RECOMMENDATION ON HULL CLEANING PRACTICE TO REDUCE DISCHARGE OF SUBSTANCES FROM ANTIFOULING PAINT

Lena Granhag and Dinis Oliveira
Chalmers University of Technology

2021

CONTENT

CONTENT 1

Summary 1

The biofouling problem 2

Attachment strength of biofouling 2

Methods for cleaning of coatings in laboratory and field 4

Cleaning of antifouling coatings with waterjet in field 4

Cleaning of coatings with brushes in laboratory 5

Cleaning of coatings with brushes in field tests 6

Results from cleaning of coatings in lab and field 7

Cleaning of antifouling coatings with waterjet in field 7

Cleaning of coatings with brushes in laboratory 7

Cleaning of coatings with brushes in field tests 7

Discussion and further development 9

Cleaning with waterjet in field 9

Test with brushes in lab and field 9

Conclusions 10

Acknowledgement 11

Further reading 11

References 11

SUMMARY

This report has been developed as a part of the COMPLETE project (*Completing management options in the Baltic Sea Region to reduce risk of invasive species introduction by shipping*) funded by the Interreg Baltic Sea Region Programme.

This report contains recommendations for hull cleaning practice to reduce the removal and discharge of substances in the case when cleaning is conducted on antifouling paints. "Substances" does here refer both to biocides leaking from the coating and paint particles/flakes released during cleaning. Todays antifouling paints are based on different mechanisms to deter fouling were the two most commonly used types are biocidal paints and foul-release paints. The biocidal paints release biocides, which are toxic to the biofouling, especially the invertebrate larval stages and thereby hinder their settlement on the surface. The most widely used substances in biocidal paints today are copper compounds. The foul-release paint instead act to limit the biofouling growth by its surface characteristics, where a "slippery" surface reduces the attachment strength of the fouling organisms.

The overall guidance for choosing antifouling solutions in the Baltic Sea needs to be based on several factors like biofouling pressure and operation profile of the ship or boat, as discussed for example in the COMPLETE project publications *Guide on best practices of biofouling management in the Baltic Sea* (Watermann et al. 2020), *Recommendations for mitigating potential risks related to biofouling of leisure boats* (Keep The Archipelago Tidy 2020) and Lagerström et al. (2020).

In general eroding or self-polishing antifouling systems are not designed to be cleaned, and agressive cleaning on this type of paint can cause damage of the antifouling system with high release of biocides and paint flakes (Earley et al. 2014, Davidson et al. 2016, Watermann and Eklund, 2019). In several Baltic Sea countries cleaning on biocidal paints is restricted, see *In-water cleaning (IWC) of boats and ships in the Baltic Sea region -current procedures and future needs* (Krutwa et al. 2020). However, as cleaning on biocidal paints are performed globally today, and information on optimized cleaning forces are lacking, biocide-containing paints were included in the conducted tests.

The tests include some common combinations of paint and cleaning methods or devices in use today. Based on the tests we recommend gentle cleaning to remove biofouling from ship or boat hull. When minimal forces are used in the cleaning device it has as little impact on the paint as possible. Cleaning need to be conducted frequently (monthly) to keep the biofouling at a low level.

THE BIOFOULING PROBLEM

On the ship and boat hull there are many different types of biofouling organisms present, for example microalgae, macroalgae, barnacles, tubeworms and mussels. The attachment strength varies between different fouling organisms. From the perspective of invasive species introductions it is important to keep the surfaces clean of larger stages of fouling or hard fouling, as these stages have the ability to reproduce and release new spores or larvae.

Attachment strength of biofouling

The attachment strength of biofouling organisms to a surface will vary both with type and stage of organism as well as with the surface and paint characteristics.

Soft biofouling like microalgae (*Amphora coffeaeformis* and *Navicula* spp.) and sporelings of macroalgae (*Ulva linza*, *Ectocarpus* sp., *Hincksia secunda*) need a shear stress of 10-280 Pa for detachment from foul-release paint (Figure 1).

