COMPLETE PLUS

Risk assessment of in-water cleaning (IWC) of ships in the Baltic Sea Region

Alessandra Engels, BSH
Nicole Heibeck, BSH
Katja Broeg, BSH

Contents

I. List of Tables

II. Abbreviations

AFS	Anti-fouling system
BSR	Baltic Sea Region
BWMC	Ballast Water Management Convention
ESD	Equivalent spherical diameter
IAS	Invasive aquatic species
IMO	International Maritime Organization
ISO	International Organisation for Standardisation
IWC	In-water cleaning
MGPS	Marine Growth Prevention System
NIS	Non-indigenous species
PIT	Proactive in-water treatment
PIC	Proactive in-water cleaning
PICC	Proactive in-water cleaning and capture
PPR	IMO's Sub-committee on Pollution Prevention and Response
RIT	Reactive in-water treatment
RIC	Reactive in-water cleaning
RICC	Reactive in-water cleaning and capture
ROV	Remotely operated vehicle
SPC	Self-polishing copolymer

III. Introduction

Biofouling describes the accumulation of organisms such as algae, bryozoa, hydrozoa, tunicata, crustacea, and many others as well as microorganisms on ship hulls and niches. If the organisms survive, non-indigenous species (NIS) can be introduced beyond their natural range, spread and cause harm to native species, the environment, economy, human health or social/cultural values (Galil et al. 2019, and references therein). In these cases, introduced NIS become invasive aquatic species (IAS). Besides ballast water, biofouling is the major pathway for the translocation of marine species by ships (Galil et al. 2019).

The problem of NIS introduced by ship's biofouling has worsened over the past few decades due to the increased volume of trade and traffic. In addition, slow steaming practices and long lay-up periods increased the accumulation of biofouling. As this trend is likely to increase even more in the future "at an alarming rate" (IMO 2020), the risk of spread of NIS does not seem to be at its zenith, going along with harmful effects in many regions of the world (IMO 2020).

Furthermore, adherent organisms and their associated increase in hull roughness increase the flow resistance, which consequently raises the drag. Deterioration of the hull surface can also be caused by corrosion or paint roughness with age, resulting in a poorer hydrodynamic performance (Anderson 2004) which leads to an increased fuel consumption. It is necessary to either raise power to maintain speed or to prolong voyage time when power is kept constant resulting in slower speed (Watermann et al. 2021). Since fuel costs are a major financial factor for a ship's operator, IWC is not only ecologically reasonable but also economically. Furthermore, the Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011) with the adoption of amendments to MARPOL Annex VI (resolution MEPC.203(62)), by Parties to MARPOL Annex VI.
Organisms can also attack and corrode the coating of the ships, which may lead to water pollution, especially if the paints contain harmful substances, pigments and particles/polymers like microplastic (Gaylarde et al. 2020).

In order to prevent or mitigate biofouling, biofouling management is conducted. The International Maritime Organization (IMO) Resolution MEPC.207(62), 2011 Guidelines for the Control and Management of Ship's Biofouling to minimize the Transfer of Invasive Aquatic Species, hereinafter referred to as "IMO Biofouling Guidelines", and the IMO Biofouling Guidance for leisure boats (Guidance for Minimizing the Transfer of Invasive Aquatic Species as Biofouling (Hull Fouling) for Recreational Craft, MEPC.1/Circ.792) have been adopted in 2011 and 2012 respectively, in order to minimize the risk of biofouling species introduction by providing information on all aspects and measures to minimize biofouling. The IMO Biofouling Guidelines are currently under revision by IMO's Sub-committee on Pollution Prevention and Response (PPR) to increase its applicability and provide more details with regard to its implementation. Efficient biofouling management encompasses a Biofouling Management Plan and Record Book of each ship as well as the ship-specific choice and maintenance of an antifouling-system (AFS) and marine growth prevention systems (MGPS). In addition, regular performance monitoring can be an important indicator for the necessity of inspection and in-water cleaning (IWC) of the ship's hull and niche areas. Periodically, dry-docking is also essential for successful biofouling management (Watermann et al. 2021).

IWC of ship hulls can facilitate the release of introduced IAS, as well as biocides and particles from AFS and MGPS into the surrounding environment (Department of the Environment and MPI 2015), and therefore, poses certain environmental risks. For this reason, IWC is explicitly or effectively prohibited in many countries, because the environmental impact of releasing IAS, biocides and particles during IWC outweighs the risks that come along with biofouling growth on a ship's hull with no action. This has also been shown in the COMPLETE Project (Completing management options in the Baltic Sea Region to reduce risk of invasive species introduction by shipping), where numerous administrations of the Baltic Sea countries reported that IWC in their coastal waters and ports is either not allowed at all or only on the basis of granted permissions. In the latter case, often no clear understanding exists on what prerequisites are needed for granting such kinds of permissions. Other information collected in the COMPLETE project showed that even in countries which reported that no permissions are granted, IWC takes place on a regular basis without any risk assessment regarding introduction of harmful aquatic organisms and input of biocides and particles from antifouling paints. At IMO PPR7, several submissions dealt with the evaluation and review of the IMO Biofouling Guidelines according to MEPC.1/Circ.811 and their applicability. As one major impediment for the implementation of the Guidelines, the unavailability of IWC opportunities worldwide was mentioned by several member states.

An additional problem is the current practice of performing IWC in countries with relatively weak environmental regulation and low costs. This is not only an ethical and environmental dilemma, it also provides no stimulus for the development of environmentally acceptable in-water cleaning methods and techniques. Therefore, in-water cleaning needs to be considered at both domestic and international levels (Department of the Environment and MPI 2015).
IWC as one important aspect of biofouling management plays also an important role in the IMO Biofouling Guidelines. Therefore, solutions for environmentally sustainable practices require a common understanding on connected risks, and their assessment as background for science-based decision making. As part of the COMPLETE Project, a proposal for a regional Baltic biofouling management roadmap (COMPLETE 2019) has been developed that has already been considered by several international committees, like HELCOM Maritime 19-2019 and 20-2020 and the HELCOM/OSPAR Task Group on Ballast Water Management Convention (BWMC) und Biofouling (HELCOM/OSPAR TG BALLAST) 11-2020. Furthermore, an extract of the Roadmap has been submitted to the IMO PPR 8 to directly support the work of the IMO Correspondence Group on the Review of the Biofouling Guidelines. As important addition to the proposed HELCOM Biofouling Management Roadmap, this document proposes a harmonized risk assessment procedure as basis for permissions of in-water cleaning (IWC) of ships in the Baltic Sea Region within the framework of the follow-up project COMPLETE PLUS by taking into account three relevant environmental aspects of IWC:

- Risk of species introduction (biosecurity risk)
- Risk of biocide input
- Risk of particle input

The risk assessment concept bases on experiences from the project but also on experiments performed in other research studies from all over the world. Administrations and Ports who are the main bodies responsible for IWC as well as transport agencies, EPAs, scientific institutes and diving companies from all interested Baltic Sea countries have been involved in the development by inviting them to provide input and discuss the applicability in their respective locations at several national and international meetings (termed as "Stakeholdermeetings" in the following). The resulting options for consideration of IWC permissions of ships in the Baltic Sea Region (BSR) in this paper are visualized in a flow chart (Appendix 1) aiming to create the decision process more transparent for both, the applicants and the responsible authorities.

