Testing of In-water cleaning systems with capture

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Authors
Jørn-Erik Hausmann, Port of Bergen (Project owner)
Tone Knudsen Fiskeseth, DNV Maritime Advisory (Project Manager)
Ingrid Sigvaldsen, DNV Maritime Class
Pernilla Carlsson, NIVA
August E. Dessen Tobiesen, NIVA
Vidar A.T. Thorsen, Norwegian Maritime Authority

Contact:
Tone Knudsen Fiskeseth, tone.knudsen.fiskeseth@dnv.com

Thank you:
Per-Ivar Johannessen (NIVA), Susan Skogtvedt Røed (NIVA), Tor Nystuen (NIVA), Tore Stang (Wilhelmsen), Tommy Svendsen, Falckdykk, Submara, Jarle Johansen, IMC Diving, Submara, Abigail Robinsen (ECOsubsea) Petter Korslund (Jotun) and Tommy Thorstensen (Jotun)

Partners:
This Pilot has been led by the Port of Bergen

Other contributors: ECOsubsea AS, VUVI AS

Foreword

Humanity's well-being is intertwined with the health of the ocean. We are founded on resilient and flourishing ocean ecosystems, and their wonders will provide prosperity for generations. Our collective wisdom and actions can safeguard this development, but ignoring sustainable ocean management can pose severe threats to ocean ecosystems.

Some few years ago *The IPBES Global Assessment Report on Biodiversity and Ecosystem Services* concluded that the rate of global change in nature during the past 50 years is unprecedented in human history. The direct drivers of change in nature with the largest global impacts have been changes in land and sea use, direct exploitation of organisms, climate change, pollution and invasion of alien species.

The role of ships' biofouling as a vector for invasive species is well-documented, and therefore the International Maritime Organization has decided to take action. In July 2023, the IMO adopted the *2023 Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species*. These Guidelines are an important first step towards harmonizing biofouling management globally, which is currently characterized by a fragmented regulatory landscape with different national requirements and guidelines.

Initiated by Norway in cooperation with other countries, the IMO has now decided to develop a legally binding framework on biofouling management to prevent the spread of invasive aquatic species via ships' hulls. That is a major step forward.

I am delighted to see the Norwegian Green Shipping Programme has initiated the pilot project "*Testing of In-water cleaning systems with capture*". It is timely, and it is needed for the ongoing work at the IMO, and for technology providers, ports and other relevant stakeholders. The GSP partners taking part of this pilot hold important parts for the future regulatory framework, both internationally and domestically!

Drawing on a comprehensive understanding of ships' biofouling, available cleaning solutions, anti-fouling coating systems, sampling and analysis methodologies, as well as current international regulations and standards on testing of in-water cleaning, the team provides valuable insight through this report.

This report represents a significant step towards achieving more environmentally responsible in-water cleaning practices. By establishing clear guidance and encouraging benchmark testing, it demonstrates a strong commitment to protect marine environments while supporting sustainable shipping activities.

This report is limited to testing of in-water cleaning with capture. More information and guidance are needed on how to demonstrate compatibility between anti-fouling coating and cleaning systems, as well as on how to manage risks related to cleaning without capture.

The wider maritime community should read and take learnings from this report. I will encourage the Green Shipping Programme to continue biofouling project activities.

Sveinung Oftedal

Chief Negotiator – Green Shipping
Department of Pollution Control
Ministry of Climate and Environment

Table of Contents

Executive summary

This report has been compiled by stakeholders engaged in in-water cleaning activities in Norway as part of the Green Shipping Programme (GSP). The Port of Bergen is the owner of this pilot project, and together with Port of Oslo they have acted proactively on the risks associated with in-water cleaning. The main objective of the pilot project was to establish a practical and representative test procedure for in-water cleaning systems (IWCS) with capture to provide independent testing and operational compliance. This protocol is designed for IWCS to demonstrate low chemical and bio-invasive risk and will support wider adoption of environmentally responsible hull cleaning practices in Norway.

IMO has developed guidelines for biofouling management (MEPC.378(80)) and in-water cleaning (MEPC.1/Circ.918) and a legally binding framework is under development. MEPC.1/Circ.918 outlines in-situ testing (cleaning of ships) for assessing the environmental impact and operational reliability of IWCS under real conditions. However, this guidance does not prescribe a specific test standard and has no details on ex-situ testing (controlled environment).

The outcome of this pilot project is the development of a test procedure, as presented in Annex 1; *Test procedure for in-water cleaning systems with capture*. This test procedure is in line with the latest IMO guidelines, and the in-situ testing follows ISO 20679:2025. However, the procedure provides adjustments for practical and efficient implementation to establish clear procedures for equipment setup, sampling, and relevant data collection that fulfils the purpose.

As part of the work, two pilot experiments were carried out; one ex-situ (land based) test where two test plates with biofouling were cleaned in a controlled environment, and one in-situ test where two in-water cleaning systems cleaned the hull surface and bulb area respectively. The analyses were performed using standardized and validated methods to ensure accuracy, reliability, and consistency. Quality control procedures were implemented throughout the pilot testing process to maintain data integrity. The results provide a reliable basis for assessment, decision-making, and further scientific or regulatory review.

The test procedure as presented in Annex 1 serves as a starting point and may require further refinement as more practical experience is gained. The procedure specifically focuses on measuring particles greater than 1 µm, as this allows for the collection of larger sample volumes, which in turn strengthens the statistical reliability of the results. This is a practical approach. Nevertheless, future protocols may have to consider including smaller particles as analytical methods and regulatory requirements evolve.

Three areas stand out where additional expertise and data are essential to develop a reliable and practical standard: 1) the testing of coating compatibility, 2) the assessment of cleaning with capture in niche areas and 3) in-water cleaning without capture;

1) Coating impact and the importance of preserving the integrity of anti-fouling coatings is an important area that was discussed in the pilot group. However, this protocol focuses on minimising pollution and therefore testing includes studies of potential release of paint particles. It is recommended that paint manufacturers and IWCS engage in studies to determine the most effective ways to preserve the coating during cleaning operations. Collaboration between these parties will help ensure that environmental impacts are reduced while maintaining the longevity and efficacy of anti-fouling coatings.
2) The pilot study has investigated cleaning of hull and one niche area (the bulb), and the protocol therefore specifically addresses cleaning operations on hull and niche area surfaces

that possess a solid, accessible structure. The pilot acknowledge that systems intended for cleaning pipes or grid-like structures, and other internal or complex geometries may need further technology development. The test procedures will need to be adjusted accordingly.

Summary of the ex-situ (land-based) test

Pilot tests in this study offered useful insights for developing the test procedure. Two steel plates ($10m^2$ each) were covered with natural biofouling species at NIVAs research station Solbergstrand. Falck Dykk, Submara cleaned both sides of these plates in a $60m^3$ test tank, according to their normal operating procedure. Water samples from the test tank were taken at key stages throughout the test (before plate insertion, after insertion, after cleaning) and analysed for particles (TSS, TOC, DOC, POC and inorganic particles) and biological activity (ATP) from bacteria and organisms >10 µm. For abbreviations, please see Table 1.

Table 1 Summary table of water concentrations in the pilot ex-situ testing with bacteria (<10 µm) measured as pg/100ml ATP (adenosine triphosphate), and organisms >10 µm measured as pg/ml ATP, total organic content (TOC) measured as mg/l, particulate organic carbon (POC) measured as µg/l and total suspended solids (TSS) measured as mg/l.

Parameter	Plate 1 Before cleaning		Plate 1 After cleaning		plate 2 Before cleaning		plate 2 After cleaning	
	Average	stdev	Average	stdev	average	stdev	average	stdev
Bacteria	198	55	192	12	165	37	136	7
Organisms >10µm	17	6	34	3	34	19	38	8
TOC	1.2	0.3	1.4	0.3	1.5	0.3	1.8	0.3
POC	40	6.6	92	14	83	8	149	13
TSS	3.9	0.7	4.4	1.6	4.1	1.1	5.6	1.0

Key lessons learned during ex-situ pilot test:

- The ATP results displayed considerable variability, making them less reliable for detecting changes in the release of viable matter during IWC treatment, especially for hard sessile organisms such as blue mussels and barnacles.
- Using the >10µm fraction allows a higher sample volume which ensure a more representative sample for ATP measurements.
- TOC results showed inconsistent deviations, indicating this parameter is not suitable for IWC testing.
- POC measurements demonstrated higher reliability than TOC.
- TSS analysis collected onto a 0.2 µm pre-weighed filter demonstrated reliable results, same with TSG which is after combustion (i.e. in-organic material).
- To improve the robustness of the protocol, it is recommended to filter a larger sample volume using a 1.2 µm pore size filter.
- Analysis of metals were not included in this pilot test since the plates were not coated with an anti-fouling coating.
- Important factor is to validate the relationship between tank volume, biofouling level, and sample volume to ensure accurate assessment of capture efficiency.
- Heavier particles may settle at the tank's bottom, so visual inspection and weighing of collected material are recommended.
- Concentration measurements are discouraged due to their susceptibility to background fluctuations.
- For practical and cost-effective sampling, focusing on overall particle mass, using TSS, POC, and inorganic matter, is preferable to tracking specific particle types. Direct comparison of

particle mass before and after cleaning offers a more reliable measure of system performance. These insights support the adoption of mass-based metrics for fair and accurate evaluation of capture effectiveness.

Summary of the in-situ test

The in-situ test aimed to compare in-situ procedures from the Bergen Protocol with international standards, including IMO Guidance (MEPC.1/Circ.918) and ISO 20679 (2025), to identify improvements and ensure best practice alignment. Tests were carried out on the ship Viking Neptun during cleaning events by ECOsubsea on the hull and IMC Diving on the bulb section, using the ISO 20679 time-integrated continuous sampling method. Background samples were taken 50m in front of the ship, and for "natural" release from the ship from 3m depth near the hull. Additionally, samples were collected at the cleaning unit, influent to the separation/treatment unit and effluent from it, providing valuable data to inform the development of benchmark test criteria for the test procedure.

Although only one replicate per analysis was performed and microplastics were not included, various parameters were tested, including biological analysis (ATP). Overall, the approach balanced scientific robustness with practical constraints, laying the groundwork for developing a practical test procedure.

The following table summarises the key results obtained from the in-situ pilot test, comparing different sampling locations and test conditions.

Table 2 Summary table of water concentrations in the pilot in-situ testing with bacteria (<10 µm) measured as pg/100ml ATP (adenosine triphosphate), and organisms >10 µm measured as pg/ml ATP , dissolved organic carbon (DOC) measured as mg/l, particulate organic carbon (POC) measured as mg/l, total suspended solids (TSS) measured as mg/l, particulate and dissolved metals measured as µg/l, such as copper (Cu-p and Cu-d), zinc (Zn-p and Zn-d), titan (Ti-p and Ti-d) and iron (Fe-p and Fe-d).

Parameter	Test 1 (EcoSubsea)				Test 2 (IMC Diving)				Harbour background	
	Background		Near cleaning unit		Background		Near cleaning unit		One grab sample >50 m away	
	avg	**stv**	**avg**	**stv**	**avg**	**stv**	**avg**	**stv**	**prior**	**after**
Bacteria	4.7	1.30	-		2.0	0.18	-		-	-
>10µm	84	6	-		178	38	-		-	-
DOC	1.6	0.06	1.6	0	1.6	0.07	1.5	0.0	1.4	1.4
POC	0.206	0.032	0.190	0.010	0.291	0.040	0.276	0.140	0.135	0.149
TSS	3.2	0.7	3.9	0.9	3.8	0.50	6.7	0.99	1.2	5.4
Cu-p	16.4		8.7		31.6		12.1		2.3	5.1
Cu-d	11.8		4.7		24.4		6.5		1.5	3.7
Zn-p	79.3		7.6		91.8		6.4		<4	<4
Zn-d	68,2		4.7						<2	<2
Ti-p	<1		<1		<1		<1		<1	<1
Ti-d	0.02		0.24		0.19		0.17		0.15	0.46
Fe-p	28.4		<10		42.9		<10		<10	<10
Fe-d	4.7		<4.0		5.71		<4.0		<4.0	<4.0

Key lessons learned during in-situ pilot test:

- In-situ testing could effectively assess IWCS over time. The cleaning efficiency was evaluated by observing the live video feed from the diver operator or ROV pilot and by comparing views of pre- and post-cleaning surface areas.

- Sampling near the cleaning unit did not provide representative results due to high uncertainty regarding the representativeness due to interferences (e.g., turbulence) from the IWCS capture.
- It was possible to characterize ambient water quality continuously throughout the test period by adding the sampling point close to the ship hull, allowing inclusion of particles from passive leaching from the coating. Variability in sample results is linked to the choice of sampling points (near the quay or cleaning unit) or fluctuating environmental conditions in the harbour.
- The open nature of in-situ tests and harbour activity interfere with the background sampling and compromise data comparability. Location needs to be carefully selected to avoid inference as much as possible.
- TSS, POC, inorganic particles and particle size distribution (PSD) and metals were relevant parameters for assessing background, influent, and effluent waters.
- Increasing sample volumes is recommended to improve reliability in results.
- Based on the results, there seems to be challenging to improve the efficiency of metal collection in cleaning systems with capture, especially for suspended metals. Enhancing this capability would contribute to more environmentally responsible cleaning practices, but for the current test procedure, suspended biocides/metals, are not included in the analyses. These parameters may be included, if future legislation find it relevant.
- ATP is a suitable method for assessment of biological activity in the effluent and background samples.

The results lead to the necessity of controlled, ex-situ testing for accurate evaluation of capture efficiency, as in-situ tests are hindered by variable and hard-to-standardise conditions around the cleaning unit.

Summary of the test procedure for in-water cleaning systems with capture

The new test procedure in Appendix 1 establishes a framework for testing in-water cleaning systems with capture. The scope of testing, as outlined in the standard and depicted in the below figure, comprises the following key areas:

1. Assessment of capture efficiency in cleaning operations.
2. Evaluation of separation and treatment efficiency for the reduction of organic cleaning debris, live organism release, and waste substances from anti-fouling coatings.
3. Measurement of cleaning efficiency to ensure effective biofouling removal.
4. Assessment of coating damage.

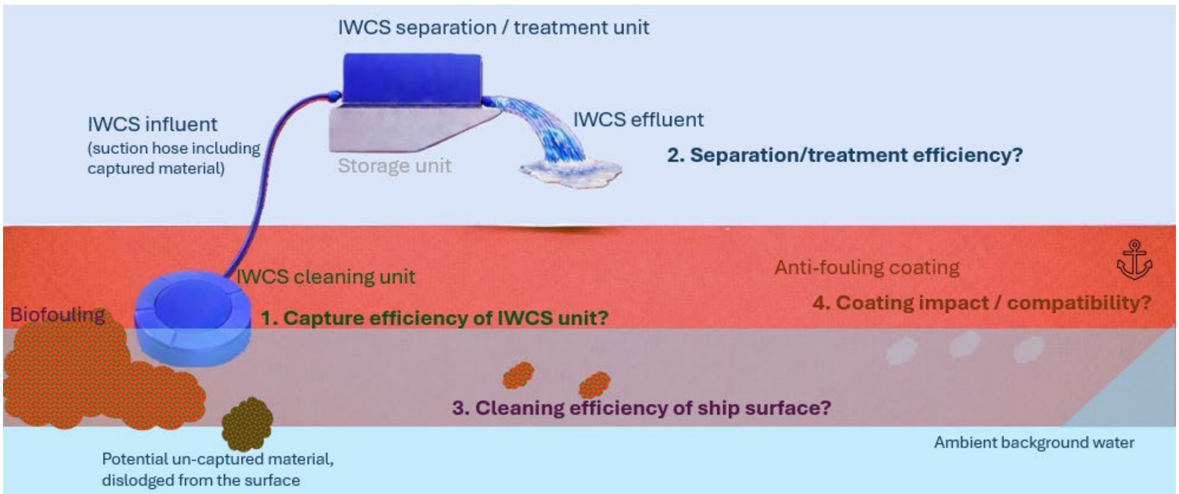


Figure 0-1 Target testing area (Source: the GSP project)

Ex-situ test procedure

The procedure emphasises controlled conditions for ex-situ testing by recommending the use of dedicated seawater tanks to assess capture efficiency and separation/treatment efficiency. Three replicate ex-situ tests in a 60m^3 tank are suggested for the assessment of biofouling capture. Test plates of at least 10 m^2 size without anti-fouling coatings are to be cultivated with natural biofouling and immersed in these tanks, or alternatively, simulated biofouling materials may be used. Analysis of total non-captured material in terms of particulate organic content (POC), inorganic particles, total suspended solids (TSS) are specified as key parameters for evaluating capture efficiency. The same parameters are analysed in influent and effluent water to assess the separation and treatment efficiency. Analysis of particle size distribution (PSD) is added as indication of filtration performance.

By testing across various levels of biofouling growth, ex-situ testing can also be suitable for evaluating various cleaning tools or settings to evaluate cleaning efficiency and the corresponding capture performance of each tool.

A separate test set-up of at least three tests in similar or smaller test tanks is suggested for assessment of capture and separation efficiency of coating particles. Test plates shall be used with different anti-fouling coating. Potential pollution from coating can be assessed by monitoring water quality indicators such as POC and TSS, as well as anti-fouling active ingredients (i.e. copper and zinc). The same parameters should be analysed in influent and effluent water to assess the separation efficiency. Presence of any of these parameters near the cleaning unit or in the effluent is an indication of pollution from anti-fouling substances, such as plastic, silicone, biocides etc. Coating plates shall be visually observed for coating damage after the cleaning event is completed. If representative distinct different coatings are applied on test ships, the efficiency of capturing and separating coating particles may also be evaluated during in situ testing. At least one in-situ test should be carried out on a ship equipped with a self-polishing anti-fouling coating containing active ingredients based on copper.

In-situ test procedure

Three in-situ tests should be performed over a period of 2 years on three different ships with representative biofouling with macrofouling at level 2 or more. For each test, it is essential to conduct cleaning operations on hull surfaces under real-world conditions, with a test duration of at least 90 minutes, one full side of a ship, or one complete niche area if relevant.

The cleaning operator should demonstrate that the in-situ result corresponds with the ex-situ test results or demonstrate performance to the satisfaction of the port authority or the delegated third-party verifier. The goal of performing the in-situ tests is to demonstrate variability in operations, applications and environmental conditions that will allow for verification of the IWCS operational capabilities and performance. In-situ shall allow for comprehensive assessment of cleaning efficiency and separation/treatment efficiency but may not be used to assess capture efficiency. During testing, systematic sampling should be performed, including collection of background, influent and effluent water at regular intervals to monitor particulate organic content (POC), total suspended solids (TSS), inorganic particles (TSG), particle size distribution (PSD), metals and any other relevant biocides. The analysis must utilise sample volumes greater than 1 litre, filtered through a 1.2 µm pore size filter, to enable accurate quantification of removal and separation efficiency.

A permit for operation is granted for a period of at least two years, contingent upon a series of successful ex-situ tests and at least one in-situ test. It is important that the cleaning team consistently demonstrate a commitment to safety and work diligently to prevent accidental releases of waste substances. In-water sampling from near the cleaning unit is not included in the procedure due to challenging conditions around the suction unit.

Benchmark test criteria for cleaning systems

Benchmark criteria, as outlined in the procedure, provide a set of reference values and performance thresholds that cleaning technologies should meet or exceed during both ex-situ and in-situ evaluations. These criteria specify acceptable measurable limits based on MEPC.1/Circ.918.

The stated test criteria do not reflect the expected maximum performance of an IWCS, but due to the various uncertainties, the pilot participants concluded that performance of at least 80% capture and 80% separation efficiency should be demonstrated as a benchmark. This will allow analysis method to include a larger sample volume using a 1.2 µm pore size filter. The reduction in accumulated particles within the 10–200 µm size range is expected to exceed 80% when comparing influent to effluent, ensuring efficient removal of the largest particles. For testing in Norway, a stepwise approval was agreed among the pilot participants. By establishing these benchmarks, the procedure ensures that all tested technologies are assessed against consistent and transparent performance metrics, facilitating comparability between different systems and supporting informed decision-making regarding the adoption of cleaning solutions in line with environmental and operational requirements.

The pilot project recommends including ATP measurements in the effluent to study biological activity from organisms >10 µm. This size group (>10 µm) allows large sample volumes and representative sampling. It is recommended to take the results into account while designing the separation unit and when considering including a treatment unit. As practical experience increases, the test criteria may need to be revisited.

