Interim-Report CLEAN, Version May 2021
In-water Cleaning Trials and Permission Requirements

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Momentive, Renolit, Phi-Stone

Index

1 Introduction

The challenge of maritime transport is keeping the role as the most energy-efficient and environmental friendly transportation system. Nevertheless, IMO calls for a reduction in gaseous emissions and release of harmful substances into the sea, as well as avoidance of fouling organisms. In short, biofouling management should be more sophisticated in the future. Apart of ecologically designed new buildings, the existing world fleet has to reduce emissions into air and water.

Shipping industry is still facing a multitude of obstacles, caused by a variety of circumstances:

- Existing over supply of vessels despite of decline in fleet growth, resulting i.a. into pressure on freight rates. Increasing demand to be flexible regarding traded waters, hampering the selection of an optimal antifouling system. Extended lay-off periods and slow steaming between 8 – 12 knots, to slow to activate some antifouling products.
- Fuel costs are the key factor of operational costs, which increase with biofouling development on the hull, even right from biofilm stage. To reduce fuel consumption and gaseous emissions, vessel operators use underwater cleaning to recreate a smooth hull. Nevertheless, eroding or self-polishing antifouling paints are not designed to be cleaned and immediate release of biocides as well as removal of the upper paint layers occur regularly.
- On the other hand the pressure on the maritime industry is increasing to implement a holistic biofouling management including ballast water treatment, fouling prevention on the hull and in niche areas. Since 2018 regional regulations requiring an active biofouling management are in force in California, Australia and New Zealand. The latter are calling for international standards on the IMO level.
- Proactive foul prevention strategies under the heading of “Clean before you leave” or ”Clean before arrival” are getting popular in combination with non-biocidal, coatings with high abrasion resistance which withstand the impact of multiple cleaning and reduce the adhesion of fouling organisms comparable to rubber-like foul release coatings.

1.1 Actual practice of fouling prevention by in-water cleaning and performance

On the background of the listed circumstances and obstacles in maritime transport, and the need to maintain a smooth hull, numerous diving companies offer underwater cleaning on poor performing antifouling paints. Due to increasing demand by shipping companies underwater cleaning is a booming business. Diving companies like GAC (HullWiper), UMC, TechHullClean, Hydrex, and FleetCleaner and others got permissions to clean in European harbours on failing antifouling paints despite of the immediate release of biocides and removal of the upper layers of the paint (Fig. 1 - 4).

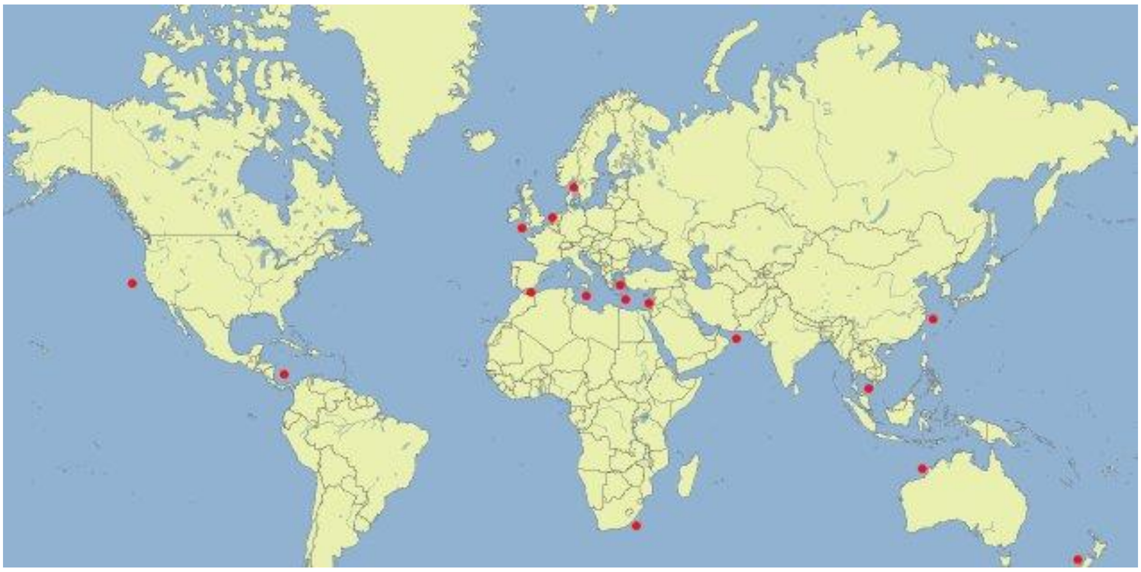

Fig. 1: Coast lines with regular underwater cleaning of vessels. Compilation based on information given on homepages of globally active diving companies

Fig. 2: Underwater cleaning service of the diving company Piccard (www.piccard.gr)

Fig. 3: Underwater cleaning of vessels in North Sea harbours: FleetCleaner, Hydrex, ecosubsea

Fig. 4: Underwater cleaning of vessels in and off Baltic Sea harbours: DG Diving, Garant Group, Neptun, Hydrex, Eprons, Piccard, Aquaworks, UMC, GAC Gothenburg (outside of map)

In Germany few companies like the Nordseetaucher GmbH developed cleaning techniques and offer services e.g. for propeller polishing. As eroding and self-polishing antifouling paints are not designed to be cleaned, the challenge for paint companies is the development of hard, abrasion resistant, non-toxic coatings which ideally possess additionally foul release properties. A couple of shipping-, diving- and paint companies are focussing on similar types of coatings. In combination with short intervals of cleaning, or proactive cleaning, they may reach different goals at the same time: A smooth hull, easy, fast and cheaper cleaning, and minimizing the transport of invasive species. This proactive fouling prevention technique is well established under the term ‚Grooming‘. Another approach is called ‘Clean before you leave’ or ‘Clean before arrival’, the latter in practice off the Californian and Australian coast. Most shipping companies are afraid of elevated costs due to frequent cleaning but some companies like Viking Line and others take advantage of special trading condition or traded waters. Vehicle carriers display extended periods of loading and un-loading with sufficient space at the quay for cleaning devices, and ferry lines in the Eastern Baltic Sea prefer the use of hard ice-class coatings all around the year, as soft antifouling paints are fast removed when trading in drifting ice. Some European ports like Rotterdam, Oslo and Gothenburg may offer reduction of port fees for vessels using environmental friendly innovations. Inter alia, underwater cleaning is included in this list, when performed in combination with collection and filtration of the removed fouling

A change to proactive fouling prevention techniques with regular cleaning on hard coatings implies technical and financial risks. The determination of the optimal time for cleaning, functionality of the cleaning technique, and the economic benefit of cleaning and fuel savings versus the use of antifouling paints with 36 or 60 months docking intervals. In addition, this strategy must comply with the requirements of active biofouling management and biosecurity.

Performing proactive underwater cleaning it will be necessary to collect and filter the removed fouling organisms. Ship hulls are not getting fouled homogeneously, but aft, bow and niches may be covered by macrofouling whereas other current exposed parts of the hull may display only a biofilm.

Investigations on the survival rate of fouling organism after hp-washing in the dry dock and after underwater cleaning with brushes revealed high percentages of survivors (Woods et al., 2012). As can be perceived in table 1 e.g. 67% of algae and 16% of barnacles may survive. To avoid the spread of invasive species it is strongly recommended to collect and filtrate the removed fouling and dispose it on land.

The potential load of the fouling community with heavy metals and organic pollutants enriched by the surrounding harbour waters (Watermann et al. 1999) is another reason to treat the solid residues after filtration as hazardous waste. It is obvious that solid residues after cleaning on biocidal antifouling paints have to be classified as hazardous waste.

Tab. 1: Survival rate fouling organisms after 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

2 Project Plan

Since 2018 a project consortium composed of representatives of the Environment Department of Bremen, of the ports management company bremenports, of the Coast Guard of Lower Saxony, of the Federal Agency of Shipping, of raw material suppliers for paint companies, of the Polar Institute Bremerhaven, of the shipping management company Laeisz, of diving and cleaning companies, and LimnoMar performs a research project on underwater cleaning of ship hulls. The project focuses on three topics:

Demonstration of practicability and efficacy of underwater cleaning of ships hulls coated with non-toxic, abrasion resistant coatings

Demonstration of collection and filtration techniques/systems for the removed fouling organisms with respect to water quality and introduction of invasive species

Drafting of application requirements for permissions of underwater hull cleaning and propeller polishing

3 Vessels and panels for cleaning trials

Several vessels participated for cleaning trials, which were full- or partly coated with a hard, abrasion resistant underwater coating. Vessels and test panel are described regarding their profile and fouling development.

3.1 ‚POLARSTERN‘

RV,Polarstern‘, a research vessel operating as an icebreaker for the Alfred-Wegener-Instituts (AWI) for polar and marine science, Bremerhaven. RV ‚Polarstern‘ undertakes regularly extended cruises in polar regions (https://www.awi.de/expedition/schiffe/polarstern.html). In the dominant traded waters, the vessel has to operate in drifting and pack ice. The hull is coated with the abrasion resistant and extremely hard paint INERTA, AkzoNobel/International). There is no antifouling paint on top due to the mechanical forces which would rapidly remove the antifouling paint under ice condition (Fig. 5).

Fig. 5: Icebreaker and research vessel RV ‚Polarstern‘, AWI

Home port:	Bremerhaven
Length:	118 metres
Breadth:	25 metres
Draught:	11.20 metres
Displacement:	17,277 Tons
Commisioned by AWI:	1982
Speed max.:	16 knots
Operational profile:	Polar region with drifting and pack ice
Days at sea:	300 days p.a.

The AWI offered the vessel for underwater cleaning trials the days just before the yearly dry-docking at Lloyd dockyards in Bremerhaven. RV ‚Polarstern‘ headed straight in summer 2019 from Antarctica with a singular one day stop at the Falkland islands to Bremerhaven. During this cruise a biofilm and short filamentous algae had developed at aft and bow, which could be detected during the diving operation (Fig. 6 – 9). Along the hull, several samples of the fouling community were collected and fixed for taxonomic determination.

