GUIDE ON BEST PRACTICES OF BIOFOULING MANAGEMENT IN THE BALTIC SEA

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CONTENT

Abbreviations

AFS	Antifouling System
AIS	Alien Invasive Species
BFMP	Biofouling Management Plan
BFRB	Biofouling Record Book
BWMS	Ballast Water Management System
BWT	Ballast Water Treatment
CRMP	Craft Risk Management Plan
CRMS-Biofouling	Craft Risk Management Standard for Biofouling
CRMS-Vessels	Craft Risk Management Standard for Vessels
DWT	Dry film thickness, final thickness of paint layers applied in drydock
ECE	Economy Commission for Europe
FRC	Foul Release Coating
IMO	International Maritime Organisation
IWI	In-water inspection
IWC	In-water cleaning
MEPC	IMO's Marine Environment Protection Committee
MGPS	Marine Growth Prevention System
NIS	Non-Indigenous Species
PIT	Proactive in-water treatment e.g by heat application
PIC	Proactive in-water cleaning
PICC	Proactive in-water cleaning and capture
PPR	IMO's Pollution Prevention and Response sub-committee
RIT	Reactive in-water treatment, e.g. by heat application
RIC	Reactive in-water cleaning
RICC	Reactive in-water cleaning and capture
SPC	Self-Polishing Coatings
TBT	Tributyltin
VICT	Vessel in-water cleaning or treatment

1 INTRODUCTION AND BACKGROUND

Maritime transport is the most energy-efficient and environmentally friendly transportation sector. Nevertheless, the International Maritime Organization (IMO) aims at further reduction of atmospheric emissions and release of hazardous substances into the sea, as well as avoidance of introduction and spread of invasive species by ballast water and biofouling. In order to minimize the latter, improvement of biofouling management is one major issue which is addressed by the IMO Biofouling Guidelines (2011 Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species, Resolution MEPC:207 (62)) as well as 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). The Guidelines are currently evaluated by the IMO sub-committee Pollution Prevention and Response (PPR). Biofouling as well as inadequate treatment with antifouling paints also of recreational boats may pose significant **environmental risks**:

- Biofouling is an essential vector for introduction and **spread of non-indigenous species (NIS)** which might become invasive and thus represent a **threat to biodiversity** (Bax et al., 2003). Numerous studies have demonstrated that NIS can be transported from one region to another by attaching to hulls and niches of ships on global voyages (Hunsucker et al., 2015; Ruiz et al., 2011) and also on leisure boats, which play an important role in the secondary spread of NIS (Ashton et al., 2014; Davidson et al., 2010; Zabin et al., 2014).
- Biofouling **increases fuel consumption** by increasing hydrodynamic drag on hulls and propellers (Kellett et al., 2015; Schultz, 2007). Thus, **atmospheric** and, in case scrubbers are used, **waterborne emissions** are also increasing with the level of biofouling.
- Current practice of biofouling prevention mainly consists of the use of biocidal antifouling paints. This type of fouling prevention causes **continuous input of biocides** like copper or organic substances into waters due to erosion, ablation and self-polishing of antifouling paints in service. Rough in-water cleaning (IWC) on antifouling paints induces immediate release of biocides and **polymeric backbone/paint flakes** (Earley et al., 2014, Watermann & Eklund, 2019, Oliveira & Granhag, 2020).
- Biofouling **increases hydro-acoustic noise** due to imperfections of the propeller blades affecting cavitation (Renilson et al. 2013).

With regard to effective biofouling management, the shipping industry is currently facing a multitude of **challenges**:

- Existing **oversupply of ships** despite of decline in fleet growth leads to low freight rates, extended idle periods and layups where hull and niche areas are prone to fouling.
- Increasing **demand of flexibility** regarding trade routes hampers the selection of an optimal route-specific biofouling management concept.
- **Extended layup** periods and **slow steaming** between 8 – 12 knots facilitate biofouling because several Antifouling Systems (AFS) need a minimum speed to 'wash-off' the fouling (e.g. self-polishing antifouling).

Fuel costs are the key factor of operational costs, which increase with biofouling development on the hull already from biofilm stage. To reduce fuel consumption, fleet operators increasingly use IWC to remove fouling and thus, decrease friction. But, eroding or self-polishing AFS are not designed to be cleaned, resulting regularly in immediate release of biocides, removal of the upper paint layers, or even damage of the AFS (Earley et al. 2014, Davidson et al. 2016).

Besides the above mentioned increase in fuel consumption, there are further biofouling-related **economic implications** to be mentioned:

- Biofouling reduces the speed of ships and therefore the time required for a given route increases, resulting in **longer voyages** or increased fuel consumption for ships.
- Longer voyages mean increasing **crew costs** relative to the distance of travel routes.
- Biofouling increases **hydro-acoustic noise** which degrades the performance of sonar on fishery and military ships as well as scientific equipment on oceanic research and wreck searching vessels.
- Biofouling reduces dry dock intervals and thus, increase **dry docking costs** and idle periods.
- Heavy biofouling may lead to **refusal of a port of call**, forcing ship owners to perform cost-intensive hull cleaning in dry dock.
- Frequent cleaning shortens the service life of most AFS (McClay et al., 2015).

Due to the environmental and economic impact of biofouling, the pressure on the maritime industry is increasing to implement a holistic and adaptive biofouling management, including fouling prevention of hull and niche areas. Since 2018, national regulations requiring an effective biofouling management are in force in California, Australia and New Zealand. The latter are calling for international standards at IMO level (MPI, 2018).

Proactive fouling prevention strategies under the heading of “Clean before you leave” or ”Clean before arrival” are getting more attention. Here, non-biocidal coatings with high abrasion resistance are frequently cleaned which withstand the impact of multiple cleaning and also reduce the adhesion of fouling organisms comparable to rubber-like foul release coatings (Watermann, 2019).

Due to its characteristics as semi-enclosed brackish water sea with shallow connection to the North Sea and heavy maritime traffic, the Baltic Sea already faces strong anthropogenic pressures and impact. Effects are beside others eutrophication, pollution with hazardous substances, and introduction of invasive species. Thus, this Best Practice Guide aims at providing information and guidance for effective biofouling management strategies suitable for the Baltic Sea Region on the basis of international and regional experiences and research.

2 WHAT IS BIOFOULING MANAGEMENT?

A holistic biofouling management covers the following aspects:

- Development of a ship-specific Biofouling Management Plan (BFMP)
- Keeping of a Biofouling Management Record Book (BFRB)
- Choice of an adequate, ship- and operation-specific Antifouling System (AFS)
- Performance monitoring
- In-water inspections (IWI) and maintenance, e.g. in-water cleaning (IWC)
- Dry docking, e.g. renewal of AFS

For each aspect, it has to be considered that decisions are based on the specific characteristics of the ship, its travel routes and operation. Tailored approaches are key for the development of an effective biofouling management. Here, we present recommendations for practices which have been developed worldwide and are applicable for the specific conditions of the Baltic Sea.