Finally, testing should demonstrate cleaning efficiency and all macrofouling must be removed from the surface, with the exception of remaining traces of calcareous skeletons, which are not expected to be eliminated.

For coating assessment, the procedure stipulate test criteria that may be used ex-situ or in-situ. It is suggested that concentrations of coating residuals in background water should not increase by more than 20% . This can be determined by measuring POC, TSS, metals (i.e. Cu), and any other relevant biocides before and after cleaning coated plates ex-situ. Natural leaching should be considered and compensated for. As this may not be demonstrated during in-situ tests, capture efficiency may be demonstrated in other tests. It is expected that the system should achieve at least 80% separation of coating particles (measured as particulate metals and TSS/TSG) to minimise the transfer of coating materials into the aquatic environment. The coating type will influence the process, and sampling and analysis methods may require further development through practical testing.

Finally, it shall be noted that while the latest IMO guidelines and ISO 20679:2025 were taken into account while developing the test procedure, this procedure may be updated over time to be aligned with the most up-to-date IMO requirements as they develop.

Monitoring

In-water cleaning events requires systematic monitoring and reporting, including biofouling levels and operation parameters, to ship and port authorities. The pilot project has therefore established reporting requirements detailed in Annex 2. This ensures transparency, reliability, and ongoing improvement. Monitoring key metrics, biofouling, cleaning efficiency, and technology-specific parameters confirms effective cleaning and capture.

Figure 0-2 Falck Dykk, Submara preparing for ex-situ IWC procedure in WST2 tank at NIVA Solberstrand in 2025. Source NIVA.

1 Introduction

The International Maritime Organization (IMO) has developed guidelines for biofouling management (MEPC.378(80)) and in-water cleaning (MEPC.1/Circ.918) and has also started to develop a legally binding framework, expected in 2029. Guideline MEPC.378(80) outlines operational guidance to ships while the circular MEPC.1/Circ.918 outlines operational guidance for conducting in-water cleaning in an environmentally responsible manner. The guidance for in-water cleaning emphasizes the importance of capturing removed biofouling material and waste substances and includes recommendations for monitoring and post-cleaning reporting.

In Norway, national regulations with the aim to control ships' biofouling to avoid spread of invasive species and minimize pollution in Norwegian waters related to in-water cleaning are expected to enter into force in July 2028.

While waiting for mandatory regulations, the Port of Bergen, the owner of this pilot project, decided to act proactively on the risks associated with in-water cleaning and initiated together with the Port of Oslo a project with DNV in 2023 to develop a procedure for approval of sustainable IWCS, with the aim to approve cleaning providers operating in Bergen and Oslo (hereafter *the Bergen Protocol*[1]). This work was inspired by the Port of Antwerp-Bruges which only permits using approved cleaning systems operated by recognised companies holding a valid port permit.[2]

[1] Procedure for approval of sustainable in-water cleaning systems, DNV report 2023-1116, Rev.0

[2] Underwater cleaning | Port of Antwerp-Bruges

To develop the Bergen Protocol further, a pilot project was formed under the Green Shipping Programme (GSP) with the Port of Bergen in lead. GSP is a partnership programme between private and public actors with a vision for Norway to establish the world's most efficient and environmentally friendly shipping.

The pilot group has carried out pilot tests to gain experience with the Bergen Protocol, while considering the IMO guidance on in-water cleaning (MEPC.1/Circ.918) and the new ISO standard for in-situ testing (ISO 20679:2025).

MEPC.1/Circ.918 outlines in-situ testing for assessing the environmental impact and operational reliability of the IWCS under real-world conditions. However, it does not prescribe a specific test standard, especially not for ex-situ testing. ISO 20679:2025, on the other hand, establishes standardized procedures for performance testing of IWCS. It includes detailed methodologies for evaluating cleaning effectiveness, capture efficiency, and environmental safety through in-situ testing.

1.1 Objective of this pilot

The main objective of the pilot was to establish practical and representative methods for demonstrating efficient capture during cleaning operations. This includes the collection of biological material and paint residues that may be released from the hull, to prevent their discharge into the marine environment. This pilot has particular emphasis on developing a robust ex-situ test method and a fit-for-purpose in-situ test method.

The main body of this report presents the pilot tests, methods and lessons learned. The pilot has examined both ex-situ (controlled environment) and in-situ (cleaning of ships in port) testing procedures, including sampling and analysis of water and material discharges during cleaning operations.

The test procedure is described in Annex 1 and is intended to support cleaning providers operating in Norway and provides a practical framework for independent testing of IWCS.

The pilot group suggests that an IWCS that meets the performance criteria outlined in the test procedure in Annex 1 should be regarded as best available technology in the context of Norwegian regulations. Shipowners are encouraged to select providers that have successfully completed such testing, thereby ensuring that cleaning operations are conducted with minimal environmental impact. Norwegian ports may then have confidence that certified providers are operating within safe and verified limits.

It shall be noted that two areas stand out where additional expertise and data are essential to develop a reliable and practical standard: 1) the testing of coating compatibility in an ex-situ environment, and 2) the assessment of cleaning with capture in niche areas. In-water cleaning without capture was not studied in the pilot but may be subject to a similar test procedure.

It should be noted that the test procedure may require refinement as more experience is gained through practical application and further pilot testing.

It is furthermore acknowledged that in certain cases, cleaning may need to be performed on mature macrofouling where coating impact cannot be avoided. In such cases, advanced capture techniques should be employed to prevent the release of paint particles and biocides. Such advanced capture techniques may also be tested according to this procedure, provided adequate test plates and ships are included in the tests.

2 Assessment of testing IWCS

During the pilot project, the team explored and evaluated various aspects of sustainable in-water hull cleaning, focusing on practical methods to test on environmental impact.

The pilot project covered several critical areas to advance sustainable in-water hull cleaning practices. NIVA undertook two comprehensive practical pilot tests, dedicating several days to the detailed analysis of water quality to assess the environmental impact of the cleaning procedures. Additionally, the project group actively participated in lessons learned discussions, ensuring that collective experiences and findings informed the ongoing refinement of sustainable in-water hull cleaning practices.

These efforts aimed to rigorously evaluate cleaning systems, ensure environmental protection, and support the adoption of best practices within Norway and beyond. The work and lessons learned are described in the following sections as follows:

- ✓ **Ex-situ testing** in controlled laboratory environments measured capture performance and environmental safety.
- ✓ **In-situ testing** evaluated equipment and procedures during actual ship operations for real-world effectiveness.
- ✓ **Monitoring and reporting** practices for tracking of cleaning processes and environmental impact.
- ✓ **Acceptance criteria** and procedures for certifying technologies and providers.
- ✓ **Knowledge sharing** and stakeholder workshops to encourage broader adoption of sustainable practices.

Through pilot testing and collaborative workshops, they gained valuable insights into effective capture techniques, assessed the performance of cleaning equipment, and analysed water quality to measure the potential release of harmful substances. Lessons learned throughout these activities informed the development of robust best practice, including a test procedures and criteria. The findings of the pilot highlight the importance of measurable parameters and representative testing environments in demonstrating environmentally responsible cleaning technologies.

The group reviewed other in-situ experiences, notably the GIA report "Evaluation of Possible Changes to Water Quality as Result of Ship Microfouling Proactive In-Water Cleaning" [1]. The study, which included six IWC service providers, highlighted logistical challenges in conducting such tests. Only two trials were completed using proactive cleaning without capture, including Jotun Hull Skater in July 2024. Jotun's experience from this trial and other trials provided valuable input.

Key lessons from the GIA study emphasised that appropriate data quality requires an appropriate level of understanding, training, preparation, and staffing to conduct the needed biofouling surveys, sample collections, and sample analyses for all forms of IWC under diverse conditions and in various port locations worldwide where cleaning activities may take place. The report concluded that future est plans should be more detailed and prescriptive, including explicit requirements for appropriate staffing, sample collection methods, sample volumes, and sample replication.

Finally, the draft proposal for Norwegian regulations on biofouling management and hull cleaning was considered. In particular, the principle of using the "best available" method played a key role in the evaluations of this working group along with the criteria used to determine what qualifies as such a method.

Figure 2-1. Diver from Falk Dykk, Submara during cleaning of plates in WST2 at NIVA Solbergstrand. Source NIVA.

2.1 Ex-situ testing

The Bergen Protocol for ex-situ hull cleaning, needed to be further developed and validated through detailed parameter analysis to ensure robust assessment of environmental safety and system performance. Controlled tests may measure the systems' ability to capture released fouling but to confirm these methods, NIVA conducted an ex-situ pilot test at Solbergstrand research station to evaluate equipment effectiveness and compliance with IMO guidelines for in-water cleaning (MEPC.Circ.918).

2.1.1 Ex-situ pilot test arrangements and planning

The main objective of the pilot ex-situ test was to analyse a comprehensive range of water quality parameters both before and after cleaning, to evaluate the effectiveness of the cleaning with capture. The primary focus was to identify measurable parameters that can reliably document any materials released from the surface during cleaning which were not captured by the cleaning system. Differences in parameter values measured before and after cleaning were assessed to determine their suitability as indicators of potential non-capture. The results were also used to recommend parameters and sampling points for future tests.

The sampling plan was developed with consideration to the available resources and the intended learning outcomes of the project.

Measured Parameters:

- ✓ **Visual Documentation:** Photographs of plates before and after cleaning.
- ✓ **ATP:** adenosine triphosphate as an indicator of viable organisms in water
- ✓ **TOC:** Total organic carbon.
- ✓ **TSS:** Total suspended solids.
- ✓ **TSG:** Total suspended glow residue is a quantification of non-organic solid material

- ✓ **POC:** Particulate organic carbon
- ✓ **DOC:** Dissolved organic carbon
- ✓ **Temperature, salinity and pH:** background parameters

TOC and DOC were measured to provide a supplementary parameter for particulate organic carbon by subtracting DOC from TOC, which is denoted as TOCp, and should be equal to the measured POC. In a similar manner TSG can be subtracted from TSS to give particulate organic matter and is denoted as TSOP. Analysis of metals was not relevant for the ex-situ tests, as the paint used did not contain any metallic components.

Optional analyses were also considered, such as measuring zinc release from sacrificial anodes and testing for heavy metals from the coating. These were identified as relevant for separate studies of potential discharge of coating particles but were not included in the routine sampling for this pilot test since the plates were not coated with an anti-fouling coating.

2.1.2 Ex-situ pilot testing environment and technology

Located on the Oslofjord near Drøbak, the facility offers advanced infrastructure for marine and freshwater research, including specialized laboratories and equipment for testing water treatment technologies, aquaculture, and environmental stressors. NIVA arranged for a crane to lift the steel plates from the incubation tank to the test tank. The crane was operated by a certified driver, following the company's safety procedures for handling heavy loads.

The hull cleaning was provided by Falck Dykk, part of Submara. Falck Dykk is a company specializing in in-water cleaning services. They installed their in-water cleaning and capturing system next to the test tank. The system, equipped with brushes and suction units to remove fouling and capture debris, was operated by a Falck Dykk diver, while a dive leader supervised the dive from the Falck Dykk car positioned beside the tank. Falck Dykk treats the captured water by filtration including a sediment tank before discharging treated effluent back into the sea. All wash water and removed material were collected for analysis to verify capture efficiency.

The setup at Solbergstrand consisted of the following:

Steel plates: Four steel plates, each measuring 2 × 5 meters and 5 mm thick were prepared to simulate a ship surface for biofouling accumulation. The plates had applied non-antifouling paint to allow quick biofouling growth and were placed in dedicated biofouling growth tank for approximately one month. The two plates with most biofouling were used at the test with the remaining plates kept as backup. On the test day, the plates were transferred one at a time to the test tank providing a test surface for two separate test runs. Figure 2-2 show test Plate 1 prior to IWC treatment, Figure 2-3 show Plate 1 after IWC treatment with soft brushes were macrofouling is still present. After observing this the next plate was cleaned with hard brushes and this gave the results shown in Figure 6.

Figure 2-2. Picture of Plate 1 prior to treatment in WST2. Macro biofilm (visible green and brownish threads and spots) covers 20-30 % of surface. There were 50-100 blue mussels per plate. The macrofouling coverage was estimated to be >1% of the plate's surface, i.e. biofouling rating "2" according to IMO. Source NIVA.

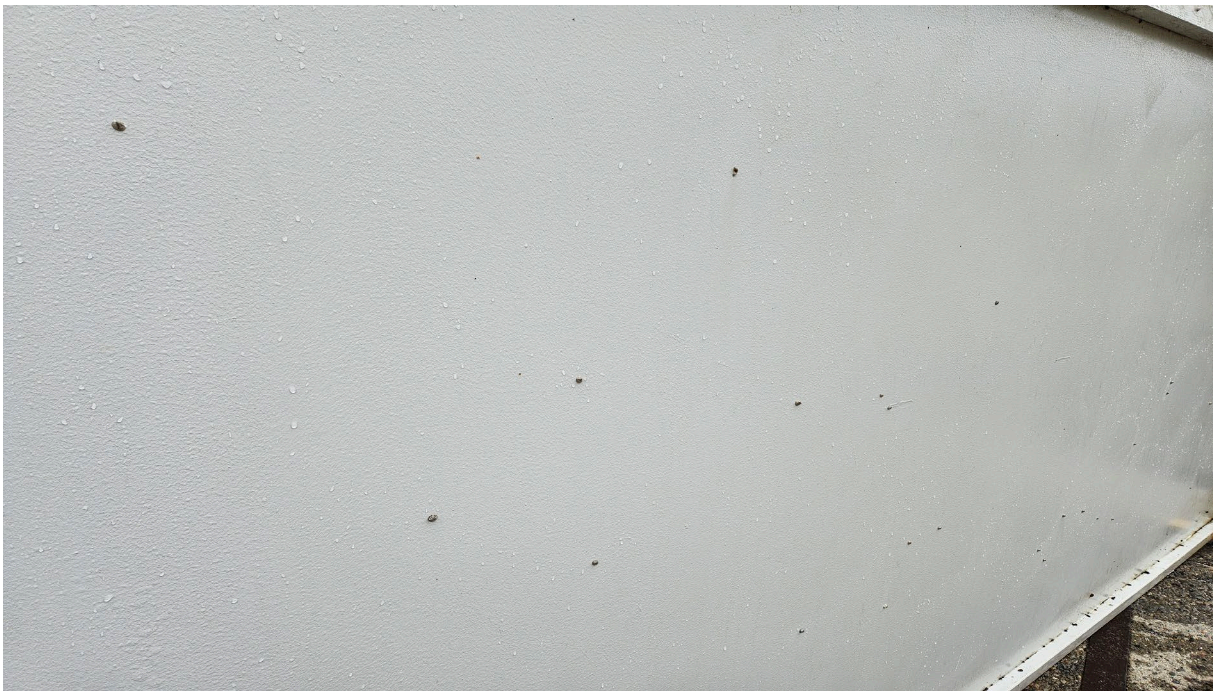


Figure 2-3 Plate 1 after cleaning with soft brushes, the small objects left are blue mussel and barnacles left after cleaning. Source NIVA

Figure 2-4 Plate 2 after cleaning with hard brushes, almost all of objects has now been removed. Source NIVA

Biofouling growth tank (WST3): The WST3 tank (180 m^3) was used for pre-conditioning steel plates in natural seawater to promote biofouling development. It was filled with a mixture of surface water, rich in plankton, and deep water, high in nutrients. Regular water changes and nutrient additions ensured optimal conditions for growth.

Test tank (WST2): This tank (60m^3) was used for cleaning operations. During testing (see Figure 2-5), the steel plates were transferred here and submerged in clean deep seawater sourced from a 60-meter intake. Using deep seawater ensured minimal plankton and suspended particles, providing a stable and controlled environment for evaluating the hull cleaning system's performance without interference from additional fouling or debris. Ideally, the test water in WST 2 would be changed between the two test plates, providing clean conditions for each test run. To save time, the water was kept but sampled for a new baseline before cleaning of the next plate. I.e. S3 from plate 1 equals S1 for plate 2.

Water samples of the test tank were taken at key stages throughout the test (before plate insertion, after insertion, after cleaning) and analysed for ATP, TSS, TOC, DOC and POC. ATP was sampled at S1 and S3 only.

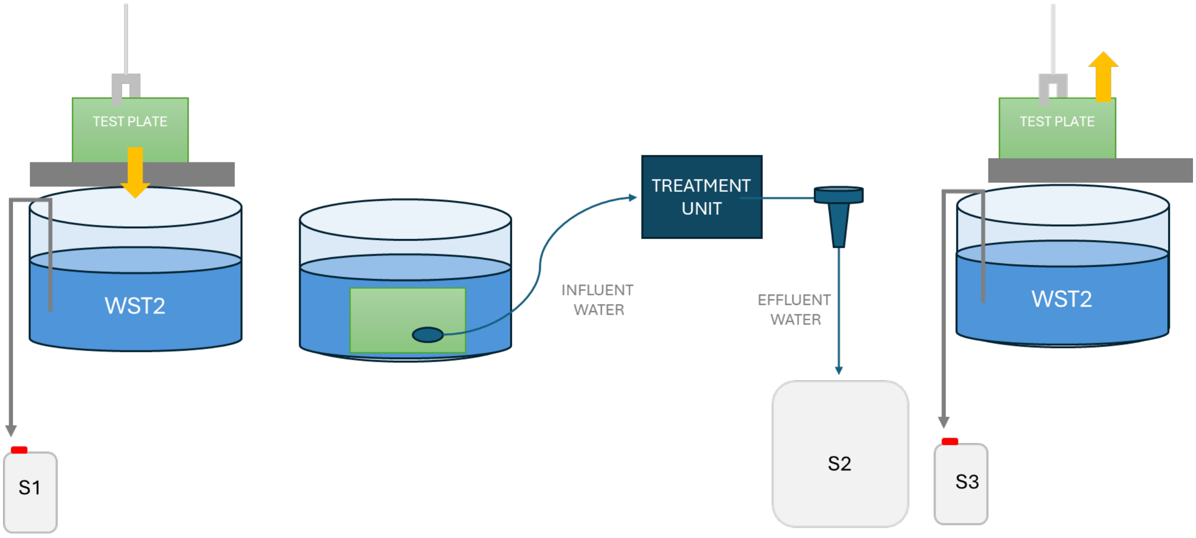


Figure 2-5. Experiment set-up. Green rectangular = test plate. Sampling points in grey: S1-S3. Yellow arrows: scraping samples. Illustration by Susan Skogtvedt Røed, NIVA.

Additional measurements included visual documentation (pictures) of plates, scrape sample from the plates (before/after cleaning) for analysis of dry weight (TSS), flow and pressure of wash water and effluent from the capturing system. The procedure emphasized minimizing contamination and ensuring repeatability.

2.1.3 Ex-situ pilot test execution

The test began with a kick-off meeting involving all personnel, where roles, responsibilities, and detailed risk assessment were reviewed to ensure safe execution. Following this meeting, preparations for installing the sampling ports and setting up the cleaning equipment were initiated. The hull cleaning system was prepared and operated according to the supplier's standard procedure with cleaning of 2 plates (2 sides), totalling 40 m^2. Each plate (2 x 10m^2) was considered as one replicate.

The sampling points were distributed as follows:

Baseline Sample (S1-a): A background water sample was collected from the WST2 test tank before any plates were introduced. This served as a reference for ambient water quality. Three replicate samples (20 L each) were taken from different depths using a siphon, while maintaining gentle water circulation. Subsamples (1L) were allocated for ATP, TOC, POC, DOC and TSS analyses.

Effluent Sample (S2): Collected after IWC treatment to verify removal efficiency and compare with influent and background water quality. I.e. treated water that in a real scenario will be released back into the sea water. Subsamples (1L) were allocated for TOC, POC, DOC and TSS analyses.

Sample of non-captured material (S3): Collected in the remaining water in WST2 after completion of cleaning. Three replicate samples (20 L each) were taken from different depths using a siphon, while maintaining gentle water circulation. Subsamples (1L) were allocated for ATP, TOC, POC, DOC and TSS analyses.

Scrape Samples (Plates): Before and after cleaning, scrape samples (20 × 20 cm) were taken from the plates for ATP and TSS analyses. Three samples per plate were collected pre-test, and six samples planned post-test from random locations. However, during scrape sampling of pre-test it was observed that significant amounts of biofilm were left after scraping prior to cleaning and areas which were cleaned had no visible biofilm left. It was therefore concluded that these samples may be omitted in future tests.