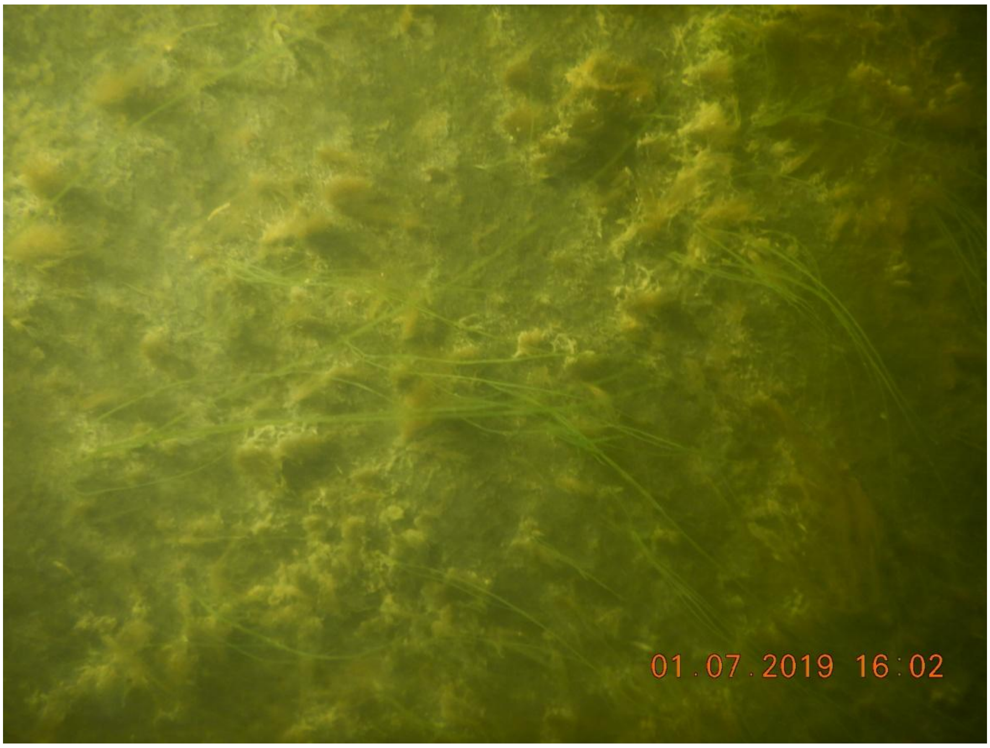

Fig. 6: Fouling community composed of biofilm and filamentous green algae, aft, ‚Polarstern' at July 1, 2019 before the underwater cleaning by DG Diving

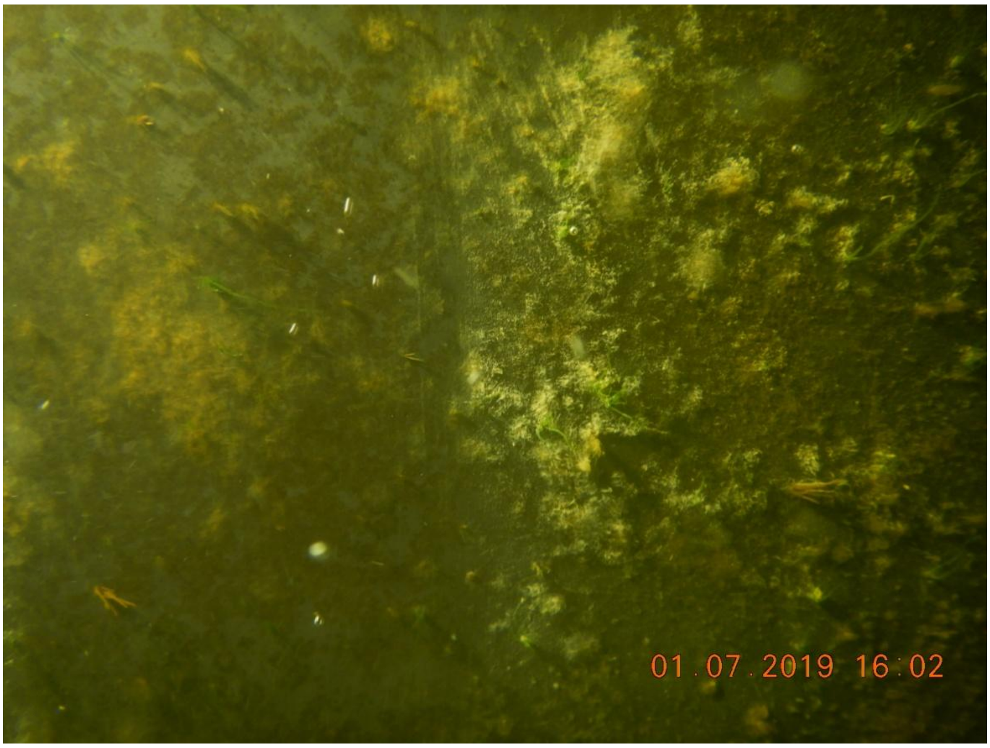

Fig. 7: Fouling community composed of biofilm and filamentous green algae, aft, ‚Polarstern' at July 1, 2019 before the underwater cleaning by DG Diving

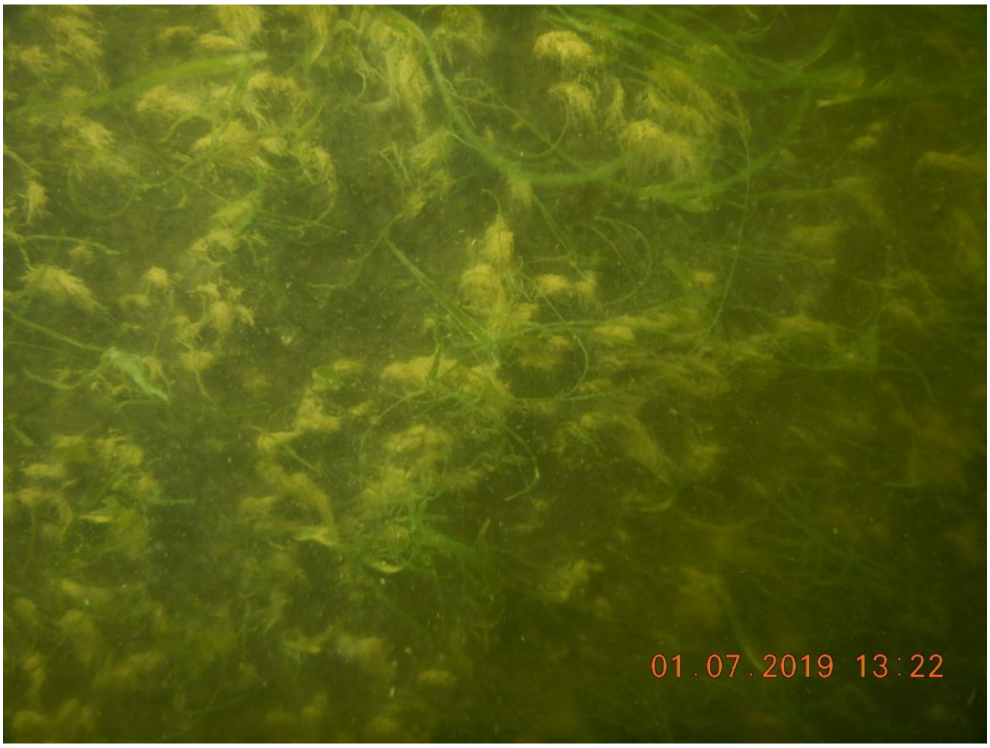

Fig. 8: Fouling community composed of biofilm and filamentous green algae, bow, ‚Polarstern' at July 1, 2019 before the underwater cleaning by DG Diving

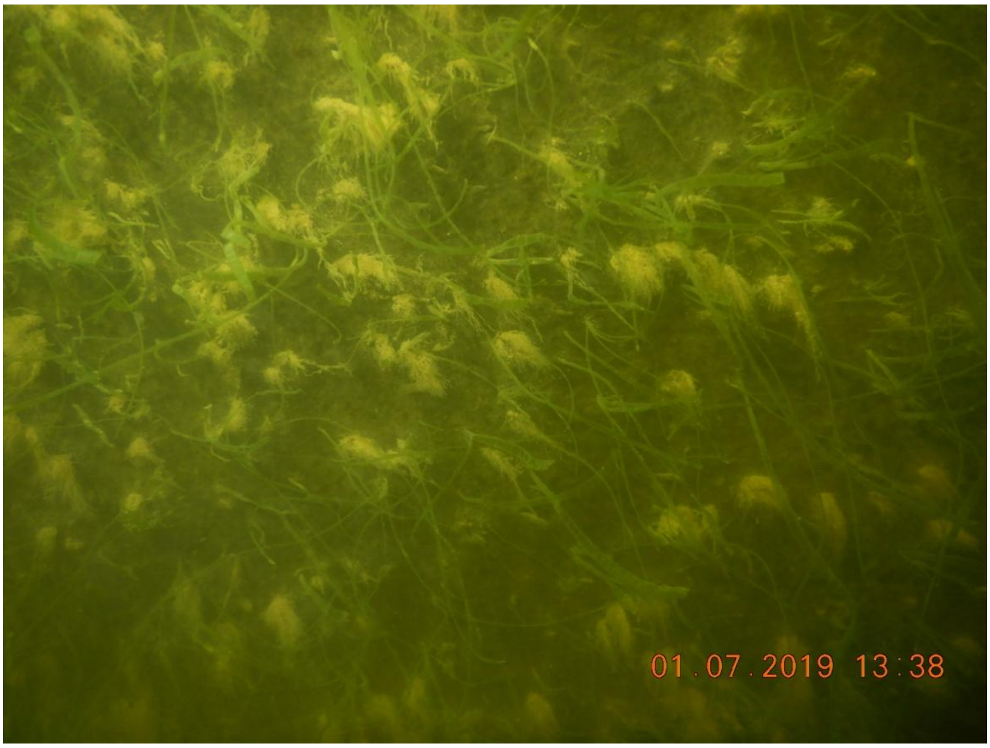

Fig. 9: Fouling community composed of biofilm and filamentous green algae, bow, ‚Polarstern' at July 1, 2019 before the underwater cleaning by DG Diving

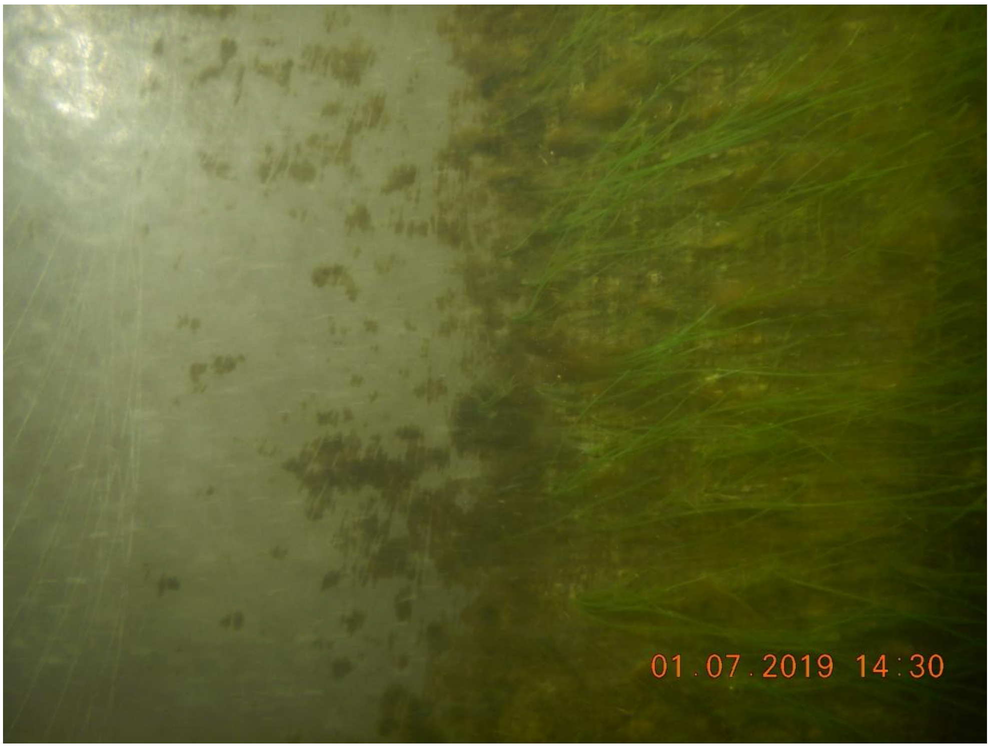

Fig. 10: Cleaned areas (left) with unremoved fouling (right) of dominantly green algae, bow area, 'Polarstern', July 1, 2019, DG Diving

The fouling could very easily be removed without remnants or damage of the paint (Fig. 10).