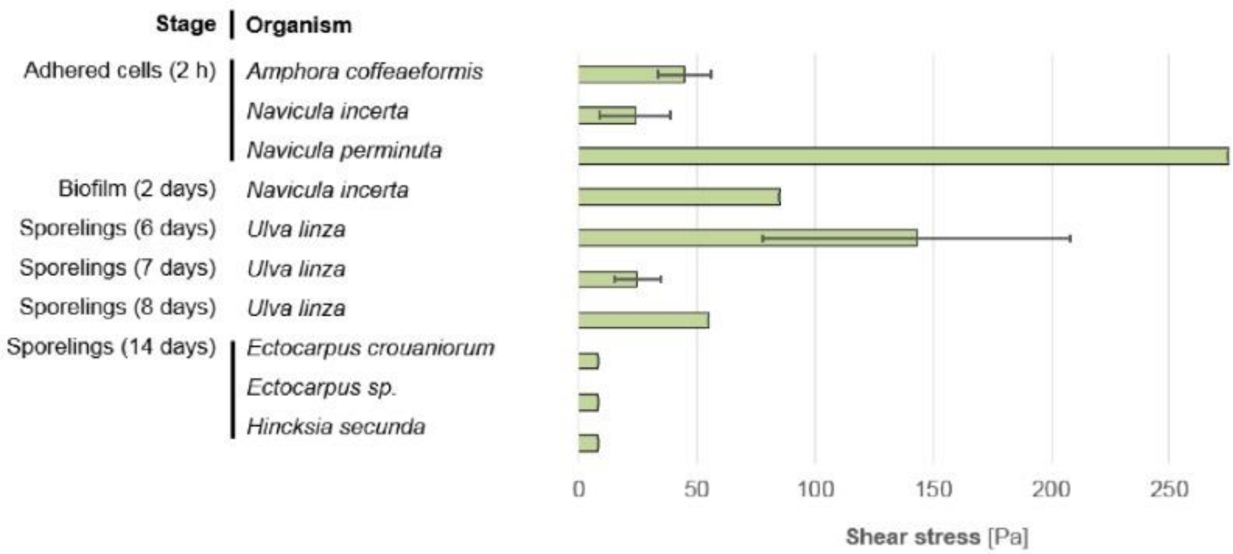

Figure 1. Forces needed for removal of microalgae and macroalgal sporelings from foul-release paint (based on literature values, graph from Oliveira and Granhag 2016).

To remove hard fouling (barnacles) from hard (epoxy) paint forces of 0.2-3.3 MPa was needed while to remove barnacles from self polishing coatings forces of 0.5 MPa was needed (Figure 2).

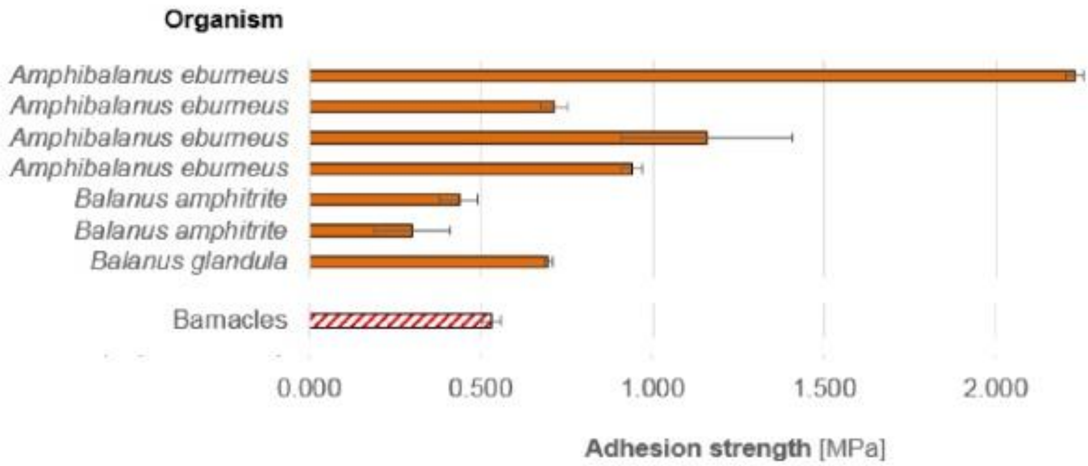

Figure 2. Forces needed for removal of different barnacles from hard paint (red) and self polishing coating (striped) (based on literature values, graph from Oliveira and Granhag 2016).

Although the data of attachment strength for different fouling organisms is rather scarce and with few data for removal from self polishing coatings, it could from the literature review by Oliveira and Granhag (2016) be seen that the forces needed for removal will be dependent on the combination of organism and paint type.