1 Risk of species introduction (biosecurity risk)

The growth and accumulation of aquatic organisms on vessels (biofouling) affects their performance and can lead to a spread of aquatic organisms outside their natural range (biosecurity risk).

The speed and intensity of biofouling growth varies depending on abiotic and biotic conditions (table 1). Important abiotic conditions are **water salinity** and **water temperature**. With an increasing salinity and/or temperature, the number of aquatic organisms increases and so does the potential for them to attach to the ship.

Table 1: Factors affecting biofouling growth on a ship.

Factors affecting biofouling growth	Reasons for increasing probability of biofouling growth
Water salinity	Increasing salinity increases the number of aquatic organisms.
Water temperature	Increasing temperature increases the number of aquatic organisms.
Depth of the water and distance to shore	The shallower the water and the closer to shore, the less species typically disperse.
Age and condition of coating	The older the coating or the worse the condition, the higher the probability of fouling to attach to the ship.
Idle time and utilisation rate of the ship	The less a ship is moving, the less water friction will prevent fouling from not attaching to the hull and niches.
Ship's speed	The more the ship's speed differs from the coating manufacturer's specifications on an accurate speed, the less biofouling growth is prevented.
Maintenance history or surface treatment at last dry docking or during the last IWC procedure	In general: The longer the time since last dry-docking or IWC and the longer the period since the last surface treatment, the higher the probability of heavier fouling attached to the ship.
Hull roughness	The rougher the hull, the higher the probability of biofouling to attach.
Trading area of a ship's voyage	If the ship has travelled areas with different occurrence of biofouling species, biosecurity risk increases.

Higher water temperature is usually accompanied by the factors of more sunlight, advantageous nutrients and other aspects linked to species' richness (Morrisey et al. 2013).
In addition to water salinity and temperature, **depth of the water and distance to shore** is affecting the risk of biofouling growth on ship hulls and niches. The deeper the water, the more species typically disperse (Yebra et al. 2004).

To keep the level of biofouling as low as possible, the ship-based factors of **age and condition of coating, idle time and utilisation rate of the ship** the **ship's speed** and the **maintenance history or surface treatment at last dry docking or during the last in-water cleaning procedure** as well as the **hull roughness** should be considered (BIMCO 2021).
There are different types of coatings (going further into detail in chapter 2) that all have different lifetime spans. There is no threshold yet on when a specific type of coating's age is considered "new", "medium" or "old", but it is clear that once expired, IWC is not recommended (Department of the Environment and MPI 2015). In hull areas where the coating is damaged, protection against biofouling growth may no longer be given (MEPC 2011). This is why also the cleaning method applied is of high importance. It should always be in accordance with the advice given by the coating manufacturer to avoid damage of the AFS or decrease of a coating's service life.
Prolonged idle periods and lower utilisation rates increase the biofouling risk of hull and niche areas. Some types of coatings are depended on a waterflow over the hull surface (polishing or water friction) to maintain the coating's surface condition and prevent biofouling sufficiently (BIMCO 2021).

Anti-fouling coatings should be individually selected to meet a ship's operation profile. Preferably, coating manufacturers declare certain specifications on an accurate speed, which, once met, prevent biofouling growth. Niche areas may be exposed to different water flows than the ship's hull and should therefore be considered separately (IMO Biofouling Guidelines).

Specifications for AFS with regard to the optimal operating conditions needed to achieve the highest antifouling effectivity are therefore essential. The same counts for information on cleaning methods, which may be applied to keep the AFS in a proper condition and minimize the input of biocides and particles during IWC (for more detail see section 2). Therefore, provision of adequate detailed information by AFS manufacturers are urgently needed.

The different levels of biosecurity risk (release of non-indigenous species) by in-water cleaning (IWC) are based on the type of fouling (micro/macro or soft/hard; see section 1.1), the percentage of coverage of fouling on the hull and whether the **trading ports of a ships voyage** (see chapter 1.2) contain the same species or not (MEPC 2011). The level of risk can be divided in low, medium and high. This categorization bases on our literature research and discussions within the stakeholder group. In our opinion, a smaller-sized division is hardly assessable and the benefit is rather low. Furthermore, a fast and certain identification of AIS within the biofouling community is not possible.

1.1 Level and type of fouling

As mentioned above, level and type of biofouling can introduce varying levels of biosecurity risk. It increases with the level of biofouling. Biofouling can be divided in soft- and hard- and micro- and macrofouling (table 2). The biofouling level increases here from the left to the right.

Table 2: Examples of biofouling types (BIMCO 2021).

Soft biofouling		Hard calcareous biofouling
Micro	**Macro**	**Macro**
Slime	Soft corals	Barnacles
	Sponges	Mussels
	Hydroids	Tube worms
	Anemones	Bryozoa
	Algae	Oysters
	Tunicates	

The process of biofouling attaching to a ship starts immediately upon the ship has entered the water no matter a newly applied AFC or a recent cleaning (Flemming 2002). Therefore, all ships show some level of fouling starting with slime layer, the microfouling/biofilm. Table 3 shows a level of fouling (LOF) scale divided in “low”, “medium” and “high” based on the ranking system by Floerl et al. 2005.
The speed and intensity of biofouling growth on the hull depend on certain factors that were presented above. Additionally, the location and design of niche areas are of high importance regarding the degree of fouling since they often represent sheltered areas, where species attachment and growth is easier than at the exposed areas of the hull.

Macrofouling contains a higher level of species introduction since the spectrum of species can be more distinctive and may be harder to remove (Department of the Environment and MPI 2015). Even non-sessile species like mobile crustaceans might use macrofouling as habitat.

Currently, the IMO Biofouling Guidelines are under revision. The ranking of the biofouling level is one central part of this revision process and it is still under discussion. When taking this proposal for a risk assessment in consideration as basis for a regional harmonization, the outcome of the revision of the Guidelines should be taken as basis for, inter alia,the biofouling level.

Table 3: Level of Fouling (LOF) (based on Floerl et al. (2005)).

LOF		Description	Visual estimate of fouling cover
0	low	No visible fouling. Hull entirely clean, no biofilm on the previously submerged parts of the hull.	Nil
1		Slime fouling only. Previously submerged hull areas partially or entirely covered in biofilm, but absence of any macrofouling.	Nil
2		Light fouling. Hull covered in biofilm and 1–2 very small patches of macrofouling (only few taxa present).	1–5 % of surfaces that have been submerged
3	medium	Considerable fouling. Presence of biofilm, and macrofouling still patchy but clearly visible and comprised of either one single or several different taxa.	6–15 % of surfaces that have been submerged
4		Extensive fouling. Presence of biofilm and abundant fouling assemblages consisting of more than one taxon.	16–40 % of surfaces that have been submerged
5	high	Very heavy fouling. Diverse assemblages covering most of the hull surfaces.	41–100 % of surfaces that have been submerged

1.2 Trading area

Biofouling originating from distant locations presents a potential threat of spreading IAS and therefore poses a biosecurity risk. In comparison, the biosecurity risk coming along from biofouling acquired in the same location with the same species composition is relatively low (Department of the Environment and MPI 2015).