After dry-docking the hull was surveyed to check the efficacy of the cleaning action. It turned out that the fouling community had entirely been removed without any visible impact on the icebreaker coating. (Fig. 11 - 13).

Fig. 11: RV ‚Polarstern' after underwater cleaning in the dry dock (Lloyd Dockyards, Bremerhaven), July 2019

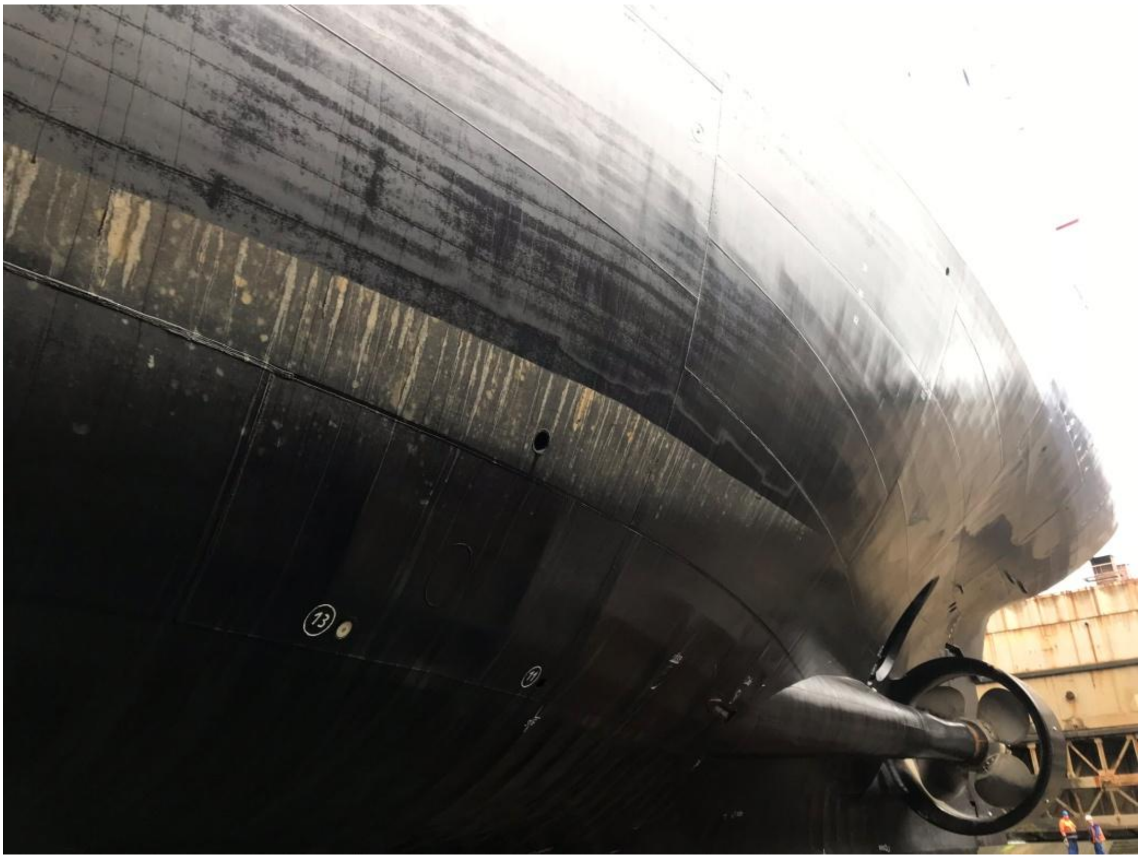

Fig. 12: 'Polarstern' after cleaning in the dockyard, portside, (Lloyd Dockyards, Bremerhaven), July 2019

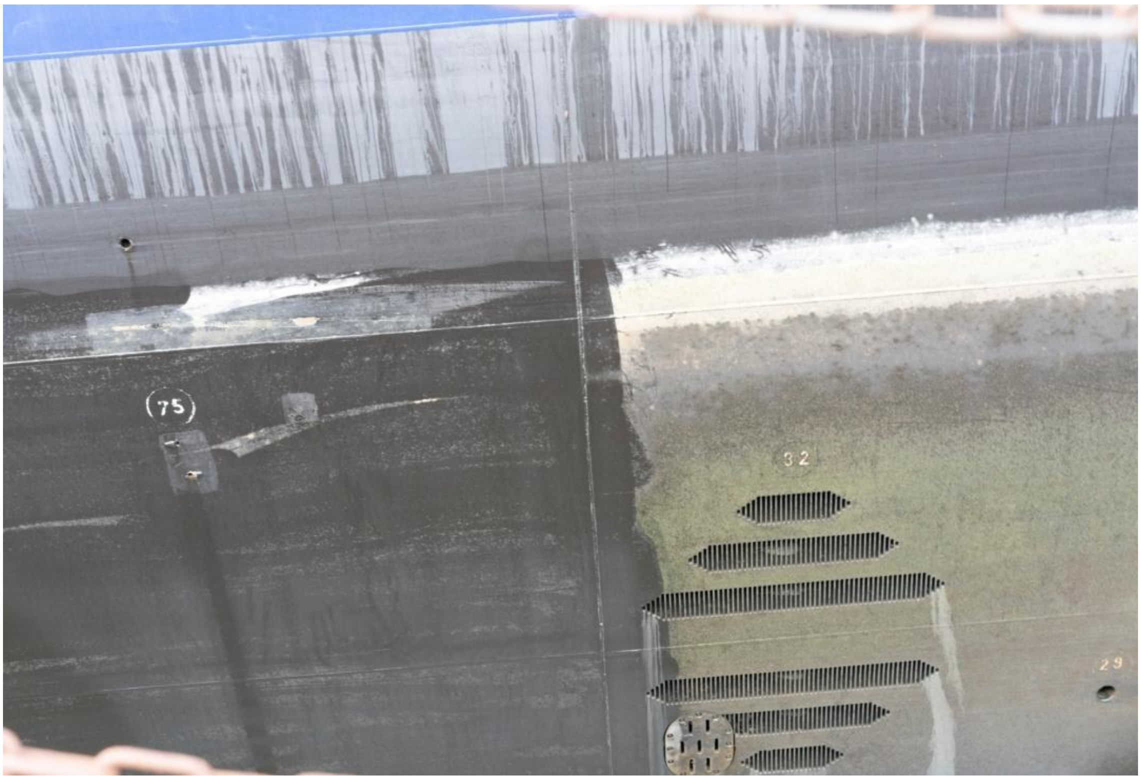

Fig. 13: RV ‚Polarstern' after cleaning in the dry dock, cleaned area left

3.2 ‚WEGA‘

The survey, wreck search and research vessel RV ‚Wega‘ of the Federal Maritime and Hydrographic Agency (Fig. 14) has previously been involved in the research project FOULPROTECT,focussing on hard, abrasion resistant, cleanable coatings (Watermann, 2017). During this project two hard coatings of the paint companies Jotun und Momentive/Wohlert have been applied on portside in November (Fig. 15). The coatings were cleaned four times in irregular intervals between 2015 and 2017.

Fig. 14: Survey, wreck search and research vessel RV ‚Wega‘, BSH

Home port:	Bremerhaven
Length:	52.06 m
Breadth:	11.40 m
Draught:	3.45 m
Displacement:	969 tons
Service Speed:	11 Kn
Operational profile:	North Sea and Baltic Sea
Days at sea:	approx. 250 days/a.
Commissioned:	October 1990

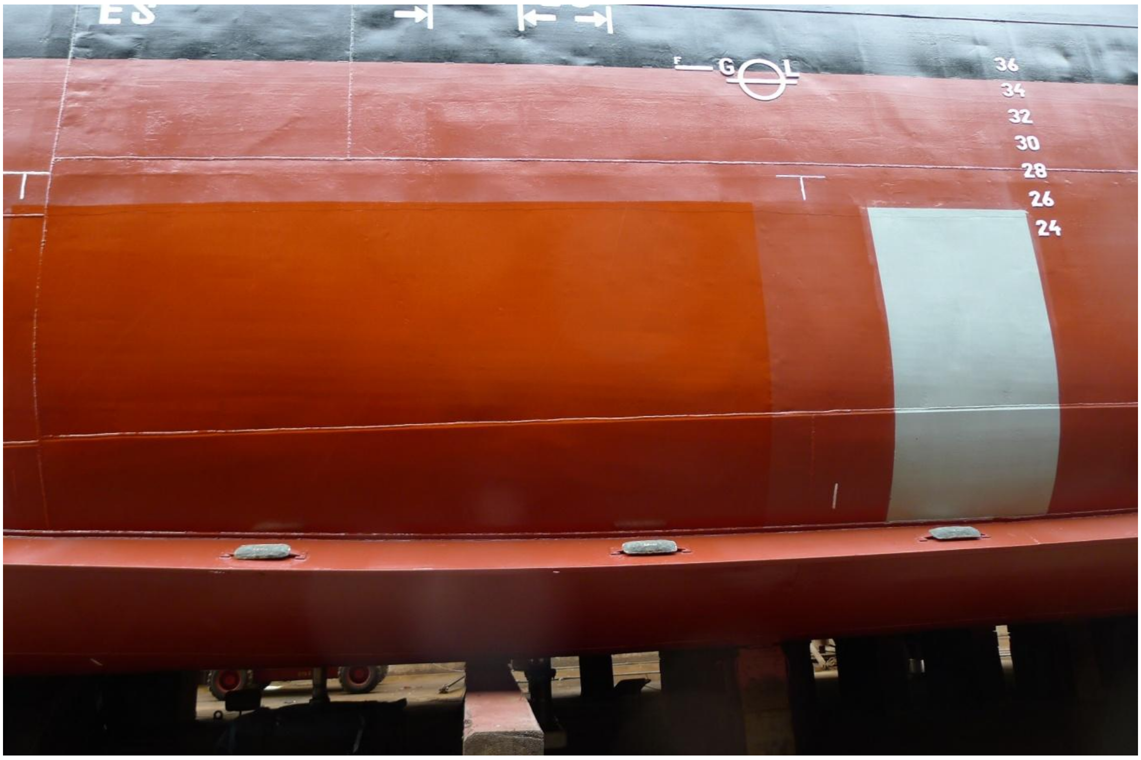

Fig. 15: Cleanable hard coatings, portside ‘WEGA’, after application, November 2015

The two test patches had been cleaned at the last time in March 2017 during dry docking. Obviously, it was of special interest to check the condition of the coatings and the degree of fouling after more than two years without cleaning. The vessels operates with her own diving crew which surveyed the fouling before cleaning and observed heavy macrofouling composed of long filamentous algae and barnacles. The fouling community on the Jotun coating before and after cleaning is depicted in figures 16 – 20.