For practical reasons, all best practice recommendations are divided into “commercial shipping” (CS) and “leisure boating” (LB).

3 BEST PRACTICE RECOMMENDATIONS COMMERCIAL SHIPPING (CS)

Based on data from the COMPLETE project, practical experiences, studies, reports, results from research and development projects worldwide as well as the first results from the evaluation of the IMO Biofouling Guidelines, best practice recommendations which are suitable for application in the Baltic Sea have been identified. This section presents the best practice examples for commercial shipping according to the biofouling management aspects summarized above.

3.1 Ship-specific Biofouling Management Plan (BFMP) and Biofouling Record Book (BFRB)

A Biofouling Management Plan (BFMP), specific for each ship, is a description of the ship’s biofouling management strategy. Some countries and regions (Australia, New Zealand, and California) implemented regulations which require the submission of BFMPs prior to arrival. The requirements for a BFMP include a description of the vessel’s biofouling management strategy and should be consistent with the IMO Biofouling Guidelines. It includes a description of the practices and AFS used for hull and niche areas. Biofouling has to be managed using one or more practices that are appropriate for the ship and its operational profile as determined by the owner, operator, master, or person in charge of the ship. Management practices must be described in the BFMP and completed actions must be documented in the BFRB (SLCC, 2018).

Due to the recent situation in maritime transport, periods in ports or off ports at anchor occur more frequently. Thus, transport of species on wetted hull surfaces is not only influenced by the quality of the biofouling management but as well by the operational profile of the ship. Consequently, the BFMP should not only contain information of the fouling prevention measures of the vessels but as well of the voyages of the last months and the time at port or anchorage (SLCC, 2017).

Actually, there are several templates for BFMP and BFRB at hand. All of them are under scrutiny and permanent discussion to validate their applicability and usefulness. The most popular template is that of the IMO Biofouling Guidelines (see Annex IMO template) which served as a base for other templates. A more detailed template has been published by IMarEST (see table 5) for further discussions and improvement. The state of California has amended the BFMP and BFRB since January 2018 for all ships calling at Californian ports, and requires completing their template at least 24 hours prior to arrival (SLCC, 2017 and 2018, or https://misp.io/). A similar procedure is in force for Australian and New Zealand ports.

Mandatory requirements based on national legislation of Australia, New Zealand and California enhanced the awareness regarding the necessity of adequate biofouling management. In contrast to the handling of ballast management systems (BWMS), which is performed by a trained crew, compilation and implementation of BFMP and BFRB is up to fleet management and crew. To increase the number of ships and fleets with ship-specific BFMPs, harmonisation and mutual recognition of the existing templates e.g. IMO, California, Australia, New Zealand will increase the acceptance of these regulations by ship owners. Furthermore, a harmonised procedure or implementation of BFMPs and BFRB can ensure global access to ports for ship owners, especially on the background of permanent changing shipping routes. On the other hand, if more port authorities require state of the art BFMPs and BFRPs, implementation of adequate biofouling management will increase.

The effectivity of biofouling management increases with the synchronization of ship, its performance, and operation with the respective biofouling management. BFMP and BFRB must be tailor-made to operate in an economic, efficient, and environmentally friendly way Therefore, it is recommended to test the effectivity of the BFMP by performance monitoring and IWI, especially if travel routes change and speed or idle periods differ from the considerations made during the development of the original plan. In this context, precise keeping of the BFRB is essential, because this is the only possibility to check the effectivity of management retrospectively.

3.2 Choice of ship- and operation-specific Antifouling System (AFS)

As already mentioned above, fouling development is strongly favoured by a discrepancy between selected AFS and the predicted operation profile of the ship. Deviations from this profile with respect to service speed, activity level, days at harbour or idle periods, as well as traded waters favour the development of fouling. The consequence is reduced antifouling performance.

On the other hand, there is the risk of significant unnecessary input of biocides and other hazardous substances to the marine environment, if AFS are chosen which contain higher concentrations of active substances than needed for an effective biofouling management.

3.2.1 Current situation in the Baltic Sea

Based on recent data, the amount of antifouling paints applied on ships navigating the Baltic Sea is roughly estimated as 7,500 tonnes per year (Baltic Lines, 2016). For mass calculations of released antifouling compounds, most studies estimate a mean leaching rate of 4 – 5 µg/cm^2/day. In the MAMPEC model, which has been developed to calculate the biocide concentration released by AFS, a leaching rate of 4 µg/cm^2/day is used (van Hattum et al., 2006). Taking a leaching rate of 5 µg/cm^2/day and 42,000 ships navigating in the Baltic Sea per year as basis, the input of paint compounds would amount to 44.4 tonnes of biocides and poly- and monomeric compounds (Watermann & Eklund, 2019).

Among the ships sailing the Baltic Sea and originating from 122 countries, 3% (approx. 300 ships per year) are registered by flag states with poor performance in Port State inspections. They are listed in grey and black lists according to criteria of the Paris MoU (Grimvall and Larsson, 2014). A few of these flag states did not sign the IMO AFS Convention (International Convention on the Control of Harmful Anti-Fouling Systems on Ships), and therefore, can be expected to still have organotin antifouling paints as their active AFS. In the COMPLETE biofouling questionnaire there was a response from a ship-owner clearly stating the ongoing use of TBT.

Concerning the input of microplastics caused by biofouling management, information is scarce. Studies by Hansen et al. (2014) and Lassen et al. (2015) assume a polishing or erosion rate of antifouling paints from commercial vessels of 70 – 80%. During the erosion/polishing process, the polymeric backbone is dissolving in seawater, ideally hydrolysing down to monomeric substances, but also releasing polymeric paint flakes. The mean portion of solid antifouling paint particles is estimated as 55% (OECD, 2009). That means that of the 7,500 tonnes of antifouling paints on ships sailing the Baltic Sea per year, 4,125 tons of microplastics per year would be released as paint particles.

As a conclusion of the above mentioned aspects, all commercial vessels entering and leaving the Baltic Sea, and those operating in the Baltic Sea must select AFS compliant with the IMO AFS-Convention, meaning that the active AFS must not contain organotin compounds, and, from October 2026 on, cybutryn.

3.2.2 Recommendations for ships in the Baltic Sea

Ships operating exclusively in the Baltic Sea may use **AFS with moderate biocide content** (max 20% of copper) **and moderate leaching rates** with a maximum of 10 µg/cm^2/day. According to the recommendations of manufacturers, these are appropriate for moderate climate and moderate fouling pressure. The latter has been proven for the Baltic Sea within several research projects (Watermann & Dahlström, 2018).