Currently, there is no tool in order to define “same location” for the Baltic Sea Region (BSR) with regard to biofouling species.
The biosecurity risk of trading areas within the Baltic Sea (low, medium, high) could be assessed based on the knowledge of the IAS present in the areas/ports of the Baltic Sea, according to the HELCOM/OSPAR Joint Harmonized Procedure (HELCOM/OSPAR 2020), for granting exemptions from ballast water management. When the same NIS are present in the ship’s trading

area, the biosecurity risk is low. The decision support tool for granting exemption under regulation A-4 of the IMO Ballast Water Management Convention (BWMC) by HELCOM/OSPAR for the North and Baltic Sea is an existing tool for identifying low risk conditions. This decision support tool bases on the "target species list", which is part of the JHP process and comprises a list of non-indigenous species that are likely to impair or damage the environment, human health, property and resources if they spread in the BSR.
An option to use this tool also in the context of IWC would be, to develop a Biofouling Target Species list in the BSR. Discussion on this option, based on discussions within the COMPLETE PLUS stakeholder group, has already started at TG BALLAST 11-2020 (Outcome of TG BALLAST 11-2020, paragraph 9.2) and could further take place at the HELCOM/OSPAR Joint Task Group Ballast and Biofouling.
We recommend that trading areas containing the same Biofouling Target Species should be defined as "**Same port and surrounding**" whereas a ship's trading area with occurrences of different Biofouling Target Species in e.g. port of departure and arrival could be classified as "**International**".

Not only as long as this differentiation of NIS and their occurrence is not standardized or defined but also afterwards, the Biofouling Management Plan and Biofouling Record Book (going further into detail in chapter 3.1.1) could be used. They comprise the ship's voyage history since the last cleaning or paint application and all relevant management measures that serve relevant authorities as information and proof regarding conducted measures. Furthermore, it informs about possible origins of the biofouling growth and helps to assess the risk of IWC (Department of the Environment and MPI 2015).

Marine Pest Alert

If a ship has travelled within areas announcing a Marine Pest Alert, IWC in the Baltic Sea is not permitted. There are no specific marine pest alert programs actively in use in the BSR but currently under development for the BWMC and could possibly be extended for biofouling species.

2 Risk of hazardous substances/biocide and particle input

AFS and MGPS are used for ship hull and niche areas to decelerate the attachment and growth of biofouling on submerged areas. Despite the deceleration of the accumulation, biofouling starts to grow within the first hours after the ship's immersion into the water and hence needs to be cleaned at some point. Ships and boats cannot be taken out of the water as often as they would need to be cleaned due to low capacities and high costs of dry docks in the BSR (Information from stakeholder meetings). Thus, the cleaning is proceeded in-water, which causes the risk of hazardous substances and particles from the hull coating entering the aquatic environment during and after IWC. Paint flakes and other particles might enter the water by blistering or delaminating or biocides could be released due to abrasion (Morrisey et al. 2013). **Age and condition of coating** therefore have a crucial impact on the environmental risk of IWC.

Coatings are usually applied every 3-5 years during dry-docking (Tamburri et al. 2020, 2). However, different coating types (going further into detail in chapter 2.1.1 and 2.1.2) work differently and have varying lifetime spans (BIMCO 2021). Consequently, there is no generally valid definition of age of coatings in “new”, “medium” or “old” but once the service life of an AFS is expired, IWC is not recommended (BIMCO 2021).

The amount of paint flakes removed via IWC and therefore the extent to which hazardous substances and particles end up in the water does not solely depend on the factors mentioned in chapter 1 (age and condition of the coating, hull roughness, maintenance history) but also on, and especially in combination with **the cleaning method** used (type of brush, cleaning machine, aggressiveness of the cleaning, etc.), **the effectivity of capture and filtration**, the **competence of the cleaning company** and the **type of coating** (Morrisey et al. 2013). For the choice of the coating type, the operational profile of the ship should be considered, including service speed, activity level, idle period and traded waters (Watermann et al. 2021). Another aspect which is highly important to consider when choosing the AFS is the construction of the ship. Niche areas need to be checked on their accessibility and cleanability. By changes in speed, they are exposed to different water flows which might lead to the recommendation of choosing a different kind of AFS for certain niche areas than for the hull of the ship (MEPC 2011, Watermann et al. 2021).
Furthermore, legal requirements for the use of AFS must be met (MEPC 2011). There are two major **types of coatings** considered in this paper, the **biocidal** and the **biocide-free** ones. Biocidal AFS are reckoned to be harmful for the marine environment as they release chemicals that might affect the fecundity, mortality and hormonal functions of aquatic organisms (Keep the Archipelago Tidy Finland 2020). For this reason, all paints for commercial shipping must be in line with the IMO AFS convention. Biocide-free fouling release coatings generate a surface where biofouling hardly can stick to and have therefore a low risk in regard to the release of biocides during cleaning activities (Keep the Archipelago Tidy Finland 2020).

2.1 Type of coatings

The subcategories of AFS types are defined slightly different in publications. This document refers to the classification from New Zealand (Morrisey et al. 2013):

- Biocidal (going further into detail in chapter 2.1):
  a) Soluble matrix (ablative),
  b) Insoluble matrix (contact leaching/diffusion),
  c) Self-polishing copolymer (SPC) and
  d) Metallic.
- Biocide-free (going further into detail in chapter 2.2):
  e) Fouling release and
  f) Mechanically resistant

Concerning biocidal coatings, the most commonly used ones are soluble and insoluble matrix coatings as well as the self-polishing copolymer (SPC) coatings (Scianni & Georgiades 2019).

a) Soluble matrix/ ablative AFS

Soluble matrix coatings have a binder implied that dissolves in seawater causing hydration and ultimately release the associated biocide. They have a life span up to 36 months (Georgiades et al. 2018).

b) Insoluble matrix/ contact leaching/ diffusion AFS

These coating types contain an insoluble binder with a high concentration of biocides. These biocides are released through diffusion and usually have a high initial release rate with a subsequently strong reduction in course of time. Their life time lasts up to 18 months (Georgiades et al. 2018).

c) Self-polishing copolymer (SPC) coating systems

SPC's degrade due to hydrolysis which causes a biocide release when the ship is moving. The coatings contain usually copper, zinc, and silyl acrylate and work effectively for up to 60 months (Georgiades et al. 2018).

d) Metallic coating systems

As mentioned above, metallic coating systems are not the most common used AFS's on ships and are more often used for offshore and fixed installations. Their life span is up to 20 years and they are based on copper or a copper-nickel mixture and also contain metal particles (Georgiades et al. 2018).

e) Foul release coating systems

These usually silicone-based coating systems aim to impair the adhesive attachment of biofouling by a "self-cleaning" process. To enable a sufficient biofouling protection, the fouling release coating systems require a high-activity and a medium- to high vessel speed (Georgiades et al. 2018).

f) Mechanically resistant coating systems

These coatings do not contain measures or biocides to prevent biofouling settlement or growth. They are hard and highly durable to withstand e.g. the abrasion caused by drifting ice in winter time. Ships coated with these mechanically resistant coating systems require regular in-water cleaning to keep them free of macrofouling (Georgiades et al. 2018).

2.1.1 Biocidal AFS

Despite of known advantages of biocide-free solutions, biocidal antifouling coatings still represent at least 90% of the hull coating market for commercial vessels (Oliveira & Granhag 2020).
As mentioned above, biocidal AFS's present an environmental risk. They are built to release biocides continuously with a leaching rate that creates a toxic surrounding for organisms and hamper their attachment to the ship hull and niche areas (Morrisey et al. 2013).