Fig. 16: Cleanable hard coating of Jotun, ‚Wega‘, April 2019 with heavy macrofouling mainly composed of filamentous algae and barnacles, before cleaning, Wega diving crew

Fig. 17: Cleanable hard coating of Jotun, ‚Wega', April 2019 with heavy macrofouling mainly composed of filamentous algae and barnacles, before cleaning, DG Diving

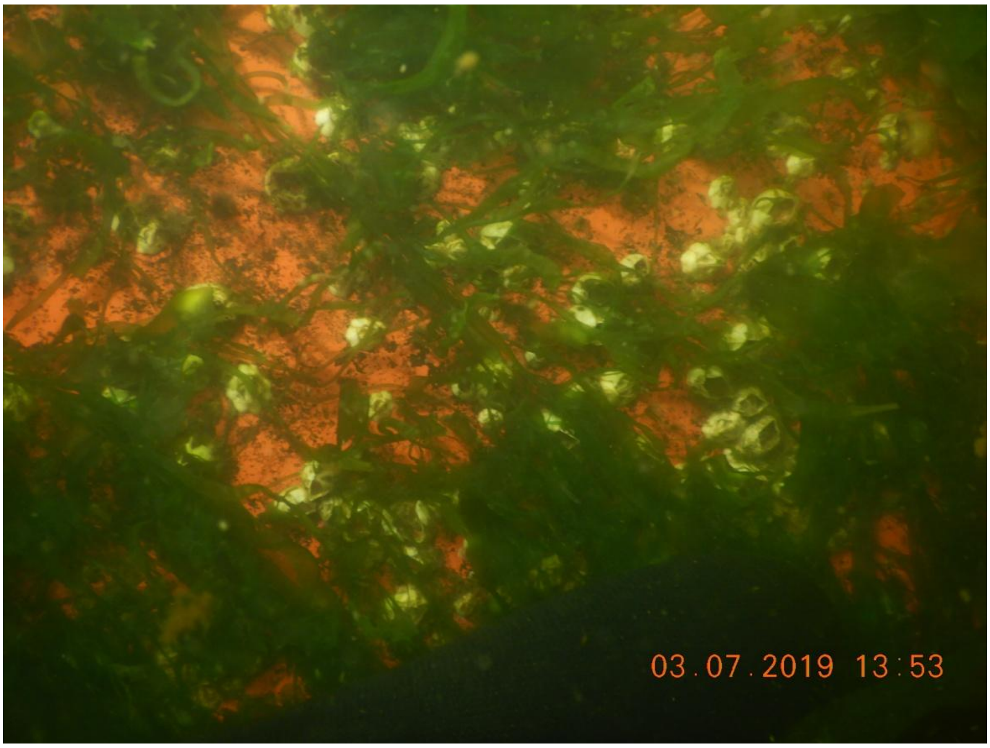

Fig. 18: Cleanable hard coating of Jotun, ‚Wega', July 2019 with heavy macrofouling mainly composed of filamentous algae and barnacles, before cleaning, DG Diving

Fig. 19: Cleanable hard coating of Jotun, ‚Wega‘, July 2019 with heavy macrofouling mainly composed of filamentous algae and barnacles, after cleaning DG Diving

Fig. 20: Cleanable hard coating of Jotun, ‚Wega‘, July 2019 with heavy macrofouling mainly composed of filamentous algae and barnacles, after cleaning, DG Diving

As can be perceived by the images, the fouling had completely been removed without damaging the coating. In addition, the cleaning with hp water in the dry dock revealed the previous complete removal of fouling and displayed an intact coating (Fig. 21).

Fig. 21: Cleanable hard coatings, portside ‚Wega', test patches left Jotun, right Momentive/Wohlert, July 2019

Heavy fouling mainly composed of filamentous algae and barnacles was present after two years on the coating of Momentive/Wohlert without cleaning (Fig. 22 and 23). In July 2019, before cleaning a comparable fouling community as on the Jotun coating was visible (Fig. 24 and 25). But on this coating the fouling could be removed completely with any damage to the coating (Fig. 26). The latter could be proofed after hp-washing in the dock (Fig. 27).

Fig. 22: Cleanable hard coating of Momentive/Wohlert, ‚Wega', April 2019, with filamentous algae and barnacles, before cleaning,Wega' Diving crew

Fig. 23: Cleanable hard coating of Momentive/Wohlert, ‚Wega', April 2019, with filamentous algae and barnacles, before cleaning, ‚Wega' Diving crew

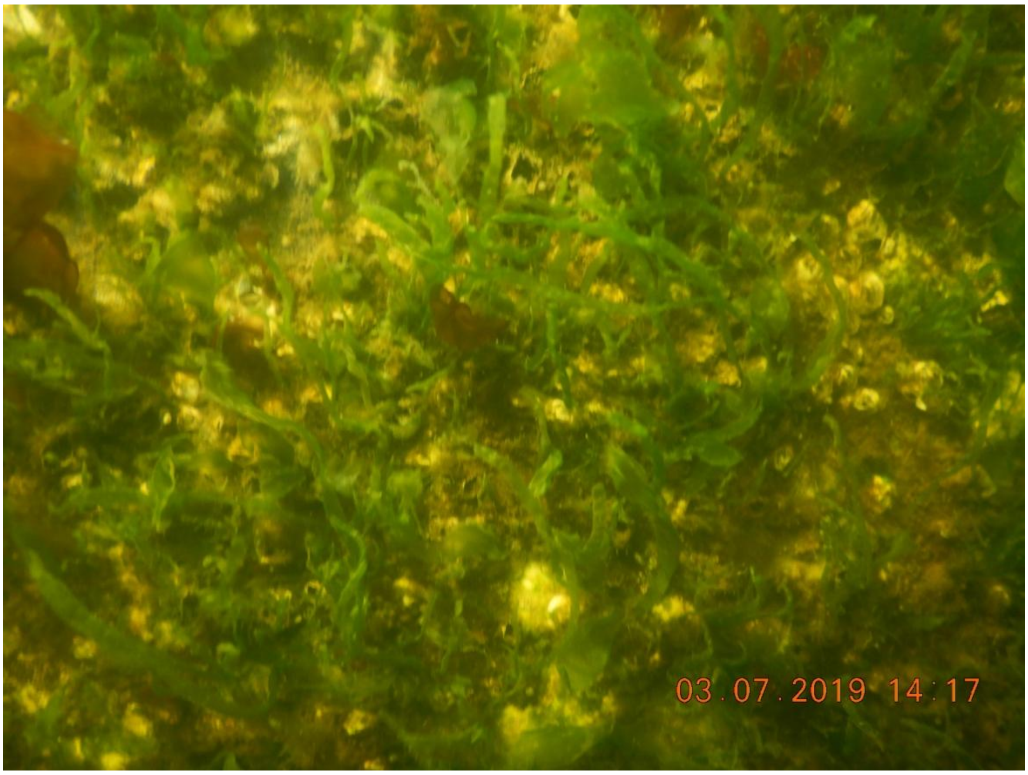

Fig. 24: Cleanable hard coating of Momentive/Wohlert, ‚Wega', July 2019, with filamentous algae and barnacles, before cleaning, DG Diving

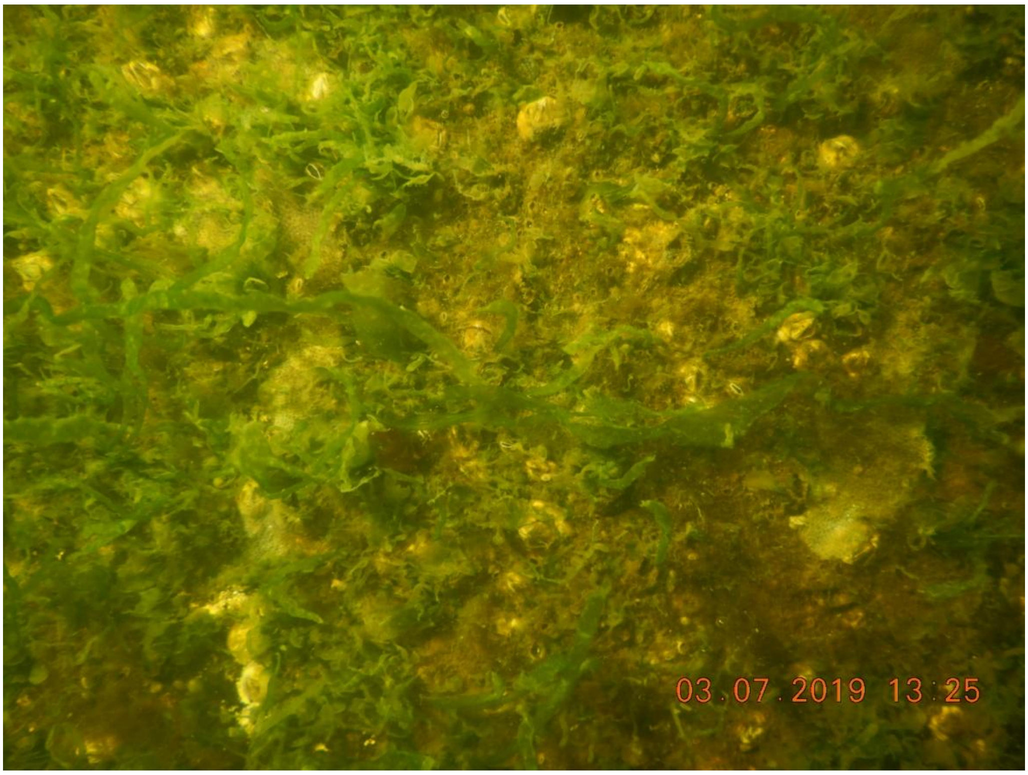

Fig. 25: Cleanable hard coating of Momentive/Wohlert, ‚Wega', July 2019, with filamentous algae and barnacles, before cleaning, DG Diving

Fig. 26: Cleanable hard coating of Momentive/Wohlert, ‚Wega', July 2019, with filamentous algae and barnacles, partly cleaned, DG Diving

The cleaning could be effected successfully at the lower areas of the coating. Efficacy of cleaning could be verified in the dry dock (Fig. 27), and the undamaged condition of the coating was revealed after hp water washing.