During cleaning of the last 10 m^2 of Plate 2, an incident of miscommunication led to no collection of the waste. Therefore 50% of all biofoulings removed from this plate were released to the tank water.

Ideally, the test water in WST 2 would be changed between different plates. To save time, the water was kept but sampled for a new baseline before cleaning of the next plate. I.e. S3 from plate 1 equals S1 for plate 2.

2.1.4 Ex-situ pilot test – results

All samples were analysed for ATP (viable organisms), TOC, POC, DOC, and TSS. The pore size of filters used were GF/F (i.e. 0.6-0.8 µm) for POC, DOC and TSS analyses. Filter size for ATP followed the recommendations from the instrument supplier for each fraction, i.e. 0.2 µm for bacteria and 10 µm for the >10-50µm fraction.

The results from the analysis conducted are presented in Table 2-1- Table 2-9

Table 2-1 ATP (bacteria: pg/100 ml), fraction >10µm (pg/ml) measurements for in-situ tests. Sample volume 100 ml. Measured according to Luminultra method for ballast water samples.

Sample/replicate	1	2	3	Average	Stdev
			Plate 1		
S1 Bacteria	149	186	258	198	55
S3 Bacteria	187	206	183	192	12
S1 >10µm	10	18	22	17	6
S3 >10µm	31	36	35	34	3
			Plate 2		
S1 Bacteria	135	206	153	165	37
S3 Bacteria	144	132	132	136	7
S1 >10µm	24	22	56	34	19
S3 >10µm	30	40	45	38	8

ATP was measured in filtered samples (0.2 µm; bacteria and biofilm organisms >10 µm, Table 2-1). The bacteria samples gave more variable ATP results with higher stdev, than >10µm samples. There was a 100 % increase in S3 (34 pg/ml) compared to S1 (17 pg/ml) for plate 1 (size fraction >10µm). For Plate 2, S1 (34 pg/ml) has, as expected the same value as S3 Plate 1, however S3 Plate 2 only show a small increase to 38 pg/ml, which is less than expected. In general, the ATP results showed high stdev which makes the results rather insensitive regarding detecting changes in release of viable matter to the surrounding water during IWC treatment. Structured microbial, including those well below 10 µm, become embedded within a cohesive extracellular polymeric matrix. This matrix functions as a molecular glue that binds cells together and even formation of multicellular, matrix-encased aggregates substantially larger than their individual microbial constituents that may exceed 10 µm in size. This means that when samples are filtered using a >10 µm filter, such aggregates will not necessarily pass through and smaller organisms might therefore be included in the >10 µm fraction [3].

Using the >10µm fraction also allow a higher sample volume which ensure a more representative sample.

Table 2-2 Dissolved Organic Carbon - DOC mg/l measurements. Sample volume 100 ml. Measured according to NS-EN 1484-1997.

Sample	1	2	3	Average	stdev
			Plate 1		
S1 DOC	1.3	1.2	1.2	1.2	0.06
S3 DOC	1.2	1.2	1.1	1.2	0.06
			Plate 2		
S1 DOC	1.2	1.1	1.2	1.2	0.1
S3 DOC	1.2	1.2	1.2	1.2	0

DOC results are presented in Table 2-2. As the aim of this study is to observe changes in organic particles, the results for DOC are only useful for the purpose of estimating particulate organic carbon by subtracting DOC from Total organic carbon (TOC) results in Table 2-3, which then give the results for particulate TOCp in Table 2-4. TOCp also have a very high stdv, however regarding S1 and S3 levels for plate 1 and 2, they increase in a relative manner that is consistent with other measured parameters i.e. POC, ATP. However, when comparing TOCp with POC as shown in Table 2-6, TOCp deviate significantly both negatively and positively, and therefore TOCp is not considered a reliable parameter to be used in the context of IWC testing.

Table 2-3 Total Organic Carbon - TOC mg/l measurements. Sample volume 100 ml. Measured according to NS-EN 1484-1997.

Sample	1	2	3	Average	Stdev
			Plate 1		
S1 TOC	1.0	1.1	1.6	1.2	0.3
S3 TOC	1.6	1.3	1.4	1.4	0.3
			Plate 2		
S1 TOC	1.7	1.4	1.3	1.5	0.3
S3 TOC	1.5	1.9	2.1	1.8	0.3

Table 2-4 Total organic carbon particulate TOCp= TOC-DOC mg/l measurements equal to Particulate Organic Carbon - POC. Sample volume 100 ml. Measured according to NS-EN 1484-1997.

Sample	1	2	3	Average	Stdev
			Plate 1		
S1 TOCp	-0.3	-0.1	0.4	0.0	0.4
S3 TOCp	0.4	0.1	0.3	0.27	0.15
			Plate 2		
S1 TOCp	0.5	0.3	0.1	0.3	0.2
S3 TOCp	0.3	0.7	0.9	0.63	0.3

[3] Ragupathi, H., Pushparaj, M.M., Gopi, S.M. *et al.* Biofilm matrix: a multifaceted layer of biomolecules and a defensive barrier against antimicrobials. *Arch Microbiol* **206**, 432 (2024). https://doi.org/10.1007/s00203-024-04157-3

POC in Table 2-5, indicate a 130 % increase in POC in S3 relative to S1 for Plate 1 and similar increase of 80 % for Plate 2. Theoretically S3 for Plate 1 should be roughly equal to S1 for Plate 2 and considering the observed stdev this seems to be the case. Increasing the sample volume for POC measurements would improve the reliability of this parameter and make POC measurements a useful tool for IWC testing.

Table 2-5 Particulate Organic Carbon - POC µg/l measurements. Sample volume 1000 ml. Measured according to NIVA method G6-2.

Sample	1	2	3	Average	Stdev
			Plate 1		
S1 POC	47	34	39	40	6.6
S3 POC	109	82	84	92	14
			Plate 2		
S1 POC	82	91	76	83	8
S3 POC	134	158	155	149	13

*Table 2-6 Comparison between TOCp and POC mg/l. % difference is TOCp/POC*100.*

Sample	TOC-DOC	POC	Diff TOCp-POC	% Difference
S1 TOCp	0.0	0.040	-0.04	-100
S3 TOCp	0.27	0.092	0.175	190
S1 TOCp	0.30	0.083	0.217	261
S3 TOCp	0.63	0.149	0.484	325

TSS in Table 2-7 and Total suspended glow residue (TSG) in Table 2-8 originates from the same water sample. The TSS analysis collects all particles in the water sample onto a 0.2 µm pre-weighed filter which is then dried and weighed. Weight of filter after combustion is TSG, i.e. in-organic material. Weight of organic particles (TSOP) is then equal to the difference between TSS and TSG and is presented in Table 2-9. Both TSS and TSG results show increase from S1 to S3 for both plates and the increase for Plate 2 is higher than for Plate 1 in accordance with that no capture of washed particles was performed for one side of Plate 2. Generally, stdv is high for both TSS and TSG, but it is not reflected in estimated TSOP. A more robust assessment could be achieved by increasing volume filtered and increasing pore size of filters to 1.2 µm. Increasing the volume filtered also makes each sample more representative.

Table 2-7 Total suspended solids TSS mg/l measurements. Sample volume 1000 ml. Measured according to NIVA method NS-EN 4793 and NS-EN 872.

Sample	1	2	3	Average	stdev
			Plate 1		
S1 TSS	4.7	3.6	3.4	3.9	0.7
S3 TSS	2.9	6.1	4.2	4.4	1.6
			Plate 2		
S1 TSS	2.9	4.4	5.0	4.1	1.1
S3 TSS	5.5	4.7	6.6	5.6	1.0

Table 2-8 Total suspended glow residue mg/l measurements. Sample volume 1000 ml. Measured according to NIVA method NS-EN 4793 and NS-EN 872.

Sample	1	2	3	Average	stdev
			Plate 1		
S1 TSG	1.9	1.4	1.2	1.5	0.4
S3 TSG	<0.9	3.3	1.9	2.0	1.2
			Plate 2		
S1 TSG	1.0	2.0	2.5	1.8	0.8
S3 TSG	2.6	2.1	3.4	2.7	0.6

Table 2-9 Total Suspend Organic Particles (TSOP mg/l) is derived by subtracting TSG (Table 2-8) from TSS (Table 2-7). Sample volume max 1000 ml. Measured according to NIVA method NS-EN 4793 and NS-EN 872.

Sample	1	2	3	Average	stdev
			Plate 1		
S1 TSOP	2.8	2.2	2.2	2.4	0.3
S3 TSOP	2.0	2.8	2.3	2.37	0.4
			Plate 2		
S1 TSOP	3.0	2.4	2.5	2.30	0.3
S3 TSOP	2.9	2.6	3.2	2.9	0.3

2.1.5 Lessons learned and insights gained from the ex-situ pilot test and experiences

The practical and technical challenges encountered during ex-situ pilot testing led to lessons learned and insights that are useful for future projects. Prior to conducting the tests, a preparatory meeting was held, and a test plan was developed by NIVA to guide the process and ensure clear objectives and procedures.

Test plates

Allowing biofouling to regrow adequately requires about a month and relies on maintaining proper environmental conditions, as well as the season. Still, using actual biofouling offers a test with genuine organisms, a range of species, and authentic "attachment strength." This results in a realistic mix of various life forms. Additionally, the extent and type of biofouling can be adjusted to align with the specific claims made by cleaning companies.

The steel test plates required strict safety precautions during handling, as each plate weighed approximately 300 kg. The first test had to be cancelled due to strong winds because lifting the plates under those conditions was considered hazardous. Hence, we recommend setting aside a few days for testing in case of high winds.

Conducting the scrape test proved problematic, as it was nearly impossible to collect biofouling samples without also removing paint from the steel plates. Furthermore, the distribution of biofouling was inconsistent and patchy, making it difficult to obtain representative samples. As the scrape test did not yield the intended results, it is concluded that this test is not necessary for future procedures.

It is not necessary to include control plates, although a validation of the ratios between tank volume, biofouling level and sample volumes needs to be validated to verify if the methodology can detect if >20% material is not captured.

Sampling

The cleaning operation only takes a few minutes. With real biological fouling, the number of trials is limited. Hence, detailed planning and good communication with all partners involved is very

important. Clear communication with the dive leader or ROV pilot and the sampling responsible should be ensured before and during the trials.
The sample volume should be large enough to provide representative results. The exact size will depend on e.g. number of samples, amount of biofouling on the test plates and background levels. An increased pore size when samples are filtered will facilitate the filtration of larger volumes of TSS analyses and should also be considered before future tests.

Heavier particles (biofouling) fell to the bottom, and we recommend a visual inspection of the tank after each IWC test collect any particles on the bottom of the tank. The collected material should be dried and weighed and added to the mass remaining in WST2 after cleaning operation. The particles, when collected, should be considered as mass not captured by the system.

Analysis

Overall, the important parameter to investigate in IWC cleaning is whether the IWC equipment can collect particles that are dislodged from the plate or not. Any kind of particle of a certain size not collected represent a risk of spreading viable organisms. Hence, to make sampling and analyses easier (and cheaper), it is better to focus on sampling of particles in general and not the specific kind of particles. We suggest that TSS is used to achieve this, and preferably in combination with POC and inorganic matter (equal to TSG). DOC (<0.2µm size fraction) will be excluded from the list of analytical parameters.

Spread of bacteria, viruses, fungi, microscopic algae and single-celled parasites are identified as a threat to the environment[4], however, although the emphasize is to collect biofouling particles >10 µm some organisms <10 µm will probably also be collected due to that they are imbedded in a multicellular, matrix-encased aggregates. It is expected that an efficient cleaning system readily captures these smaller organisms, as well as the larger organisms that pose more of a challenge.

In the separation or treatment unit, the presence of small, viable organisms can be problematic if dispersed in the water. It may be relevant for the test procedure to include sampling at S3/S4 to assess treatment efficiency, for example, by using UV treatment of the water. By incorporating these additional sampling points, it becomes possible to evaluate how effectively the treatment stage removes or inactivates smaller organisms, ensuring a more comprehensive assessment of the system's overall performance.

The ATP kit used for analyses is designed towards ballast water treatment testing. The method is suitable for soft, gelatinous plankton (size fraction 10-50µm). It is believed to be less suitable for extracting ATP from hard, sessile organisms with shells. Also, the samples from IWC testing will/can contain fragments of/organisms >50µm such as algae and small animals.

Evaluation of performance

For capture efficiency, it may be possible to find the mass of particles that are not captured by the system The increase of particles in the water tank after cleaning, and particles collected should be compared. Furthermore, an evaluation of the water tank concentrations may be used to find if there is a statistical increase after cleaning. Standard deviation from the measurements should be considered when evaluating a potential significant difference between the concentrations before and after cleaning. This statistical consideration is essential for verifying that any observed changes are not simply due to natural variation in the data but instead reflect a genuine effect of the cleaning process. A 20% increase when the natural variation has been accounted for is regarded as indicating

[4] Eugene Georgiades, Chris Scianni2 , Ian Davidson, et.al; Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges, Frontiers in Marine Science, 2021 URL=https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2021.660125

insufficient capture. In other words, if the concentration of particles or contaminants rises by more than 20% after excluding any expected variability, it suggests that the system has not effectively captured or removed the material as required by the procedure. It was agreed to specify test tank volume, sample volumes and test surface requirement to give statistical relevance.

To assess capture efficiency, it is recommended to focus solely on quantifying the mass of particles that are not retained by the system. Instead of relying on concentration measurements before and after cleaning—which can be misleading, especially when background levels are very low and small fluctuations may appear statistically significant—it is more robust to directly compare the mass of particles collected with the mass of those remaining in the tank after cleaning. This approach eliminates the risk of unfair performance criteria arising from negligible changes in concentration and ensures practical relevance in the evaluation.

Therefore, concentrations should not be used as an analytical parameter in this context. Only the actual particle mass should be used to determine system efficiency, providing a clear and reliable basis for assessment regardless of background levels. This conclusion supports fair and accurate performance evaluation of the cleaning process.

To assess capture efficiency, it is recommended to focus solely on quantifying the mass of particles that are not retained by the system. Relying on concentration measurements before and after cleaning can be misleading, especially when background levels are very low and small fluctuations may appear statistically significant. Only the actual particle mass should be used to determine system efficiency, providing a clear and reliable basis for assessment regardless of background levels.

A 20% increase in the number of particles is considered significant when natural variability has been properly accounted for because it represents a change that is unlikely to occur due to random fluctuations in the data. In other words, if, after considering the standard deviation and inherent variability in the measurement process, the average concentration or mass of particles rises by more than 20% following cleaning, this suggests that the system has not effectively captured or removed the material as required. Such an increase exceeds what would be expected from natural variation alone and therefore indicates insufficient capture efficiency. This threshold ensures that the evaluation is both statistically meaningful and practically relevant, helping to distinguish genuine shortcomings in the cleaning process from mere noise or background variation.

For separation efficiency, it may be possible to compare particle concentrations in the influent and effluent to the separation/treatment. During the pilot tests, the IWCS used sedimentation and filtration to separate particles from the influent. The influent was not sampled but it was agreed that it is possible to arrange a side stream of this influent to collect a continuous sample. Another preferred alternative would be to collect the influent in a clean tank for later sampling from a homogenized volume.

The samples should be labelled S1-S4 and harmonised between ex-situ and in-situ.

Ex-situ testing could also be suitable for evaluating cleaning efficiency by visual examination of the plate before and after cleaning. Cleaning efficiency may depend on brush type or water pressure and therefore it might be relevant to evaluate cleaning efficiency on various biofouling levels. If an IWCS provider wants to demonstrate cleaning efficiency on different brush types or water pressure set points, an experimental test set-up needs to be designed using test surface/plates with various levels of biofouling.

Figure 2-6 An IMC Diving diver in process of starting up IWC procedure in Port of Bergen 2025. Source: NIVA

2.2 In-Situ testing

DNV led the work package 2 with the objective to evaluate the in-situ testing procedures described in the current Bergen Protocol against international standards, specifically the IMO *Guidance on in-water cleaning of ships' biofouling* (MEPC.1/Circ.918) and the ISO standard for *Testing of ship biofouling in-water cleaning systems* published in 2025 (ISO standard 20679). This comparison aims to identify areas for improvement and ensure alignment with international best practices.

To gain practical experience and collect relevant data, a pilot test was conducted on the 6th of October 2025 using the ship Viking Neptune, provided by Wilhelmsen as the test object. The cleaning operation was carried out in Bergen harbour and was executed by IMC Diving (Figure 2-6) and ECOsubsea as two separate tests. DNV coordinated the test, with Bergen Havn accommodating at the location, NIVA was responsible for sampling and analysis, while Jotun supplied sampling equipment and expertise on hull coatings. Norwegian maritime authority (NMA) was also part of the working group and actively participated in discussions. Based on the findings from this pilot, the Bergen Protocol has been further developed, see Annex 1. Results and lessons learned from the test are documented and included in this subchapter.

2.2.1 In-situ pilot test arrangements and planning

The number of samples to be collected during the pilot test was evaluated in light of the limited resources available for this phase of the project. One in-situ test in full compliance with the ISO 20679, including three replicates per analysis, adds up to more than 300 samples, with a corresponding very high analysis cost (excluding travel cost, sampling, data evaluation and project management). The evaluation also considered what would be feasible for future approval projects, emphasizing the need to balance scientific rigor with practical constraints related to analytical capacity and cost-benefit. Additionally, various sampling volumes for biology analysis (ATP) was included to evaluate the most suited sampling method.

Due to cost-benefit evaluations microplastics was not included in test, however the group had an understanding that the analysis on metals would provide indications of abrasion of coating during cleaning and thus it is assumed that microplastics is released when these metals are measured (e.g. iron, zinc and copper). To analyse and ensure that microplastics reported comes from the cleaning activity, the type of microplastics need to be specified and analysed. Microplastics is wide range of different plastics with high background variations, and high contamination risk during handling and analyses of samples. Hence, for practical purposes in an in-situ cleaning test, we suggest that microplastics are considered as part of the TSS sample. I.e. high release of microplastics will (to the defined filter size) contribute to TSS (and also to TOC). Nanoplastics comes with even higher uncertainty in background contamination. According to the current minimum performance standard in IMO circular MEPC.1-Circ.918, release of plastic particles <10µm are considered acceptable. Hence, the cost-benefit of analysing micro-/nanoplastics is considered very low. During digital meetings to plan the pilot test, the sampling requirements outlined in MEPC.1/Circ.918, ISO 20679 standard and Bergen Havn Protocol were reviewed and evaluated in relation to the project's learning objectives. The purpose of this evaluation was to determine which parameters and sampling approaches would provide the most relevant insights within the scope of the pilot. Based on this assessment, the project group agreed on a sampling setup.

Samples for the pilot test were collected in accordance with the requirements set out in IMO MEPC.Circ.918, ensuring compliance with international guidance on in-water cleaning of ships' biofouling. The method utilised for sampling followed the procedures described in ISO 20679, employing a time-integrated continuous sampling approach to accurately capture water quality and released materials throughout the cleaning operation.

Measured Parameters during the pilot:

- **Visual Documentation:** Cleaning reports with photographs of ship surface before and after cleaning. Video records.
- **ATP:** adenosine triphosphate as an indicator of viable organisms in water (S1 and S4)
- **TOC:** Total organic carbon for correlation with ATP (S1, S2, S3, S4)
- **TSS:** Total suspended material of solid material on plates and in water (S1, S2, S3, S4).
- **POC:** Particulate organic carbon (S1, S2, S3, S4)
- **DOC:** Dissolved organic carbon (S1, S2, S3, S4)
- **PSD:** Particle size distribution (S1, S2, S3, S4)
- **Metals (Cu, Zn, Ti, Fe):** cupper, zinc, titan, iron (S1, S2, S3, S4)
- **Temperature, salinity and pH:** background parameters

It should be noted that the analysis of microplastics was not included in the measured parameters, although this is required according to IMO guidelines. The IMO also mandates the testing and analysis of organisms; hence, ATP was incorporated as an indicator of viable organisms in water samples.

While ISO standard 20679 does not explicitly require triplicate sampling, this is recommended to ensure statistical robustness and data reliability. For this pilot project, it was agreed that only one replicate would be analysed for each time-integrated sample (0–30 minutes, 30–60 minutes, and 60–90 minutes). This decision reflected the limited analytical resources available for the pilot project and was considered a practical compromise to obtain the most useful information with the resources available.