Copper (Cu) is the most commonly used biocide in antifouling paints and is often used in combination with organic biocides which are commonly referred to as secondary, or booster, organic co-biocides. These booster biocides aim to enhance the efficacy of the formulation by broaden the spectrum of antifouling effectiveness to more-copper tolerant organisms (Department of the Environment and MPI 2015). In this matter zinc (Zn) is commonly used as an additional compound (Tamburri et al. 2020). The fraction of copper and zinc in the paint differs thereby and so do their leaching rates (Keep the Archipelago Tidy Finland 2020).

Previous studies also demonstrated that some aggressive cleaning techniques can significantly increase biocide emissions (Schiff et al. 2004) not only by the direct release during cleaning but also indirect by a passive leaching of biocides afterwards until it becomes steady again (Morrisey et al. 2013). During IWC, there is a distinct increase of dissolved copper concentrations in close-by waters. Dissolved copper will pass through a 0.45 µm filter per definition (Morrisey et al. 2013). The passive leaching rates after cleaning have been monitored to return to steady state after ca. 3 days (Brown & Schottle 2006). Other factors affecting the concentration of released biocides from the paint include the ship's area being cleaned, the number of ships cleaned per day as well as the cleaning method used (Scianni & Georgiades 2019).
If the coating is ablative, these studies observed that released contaminants during cleaning could also result from paint particles or paint flakes. Disintegrated paint particles by water-blasting typically had a size of about 5-30 µm, consisting of 2-30% of copper (10% on average). In addition to the great loss of paint particles, the hull's surface area grew by water-blasting and sanding (Williamson et al. 1995). Paint particles therefore predicted lost their copper rapidly, within less than a day to a few weeks (Department of the Environment and MPI 2015). For the techniques of brush cleaning systems and probably also hand scrubbing, the dislodgement of paint chips (along with biofouling organisms) has been found, particularly if the biofouling included calcareous organisms such as barnacles (Conway & Locke 1994). In general, calcareous fouling can accelerate paint system failure (Department of the Environment and MPI 2015).

The rates of biocide release from antifouling coatings can vary with water parameters such as temperature, salinity, pH and water movement over the surface and copper concentration in the water (de la Court & de Vries 1973). The amount of released copper raises with increasing temperature and salinity and decreases with a pH elevation (Finnie 2006). Copper release rates of antifouling paints might vary during the coating's service-life depending on several factors such as the formulation and the environment. Additionally, differences in berthing locations, operating schedules, vessel speed, length of service, and condition of paint film surface might also play a role (Department of the Environment and MPI 2015).

2.1.2 Biocide-free AFS

As mentioned in chapter 2.1 biocide-free AFS's are either fouling-release coatings that are silicone-based to minimise adhesion strengths or mechanically resistant coatings with no active measures to prevent biofouling attachment but a physically durable surface. Mechanically resistant coatings can thus withstand regular cleaning. However, there are certain factors that

need to be given to not impair their function. Fouling-release coatings applied to ships require a certain speed and utilization rate to generate their “self-cleaning”, inactive periods or long idle times facilitate the attachment of biofouling (Department of the Environment and MPI 2015). Furthermore, biofouling growth may not be prevented optimal when there already is microfouling attached to the ship and modifies the coating surface or when the surface is damaged due to e.g. abrasion (Department of the Environment and MPI 2015).
Fouling release coatings, which are highly susceptible to abrasion damage, can only be cleaned safely with soft- or non-contact methods (Holm et al. 2003). For instance, there is a recommendation for cleaning the water line by high volume, low pressure fire hose and underwater with high pressure freshwater fan-jet lance or by hand cleaning with a rubber squeegee or high porosity sponge. Currently there are only few suitable mechanical systems available for cleaning silicone fouling release coatings (Department of the Environment and MPI 2015).

2.2 Polymers

Plastics in the marine environment are subjected to fragmentation into microplastics (MPs) by various processes (Dibke et al. 2021). Next to other factors, shipping is one relevant source for the input of MPs in ocean waters by fragmenting paint coming from AFS used on commercial vessels (Gaylarde et al. 2020). ‘Plastics’ are defined as a wider range of polymers (Sundt et al. 2015). They may contain polyurethanes, polyesters, polyacrylates, polystyrenes, alkyls and epoxies (Gaylarde et al. 2020). The particle size mainly ranges from 1µm-5 mm (Watermann & Eklund 2019).

Latest studies assess 3300-16225 metric tons of paint losses into the marine environment yearly for the EU with a 25% share of polymers. Thereby, paint particles abrased from ships probably contribute the second largest amount to marine MPs of all possible sources (Dibke et al. 2021). Since they have an ecotoxicolgical effect to the marine life but there is no restriction of using polymers for ordinary plastic products in place, studies highly recommend including ship abrased polymers in microplastic research (Dibke et al. 2021).

3 In-water cleaning (IWC)

In conclusion of the aspects and environmental risks, mentioned above, there are also certain preconditions that need to be fulfilled to consider the permission of IWC in the Baltic Sea Region.

3.1 Preconditions for the permission of IWC

- Existence of a Biofouling Management Plan **(see 3.2)**
- Existence of a Biofouling Record Book **(see 3.2)**
- Accessibility and cleanability of hull and niche areas
- Cleanability of the coating according to the manufacturer’s specifications

If one of these requirements is not met, IWC in the Baltic Sea Region should not be permitted, as the concomitant environmental risk cannot be reliably assessed.

3.2 Documentation

Performance Monitoring

Performance monitoring works by regular monitoring factors that possibly affect the performance of the fleet, for example, fuel consumption, trim, speed, hull and propeller conditions and etc. Measurements of fuel consumption at a certain speed and weather conditions (currents, tides, winds) can give some indication of biofouling on the ship. When the demand in power and fuel consumption increases to keep speed constant, inspection is advisable.

There are standards by the International Organisation for Standardisation (ISO) about “Ships and marine technology- Measurements of changes in hull and propeller performance” (ISO/DIS 19030-1, -2, -3) that ship owners can use as assistance (Georgiades et al. 2018).

Biofouling Management Plan (BFMP)

For documentation, the MEPC of the IMO recommends in their Biofouling Guidelines a ship-specific **Biofouling Management Plan (BFMP)** that contains biofouling management procedures integrated in the ship’s maintenance system (MEPC 2011). The format and content of the BFMP is to find here: IMO Biofouling Guidelines - Biofouling Management Plan, **Annex 1** and currently under revision. It includes the ship’s individual information and descriptions of the AFS, operating profile and areas on the ship susceptible to biofouling (e.g. niche areas) as well as a Biofouling Management Action Plan (BMAP). Moreover, the BFMP should contain information on the operation and maintenance of the AFS, aspects concerning the crew, disposal of biological waste and recording requirements (MEPC 2011).

Biofouling Record Book (BFRB)

In addition to the BFMP, a form for a **Biofouling Record Book (BFRB)** can be found here: IMO Biofouling Guidelines - Biofouling Record Book, **Annex 2**. This form deals with information regarding dry-docking, inspection, cleaning, MGPS, idle time, exceptional operations, biofouling risk and additional observations. The BFRB assists the shipowner and operator to evaluate the efficacy of the applied AFS and operational practices on the ship in particular, and of the biofouling management plan in general. The record book could also assist interested State authorities to quickly and efficiently assess the conducted management measures and the potential biofouling risk of the ship. (MEPC 2011).

To assess the risk of IWC, it is assumed that the information complied in those two documents are provided in advance and kept on board or recorded by digital systems. The development of a BFMP and a BFRB is, like the IMO Biofouling Guidelines, voluntary.