Fig. 27: Cleanable hard coatings, portside, ‚Wega', after hp washing in the dry dock, July 2019, left Jotun, right Momentive/Wohlert

During the research project FOULPROTECT, additional test patches had been applied in November 2015 on starboard (Fig. 28). These coatings should possess self cleaning respective foul release properties. Most of them displayed insufficient non-stick properties, and had been cleaned at dry docking in March 2017. In July they displayed heavy fouling (Fig. 29, e.g. Momentive), and were cleaned as well along the lower areas of each coating (Fig. 30, e.g. Momentive). All coatings were cleaned without remaining fouling (Fig. 31). During the hp-washing in the dry dock it turned that some of these coatings were to soft for cleaning impact, and the upper layers had been removed (Fig. 32).

Fig. 28: Foul release coatings on starboard after application November 2015, ‚Wega‘

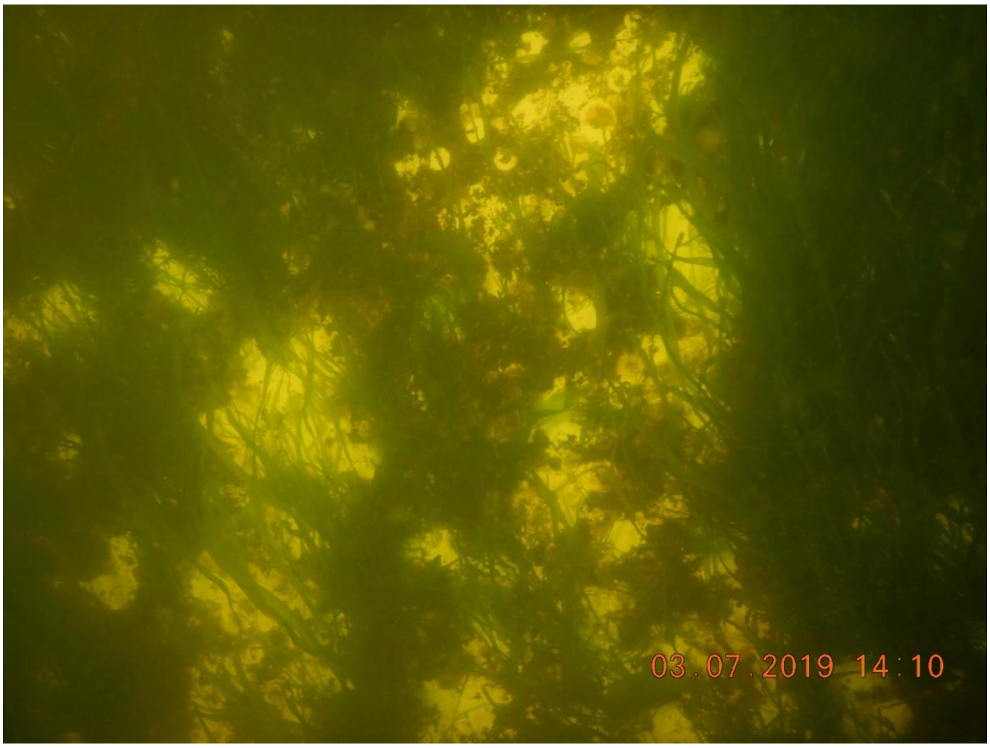

Fig. 29: Foul release coating of Momentive, starboard, ‚Wega‘, covered by filamentous algae and barnacles, July 2019, before cleaning, DG Diving

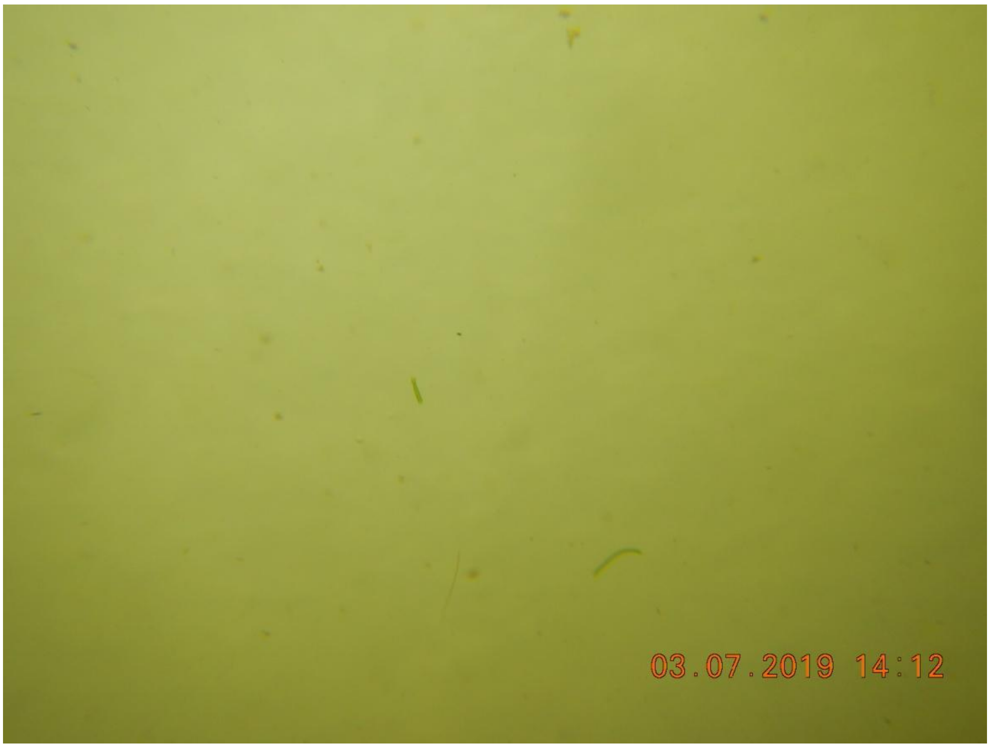

Fig. 30: Foul release coating of Momentive, ‚Wega', July 2019, lower part after cleaning, DG Diving

Fig. 31: Test patches of foul release coatings, ‚Wega', July 2019, after underwater cleaning

Fig. 32: Test patches of foul release coatings, ‚Wega‘, July 2019, after hp-washing in dry dock

3.3 Impact on water quality by underwater cleaning

TOC content in the harbour of Bremerhaven before cleaning and after cleaning passed through the filtration unit of DG Diving

The underwater cleaning machine of DG Diving is connected to water treatment system with a two-step filtration unit equipped with thieve and fleece filter (see Report DG Diving 2019; HELCOM, 2015). This unit is able to separate biofouling organisms from the cleaning process water and also remove nutrients, phosphorus and nitrogen, from cleaning process water down to 100 µm. All solid waste can be collected and handled in a proper way on shore (Fig. 33).

TOC measurements were performed by the Hamburg Authority for the Environment and Energy (BUE), to determine the impact on harbour water bodies induced by the use of harbour water for underwater cleaning. Water samples were taken just before cleaning started at berth of the vessels as reference. Samples of the effluents of the water treatment unit were taken during the cleaning action (Fig. 34). As can be perceived in table 2 and 3 the TOC values were slightly different due to different samplings stations 'Überseehafen' and 'Fischereihafen', different dates of sampling.

Fig. 33: Water treatment unit with thieve filter (100 µm pore size) above a fleece filter (100 µm pore size) with grey tube releasing the treated water back into the harbour basin.

Fig. 34: Water sampling at the effluent tube of the water treatment unit

The TOC mean value of the harbour water taken at berth of ‘POLARSTERN’ in the harbour before cleaning was determined as 5.2 mg/l and after filtration as 7.3 mg/l (tab. 2 und fig. 35).

Tab. 2: TOC-values ‚POLARSTERN‘ as mg/l

TOC-values before cleaning	TOC-values after filtration
5.1	5.4
4.8	6.0
5.4	7.6
5.4	6.2
mean 5.2	6.2
	7.5
	5.9
	7.8
	11
	6.6
	9.9
	mean 7.3

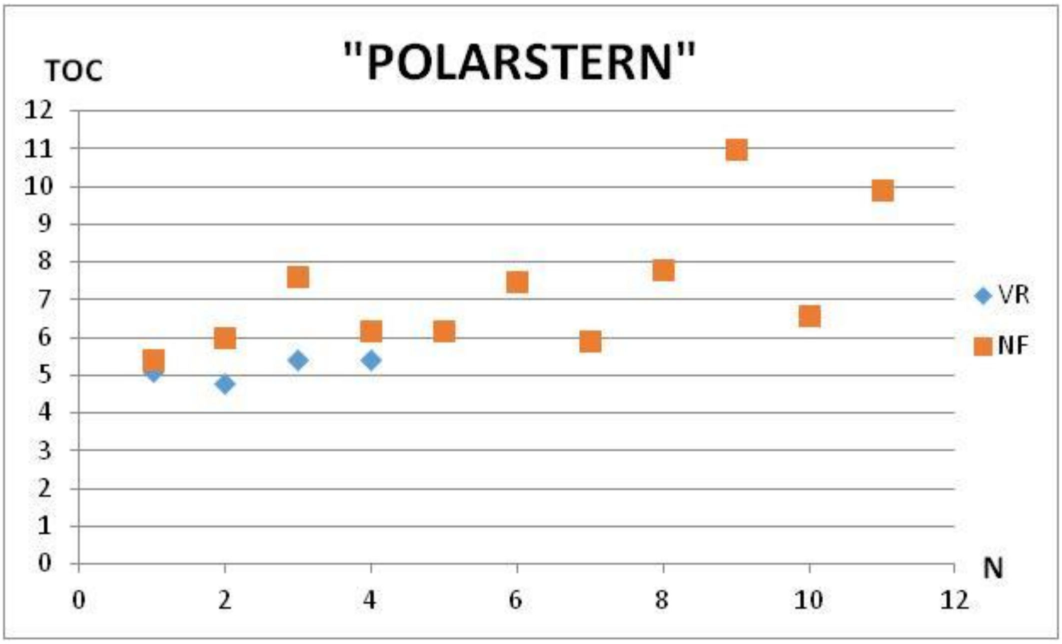

Fig. 35: TOC-values water samples of the transatlantic port, Bremerhaven, before underwater cleaning (VR) and during underwater cleaning of the hull of 'POLARSTERN', after filtration (NF)

TOC-mean values before cleaning the hull of ‚WEGA' at berth in the fishery harbour, Bremerhaven were 6.8 mg/l and during the cleaning action 7.3 (tab. 3 und fig. 36).