2.2.2 In-situ pilot test environment and technology

The pilot test was conducted on the ship *Viking Neptun*, which was docked at the cruise ship terminal Skoltegrunnskaia South in Bergen. This is a busy port area with frequent activity from ferries and other ships. Unlike estuarine environments, the port does not experience brackish water conditions or elevated sediment loads. During the test, the water was notably clear with high visibility, providing favourable conditions for both cleaning operations and sampling activities.

Viking Neptun is a three-year-old cruise ship, coated with Jotun SeaQuantum Ultra, which was applied in January 2022. The ship underwent its most recent hull cleaning in November 2024, providing a relevant baseline for evaluating the performance of IWCS during the pilot test.

ECOsubsea specializes in underwater hull cleaning and inspection using remotely operated vehicles (ROVs). For the cleaning on *Viking Neptun* by ECOsubsea, the ROV operations and sample collection of S2, S3 and S4, were carried out from a barge positioned alongside the ship. ECOsubsea conducted their cleaning operation on the hull in the morning on October 6th, 2025. The system has a cleaning unit including capture and a five-step separation progressively finer mesh sizes before discharging it back into the sea.

IMC Diving is a company specializing in in-water cleaning services. To gain experience with in-situ testing in a niche area, the bulb section of *Viking Neptun* was selected for cleaning. IMC Diving operated from the pier, with their equipment and a dive leader stationed onshore at the pier and a diver in the water performing the cleaning. IMC Diving treats the captured water by a five-step filtration including a sediment tank and progressively finer mesh sizes before discharging it back into the sea. IMC Diving conducted the test straight after ECOsubsea had finished their in-situ test on the same day. The background samples (S1) are hence taken with only a few hours in between.

2.2.3 In-situ pilot test execution

The test commenced with a toolbox meeting with the ship crew, during which the necessary ship shutdown procedures were carried out. Following the meeting, preparations for the sampling ports and cleaning equipment were initiated. These preparations took approximately 1.5 to 2 hours per system.

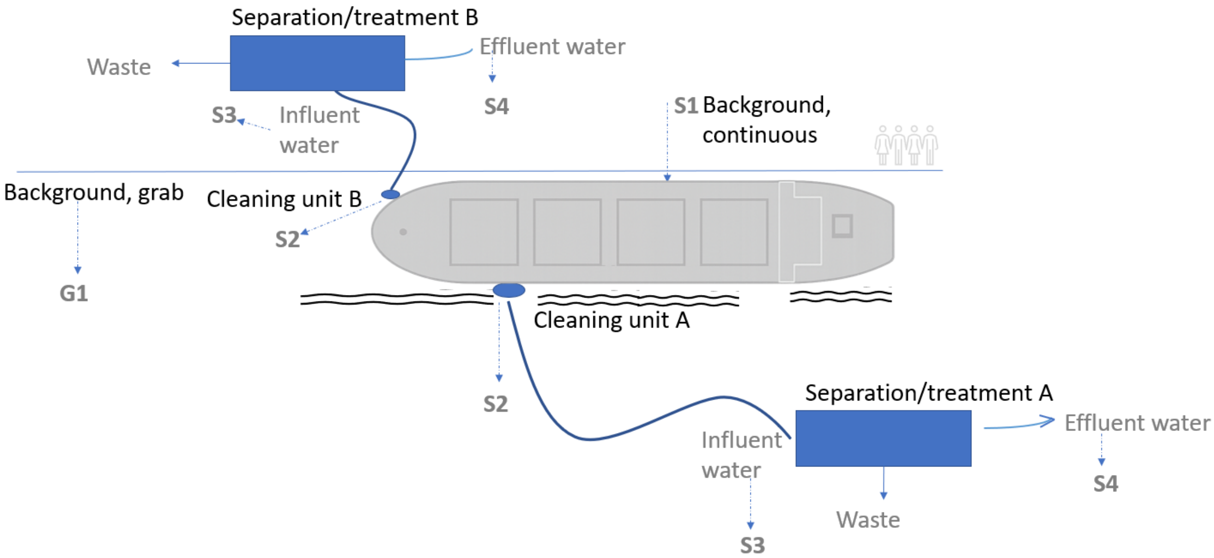


Figure 2-7 Overview of cleaning and sampling arrangements in the in-situ pilot test

The arrangement (see Figure 2-7) and preparation of the IWCS was as per their standard procedures with the sampling points S2 (cleaning unit sample), S3 (influent sample) and S4 (effluent sample) attached as appropriate:

The baseline sample (G1) a background grab sample from surface water was collected approximately one hour prior to the start of the first test and right after test execution. The sample location was close to the pier approximately 40 meters away from any ship.

The baseline sample (S1) was collected to characterize ambient water quality and establish a baseline for comparison against water sampled near the cleaning unit. Continuously, time-integrated sampling was conducted from the pier throughout both supplier tests. The sampling port was magnetically attached a few centimetres from the hull, approximately three meters below the surface, approximately midship and remained in place during both tests without being repositioned.

This location was selected to remain close to the ship's surface to capture any potential passive leaching from the coating; while ensuring it was more than 50 metres away from both cleaning operations. ECOsubsea performed cleaning on the opposite side of the ship, whereas IMC Diving cleaned the bulb and adjacent areas at the bow.

The Cleaning unit sample (S2) was collected to assess environmental release from the cleaning process at its source. Continuously, time-integrated sampling was conducted directly at the cleaning unit during both supplier tests. The sampling port was positioned at the point most likely to capture any discharge from the cleaning activity, following ISO 20679 guidance. The sampling hose, approximately 50 meters in length and 1.2 cm in diameter, was secured to the cleaning unit using cable ties.

The influent sample (S3) collected on the barge during the ECOsubsea test and on the pier during the IMC Diving test, was positioned upstream of the treatment units. Its purpose is to measure the material entering the debris processing system before treatment, providing baseline data for evaluating the efficiency by comparison with effluent (S4) and background water quality (S1), as required by ISO 20679.

The effluent sample (S4)

The pre-test evaluation of the hull was done by the in-water-cleaning supplier by their inspection recorded by camera. The evaluation after cleaning, was performed by using am inspection camera backwards during cleaning.

2.2.4 In-situ pilot test - Data collected and analysis

ATP measurements were only performed on S1 and S4 samples. The purpose was to test whether ATP measurements were able to detect possible release of living organisms during IWC treatment. Specifically, whether the effluent water introduce above background levels of live organisms, observed as an increase in S4 relative to S1. The results are presented in Table 2-10 only for S1 samples.

Table 2-10 ATP measurements for in-situ tests. Sample volume was 100 ml for Bacteria (0.2 µm filter) and 400-1000 ml for >10 µm (10 µm filter) Sample. Measured and presented according to Luminultra method for ballast water samples. Results of cATP bacteria: pg/100 ml), fraction >10µm: pg/ml.

Sample	1	2	3	Average	stdev
			ECOsubsea		
S1 Bacteria	5.86	5.05	3.32	4.74	1.30
S1 >10µm	89	78	85	84	6
			IMC		
S1 Bacteria	2.15	1.90		2.03	0.18
S1 >10µm	151	205		178	38

The DOC measurements in Table 2-11 have low stdev, however show no increase in S2 relative to S1 and small variations in other samples also. In conclusion, DOC is not a parameter to be used in future IWC testing as it does not address the main concern, release of organic particles.

Table 2-11 Dissolved Organic Carbon - DOC mg/l measurements. Sample volume 100 ml. Measured according to NS-EN 1484-1997.

Sample	1	2	3	Average	stdev
			ECOsubsea		
S1 DOC	1.6	1.7	1.6	1.6	0.06
S2 DOC	1.6	1.6	1.6	1.6	0
			IMC		
S1 DOC	1.6	1.5		1.55	0.07
S2 DOC	1.5	1.5		1.5	0.0
Grab Prior ESS	1.4	Grab After IMC	1.4		

As biofilm is mainly built up of organisms of different kinds, and POC was expected to be an important parameter for assessing loss of biofilm particles to the surrounding water. Measured POC is presented in Table 2-12. The lack of observable increase in S2 sample relative to S1 sample is the case for both treatments. The stdev varies a lot, indicating problems gathering representative samples. Increasing sample volume and increasing filter pore size from GF/F to GF/C, would enable larger volumes to be filtered, giving better representativeness.

Table 2-12 Particulate Organic Carbon - POC mg/l measurements. Sample volume 1000 ml. Measured according to NIVA method G6-2.

Sample	1	2	3	Average	stdev
			ECOsubsea		
S1 POC	0.243	0.192	0.183	0.206	0.032
S2 POC	0.201	0.188	0.181	0.190	0.010
			IMC		
S1 POC	0.319	0.263		0.291	0.040
S2 POC	0.376	0.177		0.276	0.140
Grab Prior	0.135	Grab After	0.149		

he TSS sample contains both organic and inorganic material. After combusting the TSS sample, the remaining material represents the inorganic fraction (TSG). The difference between TSS and TSG represents the total suspended organic particles (TSOP). TSS is presented in Table 2-13, and shows a small increase in S2 relative to S1 for ECOsubsea and a significant increase for IMC treatment. As for POC, increasing sample volume and using filters with larger pore size would give more representative samples with lower stdev. Also, TSG (Table 2-14) and TSOP (Table 2-15) shows increases in S2 relative to S1, with IMC being more pronounced than ECOsubsea. The relationship between dry weight organic matter and carbon weight can be expressed as: Carbon weight (C)≈0.4–0.5×Dry weight (DW), therefore TSOP should be approximately a factor 2x the POC values. However, when comparing average values of Table 2-15 with the same values in Table 2-12, the factor ranges 2.8 to 12.5, with factors close to 3 for POC values above 2 mg/l indicating that perhaps POC measurements underestimates actual levels when approaching detection limit. Again, underlining the need for larger sample volumes for POC analysis.

Table 2-13 Total suspended solids TSS mg/l measurements. Sample volume 1000 ml. Measured according to NIVA method NS-EN 4793 and NS-EN 872.

Sample	1	2	3	Average	stdev
			ECOsubsea		
S1 TSS	4	3	2.7	3.2	0.7
S2 TSS	3.2	4.9	3.5	3.9	0.9
			IMC		
S1 TSS	4.1	3.4		3.75	0.50
S2 TSS	6.0	7.4		6.7	0.99
Grab Prior	1.2	**Grab After**	5.4		

Table 2-14 Total suspended glow residue mg/l measurements. Sample volume 1000 ml. Measured according to NIVA method NS-EN 4793 and NS-EN 872.

Sample	1	2	3	Average	stdev
			ECOsubsea		
S1 TSG	1.6	0.8	0.8	1.1	0.5
S2 TSG	0.8	2.5	1.2	1.5	0.9
			IMC		
S1 TSG	1.1	1.0		1.05	0.07
S2 TSG	2.8	4.7		3.75	1.34
Grab Prior	<0.8	**Grab After**	3.8		

Table 2-15 Total Suspend Organic Particles (TSOP mg/l) is derived by subtracting TSG (Table 2-14) from TSS (Table 2-13). Sample volume 1000 ml. Measured according to NIVA method NS-EN 4793 and NS-EN 872.

Sample	1	2	3	Average	stdev
			ECOsubsea		
S1 TSOP	2.40	2.20	1.90	2.17	0.25
S2 TSOP	2.40	2.40	2.30	2.37	0.06
			IMC		
S1 TSOP	3.0	2.4		2.7	0.42
S2 TSOP	3.2	2.7		2.95	0.35
Grab Prior	0.4	**Grab After**	1.6		

Ship coatings may contain copper and zinc, while zinc may be used as corrosion inhibitor, Fe is part of the underlying coating and ship hull. Somewhat surprising S2 is lower than S1 for all metals for both ECOsubsea (Table 2-16) and IMC (Table 2-17) indicating that the S1 sampling water contains metals from the ship coating. Notice that S1 is located between wharf and shipside and may therefore collect from old deposits which is indicated by the high iron values. Very large variation between parallel samples underlines the need for better representative sampling and sample location. Metal levels of copper and titan in Grab After are both higher than Grab Prior in Table 2-17 and Figure 2-8 , which indicates that some fraction of these metals may have been released into the surrounding water during IWC operations, although other harbour activity cannot be ruled out. However, the actual magnitude of this loss cannot be quantified as a percentage relative to the amount removed from the ship's surface.

Table 2-16 ECOsubsea IWC testing. Metal analysis of Cu, Zn, Ti and Fe, both particulate (NIVA method W-SFMS-66A) and dissolved (NIVA method W-SFMS-C).

	Particulate µg/l				Dissolved µg/l			
Sample	**1**	**2**	**3**	**Average**	**1**	**2**	**3**	**Average**
S1 Cu	15.6	17.6	16	16.40	10.8	11.5	13	11.77
S2 Cu	5.57	6.26	14.4	8.74	2.26	3.66	8.16	4.69
S1 Zn	69.3	83	85.6	79.30	61.9	61.2	81.6	68,23
S2 Zn	6.87	7.15	8.73	7.58	6.84	3.72	3.53	4.70
S1 Ti	<1	<1	<1	<1	0.02	0.07	<0.01	0.02
S2 Ti	<1	<1	<1	<1	0.44	0.12	0.16	0.24
S1 Fe	26.9	35	23.3	28.40	4.65	4.7	<4.0	4.68
S2 Fe	<10	<10	<10	<10	<4.0	<4.0	<4.0	<4.0

Table 2-17. IMC IWC testing. Metal analysis of Cu, Zn, Ti and Fe both particulate (NIVA method W-SFMS-66A) and dissolved (NIVA method W-SFMS-C).

	Particulate µg/l			Dissolved µg/l		
Sample	**1**	**2**	**Average**	**1**	**2**	**Average**
S1 Cu	32.3	30.8	31.6	25.3	23.6	24.45
S2 Cu	8.15	16.1	12.1	5.85	7.13	6.49
Grab Cu prior	2.31			1.47		
Grab Cu after	5.09			3.65		
S1 Zn	93.6	90	91.8	85.4	80.6	83.00
S2 Zn	6.8	6.01	6.4	3.59	27.5	15.55
Grab Zn Prior	<4			<2		
Grab Zn After	<4			<2		
S1Ti	<1	<1	<1	0.294	0.0853	0.19
S2 Ti	<1	<1	<1	0.0748	0.268	0.17
Grab Ti Prior	<1			0.153		
Grab Ti After	<1			0.457		
S1 Fe	43.4	42.3	42.9	6.3	5.12	5.71
S2 Fe	<10	<10	<10	<4.0	<4.0	<4.0
Grab Fe Prior	<10			<4.0		
Grab Fe After	<10			<4.0		

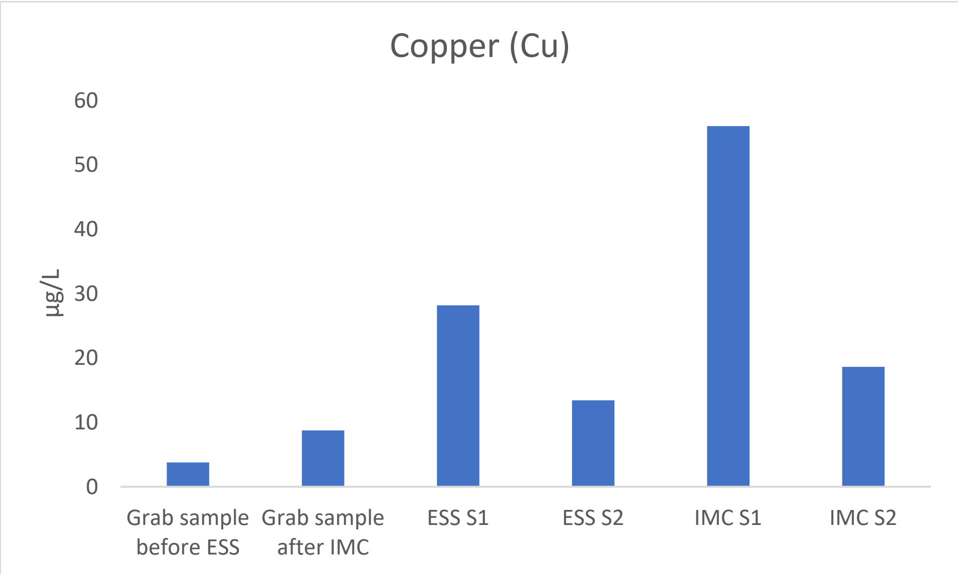


Figure 2-8 Measured total copper (Cu) concentrations in S1 (leakage from hull) and S2 (not captured by the cleaning unit) and grab samples 50m in front of the ship before and after ESS and IMC conducted their IWC tests.

Regarding particle analysis (Table 2-18)) S3 samples (not shown) seem to stand out with the highest value, which is expected of the influent. A S4 sample may be compared with S1 and S2 to evaluate IWCS capacity of capturing particles above given size. The 7-200 µm range was chosen as a conservative approach for the pilot test because the IMO In-water cleaning guidance only allows release of captured particles, including organisms, that are less than 10 µm in all dimensions. It is suggested that future analysis includes a cumulative particle number for a 10-200 µm range. As observed for metals, the S2 samples have lower particle values than S1, however Grab after having higher particle values than Grab prior indicating a release to the surrounding water during the IWC activity.

Table 2-18 Particle size analysis for ECOsubsea and IMC. The table shows the cumulative particles numbers in the size range 7.2 to 200µm and 10-200µm. The analysis was performed with an PCSS Fluid lite particle counter (Marcus KlotZ) and accompanied software at NIVA.

Sample	7-200µm	Stdev	10-200µm	Stdev
ESS S1	265	50	80	17
ESS S2	222	22	72	8
IMC S1	3738	436	1295	184
IMC S2	2493	466	840	202
Grab Prior ESS	132	5	38	11
Grab After IMC	162	3	56	19

2.2.5 Lessons learned and insights gained from the in-situ pilot test and experiences

Overall, the testing proceeded smoothly and according to schedule, with no issues that prevented the completion of operations, including sampling and analysis.

During the project, the group discussed several practical and technical considerations related to in-situ testing of IWCS. It was acknowledged that while Norwegian ports generally have good water quality, cleaning systems must be capable of operating under more challenging international conditions, where filter clogging, component overload and reduced visibility may occur.

The group noted that background water conditions can vary significantly between ports and across seasons, which may affect test consistency. This is based on data collected through NIVA's FerryBox sampling system, which is installed on board some of the Hurtigruten ships. Hence, NIVA could provide and show data for Bergen Harbor throughout the seasons. Additionally, most ships operating in Norway do not have much hard macrofouling, making it difficult to identify suitable hard fouling test subjects. It is assumed that a biofouling level ≤ 2 would be dominating for ships operating in Norway. Despite this, systems should be robust enough to handle heavy fouling when necessary.

Logistic complexity was also highlighted as another challenge, as in-situ testing requires extensive planning and is resource-intensive due to the large number of samples needed for analysis. Cruise ships were identified as the most accessible test objects due to their fixed schedules, although they may not represent the full range of operational profiles of ship subject to the biofouling requirements. Offshore ships, which often remain stationary for long periods, were also considered potential alternatives with a different operational profile.

It was discussed within the project group that a single ship may potentially serve as a sufficient test object in place of three separate ships. This is because different areas of a ship's hull can exhibit varying types of fouling and may require different cleaning brushes. As such, testing on one ship can provide diverse data points across multiple fouling conditions. However, to ensure broader relevance and comparability, it was also noted that if multiple ships are used, they should ideally have different hull coatings, as also outlined in ISO 20679. This would help capture performance variations across coating types and operational profiles as well as the ability to demonstrate separation efficiency from cleaning various coating types.

However, identifying ships with distinct different hull coatings may present challenges. It is advisable to ensure that at least one in-situ test is carried out on a ship equipped with a self-polishing anti-fouling coating containing biocides (as Cu). This particular type of hull coating is known for its potential to release waste substances during cleaning operations.

Because the open environment of in-situ tests introduces variable conditions that hinder comparability and exact data, it would be difficult to standardise coating impact tests between 3 in-situ tests due to the huge variations of coating types, operation profiles, paint application and curing methods and the age of coatings. The group agreed that the risk of paint damage underwater cleaning is not easily evaluated in-situ and therefore suggests that coating-impact assessments should be conducted in controlled and standardized environments. It is recommended that paint manufacturers and IWCS engage in studies to determine the most effective ways to preserve the coating during cleaning operations. Collaboration between these parties will help ensure that environmental impacts are reduced while maintaining the longevity and efficacy of anti-fouling coatings. With a proper way of sampling paint flakes, coating impact can also be evaluated during in-situ.