3.3 Niche areas

While the hull can usually be cleaned by divers or remotely operated vehicles (ROV) that can clean large flat areas, it is not always possible to use the same piece of equipment for all niche areas (BIMCO 2021). Niche areas on a submerged hull of a ship are more difficult to access and clean but in the same time might be more susceptible to biofouling growth even though AFS is usually applied in niche areas. Cleaning niche areas can only be performed by hand with divers and is very time consuming and consequently more expensive (Information of stakeholder group). In the same time and in contrast to the ship's hull, most of the niche areas with attached biofouling do not worsen the flow resistance and hence the do not increase fuel consumption (IMO 2020).

Out of these reasons, in this paper the niche areas of a ship are assessed differently than hull areas. In this matter, niche areas are grouped together and every group is assessed individually. There are several ways to name or group niche areas, the here used definitions for "common niche areas are:

- Dry docking support areas/strips
- Thrusters and thruster tunnels
- Rudder, including hinges and stocks
- Propellers, shafts and struts
- Cathodic protection anodes
- Seawater inlet pipes and internal systems
- Sea chests and gratings
- Sonar domes, transducers and velocity probes
- Retractable propulsion units
- Bilge keels and stabilizer fins
- Internal ships' spaces (e.g. chain lockers, bilges, bait wells)"

3.4 Cleaning methods

Since cleaning ships and boats in-water presents the before mentioned risks of species introduction, hazardous substances and particle input, IWC must be conducted with the best available cleaning method for the respective type of coating. Furthermore, the best practice recommendation is to capture and filter the cleaned fouling and washing water and to also filter biocides from it.

The rougher the cleaning technique, the higher the probability of "degradation of the anti- fouling coating system and/or biocide release (MEPC 2011)". Out of this reason it is recommended to clean the ship already in the stage of microfouling when soft cleaning methods can still be used. Additionally, it reduces the risk of spreading IAS by keeping the level of fouling as low as possible (MEPC 2011). Table 4 shows two approaches of in-water cleaning procedures.

Table 4: Two approaches of IWC.

Approaches of IWC	**Proactive In-water Cleaning (PIC)/ Treatment (PIT)/ Cleaning and Capture (PICC)**	**Reactive In-water Cleaning (RIC)/ Treatment (RIT)/ Cleaning and Capture (RICC)**
Usage	Used for prevention and reduction of microfouling (consequently macrofouling is prevented as well. The PICC system does not only capture the cleaned-off foul but also treats the effluent water.	Used for the removal of biofouling, especially when the prevention or removal of microfouling has failed and macrofouling developed. Another reason for the occurrence of macrofouling is damaged AFS.
Cleaning methods	The cleaning can be conducted by using soft brushes, water jets, or contactless systems (Scianni & Georgiades 2019, 3).	The cleaning methods include abrasive brush systems and high-pressure water jets. Since macrofouling is harder to remove, cleaning methods are more aggressive and might abrase the AFS into the aquatic environment presenting contamination risk (Scianni & Georgiades 2019, 5).

As mentioned in chapter 2.1.1, previous studies demonstrated that aggressive cleaning techniques could significantly increase biocide emissions (Schiff et al. 2004). This is one of a number of reasons why proactive systems are to recommend over reactive systems.
A study has shown that costs for IWC of oil tankers are lower for proactive cleaning than for cleaning ships in stages of hard and medium level of fouling which are usually treated with reactive cleaning systems. In every single scenario (21 in total), proactive cleaning was estimated to lead to higher annual savings (Stuer-Lauridsen & Kern-Nielsen 2021).

Table 5 gives an overview of possible IWC methods in the Baltic Sea. Beyond that, this document does not aim to evaluate specific cleaning methods. AFS-manufacturers should specify which cleaning methods are most suitable for their coatings to prevent damage and therefore keep particle and hazardous substances input as low as possible

Table 5: Overview of IWC methods for ships (modified after Watermann et al. 2021).

Method	Diver operated cleaning device	ROVs	Ship-based ROVs
Technique	• Rotating brushes, • High pressure-jetting, • Blades - with external capture and filtration	• Rotating brushes, • High pressure-jetting, with internal capture by filtrating bags	• Rotating brushes • Hydro-jetting
Application	Hull and niche if accessible	Hull	Hull
Benefit	Effective, control of cleaning effort, access to most niches, optical control	Effective, control of cleaning effort, optical control	Effective, control of cleaning effort, optical control
Risk	Application only in ports or sheltered waters without waves, currents, and turbidity	Application only in ports or sheltered waters without waves and currents. Control of bag capacity limit needed.	Exclusively applicable on biofilms, no capture of organisms and paint particles
Costs	high	low	high
Availability	Baltic Sea ports depending on permits	Baltic Sea ports depending on permits	Everywhere when laying idle in calm waters depending on permits

4 Recommendation for IWC procedures in the BSR

This paper suggests four different recommendations for IWC procedures in the BSR (table 6) which is also visualized in the flow chart (Appendix 1). IWC may be considered allowed

1. without any further restriction or inspection (green)
2. when the fouling material is captured and filtered (yellow)
3. if the fouling material is captured and filtered plus explicitly filtrating biocides and/ or a prior chemical risk assessment (orange)

or

4. IWC is not recommended or even prohibited and the ship must be cleaned in dry-dock (red).

Table 6: Key for a recommended IWC procedures in the Baltic Sea Region.

Cleaning allowed
Capture and Filtration
Capture and Filtration including biocides and/ or prior chemical risk assessment
IWC not permitted (Dry-dock)

Green: Cleaning allowed

If cleaning is allowed without capture and filtration without any further restrictions, “there needs to be a high level of confidence that there are no specific biosecurity risks associated” (Department of the Environment and MPI 2015)” based on the ship’s trading area. Therefore, IWC without capture and filtration is rated to contain an unacceptable risk in almost all cases, except for ships with a trading area of the same Biofouling species, fulfilling the preconditions of accessible hull and niche areas and that IWC on the AFS is possible according to the manufacturer’s specification. In addition to these preconditions and a low level of fouling, a risk of hazardous substances and particle input needs to be ruled out.

Since all types of AFS, biocidal and biocide-free ones, contain the risk of particle input during IWC, (information from stakeholder meeting), there is no permission of cleaning without capture and filtration proposed at the present moment.
A permission of IWC without any further restrictions in the future requires a development of coatings not containing a contamination risk.

Yellow: IWC with Capture & Filtration

As of today, IWC in the Baltic Sea is only allowed when at least the fouling material that comes off and the water used for cleaning is captured and filtered. If not captured, the cleaned material might continue to be able to exist and spread as IAS (Woods et al. 2007). Due to abrasion through IWC also particles can enter the marine environment, e.g. resulting in polymers in form of microplastics spreading and cause harm to the ecosystem.

Therefore, cleaning with capture accumulates polluted water. This polluted or contaminated water subsequently needs to be filtered and separated in waste and water influent to maintain the particle input at a certain level (Soon et al. 2021).