Tab. 3: TOC-values ‚WEGA' mg/l

TOC-values before cleaning	TOC-values after filtration
6.6	7.6
7.1	9.6
6.6	7.6
mean 6.8	9.3
	6.6
	6.8
	6.7
	6.6
	6.9
	6.5
	6.4
	6.6
	mean 7.3

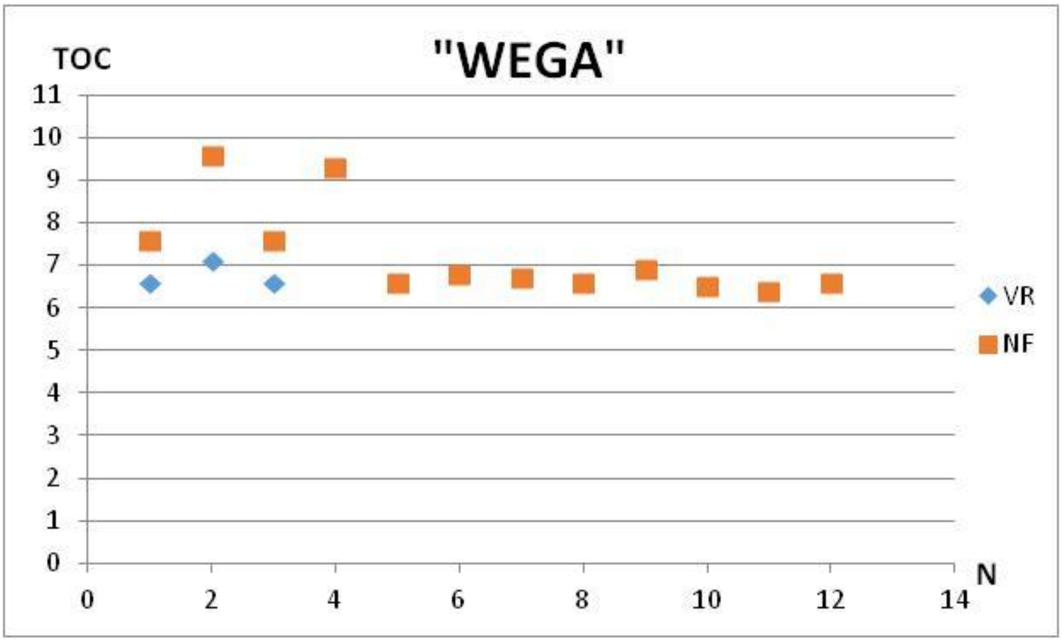

Fig. 36: TOC-values of harbour water, Bremerhaven, Fischereihafen before cleaning (VR) and during cleaning of the hull of ‚WEGA', collected after filtration (NF)

TOC-values during cleaning were slightly elevated. The mean values were identical albeit the fouling community on 'WEGA' was much developed.

Regarding the German Annex 30 for Effluents from Dockyards, the measured TOC-values were quite below the limit of 50 mg/l (Umweltministerium Schleswig-Holstein, 2018). To compare the measured TOC- concentrations with TOC concentrations in the lower Weser and the estuary, occurring in the summer time, data reported by the Lower Water Authority of Lower Saxony (NLWKN) for the lower Weser and the Weser estuary are depicted in figure 37 and table 4.

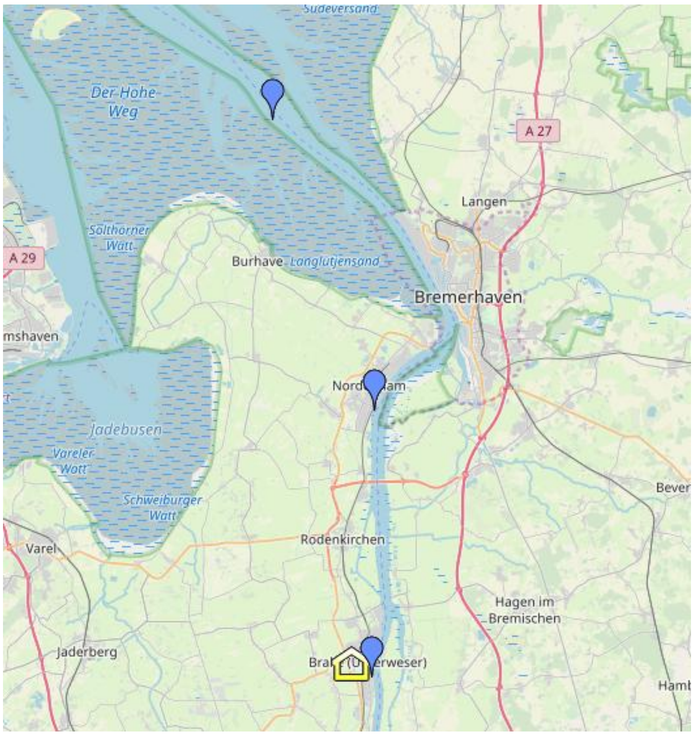

Fig. 37: Samplings stations of the NLWKN in the lower Weser and the estuary

Tab. 4: TOC-values measured by the NLWKN in lower Weser (Brake) and the estuary (Nordenham)

Sampling station	**Sample-No.**	**Date of sampling**	**DOC**	**TOC**
		TT.MM.JJJJ	mg/l	mg/l C
Weser estuary W 1	2018-04472	17.05.2018	5.1	**7.0**
Weser estuary W 1	2018-05724	14.06.2018	2.8	**4.9**
Weser estuary W 1	2018-06681	12.07.2018	2.9	**3.6**
Weser estuary W 1	2018-08702	19.09.2018	2,4	**2.4**
Nordenham	2016-01183	20.06.2016	5.8	**13**
Nordenham	2016-01457	25.07.2016	7.9	**11**
Nordenham	2016-01651	15.08.2016	5.6	**10**
Nordenham	2016-01964	19.09.2016	4.7	**14**
Brake	2018-05434	12.06.2018	5.0	**15**
Brake	2018-05987	02.07.2018	4.7	**8.5**
Brake	2018-07160	01.08.2018	4.4	**13**
Brake	2019-05310	15.04.2019	6.6	**8.3**
Brake	2019-07025	20.05.2019	5.0	**17**

As can be perceived by table 3 TOC-values in the summer time are around 2.4 and 7.0 in the estuary, at station Nordenham between 10.0 and 14.0, and at the station Brake between 8.5 and 17 auf.

In a research project of the University of Applied Science Bremerhaven, TOC concentrations were measured in the Marina Yachting Bremerhaven before and after cleaning of boat hulls. It could demonstrated that after filtration through a fleece the TOC concentrations were not elevated and remained around 4 – 5 mg/l as before the cleaning (Lompe & Schubert, 2013; the full report is available under: https://www.dbu.de/OPAC/ab/DBU-Abschlussbericht-AZ-29437.pdf).

3.3.1 Contamination of solid residues

A chemical analysis of the solid residues after filtration revealed high concentrations of copper and organotin compounds (table 5), which were likely due to the occurrence of red paint flakes in the filtration fleece. A contamination of the filtrated residues by the ice breaker coating of 'Polarstern' can be excluded. Two explanations for the contamination of the solid residues after cleaning are:

- Before the cleaning of RV 'Polarstern' the cleaning DG diving cleaned a vessel with active or non-sealed TBT-antifouling paint. Taking into account the published data it appears very unlikely that vessels in the Baltic Sea use TBT-antifouling paints as active fouling prevention system.
- Another, more likely, reason for the contamination of the solid residues may be caused by the low depth at the quay, where RV 'Polarstern' was at berth for cleaning. The draught of the vessel with 11 m was right the depths of the harbour basin. It is likely that sediment has been turned up by the vessel, and remobilized the red paint particles from the bottom.

As every harbour deals with historic layers of TBT-contaminated sediments, and turning up of old sediments cannot be excluded by cleaning actions or vessels with draught deep as the harbour basin, it will be reasonable to classify the solid residues of filtration as hazardous waste and dispose it respectively.

Tab 5: Concentrations of selected biocides in the solid filtration residue after cleaning of RV ‚Polarstern'

Biocide	**Concentration**	**Unit**
copper	44	mg/kg
TBT	160	µg/kg
DBT	140	µg/kg
MBT	54	µg/kg
Source: Institut Dr. Nowak		

3.4 Taxonomic determination of fouling to survey transport of invasive species

It is well know that several species of fouling organisms can survive the impact of underwater cleaning. To avoid invasion the use of filtration systems with small mesh sizes have to be used, down to 5 µm mesh size. Furthermore, the technical feasibility of UV- treatment of the filtrate should be tested. UV-treatment systems used in ballast water treatment systems or drinking water systems may be appropriate.

To check the transport of invasion species on the test patches of RV ‘Wega’ and RV ‘Polarstern’ samples of the fouling community were scraped off before cleaning and in the dry dock for taxonomic determination Tab. 6 and 7).

After taxonomic determination every species was marked with a colour in table 6 to distinct between indigenous species (no coloured), neobiota (marked yellow), kryptogenic species with unknown origin (marked orange) and ‘guests’ (marked blue), species which are introduced but – up to now – cannot reproduce in the North Sea and the Baltic Sea.

3.4.1 Neobiota

<u>Sessile species, belonging to the firmly attached fouling community:</u>

Barnacles, Cirripedia (*Amphibalanus improvisus,* since 1868 abundant in the Baltic Sea*; Austrominius modestus,* since 1960 found in the North Sea) Both species are regularly found in ship fouling communities in North Sea and the Baltic Sea since decades.

<u>Vagile species, which move freely in-between the attached fouling community:</u>

Skeleton shrimps, Caprellidae (*Caprella mutica*), since 1990 found in the North Sea

Crustacean, Tanaidacea, (Sinelobus sp.), since 2014 found in the Baltic Sea

3.4.2 Cryptogenic Species

The following organisms were determined as cryptogenic species, i.e. those whose origins remain unknown

<u>Sessile species, belonging to the firmly attached fouling community:</u>

Vagile species, which move freely in-between the attached fouling community

Crustacea, Amphipode (*Jassa marmorata*)

3.4.3 Guests

The term ‚guests‘ has been used for species which are being frequently introduced but cannot reproduce in North Sea and the Baltic so far.

<u>Three barnacle species belonging to goose barnacles were classified as ‚guests‘:</u>

Goose barnacles, Lepatidae (*Lepas syn. Anatifa anserifera*)

Goose barnacles, Lepatidae (*Lepas syn. Anatifa hillii*)

Goose barnacles, Lepatidae (*Conchoderma auritum*)

These three species can frequently found on drifting material, attached to the skin of whales or on the flat bottom of slow moving ships like tankers. Actually, the northern boundary for their reproduction is still restricted to the Atlantic coast of Spain. Thus, they are classified as guests in the North Sea and the Baltic Sea so far.