METHODS FOR CLEANING OF COATINGS IN LABORATORY AND FIELD

Cleaning of antifouling coatings with waterjet in field

A year-long field study was conducted in Saltholmen Marina, outside port of Gothenburg (Figure 3) on the Swedish west coast, to investigate impact of cleaning forces and frequency on biofouling at two different coating types. Panels coated with biocidal antifouling coating and silicone-based foul-release coating were deployed in April 2018 and cleaned with monthly or bi-monthly intervals (details in Oliveira and Granhag 2020). The cleaning device used is a miniaturized waterjet for operation in water, giving a maximum wall shear stress of approx. 1.3 kPa, with parameters described in Oliveira et al. 2019.

Figure 3. Saltholmen Marina outside Port of Gothenburg. Field site for cleaning of panels with waterjet and brush system.

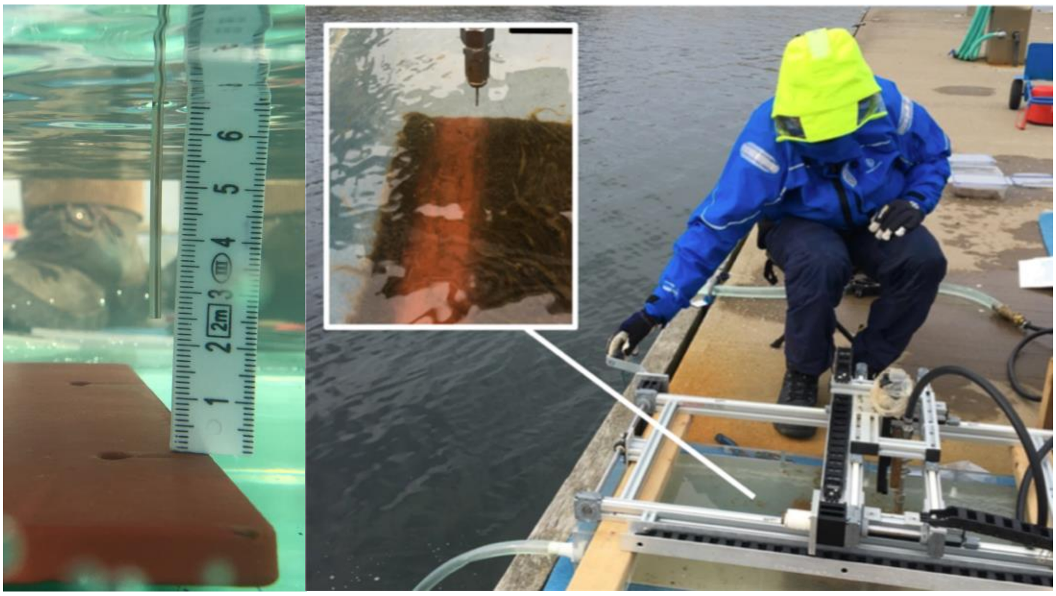

Figure 4. Waterjet device used in field experiment, waterjet nozzle (detailed figure to the left).

The height of the waterjet nozzle was together with the water pressure adjusted before each cleaning (Figure 4). Data of fouling rate on panel was taken before and after cleaning runs according to the US Naval Ships´ Technical Manual fouling rating, fr_{NSTM} (Naval Sea Systems Command 2006)

To visually investigate damage of paint we followed the definitions of damage from the standard test method ASTM D6990-05 (2005). In order to determine biocide release rates from the biocidal coatings, dry film thickness was measured before and after deployment. The copper loss / polishing rate were calculated according to the mass-balance method. This method was complemented with imaging of cross-sections, to get data on chemical content of the coating. Images of cross sections were taken using Scanning Electron Microscopy (SEM) together with Energy Dispersive X-ray (EDX) and element-count profiles were conducted along depth.

Cleaning of coatings with brushes in laboratory

Three different coatings developed for leisure boats were used in a laboratory test to study paint fragment formation and damage of paint by cleaning with a brush-device. Two of the paints contained biocides (the polishing paint Mille Light Copper and the hard paint Lefant Nautica Copper) and one paint was free of biocides (EcoPower Racing) and recommended for cleaning in hull (brushing) stations for boats. The cleaning was conducted by use of the brush part of a cleaning robot (Keel Crab) mounted in a holder. The panels were submerged in water and cleaned with set speed and distance from the brush (Figure 5).