To date, there are no harmonized regulations for waste management in the BSR. Approval of cleaning companies and their capture and filtration technology is currently in the hands of the national competent authorities. BIMCO recommends that “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) (BIMCO 2021).” Watermann et al. (2021) also suggested a filtration of “at least 10 µm [mesh sizes]” for IWC in the Baltic Sea.
In another study by Soon et al. (2021) that calculated TSS (total suspended solids) from a unit hull area, 75-94% of the particles in the polluted water were ≥8 µm. Consequently, their recommendation on a filtration system comprises a mesh size of 8 µm (Soon et al. 2021). The results of the COMPLETE project, the currently available filtration techniques and the information of the stakeholder group lead to a recommended mesh sizes of at least 10 µm, which is technically feasible and ecologically worthwhile.

Orange: IWC with Capture & Filtration plus biocides and/ or prior environmental risk assessment

IWC on biocidal coatings in the Baltic Sea Region is only allowed with a cleaning method including capture and filtration with explicitly filtering biocides and/ or a prior chemical risk assessment. Furthermore, a permission premises that the preconditions of accessible hull and niche areas and the possibility of IWC according to the manufacturer’s specification are met as well as that the biosecurity risk is not high for ships with an international trading area.

Technology that is able to filter biocides already exists in form of a charcoal filter but literature about it and practical implementation in the BSR is sparse. If not explicitly filtered, dissolved biocides can be “released into the harbour basin during cleaning (Watermann et al. 2021)”. Conducting a prior chemical risk assessment with appropriate results, IWC with Capture & Filtration could be permitted without an explicit filtration of biocides. There is no harmonized procedure in the BSR for such a chemical risk assessment yet.
As an example of how an environmental risk assessment could be proceeded, Soon et al. (2021) conducted a study for IWC in ports which was based on the MAMPEC-Model (Marine Antifoulant Model to Predict Environmental Concentrations) that is usually used for the calculation of Ballast Water Values. In their study, they calculate the total load of the environment on the basis of the release rate of TSS (total suspended solids) and the total area cleaned in a certain location at a certain time period (Soon et al. 2021). Additionally, the determination of the environmental concentration and consequently the risk, requires to include other parameters in combination. These parameters encompass hydrodynamics (e.g. tidal period, flow velocity etc.), water parameters (e.g. salinity, temperature, pH-value etc.), wind and the port layout (Soon et al. 2021). As their results presented a base for assessing an environmental risk, a harmonized procedure for a chemical risk assessment in the future could work similar.

Red: IWC not permitted/ Dry-dock

If the preconditions are not met, a marine pest alert in the ships trading area is announced or the combination of a given hazardous substances, particle input and the biosecurity risk is too high, IWC is considered unacceptable. In this case, it is recommended to haul the ship out of the water for cleaning or maintenance in dry-dock.

Taking it out of the water is expensive and usually only happens every few years and not on a regular basis. Moreover, the dry-docks are limited in size which presents one more reason why more frequent cleaning on a regular basis in dry-docks in the BSR for the majority of vessels does not happen in practice.

In the same time, cleaning macrofouling or specifically hard calcareous fouling contains a higher biosecurity risk and requires more aggressive cleaning methods which triggers a higher probability for abrasion and damage of AFS which presents a higher risk on hazardous substances and particle input.

Consequently, it is highly advised to prevent this risk or keep it as low as possible. For this matter, regular inspections and a removal of slime at very frequent interval are highly recommended.

5 Special attention to niche areas

Niche areas are very much prone to biofouling because they are sheltered spaces, which are less/not exposed to hydrostatic forces. Therefore, situations where the hull has low biofouling level, but the niches are heavily fouled might occur regularly. To the best of our knowledge, until now, there are no effective biocide free coatings on the market to protect niche areas from biofouling and most niches are therefore protected with a MGPS. The exchange with various stakeholders has revealed that IWC in niche areas should be considered, given the accessibility of niches and the suitable cleaning equipment with capture and filtration, because heavily fouled niche areas have a very high potential of introducing and spreading invasive species and this risk can only be reduced by regular cleaning.

6 Conclusion and Outlook

The proposed risk assessment as basis for permission of IWC in the Baltic Sea requires a set of information from ships as well as from the manufacturers of the applied coatings (via the ship). Therefore, it is of upmost importance that ship-specific information is available. Most information will be covered by the BFMP and the BFRB. This information e.g. should include AFS and MGPS used, details on cleanability and ingredients of the AFS, cleaning recommendations, leaching rate under cleaning operation, accessibility of niches, inspection and cleaning history and reports. In addition, quality and performance of the cleaning company must be proved in the context of requirements of the respective AFS and MGPS. Not all equipment can be used for all AFS and in all circumstances. It is therefore not recommended to apply a “one fits all”, general permission for a cleaning company but do this ship-based, after consultation with a proved/certified cleaning company.

With regard to the permission for cleaning of biocidal AFS, techniques for the capture and filtration of biocides must be further developed. In the meantime, as basis for the possibility to permit IWC on biocidal AFS, a chemical risk assessment should be developed to minimize the risk of impact of hazardous substances.

In addition to the recommendations for IWC procedures as described in this document, the development of a decision support tool for biofouling species similar to the existing HELCOM/OSPAR decision support tool for ballast water exemptions can be considered, if coatings are developed, which will not release any particles during cleaning and therefore eliminate the risk of particle input. This decision support tool bases on lists of non-indigenous species that are likely to impair or damage the environment, human health, property and resources if they spread to the sea area for which the list was created and are a key element of the joint harmonized procedure (JHP). Based on these lists, low risks routes can be defined for granting granting exemptions under regulation A-4 of the IMO Ballast Water Management Convention (BWMC). If these lists are refined to biofouling target species, they could be used to define low risk routes aiming in lower in-water cleaning restrictions for vessels travelling between ports without any target species. In cases where biofouling species are identical in traded areas, IWC could also be permitted without capture and filtration. Moreover, as soon as there will be a marine pest alert program in place in the BSR, it should also be considered in the decision process. In this context, extending the early warning system, currently developed for the implementation of the BWMC, to include also biofouling species, should be taken into consideration.

All aspects and ratings included in this proposal of a risk assessment as basis for the permission of IWC should be revisited as soon as the revision of the IMO Biofouling Guidelines has been finalized. Details might differ from what is going to be agreed internationally. It is therefore also be mentioned that the terms used and the definitions might differ from those used in the future Biofouling Guidelines and thus, need to be adopted accordingly.

IV. References

Anderson, CD. (2004): The economic importance of hull condition. Journal of Protective Coatings and Linings 21 (4), 36-39.

BIMCO (2021): Industry Standard on in-water cleaning with capture. Version 1.0.

Brown, P. & R. Schottle (2006): Copper loading assessment from in-water hull cleaning following natural fouling: Shelter Island Yacht Basin, San Diego Bay, San Diego, California. AMEC Earth & Environmental, Inc., San Diego, CA.

COMPLETE (2019): Proposal for a regional Baltic Biofouling Management Roadmap. https://balticcomplete.com/attachments/article/320/Proposal%20for%20a%20Regional%20Baltic%20Biofouling%20Management%20Roadmap%20COMPLETE%2020210309.pdf, 2021-12-07.

Conway, JB. & LP. Locke (1994): Marine fouling and underwater hull cleaning in San Diego Bay. California Regional Water Quality Control Board, San Diego Region, San Diego, CA.

De la Court, FH. & HJ. de Vries (1973): Advances in fouling prevention. Progress in Organic Coatings 1, 375-404.

Department of the Environment and New Zealand Ministry for Primary Industries (2015): Anti-fouling and in-water cleaning guidelines, Department of Agriculture, Canberra. CC BY 3.0.