Of course, the choice of AFS is dependent on the operation profile of the ships, taking into account activity level, service speed and traded areas.

Ships with high activity level and average speed of > 10 knots may also use biocide-free hard coatings in combination with IWC, or biocide-free foul release coatings (FRC).

FRC are a viable non-biocidal alternative to the above mentioned conventional biocidal antifouling coatings for the use in the Baltic Sea. These coatings rely on surface properties to mechanically preventing fouling, preferably by extruding non-persistent silicone oils, by degradable waxes, or polyethylene glycols to its surface, thus reducing both settlement and adhesion strength of biofouling. Present results, included in Annex 2 of the Biofouling Management Roadmap, show that a non-biocidal foul-release coating was more effective than a self-polishing copper antifouling coating, even under idle conditions. In the COMPLETE project, coated panels were deployed near the Port of Gothenburg, in a relatively high salinity and high fouling pressure area within the Baltic Sea Region (North Kattegat Sea, in the Outer Baltic). Visual inspections were carried out monthly. By the end of 1 year, the foul-release coating had, on average, about half the level of biofouling according to the US Navy fouling rating scale (Naval Sea System Command, 2006) compared to a conventional copper antifouling coating. These results represent a worst-case scenario for the Baltic Sea Region, due to the relatively high salinity (20-35 PSU) and high fouling pressure in this area, compared to lower salinity (<10 PSU) and lower fouling pressure in Central and North/Eastern Baltic.

In the Baltic Sea, ferries operating all around the year in the Baltic Proper use anticorrosive coatings without antifouling paints (**biocide-free hard coatings**), because conventional AFS are too soft to withstand the abrasion caused by drifting ice in winter time.

Ferries with pure anticorrosive paints have to be cleaned in-water during the fouling season from April to October weekly or bi-weekly by divers to maintain a clean hull.

An additional option is the cleaning called “grooming” of suitable antifouling paints or hard coatings as **proactive fouling prevention strategy**. Several diving companies offer IWC with tools connected to capture, filtration and waste management systems (see also 3.4 In-water cleaning).

In combination with effective and fast responding onboard performance systems, reactive cleaning in the biofilm stage is another option.

A further option for ships trading constantly between the Baltic Proper and adjacent freshwater areas like the lake Saimaa, is the use of **biocide-free self-polishing coatings** (SPCs) which are offered on the market for a range of operational profiles.

Table 1 and 2 provide a summary of the applicability of AFS based on the operational profile of the ship (area of the Baltic Sea and activity level of the ship), and an overview of biocide-free coatings.

Table 1: AFS according to operational profile

Region	Ship activity level	Coating recommendation	Cleaning strategy
Western and Southern Baltic Sea	High	-Biocide-free SPC for high activity level -Non-toxic hard coating in combination with cleaning -FRC except operation in wintertime	Proactive grooming in the biofilm stage
Western and Southern Baltic Sea	Moderate	-Biocide-free SPC for moderate activity level -Non-toxic hard coating in combination with cleaning	Proactive grooming in the biofilm stage
Western and Southern Baltic Sea	Low	-Biocide-free SPC for low activity level -FRC in combination with cleaning (not for operation in wintertime)	Regular cleaning on FRC
Kattegat to Central Baltic Sea	High	-Biocide-free SPC for high activity level -Non-toxic hard coating in combination with cleaning -FRC except operation in wintertime	Proactive grooming in the biofilm stage
Kattegat to Central Baltic Sea	Moderate	-Biocide-free SPC for moderate activity level -Non-toxic hard coating in combination with cleaning -FRC in combination with cleaning (not for operation in wintertime)	Grooming, weekly grooming in the fouling season
Kattegat to Central Baltic Sea	Low	-Biocide-free SPC for low activity level -Non-toxic hard coating in combination with cleaning -FRC in combination with cleaning (not for operation in wintertime)	Grooming, weekly grooming in the fouling season
Eastern and Northern part of the Baltic Sea	High, moderate and low	-Non-toxic hard coating in combination with cleaning -FRC except operation in wintertime	grooming, weekly grooming in the fouling season

Table 2: Overview of biocide-free coatings for ships in the Baltic Sea

Coating	Techniques	Application	Benefits	Risks	Costs	Availability
Hard coatings in combination with IWC	Epoxy-silicone hybrids, abrasion resistant with foul release properties	Hull and cleanable niches	Long service life, durable, negligible input of paint flakes	Must be cleaned pro-actively in biofilm stage	Compara-ble to current antifouling paints	Several products on the market
FRCs, cleanable	Silicone based rubber-like polymers	Hull and cleanable niches	Long service life, durable, negligible input of paint flakes	Must be protected from mechanical impact, not suitable for ice conditions	Double price compared to current antifouling paints	Several products on the market
Biocide-free SPCs	Hydrolyzing polymer backbone and additives	Hull, exposed to water flow, not for niches	Smooth hull without release of biocides	Efficacy strongly depends on activity level and service speed. Continuous input of polymeric backbone	Compara-ble to current antifouling paints	Several products on the market tailored for different vessel types

3.2.3 Niche areas

Special attention has to be paid to the niches of ships, which are especially prone to fouling. Niches are not contributing to enhanced drag or increased fuel consumption. This is the reason why operators may neglect them in case fouling management is focused only on performance (Davidson et al. 2016). However, the results of the COMPLETE biofouling questionnaire showed that when an AFS is applied, niches are also considered.

Common niche areas are:

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

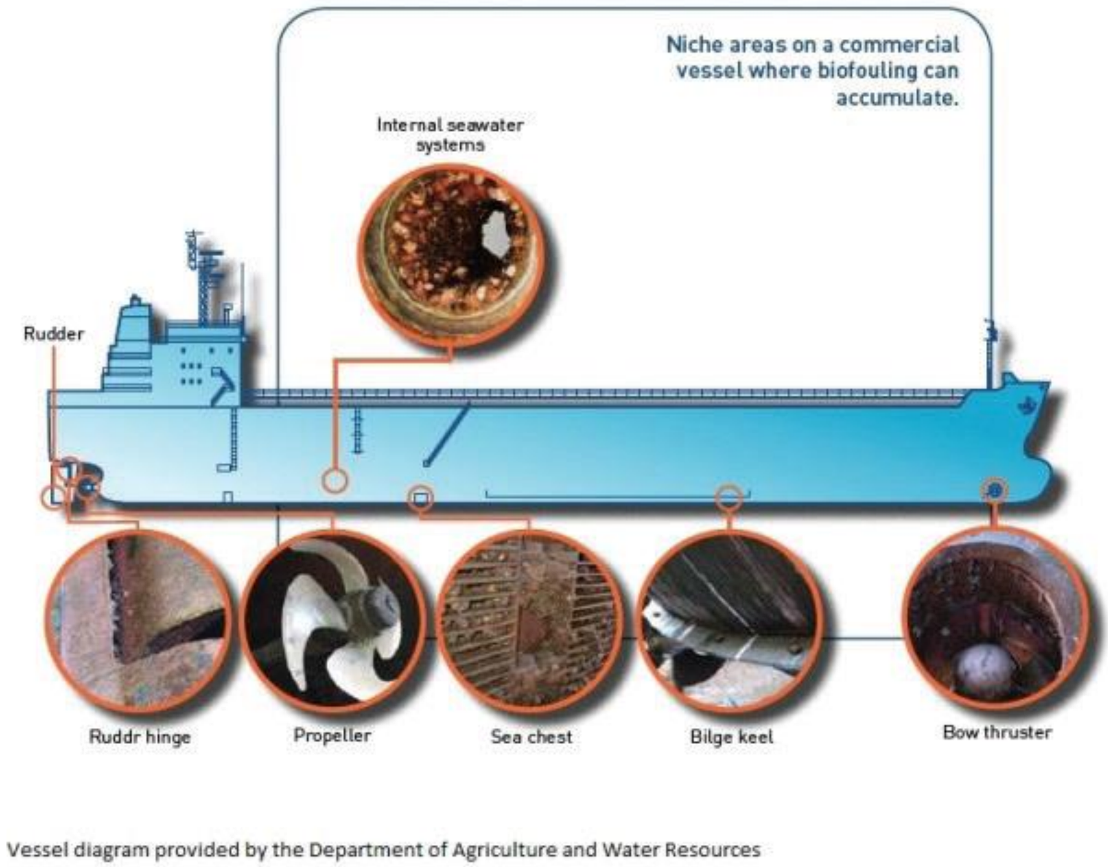

Fig. 1: Main niche areas on commercial vessels (MPI, 2018)

As niches are hot-spots of fouling, biofouling management must include effective fouling prevention techniques for these areas. Heat treatment of the cooling system, internal pipes and sea chest is an effective biocide-free technique which is offered for different dimensions of the internal system. In contrast to copper based anodes installed in the cooling systems, it can be regarded as the best environmental technique (Lewis et al. 2018).

Niche areas, for which the heat treatment cannot be used, have to be cleaned by divers, but accessibility of niche areas for cleaning is often difficult and has to be improved in newbuildings (see 3.4).

3.2.4 Performance monitoring

A powerful tool for biofouling management is the use of onboard performance systems, which deliver data on increased drag or increased fuel consumption at a given speed. Several shipping lines use their own performance systems and a couple of those are available on the market. The main data base consists of collecting and transmitting data on speed, fuel consumption, winds and currents to calculate the performance and get information on additional friction (Corradu et al. 2019).These systems are currently under validation as well as the use of the ISO Standard 190 30. This standard is called "Ships and marine technology — Measurement of changes in hull and propeller performance". It defines a set of performance indicators for hull and propeller maintenance, repair and retrofit activities. The general principles and performance indicators are applicable to all ship types driven by conventional fixed pitch propellers.

Irrespective of the performance system in use, data of increased friction can be used for biofouling management purposes and for the decision of the right time for inspections and reactive cleaning.

3.3 In-water cleaning (IWC)

As no AFS can totally avoid biofouling, proactive or reactive IWC is a commonly applied component of biofouling management. In order to perform IWC in a sustainable manner, use of non-abrasive cleaning techniques, as well as capture and filtration of removed fouling in combination with waste disposal on land is crucial. Currently, the majority of cleaning is performed on biocidal antifouling paints, which are present on approx. 95% of commercial ships and leisure boats (Yebra et al., 2004; INTERTANKO, 2016). Biocidal antifouling paints are not designed for cleaning. They are too soft and the impact of cleaning removes, beside the attached fouling organisms, approx. 20 – 30 µm of the upper paint layers. During cleaning, immediately undissolved paint particles and dissolved along with undissolved biocides are released into the water. This has multiple additional implications:

- Mechanical removal of existing paint layers reduces the service life of the AFS and thereby the docking interval
- The impact of cleaning tools depends on the amount, composition and adherence of the fouling. The heavier fouling is, the higher the effort necessary to remove it. If the AFS is completely removed or damaged, these hull areas are prone to new settlements.
- Macrofouling communities contain propagules of algae and barnacles which are hard to capture 100%. Viable spores and larvae might invade ports and coastal areas (Woods et al., 2012; IMO, 2019; Scianni & Georgiades, 2019).

To avoid the problems summarized above, various countries and maritime organisations are working on standards and the development of best environmental practice for IWC. In table 4, examples of different approaches are shown. It is obvious that regarding IWC in the Baltic Sea either no regulations exist or existing regulations are not sufficient to minimize a potential impact. When a plume of copper pigment is released during cleaning, it is too late to stop cleaning. Therefore, precautionary assessment of the environmental risk of each IWC activity is essential as basis for granting permissions for IWC.

In addition, there are practical obstacles to consider. In case of heavy fouling, damage of the AFS is almost unavoidable as divers have to increase the pressure to remove the fouling. The results can regularly be inspected on ships previously cleaned in the dockyard: Some areas are free of fouling, some areas still exhibit fouling, on others the AFS has been removed down to the corrosion protective coating.

Actual considerations and discussions to overcome these problems can be summarized as follows:

IWC on biocidal antifouling paints should best be performed by:

- Pre- and post-cleaning inspections
- To avoid damage of the AFS, a reference area on the hull should be selected to test the cleaning tools with respect to efficacy, collection and measurement of undissolved paint particles and dissolved/undissolved paint biocides.
- More extensively developed fouling should be cleaned in dry dock.

- Capture of the removed fouling organisms should be mandatory and treatment by filtration shall use mesh sizes of at least 10 µm which is technically feasible.
- Reliable and validated reports on cleaning test on reference areas including measurement results of accredited laboratories as well as pre- and post-inspections of the hull and niches shall be submitted to the operator (Oliveira & Granhag, 2020)

IWC or hull cleaning in dry dock without proper capture of biofouling waste may contribute to the spread of invasive species (table 3) as the survival of removed fouling organisms might be high (Woods et al. 2012).

Table 3: Survival rate of removed fouling organisms during IWC and dry-dock cleaning

Survival rate of removed fouling organisms %

	Dry dock	in-water
• All organisms	37.5 ± 8.6	29.2 ± 7.2
• Algae	71.1 ± 17.1	66.7 ± 16.7
• Anenomes	0	90.5 ± 4.8
• Ascidians	41.9 ± 17.1	95.1 ± 9.4
• Barnacles	33.7 ± 12.2	15.8 ± 6
• Bivalves	52 ± 16	81.7 ± 9.2
• Bryozoans	34.6 ± 17.3	51.4 ± 9.5
• Polychaetes	12.3 ±2	5.5 ± 2.9
• Sponges	0	90.7 ± 6.5

Woods et al. 2012

IWC and dry dock cleaning without effective capture and filtration systems may also lead to input of biocides and polymers (Watermann, 2019).