Figure 5. Setup for cleaning of in lab, with panels to be cleaned placed on bottom of container.

The removed paint particles/fragments were collected by rinsing the brush and filtering water in the container. The paint particles were measured (total length) and further filtered onto pre-weighted filters (GF/C, 47 mm Whatman) to get the weight of removed material (Figure 6).

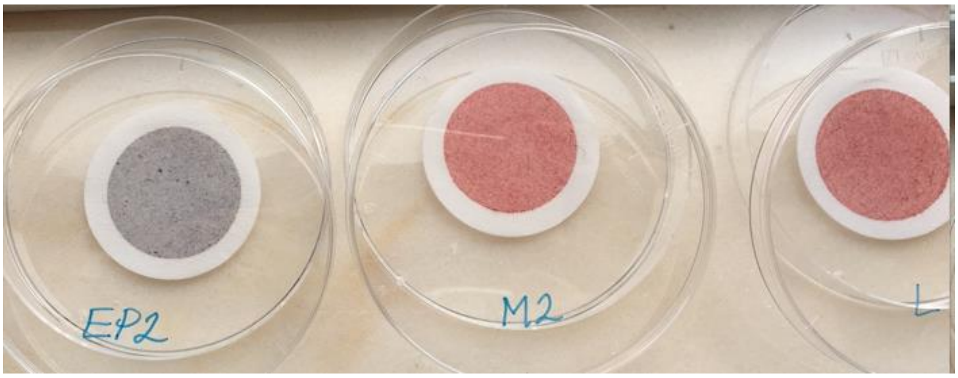

Figure 6. Paint particles from three leisure boat paints on filters.

Panels were visually inspected for damage (marks and scratches) after brushing and also the copper content in panels were measured before and after brushing using X-Ray Fluorescence, which gives concentration of copper (Cu) per area (µg/cm^2).

Cleaning of coatings with brushes in field tests

To evaluate cleaning on paint with brush-device in field, a test was conducted during summer 2019. In total 6 PVC-panels (100*150 cm), painted with two coatings recommended for use on leisure boats, were deployed in the Saltholmen marina (ca 20 PSU) during three weeks in July (10-31 July) 2019. The coatings used were Lefant T-coat (painted with Lefant Epoxi Primer (white, one layer) + Lefant T-Coat (white, one layer)) and Ecopower Racing (painted with Hempel Underwater Primer (grey, one layer) + Ecopower Racing (white, two layers)). Control panels were painted with Hempel Underwater Primer (grey, one layer). Three weeks after deployment the panels were cleaned with an underwater robot developed for use on leisure boats (Keel Crab) by running the robot two times over the panels. Photos were taken before and after cleaning and fouling of surface (% cover) estimated.

RESULTS FROM CLEANING OF COATINGS IN LAB AND FIELD

Cleaning of antifouling coatings with waterjet in field

The antifouling panels that were cleaned bimonthly and monthly had approximately half the fouling rate (based on type and % cover of fouling) compared to the uncleaned control panels (for details see Oliveira and Granhag 2020). The fouling rate on Fouling Release paints was seen to be low also without cleaning, with on average half the level of biofouling compared with biocidal antifouling coating. The panels were deployed under flow conditions with on average lower flow speeds than will be achieved on ship hulls. However, there might have been periods during the year with high enough local flow forces able to "clean" the foul-release paint panels from some biofouling.

Almost no visual damage was detected on the panels after cleaning and handling. Further were the forces used in the waterjet device calculated to have a negligible effect on the average biocide release rate of approx. 13 µg Cu/ cm^2 / day (polishing rate mass balance method). As comparison is release rate of 10 µg Cu/ cm^2 / day, from a paint during normal use (without cleaning) generally considered as needed to deter hard fouling.

Cleaning of coatings with brushes in laboratory

The measured weight (mg) of paint fragments was less from the biocide-free paint Ecopower Racing 1,9 $\pm$ 1,10 (mean $\pm$ stdev, for 3 replicates) compared to weight of fragments from the biocidal coatings Lefant Nautica copper 3,2 $\pm$ 0,15 (mean $\pm$ stdev, for 3 replicates) and Mille Light copper 2,9 $\pm$ 0,56 (mean $\pm$ stdev, for 3 replicates). The size of the particles from EcoPower Racing was in the range 40-70 µm and significantly smaller than the flakes from the paint types Lefant Nautica copper 80-160 µm and Mille Light copper 90-410 µm (for details see Stragnefeldt 2018). The visual inspection of panels for damage after brushing as well as measurement of removed copper with brushing will need further method development (see below in discussion).

