports/320-proposal-for-a-regional-baltic-biofouling-management-roadmap

Floerl, O., Peacock, L., Seaward, K., & Inglis, G. 2010. Review of biosecurity and contaminant risks associated with in-water cleaning. *The Department of Agriculture, Fisheries and Forestry, Australia*.

FORCE. *Performance of ships in service*. Retrieved August 23, 2021, from https://forcetechnology.com/en/cases/performance-of-ships-in-service

IMO. 2011. *Guidelines for the control and management of ship's biofouling to minimize the transfer of invasive aquatic species.* MEPC 62/24/Add.1, Annex 26, 1-27.

IMO. 2021. *Review of the 2011 Guidelines for the control and management of ship's biofouling to minimize the transfer of invasive aquatic species.* Report of the Correspondence Group on Review of the Biofouling Guidelines. Submitted by Norway.

Lewis, J. A. 2020. Chemical contaminant risks associated with in-water cleaning of vessels. *Department of Agriculture, Water and the Environment, Canberra, September*, *CC BY 4.0*.

Morrisey, D., & Woods, C. 2015. In-water cleaning technologies: review of information. *MPI Technical Paper No: 2015/38, Wellington New Zealand*. http://www.mpi.govt.nz/news-and-resources/publications/

Nurioglu, A. G., Esteves, A. C. C., & De With, G. (2015). Non-toxic, non-biocide-release antifouling coatings based on molecular structure design for marine applications. *Journal of Materials Chemistry B*, *3*(32), 6547–6570. https://doi.org/10.1039/c5tb00232j

Salminen, E., Hansen, J. H., Nielsen, C. W., & Wuokko, P. (2016). Nordic Shipyards Best Available Techniques (BAT). *Nordisk Minister Råd TemaNord*, *548*.

Scianni, C., & Georgiades, E. 2019. Vessel in-water cleaning or treatment: Identification of environmental risks and science needs for evidence-based decision making. *Frontiers in Marine Science*, *6*(JUL), 1–12. https://doi.org/10.3389/fmars.2019.00467

Strydom, C., Robertson, A., & Andersen, M. J. 2020. Cloud-based vessel biosecurity management to mitigate the transfer of NIS. *PortPIC'20*.

Tamburri, M. N., Davidson, I. C., First, M. R., Scianni, C., Newcomer, K., Inglis, G. J., Georgiades, E. T., Barnes, J. M., & Ruiz, G. M. 2020. In-Water Cleaning and Capture to Remove Ship Biofouling: An Initial Evaluation of Efficacy and Environmental Safety. *Frontiers in Marine Science*, *7*(June), 1–14. https://doi.org/10.3389/fmars.2020.00437

US Environmental Protection Agency. 1999. *Nature of discharge for the "Phase I Final Rule and Technical Development Document of Uniform National Discharge Standards (UNDS)."*