In tables 4 and 5, best practice IWC techniques are listed, which are available through cleaning companies in the Baltic Sea (https://balticcomplete.com/maps and BSH Biofouling Management Database). Two techniques include capture of the removed fouling and removed paint particles. The ship-based technique operates without any capture, claiming that since this technique is suitable for biofilms only, no capture is provided. But, in order to avoid species introduction, capture is necessary as even biofilm may contain NIS.

For the Baltic Sea, which is already heavily polluted by hazardous substances, an AFS should be selected which is suitable for cleaning without releasing polymers and biocides. The coatings most suitable for cleaning can be found in table 2.

Table 4: Overview of IWC methods for ships

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

Table 5: Capture and treatment of biofouling waste from IWC

Method	Techniques	Application	Benefit	Risk	Costs	Availability
Capture and filtration system connected with cleaning device	Vacuum application for capture and use of sieves with different mesh sizes, filtrate disposed on land	Hull, propeller and niches	One system with perfect connection, effective capture and filtration	Must be reliable in all types of water, including harbour water with high content of suspended matter	Rel. high	Few companies operating in the Baltic Sea
Capture, filtration, and collection in separate units (barges, tankers) for treatment of effluents	Use of sieves with different mesh sizes, filtrate disposed on land	Hull and propeller	Effective capture and filtration, high capacity	barge or tanker have to be towed alongside, special areas in ports have to be offered	Rel. high	Only one company operating in the Baltic Sea
After separate collection, filtration and treatment in BWMS	Filtration and UV treatment, filtrate disposed on land	Hull, propeller and niches depending on cleaning tool	Type approved BWMS	Few risks due to approved techniques	Costs in addition to cleaning 10 €/m^3	Few companies operate in the Baltic Sea
After separate collection treatment in dockyard facilities on land	Filtration with sieves and UV treatment	Hull, propeller and niches depending on cleaning tool	Approved techniques for dockyard waste water treatment	Connectivity with cleaning tools, risk low when pumped out of barges or tankers	50 – 200 €/m^3	Several dockyards along the Baltic Sea coast

If IWC is combined with capture and filtration systems, removed fouling organisms and paint particles are waste which has to be disposed on land. In most countries, this waste is classified as hazardous waste, because it contains a multitude of paint-bound biocides, and other toxic substances like additives and polymers. This concerns waste from cleaning on all biocidal antifouling paints.

Furthermore, it has to be taken into account that dissolved biocides **are not retained** and thus, released into the harbour basin during cleaning. Therefore, the best environmental management practice is the cleaning on abrasion resistant, non-biocidal hard coatings in combination with capture and filtration of the cleaned material and subsequent waste treatment and disposal.

3.3.1 Permits for IWC

Due to the common practice of IWC off the coast, a couple of countries developed guidelines and standards for IWC.

Currently, no harmonized procedure exists for the Baltic Sea. COMPLETE PLUS, the next phase of the COMPLETE project, aims at developing and drafting a scheme for granting permissions for IWC in the Baltic Sea as basis for discussions at HELCOM level.

3.3.2 Niches

Divers are able to clean all **externally accessible** niche areas like sea chests, thrusters, stabilizers etc. with hand held lances using hydro-jetting. Nevertheless, capture of removed fouling is challenging.

Precondition for the inspection and cleaning of niches is their accessibility which is up to now not in the focus of shipbuilders. Diving companies therefore claim to facilitate the accessibility of all niches for inspection and cleaning in new-built ships.

Recommendations for a better accessibility of niches are:

1. Easy access to rudder pintle. If the area is covered by a door, it should be hinged and should have sufficient diver access (minimum 400 mm diameter). Securing bolts, which can easily be removed and reinstalled in-water should be used
2. For tail-shaft wear down measurements, an easy access by holes, large enough for the diver's hands and equipment should be established. The minimum size for hand holes is around 200mm diameter
3. Securing of all sea chest gratings by bolts only and hinges for all gratings
4. Marking and sizing of all securing bolts
5. Counting and sizing of all drain holes

Finally, prior to launching a newbuilding or after maintenance in dry dock, photographs of all external apertures and fittings such as sea chest arrangements, overboards, transducers and thrusters etc. should be taken and be kept on board. All niche areas should have a clear numbering system so that divers can easily identify them in the future. Information should be available on board the vessel to be used when required for diving operations.

3.4 International recommendations for biofouling management

Up to now, several templates, guidelines and recommendations for biofouling management have been developed.

Their basic strategies can be summarized as:

- Implementation of IMO biofouling guidelines with ship-specific BFMP and BFRB and submission of documentation prior to arrival in ports of countries with regulation in place
- Biofouling management by proactive cleaning of hull and niches on biofilm stage ideally with capture of removed fouling (Proactive in-water treatment e.g by heat application (PIT), Proactive in-water cleaning (PIC), Proactive in-water cleaning and capture (PICC), 'Clean Before You Leave' documentation by BFRB
- Biofouling management by reactive cleaning (Reactive in-water treatment e.g by heat application (RIT), Reactive in-water cleaning (RIC), Reactive in-water cleaning and capture (RICC)) , 'Clean Before Arrival', documentation by BFRB
- Installation of performance system onboard, as in-house technology of shipping line or external provider.

In addition to these biofouling management recommendations, the risk of species introduction by ships can be estimated based on:

- Their duration of stay in ports or coast line.
- Their operational profile (in case of the Baltic Sea: operating exclusively in the Baltic Proper like most ferries, or entering and leaving the Baltic Sea in regular or irregular intervals like all cargo ships).

(modified after MPI, 2018; Scianni & Georgiades, 2019)

4 BEST PRACTICE RECOMMENDATIONS LEISURE BOATING (LB)

Actively minimizing the biofouling of leisure boats can greatly reduce the risk of spreading invasive species and can also improve fuel efficiency, operating speeds and manoeuvrability (IMO, 2012).

Therefore, the IMO developed the Guidance for minimizing the transfer of invasive aquatic species as biofouling (hull fouling) for recreational craft for owners and operators of recreational craft less than 24 metres in length. All boats can potentially transfer harmful aquatic organisms, even a trailered boat that is normally kept out of the water can act as vector (Johnson et al. 2012).