3.5 Evaluation of the taxonomic determination of the fouling communities

‘POLARSTERN’ went into the dry dock 5 days after the in-water cleaning. This offered the chance to survey the hull on the areas which has not been cleaned, including the flat bottom. In these hull areas two barnacle species which are classified as neobiotic, albeit they occur since 60 resp. 100 years in the North Sea and the Baltic Sea. The goose barnacles found on the flat bottom were classified as guests as they cannot reproduce in North Sea waters. In conclusion, ‘POLARSTERN’ straight heading from the southern hemisphere to the northern hemisphere did not introduce neobiota into the North Sea. Nevertheless, it is recommended for the future to clean the hull pro-actively prior to reaching the port or at the latest in the port, to avoid introductions.

For ‘WEGA’ similar conclusions can be drawn. This vessel is operating exclusively in the North Sea dn the Baltic Sea. As neobiotic species *Amphibalanus improvisus* und *Austrominius modestus* were presdent, which as mentioned above, can found on fouling communities on ships since decades. The degree of fouling on ‚WEGA‘ corresponded to that found at the dry dock inspection in March 2017.

Tab 6: Fouling Communities before cleaning

Phylum	Taxon	Comments	Legend
Annelida	*Pygospio elegans*		Neobiota
Arthropoda	*Amphibalanus improvisus*		Guest
Arthropoda	Aoridae gen. sp.		
Arthropoda	*Austrominius modestus*		
Arthropoda	*Conchoderma auritum*	nicht heimisch; spezialisiert darauf, sich an großen mobilen Objekten festzuheften (z. B. Wale, siehe Dalley & Crisp, 1981)	
Arthropoda	Corophiidae gen. sp. juv.		
Arthropoda	*Gammarus salinus*		
Arthropoda	*Gammarus* sp.		
Arthropoda	*Gammarus* sp. juv.		
Arthropoda	*Jassa marmorata*		
Arthropoda	*Lepas (Anatifa) anserifera*	typischer "Gast" als Fouling an Schiffen, vgl. Conchoderma	
Arthropoda	*Lepas (Anatifa) hillii*	typischer "Gast" als Fouling an Schiffen, vgl. Conchoderma	
Arthropoda	*Leptocheirus pilosus*		
Arthropoda	*Monocorophium acherusicum*		
Arthropoda	*Monocorophium insidiosum*		
Arthropoda	Mysidae gen. sp.		
Arthropoda	*Neomysis integer*		
Arthropoda	*Sinelobus* sp. nov.		
Bryozoa	*Conopeum seurati*		
Bryozoa	*Einhornia crustulenta*		
Bryozoa	*Farrella repens*		
Chlorophyta	*Cladophora sericea*		
Chlorophyta	*Ulva* sp.		
Chlorophyta	Ulvales gen. sp.		
Cnidaria	Leptothecata indet.		
Cnidaria	*Obelia bidentata*		
Mollusca	*Mytilus edulis* agg.		
Ochrophyta	Ectocarpales gen. sp.		
Ochrophyta	Phaeophyceae gen. sp.		
Rhodophyta	Acrochaetiales gen. sp.		
Rhodophyta	*Ceramium* sp.		

Bottle	Location	Ship's name	Hull area	Date	Indication	Taxon	Comment
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Austrominius modestus	
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Conopeum seurati	
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Sinelobus sp. nov.	
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Mytilus edulis agg.	
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Acrochaetiales gen. sp.	
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Ceramium sp.	C. virgatum ?
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Ectocarpales gen. sp.	
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Ulvales gen. sp.	Tubulär
1	Bremerhaven	WEGA	SLR/Backbord	03.07.2019	WG 01	Phaeophyta/Ulvales gen. sp.	Platt
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Austrominius modestus	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Conopeum seurati	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Einhornia crustulenta	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Sinelobus sp. nov.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Corophiidae gen. sp. juv.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Pygospio elegans	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Ceramium sp.	C. virgatum?
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Ectocarpales gen. sp.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Cladophora sericea	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Ulvales gen. sp.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 02	Phaeophyta/Ulvales gen. sp.	
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Amphibalanus improvisus	
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Austrominius modestus	
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Mytilus edulis agg.	
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Conopeum seurati	
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Sinelobus sp. nov.	
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Monocorophium insidiosum	
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Ceramium sp.	C. virgatum ?
1	Bremerhaven	WEGA	MOM, Backbord	03.07.2019	WG 03	Ulvales gen. sp.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Austrominius modestus	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Conopeum seurati	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Mytilus edulis agg.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Sinelobus sp. nov.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Einhornia crustulenta	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Monocorophium acherusicum	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Ectocarpales gen. sp.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Cladophora sericea	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Ulvales gen. sp.	
1	Bremerhaven	WEGA	Testfl. Steuerbord	03.07.2019	WG 04	Ceramium sp.	

Bottle	Location	Ship's name	Hull area	Date	Indication	Taxon	Comment
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Amphibalanus improvisus	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Leptothecata indet.	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Farrella repens	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Mytilidae gen. sp. juv.	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Austrominius modestus	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Ulva sp.	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Obelia bidentata	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Monocorophium insidiosum	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Corophiidae gen. sp. juv.	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Leptocheirus pilosus	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Conchoderma auritum	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Lepas (Anatifa) anserifera	
1	Bremerhaven	Polarstern	Dock	06.07.2019	PS 01	Lepas (Anatifa) hillii	
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Ulva sp.	
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Sinelobus sp. nov.	
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Monocorophium insidiosum	
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Jassa marmorata	
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Aoridae gen. sp.	♀♀
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Leptocheirus pilosus	
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Gammarus salinus	
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Mysidae gen. sp.	Stücke, Praunus sp.?
2	Bremerhaven	Polarstern	Filtrat	01.07.2019	PS 02	Neomysis integer	
2	Bremerhaven	Polarstern	Filtrat	01.07.2018	PS 02	Ectocarpales gen. sp.	Planosiphon zosterifolius oder Punctaria tenuissima
2	Bremerhaven	Polarstern	Filtrat	01.07.2018	PS 02	Ectocarpales gen. sp.	Ectocarpus sp.?
2	Bremerhaven	Polarstern	Filtrat	01.07.2018	PS 02	Phaeophyceae gen. sp.	
2	Bremerhaven	Polarstern	Filtrat	01.07.2018	PS 02	Ulvales gen. sp.	
2	Bremerhaven	Polarstern	Mittelschiff	01.07.2019	PS 03	Gammarus sp. juv.	
2	Bremerhaven	Polarstern	Mittelschiff	01.07.2019	PS 03	Jassa marmorata	
2	Bremerhaven	Polarstern	Mittelschiff	01.07.2019	PS 03	Neomysis integer	
2	Bremerhaven	Polarstern	Mittelschiff	01.07.2019	PS 03	Mysidae gen. sp.	Stücke
2	Bremerhaven	Polarstern	Mittelschiff	01.07.2019	PS 03	Phaeophyceae gen. sp.	
2	Bremerhaven	Polarstern	Mittelschiff	01.07.2019	PS 03	Ectocarpus siliculosus	
2	Bremerhaven	Polarstern	Mittelschiff	01.07.2019	PS 03	Ulvales gen. sp.	

Tab 7: Taxonomy of fouling organisms found on 'Polarstern' and 'WEGA'

4 Patrol Boat Coast Guard Lower Saxony ‚W5‘

Fig. 38: Patrol boat ‚W5‘, WSP Coast Guard Lower Saxony

Patrol boat ‚W5‘ is operating in the East Frisian Wadden Sea between Jadebusen and Weser estuary (Fig. 38).

Home port:	Bremerhaven/Wilhelmshaven
Length:	19.80 m
Breadth:	5.45 m
Draught:	1.50 m
Speed max.:	17 Kn
New building:	2021

Operating in the Wadden Sea, the patrol boat will be at berth alternating between naval port Wilhelmshaven and Bremerhaven, Geeste estuary. ‘W5’ has been coated in autumn 2020 with the hard coating OVERDRIVE/Wohlert, with two test patches on each side of the bow area of 1 m breadth. The test patches will be cleaned by a hand-held tool of SeaBoost (PowerBrush).

5 Work boat ‚MÖWE‘

Fig. 39: Work boat ‚MÖWE‘, bremenports

The work boat ‘Möwe’ is operated by bremenports in the port of Bremerhaven, in the locked areas of the port: Kaiserhafen I, II, III, Osthafen, Verbindungshafen, around the locks, and in the fishery port (Fig. 39).

Home port:	Bremerhaven
Length:	16.25 m
Breadth:	4.50 m
Draught:	0.90 m
Service speed:	7-8 kn
Activity level:	high
Berth:	„Bückingstrasse – Alte Banane“

The hull was pasted at portside in August 2019 with the foul release film ‘Dolphin S’, Renolit (Fig. 40). The film will be regularly surveyed to check the fouling development, and the necessity to clean.

Fig. 40: Foul release adhesive film ‚Dolphin S‘, mis ships ‚MÖWE’ during application August 2019

Unfortunately, the film was mechanically damaged so severely that it partially peeled off and had to be removed in 2020.

6 Propeller-Cleaning and Polishing

In parallel to the hull cleaning trials the diving company Nordseetaucher developed and tested a technique for propeller cleaning and polishing (Fig. 41). The cleaning system comprise a tool for capture of the removed fouling and the subsequent filtration of fouling particles and solved metals due to abrasion of the propeller alloy. In close cooperation with the Environmental Department of Bremen propellers of vehicle carriers, research vessels etc. have been cleaned to optimize the cleaning and the filtration unit. A proofed technique can be expected available at the end of the project, which can get permits by the authority, and may be applicable in other sea ports as well.