Dibke, C.; Fischer, M. & BM. Scholz-Böttcher (2021): Microplastic Mass Concentrations and Distribution in German Bight Waters by Pyrolysis–Gas Chromatography–Mass Spectrometry/Thermochemolysis Reveal Potential Impact of Marine Coatings: Do Ships Leave Skid Marks? Environmental Science & Technology 2021 55 (4), 2285-2295. DOI: 10.1021/acs.est.0c04522.

International Association of Ports and Harbors (IAPH, n.y.): Environmental Ship Index (ESI). Netherlands, https://www.environmentalshipindex.org/, 2021-12-07.

Finnie, AA. (2006): Improved estimates of environmental copper release rates from antifouling products. Biofouling 22, 279-291.

Flemming, HC. (2002): Biofouling in water systems–cases, causes and countermeasures. Appl. Microb. Biotechnol. 59, 629–640. DOI: 10.1007/s00253-002-1066-9.

Floerl, O.; Inglis, GJ; & BJ. Hayden (2005): A Risk-Based Predictive Tool to Prevent Accidental Introductions of Nonindigenous Marine Species. Environmental Management 35, 765–778.

Fraunhofer IMWS (2020): Hintergründe zum Biofouling. https://www.imws.fraunhofer.de/de/specials/antifouling-ms-wissenschaft/hintergruende-zum-biofouling.html#:~:text=Bio-Fouling%20hat%20dabei%20enorme,Treibstoffverbrauch%20bereits%20um%2040%20Prozent, 2021-06-07.

Galil, BS.; McKenzie, C.; Bailey, S.; Campbell, M.; Davidson, I.; Drake, L.; Hewitt, C.; Occhipinti-Ambrogi, A. & R. Piola (2019): ICES Viewpoint background document: Evaluating and mitigating introduction of marine non-native species via vessel bio- fouling. ICES Ad Hoc Report 2019. 17 pp. https://www.ices.dk/sites/pub/Publication%20Reports/Forms/DispForm.aspx?ID=35150

Gaylarde, CC.; Baptista Neto, JA. & EM. da Fonseca (2020): Paint fragments as polluting microplastics: A brief review. Marine Pollution Bulletin 162 (2021) 111847. https://doi.org/10.1016/j.marpolbul.2020.111847

Georgiades, E.; Growcott, A. & D. Kluza (2018): Technical Guidance on Biofouling Management for Vessels Arriving to New Zealand. Wellington: Ministry for Primary Industries, 16.

HELCOM/OSPAR (2020): Joint Harmonised Procedure for the contracting Parties of HELCOM and OSPAR on the granting of exemptions under International Convention for the Control and Management of Ships' Ballast Water and Sediments, Regulation A-4. Adopted as OSPAR Agreement 2013-09 and by HELCOM Ministerial Meeting Copenhagen 3 October 2013, Amended by HELCOM HOD 48-2015 (June) and OSPAR Agreement 2015-01 and HELCOM HOD 59-2020 and OSPAR Agreement 2020-01. https://helcom.fi/wp-content/uploads/2021/01/HELCOM-OSPAR-Joint-Harmonized-Procedure-for-BWMC-A-4-exemptions_2020.pdf. 2022-02-15.

Holm, ER.; Haslbeck, EG. & AA. Horinek (2003): Evaluation of brushes for removal of fouling form fouling-release surfaces, using a hydraulic cleaning device. Biofouling 19, 297-305.

IMO (2020): Biofouling. Invasive aquatic species. http://www.imo.org/en/OurWork/Environment/Biofouling.aspx, 2021-05-28.

Information of stakeholder group (2021): A stakeholder group was formed within the framework of the EU- Interreg project COMPLETE PLUS to propose a harmonized risk assessment procedure as basis for permissions of in-water cleaning (IWC) of ships and boats in the Baltic Sea Region. Therefore, administrations and Ports who are the main bodies responsible for IWC have been involved in the development as well as transport agencies, EPAs, scientific institutes and diving companies from all interested Baltic Sea countries by asking for input and discussing the applicability in their respective locations at several national and international meetings.

Keep the Archipelago Tidy Finland (2020): Recommendations for mitigating potential risks related to biofouling of leisure boats. https://balticcomplete.com/attachments/article/299/recommdendations%20for%20biofouling%20management_KAT.pdf

Marine Environment Protection Committee (MEPC, 2011): 2011 Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species. Annex 26, Resolution MEPC.207(62).

Morrisey, D.; Gadd, J.; Page, M.; Floerl, O.; Woods, C.; Lewis, J.; Bell, A. & E. Georgiades (2013): In-water cleaning of vessels: Biosecurity and chemical contamination risks. MPI Technical Paper No: 2013/11.

Morrisey, D. & C. Woods (2015): In-water cleaning technologies: Review of information. MPI Technical Paper No: 2015/38. ISBN No: 978-1-77665-128-3 (online) ISSN No: 2253-3923 (online).

Oliveira, DR. & L. Granhag (2020): Ship hull in-water cleaning and its effects on fouling-control coatings, Biofouling, 36:3, 332-350, DOI: 10.1080/08927014.2020.1762079, 2021-05-05.

Schiff, K.; Diehl, D. & A. Valkirs (2004): Copper emissions from antifouling paint on recreational vessels. Mar Pollut Bull. 48:371–377. doi:10.1016/j.marpolbul.2003.08.016

Scianni, C. & E. Georgiades (2019): Vessel In-Water Cleaning or Treatment: Identification of Environmental Risks and Science Needs for Evidence-Based Decision Making. Front. Mar. Sci. 6:467. doi: 10.3389/fmars.2019.00467

Soon, ZY.; Jung, JH.; Loh, A.; Yoon, C.; Shin, D. & M. Kim (2021): Seawater contamination associated with in-water cleaning of ship hulls and the potential risk to the marine environment. In: Marine Pollution Bulletin 171, 112694.

Stuer-Lauridsen, F. & K. Kern-Nielsen (2021): Integrating Cleaning of Hull and Niche Areas – Is There a Commercial Niche without Regulation?. In: Bertram, V. (Ed.) 2021: 2nd Port In-Water Cleaning Conference. PortPIC'21.

Sundt, P.; Schulze, PE. & F. Syversen (2015): Source of microplastic-pollution to the marine environment. rep. no. M-321. mepex 108

Tamburri, MN; Davidson, IC; First, MR; Scianni, C.; Newcomer, K.; Inglis, GJ.; Georgiades, ET.; Barnes, JM. & GM. Ruiz (2020): In-Water Cleaning and Capture to Remove Ship Biofouling: An Initial Evaluation of Efficacy and Environmental Safety. Front. Mar. Sci. 7:437. doi: 10.3389/fmars.2020.00437, 2021-06-02.