In contrast to commercial ships, leisure boats stay most of the time when they are in water fixed at berth. The majority of boaters in the Baltic Sea are day-sailors, and a minority are so called 'blue-water' sailors who are moving across the whole Baltic Sea, leaving the region or coming back from other biogeographic regions (Martin et al. 2019). Spread of species can even occur when boats are sold. Marine organisms might hide in humid niches where they survive for several weeks. A similar problem can result from motor boats which are transported by trailers from one water body to another. If these boats are not thoroughly cleaned before being moved on a trailer, organisms can be transported (Dalton & Cottrell, 2013). The best documented example is the transport of zebra and quagga mussels by motorboats from central Europe to the Baltic Sea region including adjacent freshwater areas (De Ventura et al. 2016).

Thus, the effective biofouling management of leisure boats to avoid introduction and spread of species is dependent on the operational profile of the boat. It is up to the boat owners and marinas to implement strict rules of cleaning boat and niche areas before each transport (Mueting & Gerstenberger, 2011). The European code of conduct on recreational boating and invasive alien species is characterized by the terms 'Check - Clean - Dry' which is propagated by the European Boating Association (EBA, 2016).

Due to the extended periods moored at berth, all leisure boats have some biofouling, even if recently cleaned or treated with AFS. The development of biofouling is influenced by factors such as:

- Knowledge of type, age and condition of AFS and hull cleaning practices
- Operating profile, including speeds, time underway compared with time moored or anchored
- Water temperature, biofouling pressure and where the craft is normally kept (e.g. on land, in a marina or on an estuarine mooring)
- Visited marinas and biogeographic regions
- Design and construction, particularly areas that are more susceptible to biofouling (e.g. rudders, propellers and propeller shafts)
- The awareness of the problem by boat owner and marina

4.1 Boat-specific Biofouling Management Plan (BFMP) and Biofouling Record Book (BFRB)

A first step to improve biofouling management of leisure boats is the recommendation to have a certificate on board which delivers information about the actual AFS (specification, age and condition). In contrast to the IMO Guidance, the certificate should already be applied to boats > 8m, which is the common length of boat around the Baltic Sea. In addition, receipts of cleaning actions and receipts or documentation by marinas on the cleaning before overland transport should be indicated in the log-book, which has to be present on each boat sailing coastal waters as appropriate surrogate to the BFRB.

Since several years, an International Certificate for Operators of Pleasure Crafts is under discussion (ECE, 2010). The EBA considers that the standards provide a reasonable and appropriate level of competence for sailing in recreational boats with due regard to the safety of navigation and crew, and the protection of the environment. The EBA urges governments to adopt this standard. It may be worth to include this initiative for the development of an international certificate which covers demands of safety, biosecurity and environmental behaviour (EBA, 2019).

4.2 Choice of boat- and operation-specific Antifouling System (AFS)

For leisure boats mainly located in the Baltic Sea, a biocide-free AFS or an AFS appropriate for the regional fouling pressure in combination with good maintenance are the best ways for preventing biofouling accumulation (Lindgren et al. 2018; Lagerström et al. 2020). In addition, regularly operating boats between marine and fresh waters may help to reduce the accumulation of biofouling, because many marine fouling species do not easily survive in fresh or brackish water and vice versa. Nevertheless, interviews with boat-owners revealed that the recommendation to use appropriate AFS according to fouling pressure and region requirement may meet some serious obstacles:

- The choice of antifouling paint and biofouling management of leisure boats is not driven by economic reasons and rational considerations but often by tradition.
- Most boat owners have no exact knowledge of their AFS. The active layer may be known but applied in excess, the old layers are often unknown.
- Apart of speed boats, fouling of niches creates no adverse effect on speed and manoeuvrability and is thus, often unconsidered.

(Martin et al., 2018; Watermann & Dahlström, 2018; Bergmann et al., 2019).

Application of an inappropriate AFS may result in the accumulation of biofouling or unnecessary release of biocides into the sea. Therefore, following state of the art recommendation is an essential contribution to improve the environmental health of the Baltic Sea.

The background for the choice of the appropriate AFS is the operational profile of the boat and the visited waters respectively their fouling pressure. In-line with the legislation implemented e.g. in Sweden (Fig. 2) is the use of AFS with:

- higher copper content in the Western Baltic Sea,
- low copper content in the Central, and
- biocide-free in the Eastern part of the Baltic Sea and in freshwater.

The salinity of the Baltic Sea decreases from West to East. Along this gradient, the fouling pressure decreases. Hard-shelled calcareous fouling can be found in the Western and Southern Baltic Sea, whereas in the Central and the Eastern part fouling is composed of soft organism and more typical for freshwater (Lagerström et al. 2020).

Nevertheless, data showed that many boat owners apply excessive paint layers despite paint manufacturer's recommendations to repaint only on hull areas with fouling development (Eklund & Watermann, 2018). To avoid the use of AFS with excess copper, recommendations based on exposure trials around the Baltic Sea have been outlined:

- From **Kattegat to the Central Baltic Sea** AFS are effective with copper release rates of 5°µg/cm^2/ day. In biofouling hot spot areas the efficacy can be enhanced by zinc oxide (Lindgren et al. 2018; Wrange et al. 2020).
- In the **Eastern part of the Baltic Sea (East coast of Sweden)** antifouling paints with leaching rates of 2 µg/cm^2/ day shall be effective.
- In the **Eastern and Northern part of the Baltic Sea and adjacent freshwater areas** biocide-free coatings in combination with cleaning effectively prevent fouling. Suitable coatings include silicone-based foul release coatings and epoxy-silicone hybrids as hard, abrasion resistant coatings.

However, biocide-free foul release coatings (FRCs) have been shown to be effective in the whole Baltic Sea (Waterman & Dahlström, 2018). Table 6 provides a summary of AFS for leisure boats.

As in ships, niche areas of leisure boats are hot spots of fouling and deserve special attention.