Capture efficiency of paint particles can be targeted via ex-situ tests, while testing across a matrix of coatings and/or brushes. Separation efficiency of specific coating particles can be standardised via ex-situ or in-situ testing.

MEPC.1/Circ.918 specifies that in-situ testing must be carried out on surfaces of at least three different ships. To ensure statistical reliability and repeatability of results under varying conditions and surface characteristics, three ships should be included in a test procedure without reference to specific coating requirements. Due to variations along the hull in drag etc., certain areas will have more/less antifouling paint released during a cleaning event. Hence, if different areas are supposed to be considered as replicates of each other, they should be from comparable areas from the ship, e.g. water line and deep, “sheltered” areas are most likely not suitable as replicates of each other.

As the hull used for the pilot test was evaluated to have a fouling rating 2 (microfouling with multiple macrofouling patches and macrofouling along the water line), the cleaning operations for ECOsubsea lasted shorter than the planned 90 minutes. During the test, it was decided to shorten the time-integrated sampling for ECOsubsea to three samples of approximately 15 minutes each, instead of the originally planned 30-minute intervals. Due to the speed of the cleaning unit and limited length of the sample hose the accessible cleaning area was completed in 45 minutes. For IMC Diving, the final sampling site was omitted since the diver came close to the no decompression limit (NDL). The bulb and SB thruster area was cleaned and treated as two separate sampling sites. Although the total test duration for ECOsubsea was shorter than for IMC, the ECOsubsea system cleaned a larger area at a higher speed. This indicates that test duration should be accommodate to differences in cleaning speed.

The project sought to incorporate the documentation and quality-assurance requirements set out in MEPC.1/Circ.918 and doing so proved beneficial. Applying these requirements supported appropriate consistency, transparency, and traceability throughout the test reporting process.

Sampling arrangements

The length of sampling hose or flexibility of sampling port S2 movability will restrict the area accessed during cleaning, which in turn affects the ability to meet the required 90-minute duration. While suggestions were made to either reduce the cleaning speed or repeat cleaning over the same area, it was decided to shorten overall cleaning time to align with standard procedures as recommended by the MEPC.1/Circ.918.

During the pilot test, several practical insights were gained regarding sampling setup and coordination. One key observation was that clear communication and coordination were identified as critical success factors. A well-defined timeline and direct communication between the sampling team and the diver/ROV operator are necessary to avoid sample dilution of S2 samples, especially if cleaning operations are paused during testing. It is challenging to document that sampling did not occur while the brush was off the hull, highlighting the importance of close coordination and clear instructions. Physical proximity between the sampling lead and the operator was identified as beneficial for maintaining control over sampling timing.

The importance of selecting hoses with a diameter wide enough to accommodate the expected biofouling was also noted as an important learning. Although clogging was not observed during this test, narrow hoses pose a risk of blockage and may fail to capture larger biofouling particles effectively. Ensuring appropriate hose diameter is therefore essential to maintain sampling reliability and avoid loss of relevant material.

Additionally, long hoses can introduce sampling lag, although this can be mitigated by using hoses with a larger diameter. Hose length for the S2 sample also affects the operational reach of the cleaning unit during the in-situ test and can determine whether a sufficient area can be cleaned for the required 90-minutes —unless, for example, a service boat moves alongside the operation.

The sampling pump should be capable of lifting water all the way to the pier, which is often the most practical location for sample handling. Ensuring sufficient water flow is critical; while excess water can be managed, insufficient flow or clogging can halt the operation entirely. Therefore, hose diameter, hose length, and pump capacity must be aligned with the expected cleaning conditions.

Hose diameter, length, and pump capacity must therefore be aligned with expected conditions to ensure sufficient water flow and avoid operational delays.

A practical consideration is that all sampling ports must be planned in advance by the cleaning provider and approved by the testing or certifying organization. It is not feasible to bring equipment for every possible size and type of sampling ports, making prior planning and agreement essential to ensure a proper setup and data collection. Isokinetic sampling port as per ISO standard 11711-1 (Ships and marine technology — Ballast water sampling and analysis — Part 1: Discharge sampling port) should be used as guidance.

Sampling and analysis results

The study was designed around participation from two IWC service providers, with the aim of examining environmental aspects of IWC rather than evaluating the performance of any specific system or operator. Because the dataset originates from only two identifiable sources, the scope for sharing results in an anonymized or aggregated form is inherently limited.

Sections S3 and S4 are not included in the shared documentation, as the information contained in these sections is considered technology-sensitive and may reveal details that could compromise proprietary system design.

In-situ testing should involve at least three ships to adequately capture operational variability. At the same time, the scope of sampling must be streamlined by focusing only on parameters that directly support the evaluation of cleaning, capture, and treatment performance. Measurements that provide limited value or represent background noise should be excluded to ensure efficient and meaningful data collection.

The ATP method was developed to detect biological concentrations aligned with ballast water discharge standards. During in-situ hull-cleaning operations, however, organism levels often fall outside the method's optimal accuracy range, making ATP less reliable for evaluating cleaning performance. For in-situ testing, particle-based parameters—TSS, TSG, metals/biocides, and POC—provide more robust and meaningful data and should therefore be prioritized.

ATP remains relevant specifically at sampling point S4, where it can help determine whether any viable organisms pass through the separation/treatment unit.

Recommended sampling points for these parameters are G1 (located farther from the ship than in the present test), S1, S3, and S4.

Cleaning efficiency

The cleaning efficiency was evaluated by observing the live video feed from the diver operator or ROV pilot. Comparing views of pre- and post-cleaning surface areas could be used to assess cleaning efficiency. It may prove difficult to evaluate if the observed cleaning fulfilled the cleaning criteria since it is based on the subjective evaluation of the observer. For transparency purposes, representative photos, at least three per area cleaned (before and after) should be attached to the test report. Video recordings should also be available on request.

G1- background grab sample

The G1 sample was intended to characterize ambient water quality in the harbour. The metal concentrations (particular and dissolved Cu, dissolved Ti) in the G1 sample increased throughout the test period with a factor of 2-3 (from grab sample before and after final test; Table 17), indicating that this location was influenced by the ship and the pilot test activities. The POC was 0.135 mg/L before any IWC activity and was 0.149 mg/L after the IWC ended. TSS increased 4.5 times between the measurements while PSD went from 132 to 162 accumulated particles (size fraction 7-200 µm). TSS and PSD may be affected by other activities in the harbour (especially ships passing who may whirl up particles from the bottom or break up larger aggregated particles).

S1 -continuous background sample

Sample S1 was intended to characterize ambient water quality close to the ship hull and establish a baseline for comparison against water sampled near the cleaning unit. However, both our theoretical evaluations and the practical experience during the pilot test showed that identifying a representative and reliable S1 sampling location is highly challenging.

Throughout the test period (from sample ESS S1 to IMC S1) the metal concentrations in the S1 sample increased. Copper doubled in concentration (both filtered and un-filtered fractions), and filtered titan increased four times. Zinc and iron were roughly similar/slight increase. These trends suggest that the semi-closed environment between the ship hull and the pier, and/or changes in current conditions, contributed to the accumulation of naturally leached coating materials. As a result, the S1 location proved unsuitable as a true background reference location. Metal concentrations showed high variation over only a few hours, and tidal currents may also have affected the results, since they decreased between the first S1 and the final S1 sample.

To remain aligned with the MEPC.1/Circ.918, background samples are still required. Therefore, it is proposed to keep the S1 sampling in the procedure for in-situ testing. A background sampling point should be located in an area with environmental conditions comparable to those at the cleaning unit, for example by maintaining a similar distance from the hull, while ensuring it is sufficiently far away to avoid influence from the cleaning activities. This approach is resource-demanding, as the location is separate and requires personnel to operate the sampling port.

A G1 grab sample >50m away from the ship is useful for comparison to see background without interference from natural leaching coating substances.

S2 – Sampling around the cleaning unit

The S2 sampling point was intended to assess environmental release from the cleaning process at its source, positioned to capture discharge from the cleaning activity in line with ISO 20679 guidance. The small diameter of the sampling hose might have discriminated some particles, and the sampling point was unlikely to capture heavier or larger biofouling material released during cleaning. The significant difference in suction capacity between the sampling and IWC capture systems, along with the water jet system flushing surrounding water into the cleaning unit, may impact sampling. Biocide concentrations in S2 samples were indeed generally lower than those observed at S1, which may indicate that the sampling point was not representative or rather measuring the ambient water that flows towards the cleaning unit due to capture effect (i.e. suction). The sampling arrangement is considered unsuitable for obtaining a representative sample, and confidence in these results is low. While an alternative sampling arrangement should be considered, we conclude that obtaining a truly representative sample from the S2 sampling port in an open environment remains challenging. The pilot group concluded that ex-situ testing is more suitable for assessing system capture efficiency.

S3 influent sample

The test results of influent samples revealed relatively high concentrations of metals, with the highest values observed at greater depths below the waterline. This pattern likely reflects ongoing wear around the waterline, which gradually reduces the coating's integrity and lowers metal leaching. In contrast, deeper areas retain better coating and may release more metals during cleaning events. Based on this finding, an assessment of worst-case scenarios with regards to collection of metals should be conducted with tests at lower depths where metal concentrations are more pronounced. It is also important to note that due to the varying initial conditions at each depth, cleaning at three different depths on the same ship cannot be considered replicates for metal analysis. It should also be noted that biofouling was more predominant near the water line.

S4- effluent sample

The findings of high concentration of metals in the effluent suggest that cleaning operations conducted without sufficient separation may result in significant dispersion of copper and other metals into the marine environment. This would of course also be dependent on the softness/hardness of the brush. Given the relatively high and detectable levels of these metals measured at the pilot in-situ test, it is recommended that they be included in future in-situ testing procedures for at least S1, S3 and S4 samples. Based on the results, there seems to be considerable potential for improving the efficiency of metal collection in cleaning systems with capture. Enhancing this capability would contribute to more environmentally responsible cleaning practices.

Optical disturbances from the paint

Underwater lighting was found to cause optical illusions that distorted colour perception, leading to discrepancies between camera images and the actual colour of samples. This often led to uncertainty about which layer of coating was observed. To reduce these inconsistencies, it may be helpful to adjust camera and lighting settings or collect a sample on land for comparison. Having access to the ship's paint specifications proved useful for anticipating the colour layers and interpreting results accurately.

The water samples, particularly the influent, showed visible signs of paint contamination. Concerns were raised about possible paint damage caused by underwater cleaning, but it was not possible to determine from comparing the S3 and S4 samples with S1 samples. It is recommended to develop specific ex-situ-tests to evaluate the impact from cleaning operations on hull coatings.

2.3 Monitoring of cleaning processes

The pilot aimed at creating a standard for post in-water cleaning reporting. A reporting standard was developed by building upon the framework presented in Appendix 2 or the IMO 2023 Guideline (MEPC.380/78), ensuring that monitoring and reporting are consistent with global best practices. By considering industry methods and aligning with the IMO framework, the group finalized a set of reporting criteria detailed in Appendix 2 of this report. The group agreed that the report should include:

1. Ship details and last port of call
2. Antifouling coating and last drydock
3. Details of cleaning provider
4. Tools and cleaning technologies used
5. Cleaned areas
6. Parameters monitored (e.g. flow measurements of suction line, filter performance)
7. Description of any problems encountered
8. Observations of:
    - biofouling levels before and after cleaning to verify cleaning effectiveness
    - Anti-fouling wear/tear or sign of previous damage

According to IMO guidelines, the IWCS system should be equipped with simple and effective means for operation and control. A continuous self-monitoring function should be in place to detect proper functioning or system failures, covering both collection and other related processes. The system must also include facilities to produce records of these functions, such as displaying, printing, or exporting data.

Most IWCS only offer live video feeds for monitoring cleaning efficiency. The pilot team briefly evaluated the potential for using sensor technology during operations to monitor proper capture, waste separation/treatment and discharge operations. The pilot team also discussed the opportunity for having audible and visual alarms presented at the control stations from which the IWCS can be operated. These alarms should signal any malfunction that could compromise the correct operation of the system, e.g. filter failures that may result in unintended discharge of waste materials. Where applicable, the system should include mechanisms to stop cleaning in case of failure.

While ships are required to maintain detailed records of ballast water operations for two years to comply with the Ballast Water Convention, a more practical approach for biofouling management would be to prepare concise reports documenting the latest hull or niche area cleaning as relevant for the next port of call. This could include photographic evidence and a summary of cleaning activities, rather than maintaining extensive operational records over a two-year period.

2.4 Approval processes and acceptance criteria

The pilot project has evaluated the criteria outlined in the IMO guidelines concerning system approval and reporting, with a focus on assessing their relevance and applicability to national practices.

For testing in Norway, it was agreed that a stepwise approval approach should be allowed. The approval process for IWCS should consist of two key steps. An Interim approval is contingent upon a series of successful ex-situ tests and one in-situ test:

1. Ex-situ (land-based) testing: The IWCS must undergo ex-situ tests that clearly demonstrate its ability to capture invasive species and other organic materials. Ex-situ testing is also needed to assess the effects of cleaning on various hull coatings and confirm minimal waste release during the process.
2. In-situ (full-scale) testing: The IWCS must complete one in-situ test conducted under real operational conditions. This test must prove that the system can effectively separate and treat the influent water, show high cleaning efficiency, and maintain operational safety throughout the process.

For full approval on accordance with IMO Circular MEPC.1-Circ 918, it is required to successfully perform three in-situ tests, which the group agreed could be conducted over two years to guarantee reliable and consistent system performance; see Figure 1 below.

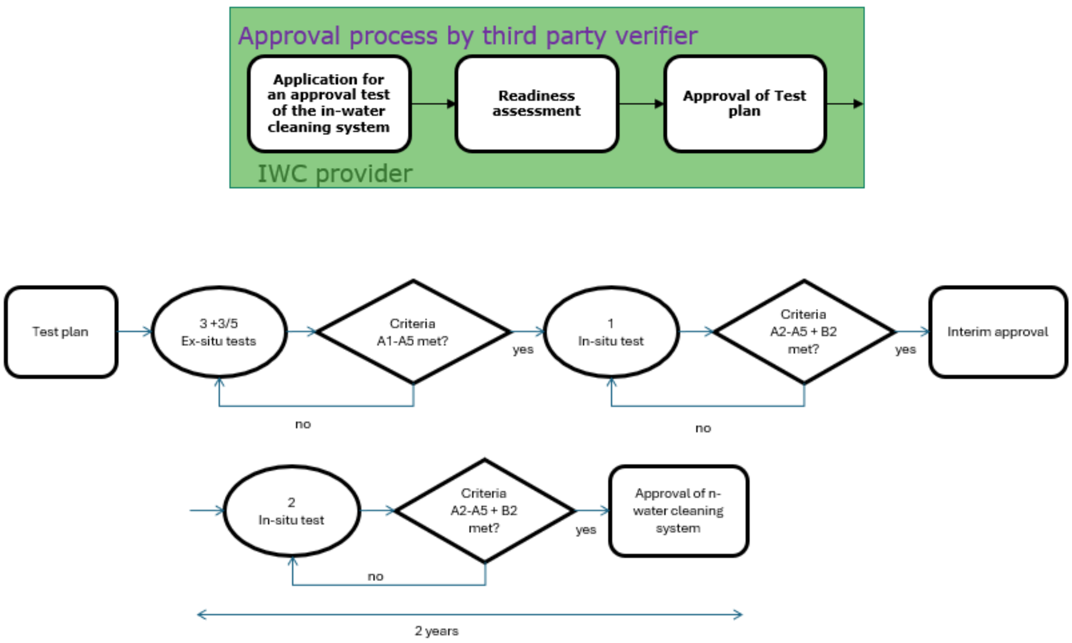


Figure 2-9 Proposed approval and test procedure for an IWCS operated in Norwegian ports

Benchmark test criteria

The group discussed performance standard in IMO Circular MEPC.1-Circ 918 and developed practical criteria for the procedure in Annex 1. It was also acknowledged that capture technologies need to mature in line with new regulations and to encourage investment in capture technologies, clear acceptance criteria need to be established. The pilot group identified five target areas for sustainable in-water cleaning, as presented in Table 2-19.

Table 2-19 Proposed key principles that should be covered by a test category and suggest benchmark tests that should be fulfilled in order to get permission to operate in ports.

Key Principle of protection	Test category	Benchmark Tests
Maximum feasible reduction of organic cleaning debris and waste substances	Capture efficiency Separation efficiency	Three replicate ex-situ tests should be performed with aim to: ✓ Demonstrate efficient capture and minimum release to surroundings. ✓ Demonstrate separation efficiency for minimum pollutants, organisms and other debris in the effluent. Three in-situ tests should be performed with aim to: ✓ Demonstrate separation efficiency for minimum pollutants, organisms and other debris in the effluent.
Minimize live organism release	Treatment efficiency	The above replicate ex-situ and in-situ tests can also be used to demonstrate minimum live organisms in effluent.
Effective biofouling removal	Cleaning efficiency	Replicate ex-situ and in-situ tests should show that cleaning leaves surfaces free of biofouling.
Limit pollutant release	Capture efficiency Separation efficiency	Three replicate ex-situ tests can be performed with aim to: ✓ Demonstrate minimum release of coating particles. ✓ Demonstrate separation efficiency for pollutants in the effluent. OR Three in-situ tests should be performed with aim to: ✓ Demonstrate separation efficiency for pollutants in the effluent.

Based on pilot ex-situ and in-situ test results, the pilot group proposed a set of test criteria. The test criteria are described in section 3.3 of the test procedure in Annex 1.

When a system is approved, the group discussed if it is relevant for IWCS to take samples of the effluent on a regular basis, i.e. self-testing once a year. Self-tests do not require third-party oversight but can offer continuous assurance of system functionality towards ports. These self-tests may form an integral part of the overall compliance assessment; however, it is at the discretion of ports or relevant authorities to request such tests as part of their approval or monitoring process.

ANNEX 1

Green Shipping Programme

Test procedure for in-water cleaning systems with capture

Issued by:
The Green Shipping Programme, February 2026

Project owner: Jørn-Erik Hausmann, Port of Bergen

Authors
Ingrid Sigvaldsen, DNV Maritime Class
Pernilla Marianne Carlsson, NIVA
August Tobiesen, NIVA
Vidar A.T. Thorsen, Norwegian Maritime Authority
Tone Knudsen Fiskeseth, DNV Maritime Advisory

Table of Contents

1 INTRODUCTION

Biofouling is the accumulation of microorganisms, plants, algae and animals on submerged structures in the aquatic environment. The introduction of invasive aquatic species (IAS) to new environments by ships' biofouling has been identified as a major threat to the world's oceans and to the conservation of biodiversity. Biofouling not only facilitates the spread of IAS via ships, but these organisms can also act as pests when released into sensitive environments. Additionally, cleaning fouled surfaces underwater may release harmful substances from anti-fouling coatings, increasing pollution risks.

The Norwegian national regulations for biofouling management will take effect on 1 July 2028. The purpose of this procedure is to ensure that cleaning activities in Norwegian ports are performed by systems which have demonstrated their ability to minimize the risk of releasing potential harmful organisms and substances to the marine environment.

The objective of this test procedure is to define criteria for successful testing of in-water cleaning systems (IWCS) used for cleaning ship surfaces, such as ship hulls, propellers, and surface niche areas. The procedure covers IWCS that perform mechanical removal of biofouling, have a cleaning unit for capturing biofouling and debris dislodged from the ship surface and a separation/treatment unit for managing wastewater before discharged to sea. The procedure does not cover IWCS that have no capture or IWCS that apply treatment to inactivate biofouling without removal from ship surfaces (e.g. treatment in seawater inlets or sea chests). However, such systems may apply this procedure as found relevant. If a port allows cleaning without capture, the biosecurity risk should be evaluated, and the IWCS should demonstrate through testing that chemical risk due to release of AFC residues is minimized.

This procedure identifies challenges with in-water cleaning and describes the principles behind the defined test criteria presented in this test procedure. It also suggests monitoring points to ensure compliance with tested parameters and environmental standards. The procedure does not cover third-party review of design, construction, training, or operation by the IWCS supplier.