Cleaning of coatings with brushes in field tests

Cleaning of coatings in field show that after exposure for 3 weeks in July, the hull cleaning robot using brushes had effect both on Ecopower Racing and Lefant T-coat (Figure 7). The effect was larger on Ecopower Racing with about 70-80% removal of soft fouling (algae), compared to removal of about 30-40% from Lefant T-coat (3 replicates).

Figure 7. Field test panels deployed in Saltholmen marina July 2019, before and after cleaning, from left Ecopower Racing, Grey Primer (control) and Lefant T-coat.

The control panels had only soft fouling (algae) after 3 weeks exposure. A second set of panels that also were deployed the 10th July, but not cleaned, were totally covered by adult barnacles after 2 months. The forces generated by the cleaning device were not strong enough to perform any removal tests on those heavily fouled panels.

DISCUSSION AND FURTHER DEVELOPMENT

Cleaning with waterjet in field

For the cleaning of field panels with waterjet, we used a device for which also theoretical calculations of expected forces were conducted and described. Information of the forces generated by the cleaning device is preferred and needed in tests with aim to compare for example removal of fouling from different products (tested with same type/level of fouling). For boats and ships in operation there will be a range of possible combinations between fouling organism (species and stage) and coating conditions (type, age, biofilm condition). For detailed information of expected forces to be useful also knowledge of the fouling organisms present and their attachment strength values will be required. This is a field where currently more data is needed.

The cross-sections images and chemical analyses of paint layers is an informative way to describe the paint matrix and release of copper from the paint system during cleaning. In this experiment panels were exposed in idle conditions between the cleanings and the coating would likely have reacted differently if instead exposed to intermittent water flow, as is the case for ships in operation.

Test with brushes in lab and field

The length of the individual paint flakes was measured in microscope, but we also observed that larger aggregates were formed during water movement. To study the fate of particles under natural conditions would give useful information on for example total size of particle aggregations and the ability to spread, which could have implications for development of waste capture equipment and facilities.

The panels were inspected for damage after brushing and scratches could be detected but not measured in a way which enabled comparisons between paints. For future studies a standardized method to measure/evaluate the damage would be needed. One method practiced in earlier studies is to use paint layers of various colors, which will facilitate to estimate the depth of scratches. The copper content measured at panels after brushing, were seen to have large variation, why we believe that measurements on brushed panels need to be developed further or analysed with another method.

The lab tests were performed on panels without fouling and removal of fouling will likely affect the resulting paint damage, especially in cases with hard fouling. The force used in the cleaning device for biofouling removal should optimally be matched for each combination of fouling rate and paint characteristics. To conduct a test cleaning on a smaller hull area with representative fouling is useful as control for any paint damage.

More field data on cleaning of hull surfaces is needed to get a better picture of fouling pressure in different regions and during various seasons. In a recent study within the COMPLETE project, five different antifouling paints were evaluated on a leisure boat during the season 2020. The growth and composition of biofouling varied between the paints and for some of the paints cleaning during the season was needed (https://www.syke.fi/en-US/Current/Antifouling_paint_choices_may_impact_the(59731).

As our studies and also previous work has shown that paint flakes will be released during cleaning operations, it is important to develop a waste capture mechanism both for paint fragments and for removed biological material.

CONCLUSIONS

Cleaning on biocidal paints is not recommended either on ships or leisure boats in the Baltic Sea (Watermann et al. 2020, Keep The Archipelago Tidy 2020) and some countries have restrictions for cleaning on biocidal paints in ports (Krutwa et al. 2020). Hull cleaning can also take place outside ports and information might then not be reported to environmental authorities. As cleaning on biocidal paint is still performed globally, biocide-containing paints were also included in the conducted tests.

In the waterjet tests with controlled forces the balance between removal of biofilm without paint damage could be found and was seen to require a monthly cleaning interval on both biocidal and foul release paints.