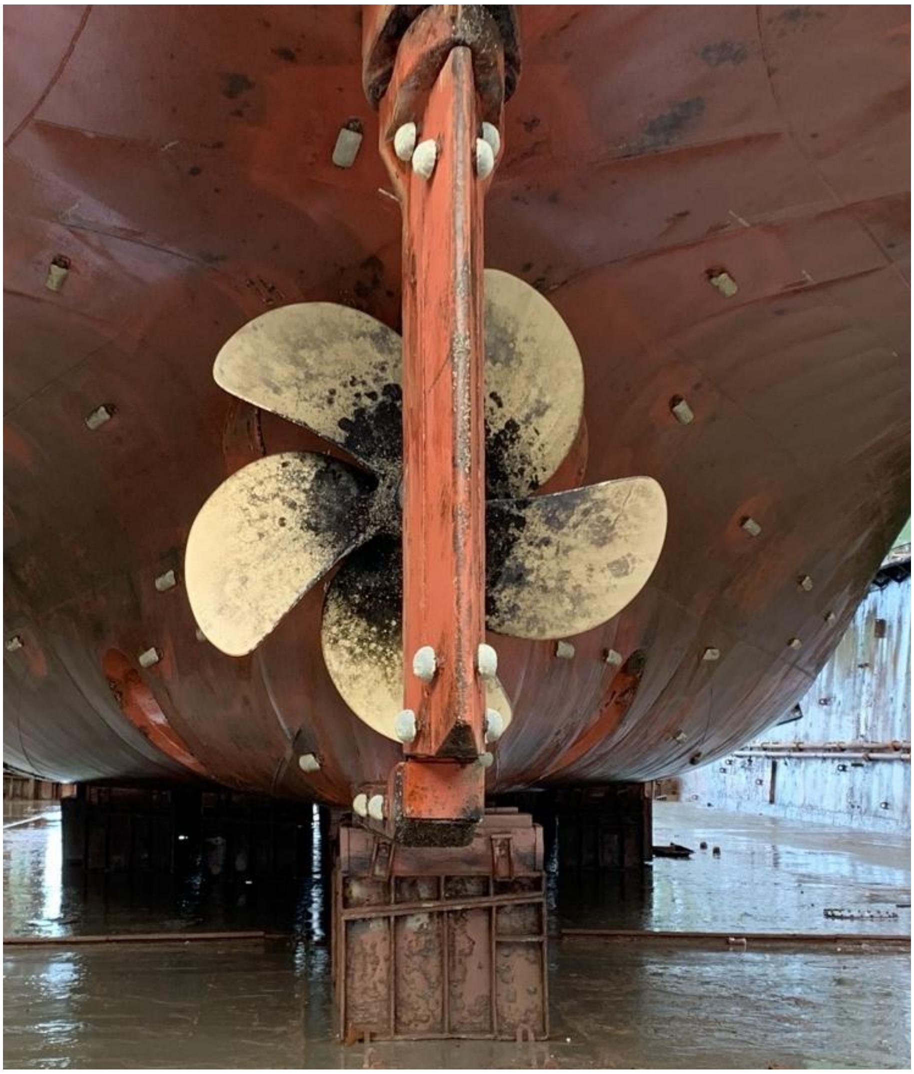

Fig. 41: Propeller of 'WEGA' in dry-dock, March 2021

7 Steel panel BREDO-Dockyards

For cleaning trials with direct control of efficacy a steel panel was coated with the hard coating Overdrive and statically exposed at Bredo Dockyards, Bremerhaven. The panel is totally submerged but can be lifted above the water on demand (Fig. 42). The steel panel served as test area for smaller cleaning robots.

November 2019 after 7 months of exposure, the cleaning robot KeelCrab was tested (Fig. 43). The fouling community on the steel panel was composed of smaller and larger barnacles with base plate diameters of 3 - 4 and 5 – 7 mm respectively, to a minor degree tunicates, hydrozoa and short filamentous algae were present. The fouling coverage was estimated as 15% (Fig. 44 and 45).

Fig. 42: Steel panel BREDO Dockyards, for cleaning trials with cleaning trials

Fig. 43: KeelCrab cleaning robot

Fig. 44: Fouling on steel panel after 7 months of static exposure Bredo-Dockyards, Bremerhaven

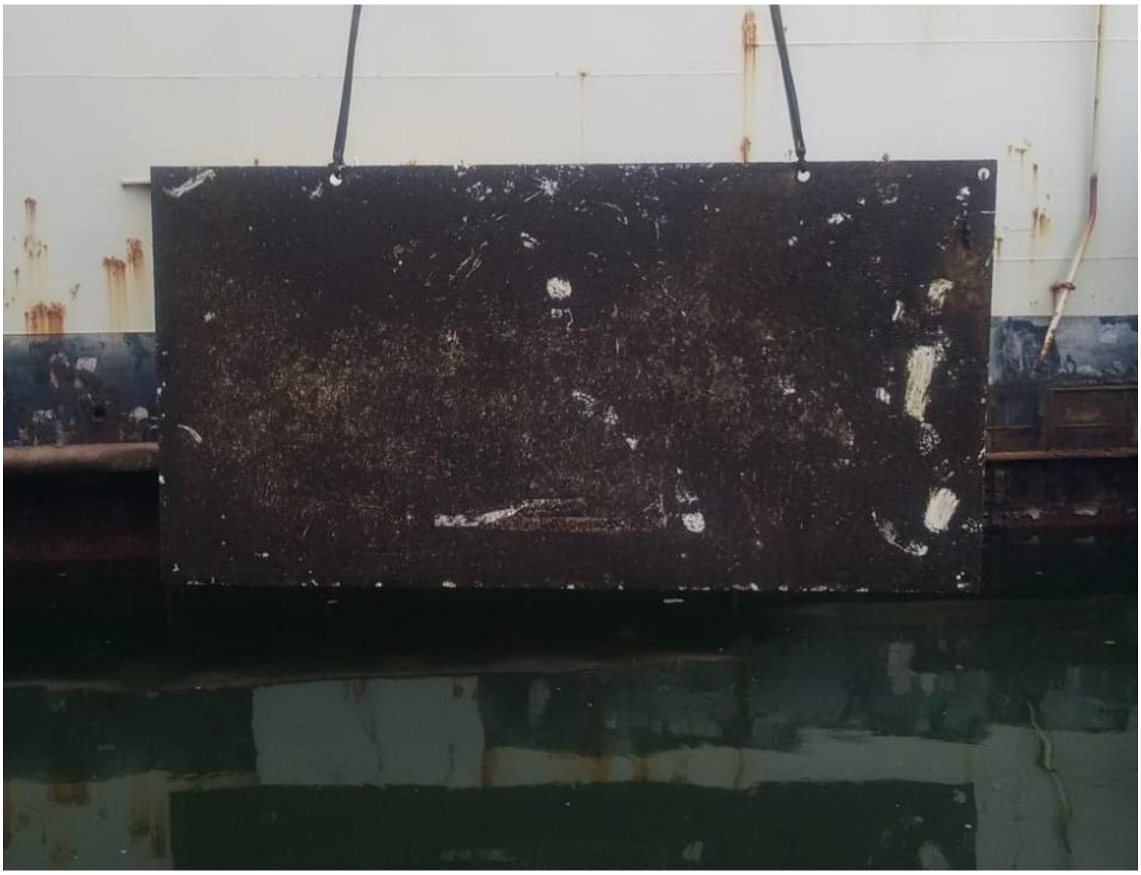

Fig. 45: Steel panel after 7 months of static exposure, before cleaning


Fig. 46: KeelCrab in action on the steel panel, November 2019


Fig. 47: Close-up of cleaned area of steel panel, November 2019

KeelCrab cleaned effectively the painted surface. Apart of some larger barnacles the fouling could be removed (Fig. 46 and 47). The condition of the paint was undamaged and possessed its hydrophobic surface even after cleaning.

8 In-Water Cleaning of ‘Gabriella‘, port of Helsinki

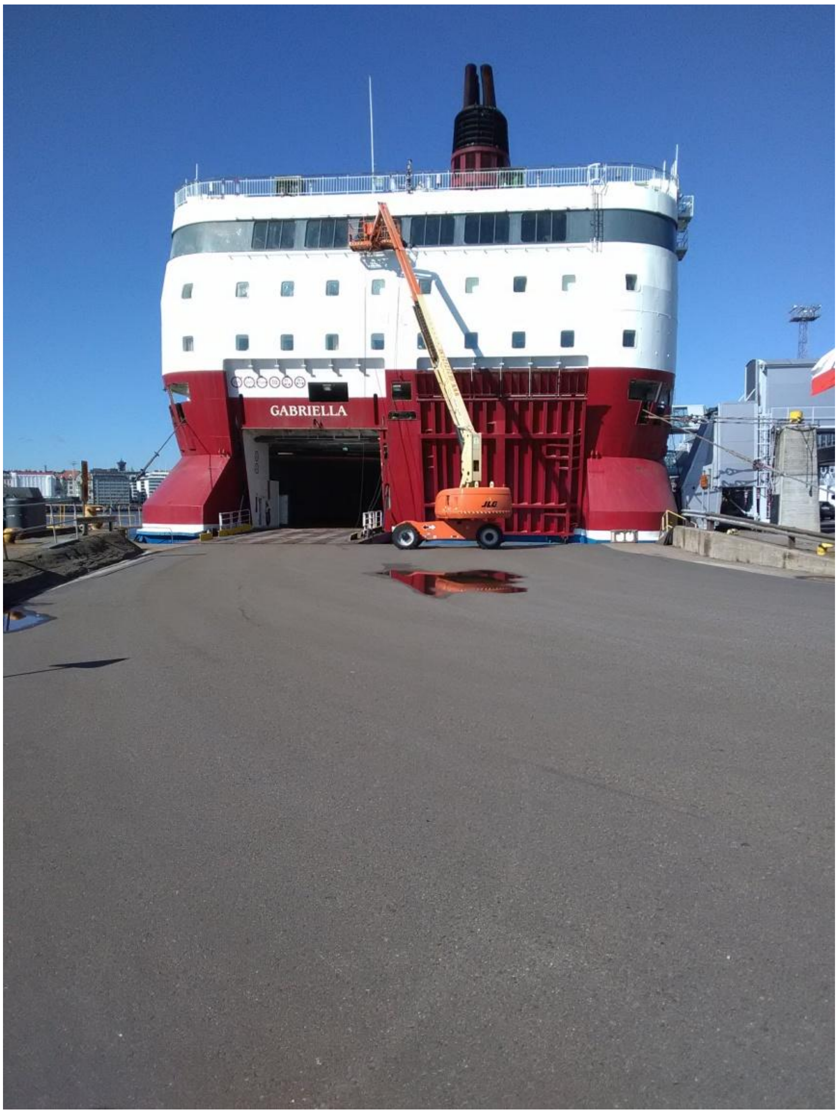

Fig. 48: Ferry ‚Gabriella‘ in the port of Helsinki

In September 2020 DG-Diving offered the opportunity to participate at the in-water cleaning of a ferry in the port of Helsinki (Fig. 48). The shipping company VIKING use since more than ten years anticorrosive, abrasion resistant coatings instead of antifouling paints. This practice is due to regular operation in drifting ice by which antifouling paints may completely be abraded. The cleaning was performed by DG-Diving on the ferry ‘Gabriella’ which is going to be cleaned bi-weekly in the fouling season (Fig. 49). The hull of the ferry is coated with HEMPADUR MULTI-STRENGTH GF 35870, an amine-adduct cured epoxy coating, reinforced with glass flakes. It is a hard, impact and abrasion resistant coating recognized as ice coating by Lloyds Register. The cleaning action served as well to gather information on the biofouling management of the shipping company VIKING. These informations were fueled into the preparation of the movie on the CLEAN project.


Abb. 49: In-water cleaning of ‚Gabriella‘ in the port of Helsinki

9 Outlook and next steps

Preparation of a YouTube movie about the project activities and the in-water cleaning of ships and leisure boats

Development of an application scheme including requirements for future permissions of in-water cleaning in ports

Microscopic control of cleaning effluents with regard to size and survival of organisms, comparison of several methods and

Optimization of capture and separation techniques for propeller and hull cleaning

Preparation of a conference in Bremen, September 14, 2021

10 References

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