The procedure is based on elements from:

1. DNV Report 2023-1116, Rev. 0, Test procedure for in-water cleaning systems with capture of biofouling /1/

- MEPC.1/Circ.918 Guidance on in-water cleaning of ships' biofouling /2/
- ISO 20679 Guidelines for Testing Ship Biofouling In-Water Cleaning Systems /3/.
- BIMCO Approval procedure for in-water cleaning /4/

1.1 Definitions

Anti-fouling coating (AFC) means a surface coating or paint designed to prevent, repel or facilitate the detachment of biofouling from hull and niche areas that are typically or occasionally submerged.

Ex-situ test is laboratory or land-based testing in a controlled environment to confirm that the system meets the test criteria set out in this procedure.

Invasive species are non-native species to a particular ecosystem which may pose threats to human, animal and plant life, economic and cultural activities and the aquatic environment.

In-situ test is full-scale testing of a IWCS carried out on a ship in port to confirm that the system meets the test criteria set out in this procedure.

In-Water Cleaning System (IWCS) is a complete system of mechanical methods to remove biofouling under water (the in-water cleaning unit) and the transport and collection of the biofouling (capture in a separation/treatment unit). It has associated control/monitoring instruments and may also include treatment or shrouding methods to inactivate biofouling organism. The entire IWCS is defined as either a package or a modular system which is subjected for approval testing. An illustration of an IWCS is presented in Figure 1-1 below.

In-Water Cleaning System service provider (IWCS service provider) is an organization that undertakes the planning, conducting and documenting of in-water cleaning operations consistent with the guidance of MEPC.1/Circ.918, which may be a separate organization from the IWCS manufacturer.

Niche area is a subset of the submerged surface areas on a ship that may be more susceptible to biofouling than the main hull owing to structural complexity, different or variable hydrodynamic forces, susceptibility to AFC wear or damage, or inadequate or no protection by marine growth prevention system.

Port authority is the official organization that controls and manages the activities in a port.

Third-party verifier is the verification organization that is delegated by the port authorities to oversee the preparation work and approval tests as well as serving as point of contact for both the service provider and the testing organization.

Testing organization is a third-party laboratory or facility that is independent of the service provider and the manufacturer, vendor or supplier of the IWCS (or its major components) and the coatings being tested and that is approved, certified, and audited by an independent accreditation body to conform to relevant standards (e.g. ISO/IEC 17025).

Representative sampling is sampling that reflects the relative concentrations (biocides and particles) and numbers and composition of the populations (organisms) in the volume of interest. Samples should be taken in a time-integrated manner, and the sampling port should be installed, taking into account ISO standard 20679 and other guidelines which may be developed by IMO.

Sampling port refers to the means provided for sampling treated or untreated water as needed in this procedure.

Successful test isa valid test cycle (where the test organization fulfilled the experimental test requirements) and the IWCS functions to its specifications and treated water is determined to meet the performance criteria described in chapter 3.3.

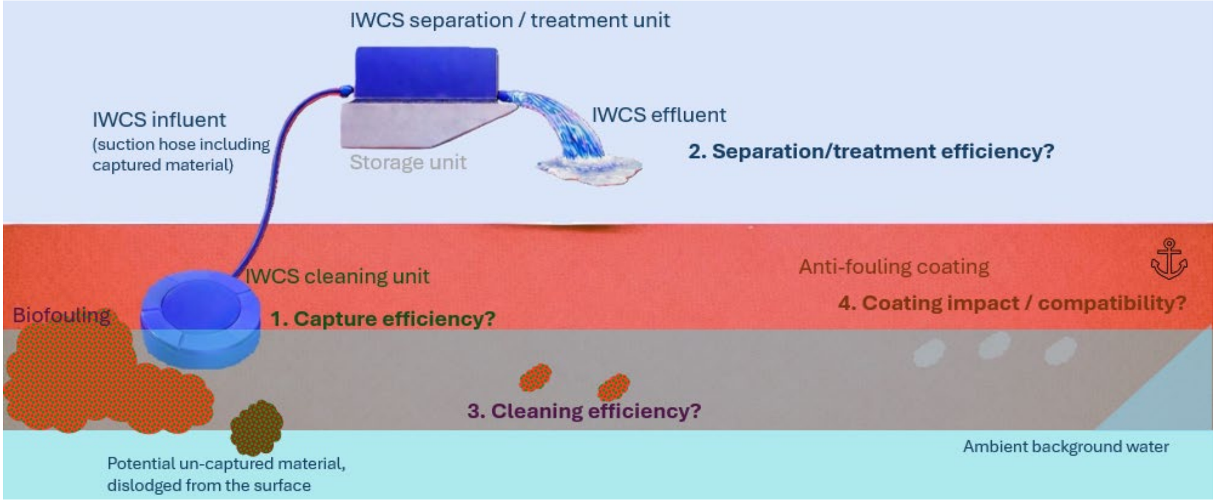


Figure 1-1 Definition of components and elements included in testing of an IWCS

2 Monitoring of in-water cleaning operations

Monitoring during testing provides evidence of IWCS performance, waste capture/treatment, and safety-related functions and should be applied for the duration of the tests to ensure repeatability, traceability, and quality of results.

A continuous self-monitoring function of an IWCS may include several options, for example sensor technologies, cameras and other means of control. Monitoring may include the following parameters:

- Means to inspect the biofouling rating (with rating in accordance with table 1 of MEPC.378(80) on test surfaces before and after cleaning)
- Pressure for water jet
- Brush/cleaning head rotational speed (rpm)
- Monitoring of distance to surface
- Suction/collection influent flow rate
- Effluent/discharge flow rate
- Filtration inlet and outlet pressure
- Differential pressure across filtration units
- Treatment-specific sensors (e.g. UV intensity sensor, temperature) as applicable
- Filter condition indicators (e.g. clogging detection, filter screen rupture/damage)

All relevant operational parameters should be continuously recorded (with synchronized timestamps). Any failure that may lead to accidental discharge of waste substances should lead to a stop in operation. Any system warnings, alarms, or automatic shutdowns should be automatically logged with time, parameter values, and event descriptions. The complete dataset should be included in (or referenced by) the final test report and retained by the testing organization per its quality system.

3 TEST CRITERIA

This chapter identifies the challenges to be addressed through test criteria (chapter 3.1), the principles behind the test criteria (chapter 3.2), and finally the specific test criteria for this procedure (chapter 3.2). The service providers should demonstrate that the IWCS meets the minimum test criteria3.3.

3.1 Identifying the challenges to be addressed through test criteria

To develop effective test criteria for IWCS, it is first essential to identify the specific challenges that the criteria are intended to address.

In-water cleaning of macrofouling, where all debris is released directly into the surrounding sea, can lead to the following environmental and health challenges.

Spread of non-native and invasive species.

Organisms attached to ship hulls can be both non-native and invasive. Invasive species are introduced organisms that become overabundant and damage the ecosystems they enter, and in-water cleaning of biofouling can unintentionally contribute to their spread by dislodging organisms that survive the cleaning process. Cleaning may also release reproductive material, including larvae, spores, and gametes, which remain viable in the water and can easily settle on nearby structures or seabed. This creates a concentrated local pulse of biological material, especially problematic in ports or sheltered areas where conditions are favourable for settlement and rapid growth.

Hull biofouling acts as a pathway for microorganisms such as bacteria, viruses, fungi, microscopic algae and single-celled parasites to spread. Pathogenic bacteria can affect fish and shellfish, toxic microalgae can trigger harmful algal blooms, and fungi or parasites can harm both wild and farmed marine species. These organisms are small, resilient and reproduce quickly, so even minimal introductions can have serious consequences. During in-water hull cleaning they may be released from biofilms, spreading antibiotic resistance, transmitting disease to marine life and disrupting local ecosystems.

The risk posed by pathogens in ballast water has been recognized for many years, and recent research shows that the same types of pathogens are present in marine biofouling on ships and other structures. This has led to growing awareness that ship biofouling can pose a direct pathogenic threat to humans. Studies, including those by Georgiades et al. (2021)/10/, have highlighted the role of ships in carrying and distributing potentially harmful organisms to both aquatic ecosystems and human environments, emphasizing the need for preventive management measures. Reflecting this concern, the 2023 IMO Guidelines now explicitly include pathogens within the definition of 'biofouling', underlining the importance of addressing biofouling as a vector for human and environmental health risks /6/.

Release of toxic antifouling paints

In-water cleaning of soft self-polishing antifouling paint removes mainly fouling organisms but also portions of the polymer-based coating, which is normally designed to release copper and organic biocides at a controlled rate. Depending on compatibility, mechanical cleaning may release much larger amounts of copper, booster biocides, and fine paint particles that become microplastics into the water. Detached organisms and reproductive material, such as larvae and spores, are also released. This sudden combination of chemical, microplastic, and biological material can be toxic to plankton and benthic organisms, degrade sediment quality, and facilitate the spread of invasive species, making in-water cleaning a significant environmental concern.

Release of organic material

Releasing large amounts of hull biofouling into oceans and harbours can have significant environmental impacts beyond invasive species. Detached biofouling can add substantial organic matter and nutrients to the water, which can trigger eutrophication, deplete oxygen, and create hypoxic conditions that stress fish and benthic organisms. The decomposition of this material increases biochemical oxygen demand, enriches sediments, reduces water clarity, and can release compounds like ammonia, further affecting local ecosystems. These effects are particularly pronounced in enclosed or poorly flushed waters, highlighting the need for controlled removal and proper disposal rather than letting biofouling disperse freely.

Hull coating damage

More aggressive in-water cleaning methods, such as high-pressure water jets or abrasive brushes, can physically abrade the hull surface, removing not only fouling organisms but also portions of the protective coating. This prematurely strips layers designed to release biocides at a controlled rate, reducing the coating's effectiveness. Compromised coatings may increase the risk of localized corrosion by exposing bare metal or primer layers to seawater and create rough or damaged surfaces that facilitate faster biofouling regrowth, as the disrupted biocide release is less effective at preventing organism attachment. Overall, such cleaning reduces coating lifespan, undermines antifouling performance, and can increase maintenance costs and fuel consumption.

Safety

In addition to environmental and health challenges, in-water hull cleaning can present risks for personnel. Divers face physical strain from prolonged underwater work and handling heavy equipment, as well as potential decompression issues. Exposure to microorganisms, biofilms, and toxic antifouling chemicals can cause infections, skin irritation, or respiratory problems. Waterborne pathogens and contaminated sediments add further health hazards.

Operational risks include drowning, entrapment under the hull, injuries from high-pressure tools, and fatigue-related errors, especially in cold water or low-visibility conditions. Security and regulatory factors require controlled access, adherence to environmental protocols, and specialized training. Proper protective equipment, planning, and monitoring are essential to safeguard health and ensure safe and compliant operations.

Efficient removal of macrofouling, e.g. in niche areas, may be essential to maintain a ship's seaworthiness. Heavy fouling may limit sea water intake or discharge, increases drag, reduces speed, raises fuel consumption and diminishes overall efficiency.

3.2 Identifying the principles of test criteria

Identifying the principles of test criteria is important because they provide the foundation for designing and applying the criteria in a consistent, credible, and effective way. While section 3.1 presents the problems to be addressed, the principles presented in this section guide how the criteria are applied, ensuring solutions are practical, adaptable, and support innovation.

1. **Maximum feasible limitation of pollutant release during in-water cleaning operations**

Efficient IWCS that minimize pollutant release from anti-fouling coatings should be employed, following the core principle that ships should actively reduce their environmental impact.

2. **Maximum feasible reduction in the release of live organisms**

Minimizing the release of live organisms during in-water cleaning is essential. Effective cleaning systems should prevent the release of biological material to maintain ecological balance, safeguard fisheries and aquaculture, and uphold the maritime principle of avoiding unintended transfer of living organisms.

3. **Effective removal of biofouling**

It may be challenging to remove stubborn growth while managing associated risks. Cleaning technology should therefore combine strong removal capability with containment systems, ensuring thorough cleaning while protecting the environment.

4. **Preserving the ship's anti-fouling system**

Reducing harm to a ship's antifouling system is a fundamental aspect of conventional ship maintenance. Effective maintenance practices, therefore, require a careful balance: cleaning should be sufficient to remove harmful growth, yet gentle enough to preserve the coating that protects the ship. This practice continues the long-standing maritime principle of maintaining a ship with care, avoiding harm to key systems.

5. **Maximum feasible reduction in the release of organic cleaning debris and waste substances**

Preventing the release of waste is essential, thus cleaning debris should not disperse freely into the sea during in-water cleaning. Proper collection allows waste to be safely transported ashore for controlled disposal, safeguarding both ecosystems and human health. This is particularly critical in sheltered or poorly flushed waters, where organic matter can accumulate, oxygen levels may drop, and conditions deteriorate quickly.

Together, these five principles form a well-established approach to in-water cleaning. They recognize that a ship in the water carries responsibilities beyond the ship itself. Issues such as invasive species, toxic coatings, organic buildup, coating wear, and personnel safety all highlight the need for technology that meets modern environmental standards. The best available technology, therefore, is not just the newest or fastest option, it is the one that protects the ship, its crew, and the waters on which all maritime life depends.

3.3 Specific test criteria

IMO 2025 Guidelines for in-water cleaning do not define discharge limits for waste that is generated during in-water cleaning /2/. Instead, the IMO guidelines use an approach of statistical comparisons: waste released from cleaning should not significantly exceed local background levels.

In this test procedure for IWCS with capture, an effort has been made to transfer the approach of IMO guidelines into practical measurable test criteria (benchmark tests) where an IWCS can successfully demonstrate performance to a minimum threshold. Successful testing is independent of background levels, which may vary significantly between ports.

In general, suggested benchmark tests include measurements of particles. Particulate organic content (POC) may originate from biofouling and microplastic residues from coatings while measurements of total suspended solids (TSS) include all particles (organic and inorganic) originating from biofouling and coating. The particle size distribution should also be measured.

When testing an in-water cleaning system, the benchmark tests as specified in **Error! Reference source not found.** applies.

Table 1-1 Benchmark test criteria for ex-situ and in-situ testing

Category	Description	Test criteria	Test requirements
A1	Capture efficiency	Reference to IMO MEPC.1-Circ.918: *6.2.1.4.1 -not significantly increase suspended solids, dissolved biocides, particulate biocides, plastics or microplastics **near the cleaning unit**.* A1 Benchmark test: a) Less than 20% of the dislodged biofouling mass is released to the background water, measured as POC and TSS mass volumes of particles. b) IWCS should strive for less than 10% in a) above.	Three replicate ex-situ tests including: • Test plate or test surface with size of at least 10 m^2 and with relevant biofouling as per the IWCS specification. • Test tank with maximum 60m^3 of test water (in case of higher volumes, larger test surface is needed). • Test water quality with less than 5 mg TSS/L of particles. • Test water quality with less than 1 mg POC/L of organic particles • During cleaning test; Influent or effluent to be stored in an IBC tank with volume monitoring.
A2	Separation efficiency	Reference to IMO MEPC.1-Circ.918: *6.2.1.4.1 -not significantly increase suspended solids, dissolved biocides, particulate biocides, plastics or microplastics ...in any released effluent, **relative to ambient levels*** A2 Benchmark test: c) At least 80% separation of biofouling, measured as POC and TSS particles in influent and effluent). d) IWCS should strive for at least 90% in c) above.	Three replicate ex-situ tests as specified above. To be repeated for three in-situ tests. .
A3	Separation efficiency	Reference to IMO MEPC.1-Circ.918: *6.2.1.4.2 only release captured **particles**, including organisms, that are less than 10 µm in all dimensions* A3 Benchmark test: e) At least 80% reduction in accumulated particles in the size range 10-200 µm when comparing influent with effluent. f) Strive for at least 90% in e) above.	Three replicate ex-situ tests. To be repeated for three in-situ tests.

Category	Description	Test criteria	Test requirements
A4	Treatment efficiency	Reference to IMO MEPC.1-Circ.918: *6.2.1.4.2 only release captured particles, including **organisms**, that are less than 10 µm in all dimensions* A4 Benchmark test: g) ATP measurements of the effluent should not increase more than 20% compared with the background.	Three replicate ex-situ tests. The test water quality should hold a minimum level of ATP measured as pg/ml. The benchmark test A4 may be repeated in-situ but the comparison with the background may not be relevant if the ATP content is high.
A5	Cleaning efficiency	Reference to IMO MEPC.1-Circ.918: *6.2.1.1 - produce clean surfaces having a fouling rating less than or equal to 1;* A5 Benchmark test: h) All macrofouling is removed, with the exception of remaining calcareous skeletons.	Three replicate ex-situ tests To be repeated for three in-situ tests.
B	Coating particle capture and separation*	Reference to IMO MEPC.1-Circ.918: *6.2.1.2: not visibly damage compatible coating types;* *6.2.1.3 in the case of cleaning without capture, not significantly increase dissolved biocides, particulate biocides, plastics or microplastics near the cleaning unit, relative to ambient levels;* B1: Benchmark capture test: a) No visible damage and no more than 20% increased concentration of coating residuals in background water, measured as POC, TSS, inorganic (TSG), metals (e.g., zinc, copper) and/or other relevant biocides. B2: Benchmark separation test: b) At least 80% separation of coating particles, measured as TSS and POC, TSG particles, metals (e.g., zinc, copper) and/or other relevant biocides. For coating residues (e.g., zinc, copper, biocides) smaller than 1 µm, it may prove challenging to demonstrate separation efficiency. Efforts shall be made to reduce finer particles in size range >1 µm depending on coating specifics. .	Three Ex-situ test OR three in-situ tests: Ex-situ testing: • At least 3 test plates with distinct different anti-fouling coatings that are representative for ships the IWCS intends to clean. The coating manufacturer shall be advised. • Each test plate should be at least 1 m^2 (size should be sufficient for operating the cleaning unit) • Test water should be at least 10 m^3 • Cleaning should continue for a defined time period that represents a representative set of cleaning events for a ship. In-situ testing: • For B1: No visible damage on distinct different coatings of three ships. • For B2: No more than 20% increased concentration of POC, TSS, and inorganic coating residues (e.g., zinc, copper) when comparing effluent samples with simultaneous samples of the ambient background. Repeated for distinct different coatings of a total of three ships.

* Further studies of coating impact and compatibility may be developed, if relevant. Cleaning studies while the system applies no capture, can be used to observe changes in concentration of POC, TSS, inorganic coating residues (e.g., zinc, copper) and relevant biocides before and after cleaning. Results should be compared with passive leaching from the coating.

4 TEST PROCEDURE

The port authority or the relevant third-party verifier as delegated by the port authority, is responsible for approval of in-water cleaning system service suppliers. An approval shall include review of technical documents, and test documents provided in accordance with this procedure. It is expected that the relevant third-party verifier has been provided with detailed information on system design, construction, functionality, operation and procedures and that this information has been evaluated to confirm the IWCS is ready for testing.

Planning prior testing

Prior to testing, the IWCS service provider should submit documentation sufficient for the testing organization to plan and conduct the test program, including system design and configuration, operating principles, intended ranges of use (e.g., coating types and fouling levels), capture and treatment configuration, and relevant operating and safety procedures. The testing organization should review this documentation to establish the test plan, instrumentation, and safety controls required by this procedure.

Testing should be performed on the final, production-ready configuration (hardware and software/firmware) intended for operational deployment. Any deviations from production configuration should be described and justified; all deviations should be recorded and reported.

The service provider should ensure the IWCS is safely designed and maintain appropriate safety procedures. Meanwhile, the testing organization should apply specific safety measures for each test following its own safety management protocols. By implementing a thorough quality control and assurance program, the testing organization should uphold standards as approved, certified, and audited by an independent accreditation body.

Any operational limitations identified prior or during testing (e.g., coating types, fouling rating levels, capture/treatment configurations) should be documented in the test protocol and the report.

Test sequence

This procedure applies a stepwise testing process consisting of ex-situ tests followed by in-situ testing. The benchmark tests are the minimum criteria required to fulfil a successful test. An IWCS should as a minimum successfully demonstrate the following ex-situ benchmark tests, A1, A2, A3, A5 and B1 before beginning in-situ testing. Some ports may also require a prior successful A4 test on live organisms. Subsequently, it is considered sufficient to complete at least one in-situ tests before the system may receive an interim approval. The remaining two in-situ tests should be completed within two years.

Test categories and relevant benchmark test criteria

Each test must include sampling for all the relevant test categories, as described in the Table 4-1. This ensures that capture efficiency, separation efficiency, treatment efficiency and cleaning efficiency are evaluated simultaneously within the same test runs as follows:

Table 4-1 Test categories and relevant benchmark test criteria with corresponding sample points.