In the lab test with brushes the hard non-biocidal paint was shown to be most suitable for cleaning in comparison to biocidal coatings (polishing and hard paint type) with less removal (in weight) and with removal of smaller paint fragments. As our tests and earlier studies has shown that paint flakes can be removed during cleaning, it is important to ensure an efficient capture of the cleaning waste.

For efficient cleaning, to hinder that hard fouling develop on the hull, we recommend that cleaning is performed frequently (i.e. at least monthly intervals during season with fast biofouling growth). This was shown for the types of coatings investigated in field (ship hull coatings and leisure boat coatings developed for cleaning). The fouling pressure at the field site for testing was high and for the prevailing fouling pressure to be expected in different locations around the Baltic Sea we recommend that recent studies are consulted (Watermann et al. 2020, Wrange et al. 2020).

ACKNOWLEDGEMENT

Thanks to Björn Källström, Gothenburg Marine Biological Laboratory and Felicia Stragnefeldt, Gothenburg University for assistance in lab and field tests.

FURTHER READING

On leisure boat painted with different antifouling paints:

https://www.syke.fi/en-US/Current/Antifouling_paint_choices_may_impact_the(59731))

On ship hull fouling management:

Roughest hour - approaches to ship hull fouling management, PhD thesis by Dinis Soares Reis De Oliveira: https://research.chalmers.se/en/publication/514200

REFERENCES

ASTM D6990-05. (2005). Standard practice for evaluating biofouling resistance and physical performance of marine coating systems (Reapproved 2011). West Conshohocken, PA.

Davidson, I., Scianni, C., Hewitt, C., Everett, R., Holm, R., Tamburri, M., Ruiz, G. (2016). A Mini-review: Assessing the drivers of ship biofouling management – aligning industry and biosecurity goals. Biofouling, 32, 4, 411–428.

Earley, P.J., Swope, B.L., Barbeau, K., Bundy, R., McDonald, J. , Rivera-Duarte I. (2014). Life cycle contributions of copper from vessel painting and maintenance activities. Biofouling. 30:51–68. doi:10.1080/08927014.2013.841891.

Keep The Archipelago Tidy (2020). Recommendations for mitigating potential risks related to biofouling of leisure boats, COMPLETE project report, 8 pp.

Krutwa, A., Klemola, E., Broeg, K. (2020). In-water cleaning (IWC) of boats and ships in the Baltic Sea region -current procedures and future needs, COMPLETE project report, 23 pp.

Lagerström, M., Ytreberg, E., Wiklund, A-K., Granhag, L. (2020). Antifouling paints leach copper in excess – study of metal release rates and efficacy along a salinity gradient., Water Research 101016 https://doi.org/10.1016/j.watres.2020.116383

Naval Sea Systems Command. (2006). Chapter 081 – Water- borne underwater hull cleaning of Navy ships. In: Nav Ship's Tech Man. Washington (DC). US Naval Ships´ Technical Manual fouling rating frNSTM.

Oliveira, D., Granhag, L. (2016). Matching forces applied in underwater hull cleaning with adhesion strength of marine organisms. J Mar Sci Eng. 4:66–78. doi:10.3390/ jmse4040066

Oliveira, D.R., Larsson, L., Granhag, L. (2019). Towards an absolute scale for adhesion strength of ship hull microfouling. Biofouling. 35:244–258. doi: 10.1080/08927014.2019.1595602

Oliveira, D.R., Granhag, L. (2020). Ship hull in-water cleaning and its effects on fouling-control coatings. Biofouling, doi: 10.1080/08927014.2020.1762079

Stragnefeldt, F. (2018). Slitage av båtbottenfärger från skrovrengöring. Kandidatuppsats miljövetenskap, Institutionen för biologi och miljövetenskap, Göteborgs Universitet.

Watermann, B., Eklund, B. (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? Mar. Pollut. Bull. 144: 146-151

Watermann, B.T., Broeg, K., Krutwa, A., Heibeck, N. (2020). Guide on best practices of biofouling management in the Baltic Sea, COMPLETE project report, 34 pp.

Wrange, A.-L., Barboza, F.R., Ferreira, J., Eriksson-Wiklund, A.-K., Ytreberg, E., Jonsson, P., Watermann, B., and Dahlström, M. (2020). Monitoring biofouling as a management tool for reducing toxic antifouling practices in the Baltic Sea. J. Environm. Manag., 264, 110447.