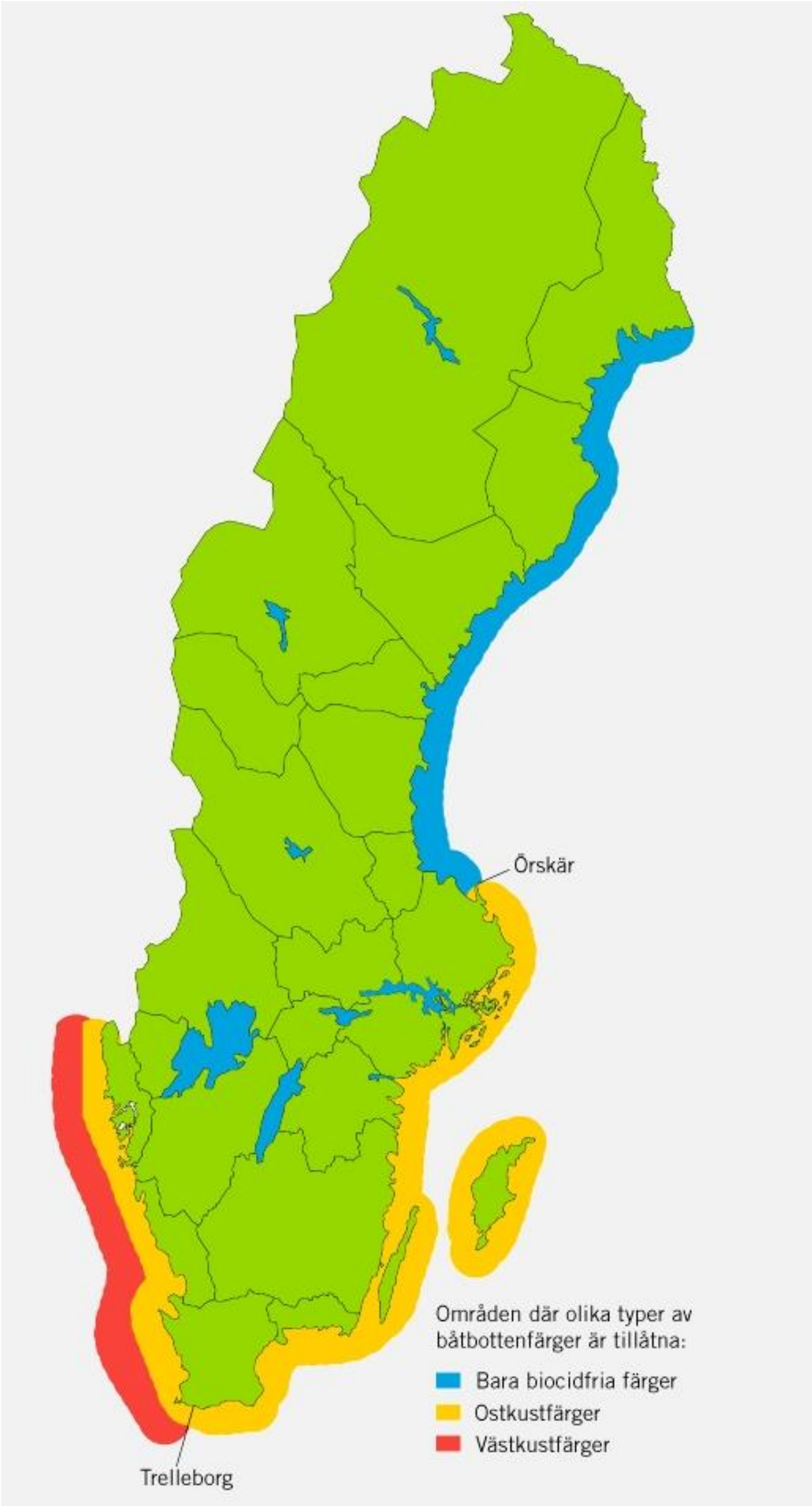

Fig. 2: Regional authorization for application and use of AFS along the Swedish Coast, Red: Biocidal AFS with high copper content, yellow: Biocidal AFS with low copper consent and blue: biocide-free AFS. Source: www.kemi.se/bekampningsmedel/biocidprodukter/vanliga-typer-av-biocidprodukter/batbottenfarger--om-du-maste-mala

Table 6: Overview of AFS for leisure boats in the Baltic Sea

Coating	Techniques	Application	Benefits	Risks	Costs	Availability
Hard coatings in combination with IWC	Epoxy-silicone hybrids, abrasion resistant with foul release properties	Hull and cleanable niches	Long service life, durable, negligible input of paint flakes	Must be cleaned pro-actively in biofilm stage	Comparable to current AFS	Several products on the market
Foul release coatings (FRC)	Silicone based rubber-like polymers	Hull and cleanable niches	Long service life, durable, negligible input of paint flakes	Must be protected from mechanical impact, not suitable for ice conditions	Double price compared to current AFS	Several products on the market
Biocide-free SPCs	Hydrolyzing paint matrix without biocide release	Hull	Smooth hull without release of biocides	Efficacy strongly connected with activity level, and speed	Comparable to current AFS	Several products on the EU-market tailored for different boat types
AFS with copper release of 5µg/cm^2 per day	Hydrolyzing paint matrix and biocide release	Hull and niches	If boat is active, fouling prevention	Input of biocides	Varying costs depending on copper content	Many products on the market

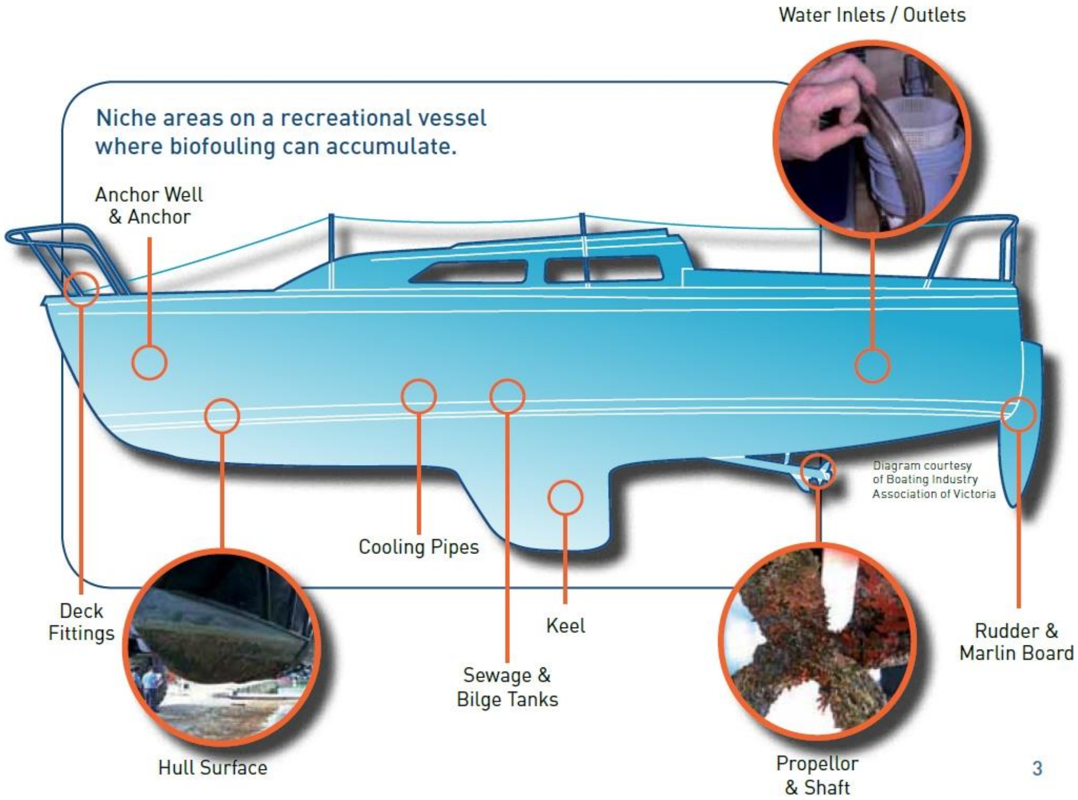

Fig. 3: Niche areas of leisure boats (MPI, 2018)

4.3 Cleaning of leisure boats

4.3.1 Current situation in the Baltic Sea

As mentioned above, maintenance and cleaning are essential aspects to consider for an effective biofouling management of leisure boats. If cleaning is not performed in an environmentally and sustainably manner, it might pose risks for the Baltic Sea environment by release of antifouling paint particles, biocides, polymeric backbone, and invasive species (Bighiu et al. 2017; Martin et al. 2018, 2019). It is common practice to clean the hull at the end of the season by high-pressure washing, often without necessary protection measures and collection of waste water.