Tests	Benchmark test criteria	Sample points
Three replicate ex-situ tests	A1 - A5	**S1:** in-tank baseline prior to any cleaning activities **S2**: in-tank non-captured material, after cleaning **S3**: influent water **S4:** effluent water **W1**: weight of waste collection
Optional three replicate ex-situ tests	B1 + B2	**S1:** in-tank baseline prior to any cleaning activities **S2**: in-tank non-captured material, after cleaning **S3**: influent water **S4:** effluent water
Three in-situ tests	A2 - A5 + B2	**G1:** background in harbour **S1:** baseline during cleaning activities **S3**: influent water **S4:** effluent water **W1**: weight of waste collection

Experimental set-up

To ensure that the results are representative of the full range of conditions under which the IWCS is intended to operate, a test matrix should be evaluated and formally accepted by the third-party verifier prior to testing. This is to ensure, as much as possible, that the selected configurations reflect the design limitations of the IWCS and that these limitations are appropriately challenged during the tests.

The test matrix ensures that relevant scenarios for both capture, separation and cleaning efficiency are included within the three primary test runs. Parameters such as brush type, fouling severity, cleaning pressure, and other relevant operational variables are carefully combined in a matrix to represent relevant conditions for the system.

Verification through this matrix-based approach confirms that:

- the IWCS can achieve the required cleaning efficiency even under varying fouling conditions
- the system does not damage or negatively interact with the coating when operated under its most abrasive configuration.

This process ensures that the system's operational boundaries are well understood, validated, and documented before field use.

Test plans

The testing organization should plan and conduct the IWCS experiment, assessing performance under various operational, application, and environmental conditions as much as feasible. Experimental set-ups for ex-situ and in-situ tests should be detailed in separate Test Plans.

The test plans should at least include:

.1 identification of all organizations involved in the test;

.2 outline of the experimental design for ex-situ or in-situ test;

.3 description of the performance claims and limitations relevant for the respective test;

.3 specify the number, position, dimension, coating type and cleaning duration of test areas, which should include the following areas if relevant to the IWCS:

.1 areas of flat hull (or test plate in the case of ex-situ test)

.2 curved areas (e.g. the turn of bilge and angles where the orientation of the surface changes abruptly, such as the chine, keel and skegs); and

.3 niche areas (e.g. propellers, propeller shafts, rudders or anodes);

.4 if coating; specify the suspended solids, dissolved biocides, particulate biocides, to be assessed, which should at least include copper or other active ingredients, iron, and zinc if present in the coating;

.5 include a methodology for qualifying and quantifying each of the benchmark test criteria in this procedure. The methodology to study coatings, needs to be adjusted to relevant coating type (e.g. water quality parameters and observation of visible damage);

.6 govern the identification, collection, preservation, integrity, chain of custody, transportation and processing of samples, including the cleanliness of any containers used and procedures relating to compromised samples;

.7 set out quality assurance procedures for written and electronic data, including the quantitative and qualitative data to be recorded and data analyses to be undertaken (including appropriate statistical analysis);

.8 identify any environmental or other conditions that should be verified at the time of testing to ensure that results will be representative (e.g. background levels of suspended solids, metals and carbons represented in coatings);

.9 be sufficient to establish that the discharge will meet all local regulations and requirements of jurisdictions where cleaning may take place, including with respect to biological and chemical parameters; and

.10 identify how results will be reported.

4.1 Ex-situ testing

This chapter outlines the procedures and methodologies for ex-situ testing of IWCS. Ex-situ tests are conducted under controlled land-based conditions and are mainly intended to evaluate the system's capacity for capture. These tests further enable assessment of the impact of cleaning operations on hull coatings, ensuring that both capture efficiency and coating integrity are thoroughly examined prior to real-world deployment.

4.1.1 Capture and separation/treatment efficiency

For capture and separation/treatment efficiency testing, test plates are cultivated with biofouling under controlled conditions to ensure consistent growth across all plates. Other types of material (e.g. dye, peas/corn etc, added to the paint) may also be used to simulate biofouling. Alternatives will be evaluated case-by case.

During testing, the plates and the IWCS should be submerged in a test tank filled with test water for simulation of cleaning operations. Background water samples should be taken before and after cleaning operation (S1 and S2) to evaluate if the materials dislodged from the plates are released to the background waters. Captured influent (S3) and treated effluent (S4) should be sampled for evaluation of separation/treatment efficiency. Samples should be analysed for parameters as presented in Table 4-3. Test water volumes (V1- V3) should be monitored for calculation of total particle mass of each parameter.

The experimental set-up including sample points are illustrated below in Figure 4-1.

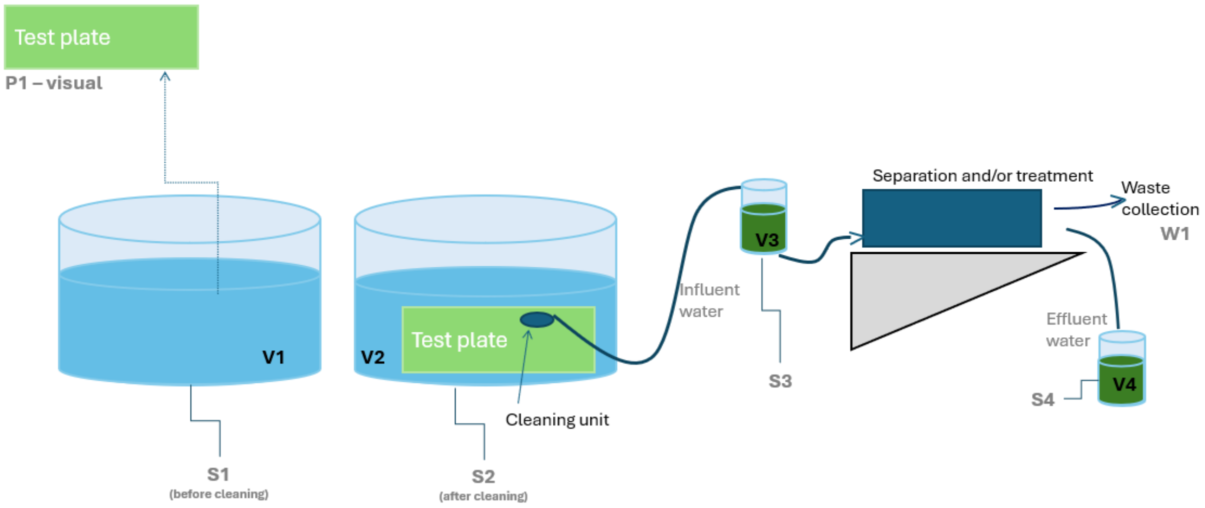


Figure 4-1 Illustrative presentation of ex-situ test set-up of an in-water cleaning unit, with a separation/treatment unit. V1 is the volume of water present in the test tank prior to any cleaning. V2 is the volume after cleaning is completed. V3 is the captured volume that subsequently is transferred to volume V4 as managed water. S1-S4 are sample points.

Preparation of test environment

The following should be established for each test trial.

Test plates: The test surface should be of sufficient width and length for the in-water cleaning device to run a normal cleaning operation to simulate a typical ship surface cleaning. The test should be divided into flat hull operations (i.e. flat and lean test plates) or as niche areas (curvature, propel or similar) if the IWCS is intended to clean niche areas. When selecting a type of niche area for testing, it is recommended to select a niche that is representative of other niche areas that the IWCS may clean. This approach ensures that the test results are relevant and applicable to a range of challenges the system may encounter in actual operations.

Prior to testing, the facility owner and service provider should agree on the size and curvature arrangement on the test plates. The plates may not have anti-fouling coating if natural biofouling growth is used for the test plates.

The test surface should have three replicates of minimum dimensions of either:

- Flat, curved or angled surfaces of minimum 10 m^2; or
- Surface shaped as relevant niche areas (e.g., propellers and shafts, rudders, anodes) of minimum 10 m^2 or relevant size for specific niche area.

Three plates, where each should have 10 m^2 of area 100% covered with biofouling.

The test surface may be larger than 10 m^2, but the area intended to be cleaned should be of minimum 10 m^2. The plates should be placed in a vertical position or relevant equivalent position as on a ship surface during testing.

Prior to testing, the test organisation should determine the biofouling by visual inspection and documentation. The test organisation should also rate the biofouling on the test surface with a fouling rating number in line with criteria listed in Table 4-2, which correspond with IMO Resolution MEPC.378(80) /6/ and US Navy /7/.

A pragmatic assessment of biofouling type (to the nearest species level possible), viability and cover percentage of biofouling organisms should be reported using the description in Table 4-2

The biofouling rating would typically be Soft 30 or Hard 40 for ex-situ testing, but higher rating can be tested if specified by the service provider for the equipment specification intended to test.

Table 4-2 Rating scale for assessment the extent of biofouling

IMO Rating	FR Description - US Navy	Description		Minimum cover of test plate (visual estimate)
0	**Soft 0**	No fouling. Surface entirely clean. No visible biofouling on surfaces.		
1	**Soft 10**	**Microfouling**. Submerged areas partially or entirely covered in microfouling. Metal and painted surface may be visible beneath the fouling.	Light shades of red and green (incipient slime). Bare metal and painted surfaces are visible beneath the fouling.	Partially or 100%
	Soft 20		Slime as dark green patches with yellow or brown coloured areas (advanced slime). Bare metal and painted surfaces may be obscured by the fouling.	
2	**Soft 30**	**Light macrofouling**. Presence of microfouling and multiple macrofouling patches. Fouling species cannot be easily wiped off by hand.	Grass as filaments up to 3 inches (76mm) in length, projections up to 1/4 inch (6.4mm) in height; or flat network of filaments, green, yellow or brown in colour; or soft non calcareous fouling such as sea cucumbers, sea grapes, or sea squirts projecting up to 1/4 inch.	1-15% of surface has macrofouling
	Hard 40		Calcareous fouling in the form of tubeworms less than ¼ inch in diameter or height.	
	Hard 50		Calcareous fouling in the form of barnacles less than ¼ inch in diameter or height.	
3	**Hard 60**	**Medium macrofouling**. Presence of microfouling and multiple macrofouling patches.	Combination of tubeworms and barnacles, less than ¼ inch (6.4 mm) in diameter or height.	16-40% of surface has macrofouling
	Hard 70		Combination of tubeworms and barnacles, greater than ¼ inch in diameter or height.	
4	**Hard 80**	**Heavy macrofouling**. Large patches or submerged areas entirely covered in macrofouling.	Tubeworms closely packed together and growing upright away from surface. Barnacles growing one on top of another, ¼ inch or less in height. Calcareous shells appear clean or white in colour.	41-100% of surface has macrofouling
	Hard 90		Dense growth of tubeworms with barnacles, ¼ inch or greater in height; Calcareous shells brown in colour (oysters and mussels); or with slime or grass overlay.	

IMO Rating	FR Description - US Navy	Description	Minimum cover of test plate (visual estimate)
	Composite 100	All forms of fouling present, Soft and Hard, particularly soft animals without calcareous covering (tunicates) growing over.	

Water quality: The test tank for ex-situ testing should contain sea water with a sufficient volume to completely submerge the test plates and the cleaning unit. The test water volume should be no more than 60 m^3 to avoid dilution of biofouling residuals during the test. The water in the test tank should have minimal contamination from particles and biofouling materials, see test criteria in Table 1-1. The water should have similar condition as the environment for test plate preparation (i.e. salinity, pH, etc).

Test execution

A valid test cycle should follow the steps below:

1. Preparation of at least 3 test plates. If using in an aquatic environment with natural biofouling growth. The biofouling rating should be determined and documented according to Table 4-2 Both sides of the plates may contain biofouling.
2. Prepare maximum 60 m^3 test water with minimal trace of particles and organisms as specified in Table 1-1. The conditions should be similar to the growth environment for the tested plates.
3. Pump test water to the test tank while taking an in-line sample or 3 grab samples from three different levels inside the test tank for analysis of the water baseline conditions before cleaning (S1).
4. Submerge the test plate into the test tank immediately before the IWCS is ready to start. Contamination of the test water should be avoided as far as practicable in this step. A grab sample for indicative analysis may be taken to identify if the process to submerge the plates has unintentionally released biofouling organisms into the water column.
5. Submerge the IWCS into the test tank and prepare for cleaning. The test run starts when the cleaning device is in position and operational conditions of the IWCS is declared ready by the service provider.
6. In-water cleaning. The system should be operated within the intended operational window (flow rate, pressure, etc.) for normal operation on ship surfaces. The operational parameters should be logged and documented in the test report.
7. Capture of biofouling should take place by the cleaning unit, and the total influent volume (V3) should be collected.
8. The cleaning activity is completed after cleaning the test plate on both sides in accordance with the service provider's operational procedures.
9. After retrieving the IWCS from the test tank and removing the plate test plate, the volume V2 should be stirred to obtain a homogenous suspension.
10. Water samples shall be taken for analysis of the water quality after cleaning (S2).
11. After collecting sample S2, and waiting for suspension to settle, a visual inspection of the tank bottom shall be performed to determine if any large particles have been released during the cleaning test. The particles shall be collected (as good as practically feasible), dried and weighed.
12. The influent sample (S3) should preferably be taken as 3 grab samples after the volume V3 has been homogenized by stirring.

13. The influent water should be processed subsequently by running the separation/treatment unit and the effluent should be collected in a separate test tank (V4).
14. A sample of the effluent (S4) should be taken as 3 grab samples after the volume V4 has been homogenized by stirring.
15. The test run is completed after cleaning the test plate and treatment of the influent in accordance with the service provider's operational procedures.
16. The weight of the total biofouling waste shall be recorded (W1)
17. Repeat the process in 2-16 for test plate 2 and 3 and calculate the results to determine if the benchmark criteria are successfully met (see Table 1-1) using the calculation method described later in this chapter.

Sampling procedure for ex-situ test

The minimum sample volumes are outlined in Table 4-3. Sample volumes should be validated by the test organization to ensure representative sampling.

The captured biofouling and debris in the separation unit should be collected and weighed separately for each test cycle.

Analysis methods for ex-situ test

The measurements of test tank baseline water conditions and relevant performance parameters should include the parameters listed in Table 4-3.

Table 4-3 Water quality parameters, samples, and analyses relevant to ex-situ testing. For ATP (adenosine triphosphate) measurements, the analytic approach is described in Peperzak (2023) /5/.

Parameter	Sample	Minimum sample volume	Processing preservation	Analytic method
Salinity, pH, Temperature	S1, S2,	In-line measurements	NA	NA
Total suspended solids (TSS) and glow residues (TSG)	S1, S2, S3, S4	3 subsamples: 1000 – 3000 ml	Process immediately or store at 4°C for maximum 1 week	NS 4733; NS-EN 872
Particulate Organic Content (POC)	S1, S2, S3, S4	3 subsamples: 1000 – 3000 ml	Process immediately or store at 4°C for maximum 1 week	Method G6-2
Particle size distribution (PSD)	S3, S4	3 subsamples 1000 – 3000 ml for	Process immediately or store at 4°C for maximum 1 week	
Live organisms	S1, S4	The effluent should be collected for size fraction ≥10um	Immediately	ATP as pg/ml
Weight	W1	Complete waste (biofouling and debris captured)	Immediately with minimum variation of water content.	Calibrated scale

For Coating assessment:		
Particulate Copper (Cu)	S1, S2, S3, S4	Relevant sample volume and container for the analysis of >1.2 µm particulate copper
Particulate Zinc (Zn)	S1, S2, S3, S4	Relevant sample volume and container for the analysis of >1.2 µm particulate zinc
Other biocides when relevant (i.e Irgarol or other particulate substance)	S1, S2, S3, S4	Relevant sample volume and container for the analysis of >1.2 µm

Benchmark criteria

To determine the in-water capture efficiency, the particle concentration in S1, S2 and S3 should be determined. S2 may include visual observations and collection of larger particles at the tank bottom. Any collections of such particles should be handled similarly to the other samples intended for particle analysis (for example, by drying and weighing them) to ensure consistency in the analytical process.

The benchmark test criteria related to in-water capture efficiency (A-1) is based on the capacity to capture biofouling mass dislodged from a test plate:

$$Capture\ efficiency\ A1: \frac{mass\ accidentally\ released: S2 * V2 - S1 * V1}{total\ mass\ disloged: (S2 * V2 - S1 * V1) + S3 * V3} * 100\ < 20\%$$

V1 and V2 is the volume of water in the test tank before and after cleaning, while V3 is the volume of collected influent. S1-S3 is corresponding sample points of these volumes.

For separation efficiency, the particle concentration should be determined at the influent (S3) and effluent (S4). The benchmark test criteria related to separation efficiency (A2) is calculated as follows:

$$Separation\ efficiency\ A2: \text{S4} < 20\% \text{ of S3}$$

For retention capacity of particles above 10 µm in size, the particle size distribution in the influent (S3) and effluent (S4) sample shall be analysed. The benchmark test criteria related to separation efficiency (A3) is based on the retention capacity as follows:

$$Separation\ efficiency\ A3: \text{Accumualted particles above 10 µm in sample S4} < 20\% \text{ of accumualted in sample S3}$$

For treatment efficiency, the biology can be determined for the effluent (S4) and compared with the background. The benchmark test criteria related to treatment efficiency (A4), is based on the ATP (adenosine triphosphate) method that measures adenosine triphosphate to assess the presence and activity of living organisms in a sample. In this analysis, ATP testing can be used to quantify biological contamination and evaluate the effectiveness of a treatment processes by detecting changes in microbial activity after treatment and compare with the receiving waters, the background sample.

$$Treatment\ efficinecy\ A4\text{: ATP in S4} < 120\%\text{ of ATP in S1}$$

For the benchmark test criteria related to cleaning efficiency the fouling rating and percentage covered must be made from the composite photographs of each photographed area. A pragmatic assessment of type (to the nearest species level possible), viability and cover percentage of biofouling organisms should be done.

4.1.2 Coating capture and separation testing

The assessment of coating damage and capture during in-water cleaning and subsequent separation efficiency is also a critical aspect of the experimental procedure. This experiment can be carried out similar to the above capture and separation efficiency tests, or during three in-situ tests if the ships coatings are distinct different. For ex-situ testing, test plates should be coated according to a specifications from the coating manufacturer, ensuring uniformity and representativeness. After an ex-situ cleaning process, a thorough visual inspection of the plate surfaces should be conducted to assess for any damage. These observations should be recorded alongside quantitative measurements of water quality to provide a comprehensive evaluation of potential release of coating substances.

To evaluate the environmental impact during in-water cleaning of various coating types, the following benchmark criteria have been established. These criteria focus on minimising pollution and assessing the separation process:

- Criterion B1 – Coating capture and damage: The potential coating damage following cleaning should be quantified through both visual inspections. Measurement of potential release of coating particles should not exceed with more than 20%, (passive leaching taken into account). Supporting photographic documentation and measurements of POC, TSS and (in)organic coating residues (e.g., zinc, copper, other biocides) shall be used to assess potential contamination.
- Criterion B2 –Separation efficiency of coating particles: Separation efficiency of coating particles should be determined by measuring the mass of particles in influent and effluent samples post-cleaning, ensuring that retention capacity for particles remains above 80%.

All observations and measurements should be recorded in accordance with a procedure outlined by the independent test organization, and results should be evaluated against these criteria to ensure comprehensive assessment of coating particles:

$$Coating\ capture\ B1\text{: S2} - \text{S1 (IWCS of coated plate)} < 120\%\text{ of S2} - \text{S1 (passive release)}$$

For separation efficiency, the concentration of potential contaminants should be analysed in the influent (S3) and effluent (S4). The benchmark test criteria related to separation efficiency (B2), is based on the retention capacity of removing at least 80% of all particles as follows and retention capacity of particles above 10 µm in size, as follows:

$$Separation\ efficinecy\ B3\colon \mathrm{S4/S3} < 20\%$$

$$Separation\ efficinecy\ B2\colon \text{Accumualted particles above 10 µm in sample S4} < 20\% \text{ of accumualted in sample S3}$$

4.2 In-situ testing

An IWCS should undergo in-situ testing on surfaces of at least three different ships.

With the complicating factors around planning of in-situ testing, it may be difficult to prove that the three ships have distinct different coating types, the highest level of biofouling level and the most challenging conditions, as proposed in the IMO guideline (MEPC.1/Circ.918). Therefore, the main objective of this procedure is that each ship shall exhibit representative biofouling and at least some areas should have macrofouling at level 2 or more. The chosen testing site should allow easy access for equipment and, ideally, offer water with high visibility and minimal contamination.