Watermann, E. & B. Eklund (2019): Can the input of biocides and polymeric substances from antifouling paints into the sea be reduced by the use of non-toxic hard coatings? Marine Pollution Bulletin 144, 146-151. https://doi.org/10.1016/j.marpolbul.2019.04.059

Watermann, BT.; Broeg, K.; Krutwa, A. & N. Heibeck (2021): Guide on best practices of biofouling management in the Baltic Sea. https://www.balticcomplete.com/attachments/article/321/Guide%20on%20best%20practices%20of%20biofouling%20management%20in%20the%20Baltic%20Sea_20210308.pdf

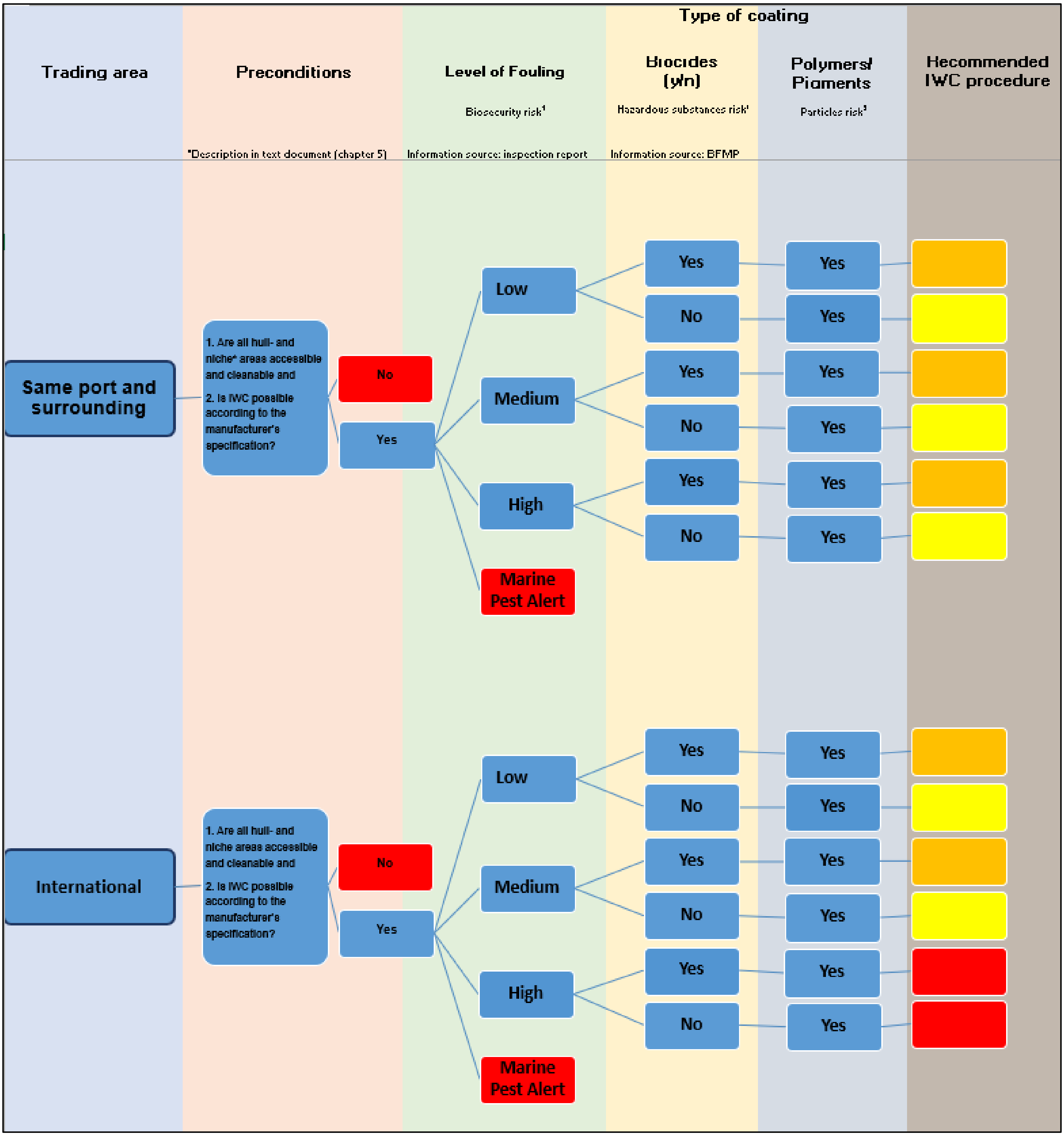
Williamson, RB.; Wilcock, RJ.; Van Dam, LF.; Lee, DJ. & R. Schriner (1995): The characteristics and fate of copper-based antifouling paint residues in the marine environment around Auckland: Final report. Consultancy Report ARC307. National Institute of Water and Atmospheric Research Ltd., Hamilton, New Zealand.

Woods, C.; Floerl, O.; Fitridge, I.; Johnston, O.; Robinson, K.; Rupp, D.; Davey, N.; Rush, N. & M. Smith (2007): Efficacy of hull cleaning operations in containing biological material. II.

Seasonal variability. MAF Biosecurity New Zealand Technical Paper No. 08/11. Ministry for Agriculture and Forestry, Wellington, New Zealand.

Yebra, DM.; Kiil, S. & K. Dam-Johansen (2004): Antifouling technology - Past, present and future steps towards efficient and environmentally friendly antifouling coatings. Prog. Org. Coatings 50, 75–104.

Appendix 1: Flow chart of recommended IWC decisions for ships in the BSR.



Appendix 2: Background information to the flow chart.

Trading area Voyage history since the last cleaning.		
Same port and surrounding		
International		
Preconditions for IWC		
Cleaning Technique/ Method	According to manufacturer's specifications.	
Niches	All niches have to be accessible and cleanable.	
Level of Fouling **1) Biosecurity risk (BSR)** Growth and accumulation of aquatic organisms (biofouling) on vessels affects their performance and can lead to a spread of organisms removed from the hull. If the organisms survive, alien species can spread and present a threat to native species which finally endangers biodiversity. When they do not have natural enemies, they can reproduce unimpeded and ultimately disturb the established ecosystems (BIMCO 2021, 47).		
(based on Floerl et al. 2005, 765–778)		
Level of Fouling	**Description**	**Visual estimate of fouling cover**
Low	• No visible fouling. Hull entirely clean, no biofilm on the previously submerged parts of the hull. • Slime fouling only. Previously submerged hull areas partially or entirely covered in biofilm, but absence of any macrofouling. • Light fouling. Hull covered in biofilm and 1–2 very small patches of macrofouling (only few taxa present).	• Nil • 1–5 % of surfaces that have been submerged.
Medium	• Considerable fouling. Presence of biofilm, and macrofouling still patchy but clearly visible and comprised of either one single or several different taxa. • Extensive fouling. Presence of biofilm and abundant fouling assemblages consisting of more than one taxon.	• 6–15 % of surfaces that have been submerged. • 16–40 % of surfaces that have been submerged

High	• Very heavy fouling. Diverse assemblages covering most of the hull surfaces.	• 41–100 % of surfaces that have been submerged.
Type of coating		
Biocides (Yes/No) **2) Hazardous substances risk (HZR)** Biocidal coatings release chemicals (i.e. copper and zinc) which harm organisms (regarding i.e. their fecundity, mortality and hormonal functions) and lead to an accumulation in the marine environment (i.e., water column, sediments) (Oliveira & Granhag 2020, 333).		
(based on Morrisey et al. 2013, 43).		
Yes (biocidal coating)	Soluble matrix/ablative	
	Insoluble matrix/contact leaching/diffusion	
	Self-polishing copolymer (SPC)	
	Metallic	
No (biocide-free coating)	Fouling release	
	Mechanically resistant	
Polymers/ Pigments (Yes/No) **3) Particles risk (PTR)** Antifouling paint used on commercial vessels is one on the most relevant sources for the distribution of microplastics in ocean waters (Dibke et al. 2021, 2285). The paint fragmenting (Gaylarde et al. 2020, 1) has an ecotoxicological impact (Dibke et al. 2021, 2288).		