Despite their ban on small boats in the EU in 1989, organotin compounds (OTCs) are still being released into the environment e.g. due to their presence in historic paint layers on leisure boats. Paint samples scraped from leisure boats from three countries around the Baltic Sea were analyzed for total tin (Sn) and OTCs (Lagerström et al. 2017). The hull paint samples had high tin concentrations and results showed that tributyltin (TBT) was detected in all samples with concentrations as high as 4.7 g (as Sn)/kg paint. TBT was however not always the major OTC. Triphenyltin (TPhT), which is as hazardous as TBT, was present in many samples from Finland.

Ytreberg et al. (2016) published results based on a new developed XRF-method which revealed that over 10% of Swedish leisure boats (n = 686) contained >400 mg/cm^2 of tin in their antifouling coating layers. For comparison, one layer (40 mm dry film) of a TBT-paint equals ~ 800 mg Sn/cm^2. Even though the XRF analysis did not provide any information on the speciation of tin, the high concentrations indicated that these leisure boats still had old, remaining OTC coatings present on their hull. The risk for leaching of organotin compounds into the environment arises during maintenance work such as scraping, blasting and essentially during high pressure hosing activities (Koroschetz & Soler, 2018).

Moreover, high loads of copper were detected even on boats sailing in freshwater, despite the more than 20 years old ban in Sweden, Denmark and Finland.

The use of copper-based AFS contribute to the contamination of marina soils and adjacent marine sediments (Eklund et al. 2010; Eklund & Eklund, 2012), mainly due to improper maintenance practice. In addition, AFS with copper as the main biocide are used in excess on leisure boats leading to an unnecessary input during service (Eklund & Watermann, 2018). The application of AFS with copper contents ranging from 10 -30% on leisure boats around the Baltic Sea is estimated as 400 t/y (Watermann & Eklund, 2019).

Bighiu et al. (2017) revealed in biofilm waste from boat hulls coated with biocidal AFS a content of 28 g copper/kg dw and 171 g zinc/kg dw. Together with the waste water, biofilms are washed to the boatyard soil or directly into the adjacent water bodies. Apart of essential inputs of antifouling biocides and paint particles, leisure boats may harbour rich macrofouling communities, when they are not moved and/or the antifouling fails (Fig. 5).

A number of studies on the input of microplastics from cleaning of leisure boats have been performed in the Baltic Sea and the Norwegian coast (Magnusson et al. 2017; Lassen et al. 2015; Sundt et al. 2014). Obviously, the degree of protection measures influences the input of paint particles into the adjacent water bodies significantly. There is a multitude of studies indicating that in leisure boat harbours the retention and collection of antifouling paint particles originating from scraping, dry sanding, and high pressure-washing outside of washing areas is insufficient (Eklund et al. 2010, Eklund & Eklund, 2012; Eklund et al. 2014b, Lagerström et al. 2017).

4.3.2 Recommendations for cleaning

To minimize environmental risks posed by cleaning of leisure boats, the following **recommendations** should be considered:

The cleaning practice for leisure boats must be regarded during service in water and out of water as an interim cleaning in the middle of the season or before moving the boat to another water region via land (table 7). Along the Swedish East coast numerous cleaning stations (approx. 20 stations) offer IWC with brushes and capture of fouling by underwater floating foils beneath the stations. A crucial aspect is the type of coating on which cleaning is allowed. Actually, some Swedish municipalities allow IWC on boats with antifouling paints older than 12 months, which cannot be regarded as recommendable practice. In other countries like Germany IWC on biocidal antifouling paints is not permitted but permits for cleaning on biocide-free paints can be applied for at lower water authorities. The best practice is cleaning on abrasion resistant, non-biocidal hard coatings which release no biocides during the cleaning and where the abrasion of paint flakes is minimal (Watermann & Eklund, 2019). Table 7 summarizes cleaning methods for leisure boats.

Niche areas of leisure boats are of high importance for the transfer of species as motorboats and to a lesser degree sailing boats are trailered for weekends or summer holidays from freshwater lakes to the Baltic Sea and vice versa. Apart of the cleaning effect by varying between freshwater and marine waters, brackish water organisms like Zebra- and Quagga mussels can be transported and survive in a wider range of salinities. As some niche areas on leisure boats are hard to access, the best technique to remove fouling of these areas turned out to be high pressure-jetting with hot water with duration at each critical point of several seconds. Leisure boats have no facilities to enclose the internal cooling system. For the treatment of the internal cooling system, mobile tools to inject hot water have been developed and may be offered on the market in the near future (Cahill et al., 2019a and b).

Table 7: Best cleaning and fouling prevention practices for hull and niches of leisure boats

Method	Techniques	Application	Benefits	Risks	Costs	Availability
Stationary IWC	Rotating brushes, capture by underwater foil	Hull	Smooth hull without fouling	Only effective when cleaning in biofilm stage, niches not covered	Approx. 10-13 €/m boat length	Stations in Sweden and in Finland
HP-Jetting with capture and treatment	Hot water >60°C for 5 sec.	Hull and niches	Cleaning of niches possible	Too fast, too short application, using cold water	Approx. 10 €/h	Nearly every marina with slip way and hp-washer
Hp-jetting with capture and filtration	Hp-jetting with or without rotating nozzles	Hull and niches	Cleaning of niches possible	Risk of overspray	Approx. 20 – 40 €	Boat must be lifted out of water and the area must be available
Enwrapping foils to hamper the settlement of fouling organisms	Rough or smooth foils wrapped around the hull at berth	Hull and niches	Easy to apply	Only applicable in boxes	Approx. 1- 15 € /m boat length	Available on the market around the Baltic Sea
Inflatable hull enclosures to hamper the settlement of fouling organisms	Inflatable foil enclosed around the hull	Hull and niches	Easy to apply	Only applicable in boxes	250.00 €/m boat length	Internet order

Further recommendations can be also found in the COMPLETE report "Recommendations for mitigating potential risks related to biofouling of leisure boats" compiled by Keep the Archipelago Tidy Finland (2020).

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