If the tests include three ships featuring distinct different coatings, the test criteria B1 (coating damage) and B2 (separation of coating particles) may be demonstrated during in-situ testing instead of ex-situ.

For each ship, a test should have a duration of at least 90 minutes of cleaning operation or cleaning of at least one full ship surface or niche area if relevant. As stated in the IMO guidelines; *In the case of niche areas having shorter cleaning times, at least 30 minutes of cleaning should be conducted, whenever possible. For all tests during each cleaning event there should be no repeated cleaning of the test area, beyond that which is part of normal operations.*

The cleaning operator should demonstrate that the in-situ result corresponds with the ex-situ approval test results or demonstrate performance to the satisfaction of the port authority or third-party verifier, as relevant. The goal of performing the in-situ tests is to demonstrate variability in operations, applications and environmental conditions that will allow for verification of the IWCS's operational capabilities and performance.

Preparations before test

All testing should be coordinated with local port authorities and the ship.

Estimates of fouling rating and percentage covered should be made from the composite photographs of each photographed area. Any additional video collected by the IWCS itself, during surveys or cleaning events, should be provided to the test organisation.

Pragmatic assessment of type and viability of biofouling organisms should be done to measure and record biofouling to a level sufficient for the test organization's data quality requirements (i.e., comprehensive, robust, and standardized measurements).

Indicators of viability should normally not be necessary, but it shall be noted that viability is specific for different types of biofouling organisms. New Zealand has identified specifics for some species which may be used as reference /9/.

The biofouling rating should not exceed the maximum accepted rating as specified by the IWCS service provider.

Test execution

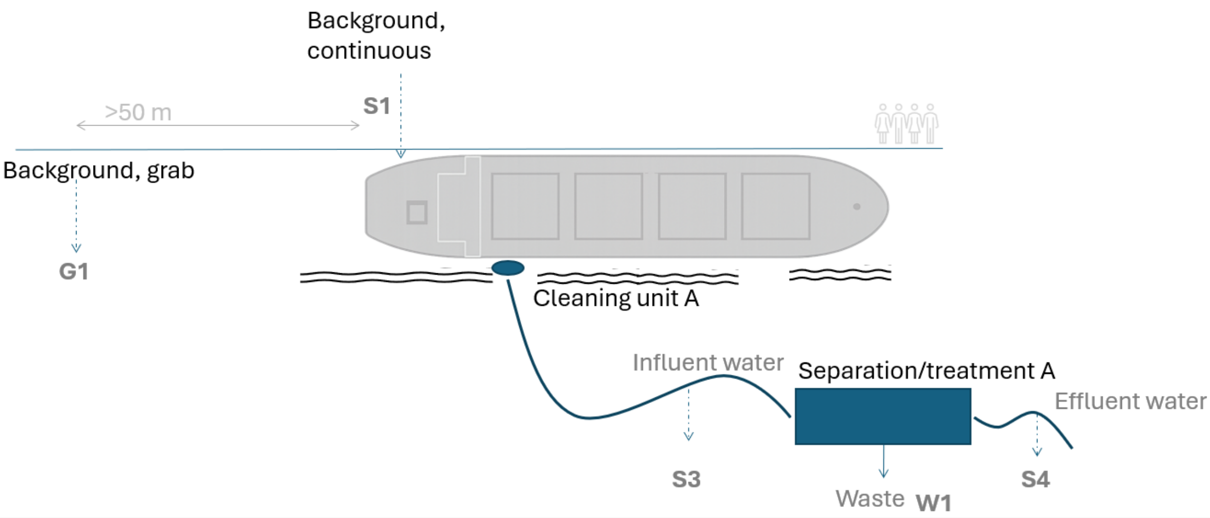


Figure 4-2 Illustration of in-situ test operations and sample locations (G1 and S1-S3). Collection of waste shall be weighted (W1)

The in-water cleaning system should operate in a normal cleaning mode for the duration as specified, while taking safety measures as required. During the test period, the in-water cleaning system should be operated as determined by the service provider. The range of operating parameters defined during ex-situ testing (or a scaling of those parameters) should be demonstrated during in-situ testing.

Sampling for the various performance measures described below can take place in smaller designated subsections of the test ship's cleaned areas, or during a series of smaller time periods (totalling 90-minutes). For each period, at least three replicate samples should be analysed.

Furthermore, the total area cleaned during the sampling of the test trial should be recorded on video. Video recordings of the cleaning event should be captured of each test trial as supporting documentation of service provider claims on capture efficiency. An inline sampling for TSS measurements should also be used to demonstrate continuous capture during the in-water cleaning.

An in-situ test should be carried out as outlined in the following steps:
A valid test cycle should follow the steps below:

1. The biofouling of the ship surface should be inspected to categorize the biofouling rating as listed in Table 4-2.
2. The test area should be defined based on the biofouling conditions and the construction of the hull (i.e. what the system is designed for).
3. A grab sample of sea water should be taken in the test location but in a distance from the ship to avoid any influence from ship discharges or passive leach of anti-fouling substances. The sample analysis is considered the water baseline before cleaning (G1).
4. Sample ports for S3 and S4 should be arranged with inline iso-kinetic sampling whenever feasible.
5. A sample hose should be submerged for continuous background measurements (S1). A sample pump should continuously collect a sample volume at a fixed location near the ship surface, to detect particles released through passive leaching of biocides from the anti-fouling coating. The location should be at a distance of minimum 50 m away from the cleaning event, within the same depth as the planned cleaning area, up current. The location chosen should have similar condition as the location of the cleaning event (i.e. same distance from coated surface). Note: Between the ship and the quay, the water may be stagnant, and biocides and particles may not

dilute as rapidly as on the other side of the ship. The sampling capacity should be sufficient to draw at least 10 – 20 litres /hour of a continuous water sample during each sample period.

6. Submerge the in-water cleaning system in the water and prepare for testing. The test cycle starts when the cleaning device is in position and operational conditions of the in-water cleaning system are declared ready by the service provider.
7. Sampling should begin with a delay after the cleaning operation begins, to ensure that the water samples include biofouling capture (depends on the length of the hose). The sampling system should be rinsed/properly cleaned before sampling begins.
8. In-water cleaning should be performed by the system service provider according to their standard operating procedure, including the recommended maintenance frequency (e.g., changing or cleaning of filters and filter cartridges). The operational parameters should be logged and documented in the test report, indicating each period of the test. The operating parameters should be reported and compared with the ex-situ test parameters.
9. Sampling of background, influent and effluent water should take place from start to end of the in-water cleaning event (S1, S3 and S4).
10. At both S1, S3 and S4 a series of three sequential, continuous time-integrated samples should be collected over a minimum of 90-minute. The samples should be collected with the appropriate pump and hose systems (e.g., sufficient power and flow rates), see Figure 4-3.

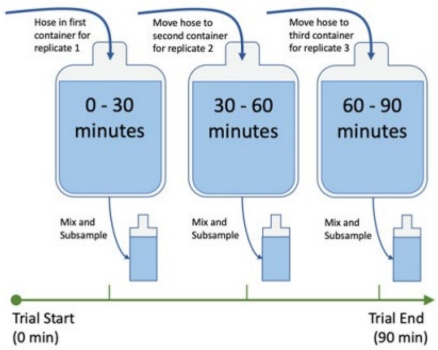


Figure 4-3 Presentation of three-replicate, continuous, sequential, time-integrated water quality sampling, at each sample location, during an in-situ test (Source: ISO 09279).

11. The effluent water volume should be monitored.
12. The test run should stop by following a normal operational stop procedure.
13. Measure the weight of the total biofouling collected as waste (W1) (mass of biofouling). The weight should be assessed and correspond somehow to the biofouling level determined before cleaning. The waste shall be disposed of safely.
14. Calculate the results to determine if the benchmark criteria are met (see Table 1-1) using the calculation method described later in this chapter.

Analysis methods for in-situ test

At least three replicate sub-samples should be analysed per sample. The total sample volume should be at least as given in Table 4-4.

Table 4-4 W4ater quality parameters of baseline test water (S1) and collected wastewater with biofouling (S3) and discharge (S4). For ATP measurements, the analytic approach is described in Peperzak (2023) /5/.

Parameter	Sample	Minimum sample volume	Processing preservation	Analytic method
Salinity, pH, Temperature	S1	Ex-/In-situ data (sensor probe)	NA	NA
Total suspended solids (TSS) and glow residues (TSG)	S1, S3, S4	Three time periods with 3*1000 – 3000 ml	Process immediately or store at 4°C	NS 4733; NS-EN 872
Particulate Organic Content (POC)	S1, S3, S4	Three time periods with 3*1000 – 3000 ml	Process immediately or store at 4°C for maximum 1 week	method G6-2
Particle size distribution (PSD)	S3, S4	Three time periods with 3*1000 – 3000 ml from a filtered sample - accumulated particles in range 10-200 µm.	Process immediately or store at 4°C for maximum 1 week	
Live organisms	S1, S4	The effluent should be collected, and triplicate measurements should be made for ATP measured and reported as ATP for the size fraction ≥10um.	Immediately	ATP as pg/ml
Particulate Copper (Cu)	S1, S3, S4	Relevant sample volume and container for the analysis of >1.2 µm particulate copper		
Particulate zinc (Zn)	S1, S3, S4	Relevant sample volume and container for the analysis of >1.2 µm particulate zinc		
Other biocides where relevant (i.e Irgarol or other particulate metals)	S1, S3, S4	Relevant sample volume and container for the analysis >1.2 µm		

Benchmark criteria determination for in-situ tests

In-situ tests cannot determine in-water capture efficiency, but flow rate and suction pressure should be monitored and compared to ex-situ test parameters as an indication if the same or better capture efficiency is met.

For separation efficiency, the concentration of biofouling and waste particles can be determined for the influent (S3) and effluent (S4). The benchmark test criteria related to separation efficiency A2 is as follows:

$$Separation\ efficincey\ A2\colon \mathrm{S4} < 20\% \text{ of } \mathrm{S3}$$

Concentration of the discharge may vary throughout the test period. Preferably the concentrations in S4 should be analysed from a tank with total collected discharge, where the content is homogenized. However, as this may prove challenging for large volumes of water, using a iso-kinetic sample port may be sufficient to capture the variations of concentration.

For waste substances, i.e. Cu and Zn, the effluent concentration should be compared with the background sample S1. It is expected that S1 includes biocides (including dissolved biocides) if the coating has passive leaching, and therefore it is relevant to compare the concentration in S4 with S1. However, evaluation on acceptable S4 concentrations depends on the background level.

The benchmark test criteria related to separation efficiency A3, is based on retention capacity to remove at least 80% of particles above 10 µm as follows:

$$Separation\ efficency\ A3\text{: Accumulated particles above 10 µm in sample S4} < 20\% \text{ of accumualted in sample S3}$$

For treatment efficiency, the biological activity can be determined for the effluent (S4) and compared with the background. The benchmark test criteria related to treatment efficiency (A4) is based on the ATP method that measures adenosine triphosphate to assess the presence and activity of living microorganisms in a sample. In this analysis, ATP testing can be used to quantify biological activity and evaluate the effectiveness of a treatment processes by detecting changes in microbial activity after treatment and compare with background samples.

$$Treatment\ efficinecy\ A4\text{: ATP in S4} < 120\% \text{ of ATP in S1}$$

In addition to comparing the effluent with the background, it may also be appropriate to compare with the effluent obtained from ex-situ tests in order to confirm continued performance.

For the benchmark test criteria related to cleaning efficiency, the fouling rating and percentage covered should be made from the composite photographs of each photographed area. However, more importantly the video or live monitoring of the complete cleaning event should be shared with the test organisation.

For the cleaning efficiency, the following methods should be considered for use of camera:

- Cameras should be able to obtain a high-definition digital colour image while underwater and the video should be taken at a slow enough pace to ensure blurring does not occur.
- Use of the installed cameras on the cleaning unit showing videos in front of (before video) and behind the cleaning unit (after video).
- For niche areas and the propeller, the entire area (as far as possible) should be photographed or captured on video during cleaning.
- In case of using divers during cleaning or inspection, the safety should follow national regulation and the 2023 IMO Diving Code /8/.
- Photographs and videos should clearly depict the condition biofouling capture and be taken in a consistent manner in terms of angle and distance from the surface during each run.
- Visibility under water is instrumental for cameras used for video and photographs. The water visibility should be a least 0.5 metres during the testing.
- The pictures and video should include or be accompanied by the name of the ship. The dive/camera operator should carefully choose the camera settings to ensure proper lighting, exposure, focus, colour, tone, etc. for capturing an accurate image.

For separation efficiency on coating particles, the concentration of potential contaminants should be analysed in the influent (S3) and effluent (S4). The benchmark test criteria related to separation efficiency (B2), is based on the retention capacity of removing at least 80% of all particles and retention capacity of particles above 10 µm in size, as follows:

$$Separation\ efficinecy\ B3\text{: S4/S3} < 20\%$$

$$Separation\ efficinecy\ B2\text{: Accumualted particles above 10 µm in sample S4} < 20\%\text{ of accumualted in sample S3}$$

4.3 Reporting of test results

A complete documentation package should be prepared for each in-situ test. This package should include:

- A detailed test plan outlining objectives, scope, and methodology.
- A sampling plan specifying locations, frequency, and methods.
- Calibration records for all instruments used during testing.
- Operational parameters recorded and verified throughout the test period.

Photographic and video documentation should be provided for all test activities. Each image and video should include metadata specifying date, time, location, and equipment identification.
A documented chain of custody should be maintained for all collected samples. Records should include signatures, timestamps, and transfer details to ensure traceability and integrity.

Test results should be reported in a standardized format that includes:

- Summary tables of key findings.
- Raw data sets.
- Calculations that demonstrate pass or fail to the test criteria.

The results of each replicate should be reported, along with average results, standard deviation and method detection limit. The test results from each sample taken during in-situ testing should be used to determine the benchmark criteria and reported per test. Methods used should be validated and sample volumes sufficient (>1L) to avoid standard deviations above the benchmark criteria levels.

All environmental conditions during testing, including temperature, salinity, and tidal flow, should be documented. Any deviations from the approved test plan should be recorded and justified.

For evaluating the sample results and comparing with the benchmark criteria, each test cycle (ex-situ test) or test period (in-situ test) shall not exceed the required criteria within each parameter. These values should be statistically analysed, for example using Student's t-test, to verify the observed differences.

5 REFERENCES

/1/ DNV (2023). Test procedure for in-water cleaning systems with capture of biofouling, DNV Report 2023-1116, Rev. 0.

/2/ IMO Circular MEPC.1-Circ 918, IMO Guidance On In-Water Cleaning Of Ships' Biofouling

/3/ ISO Draft standard 20679, Guidelines for testing ship biofouling IWC systems

/4/ BIMCO (2021). Approval procedure for in-water cleaning companies.

/5/ Peperzak, L. (2023). The critical adenosine triphosphate (ATP) concentration in treated ballast water. *Marine Pollution Bulletin* https://doi.org/10.1016/j.marpolbul.2022.114506

/6/ IMO Resolution MEPC.378(80), Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species.

/7/ Naval Sea Systems Command (2006). US Naval Ships' Technical Manual fouling rating, fr NSTM.

/8/ IMO Resolution MSC.548(107), International code of safety for diving operations.

/9/ New Zealand MPI Technical Paper No. 2015/39, Procedure for evaluating in-water systems to remove or treat vessel biofouling.

/10/ Georgiades, E., Scianna, C., Davidson, I., Tamburri, M., First, M., Ruiz, G., Ellard, K., Deveney, M. and Kluza, D. (2021). The Role of Vessel Biofouling in the Translocation of Marine Pathogens: Management Considerations and Challenges. *Frontiers in Marine Science*, Vol. 8, https://doi.org/10.3389/fmars.2021.660125

ANNEX 2

Green Shipping Programme

Standard for reporting from in-water cleaning

Name of ship: ....

IMO number: ....

Ship dimension (LOA, draft): ....

Location/port: ……………………………………………………………………

Last port of call: ………………………………………………………………..

Information on coating specification (e.g., colour and biocides):………………….

Information on coating/specification for niche area (e.g, propeller):………………

Last drydock date (indicating age of coating):……………………………………….

Date of the cleaning: …………………………………………………………….……..

Cleaning company:………..…………………………………………………………....

Diver/ROV operator team: Standard reporting from in-water cleaning ……………..

Weather condition: ………………………………

In-water conditions (visibility): ………………………………………………………..

Technology/equipment used for cleaning ………………………………………..…

Any special tools for cleaning specific areas? ………………………………..………

Technology/equipment used for capture/treatment: ………………………………

Cleaned areas (Hull and/or niche area) : ………………………………………………..

Time period of the cleaning: : ………………………………………………………..

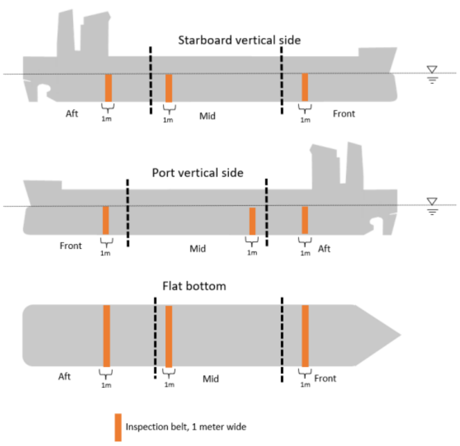
Cleaned areas are indicated in the tables on following pages.

Table: Cleaning summary and biofouling survey of ship's hull

Cleaned areas of Hull below the waterline [examples]	Biofouling rating before cleaning (0-5)	Biofouling rating after cleaning (0-5)	Signs of wear/tear/ previous damage to coating?
One photo of before and after per			
Port vertical side			
Front, below water line			
Mid, below water line			
Aft, below water line			
Front, 2-5 m deep			
Mid, 2-5 m deep			
Aft, 2-5 m deep			
Starboard vertical side			
Front, below water line			
Mid, below water line			
Aft, below water line			
Front, 2-5 m deep			
Mid, 2-5 m deep			
Aft, 2-5 m deep			
Flat bottom			
Front, below water line			
Mid, below water line			
Aft, below water line			
Front, 2-5 m deep			
Mid, 2-5 m deep			
Aft, 2-5 m deep			

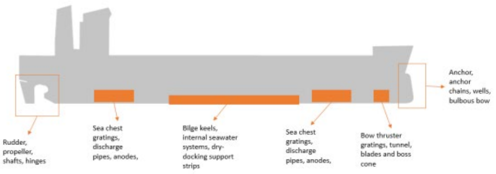
PHOTO: Number of photos to attach a report depends on the ship size. At least tree gradients should be covered; front, mid and aft, but more gradients may be relevant for larger ships. The below example includes 18 photos starboard, 18 photos portside and 9 photos of the flat bottom, as well as before and after-cleaning photo, as follows:

1. 3 photos in each area (front, mid aft) near the water line
2. 3 photos in each area (front, mid aft) 2-5 m below the water line
3. 3 photos in each area (front, mid aft) of the bottom



Note that photos in the front should include coating impact from the anchor chain, if relevant.	
Reference to additional supporting evidence (photos/videos):	
Comments:	

Table Cleaning summary and biofouling survey of ship's niche areas:



Cleaned Niche areas [examples]	**Biofouling rating before cleaning**	**Biofouling rating after cleaning**	**Signs of wear/tear/ previous damage to coating?**
subsection X			
Bow			
Bow thruster			
Bilge keels			
Sea chest gratings			
Location 1			
Location 2			
Stern			
Propeller and its shaft			
Rudder and rudder shaft			
Discharge pipes			
Rope guards			
Sounders/instruments			
Sacrificial anodes			
Internal seawater systems			
….			
….			
Description of activity and reference to supporting evidence (photos/videos):			
PHOTO: Attach at least one photo of before and after in each niche area. See illustration for examples of niche areas			
Reference to additional supporting evidence (photos/videos):			
Comments:			

Description/Documentation of capture performance (i.e. flow measurements of suction line, photo of cleaning unit in operation, etc)

Description/Documentation of treatment (e.g. filter performance):

Description of waste disposal with supporting evidence (e.g. receipts):

Description of any problems encountered during cleaning including details of any damage to the AFS that may have occurred

Signature of cleaning organization: ……………………..…………………………...……