Evaluation of Possible Changes to Water Quality as a Result of Ship Microfouling Proactive In-Water Cleaning

Report

Submitted by Dr. Mario N. Tamburri

Table of Contents:

1. Executive Summary

In-water cleaning (IWC) has long been incorporated as part of ship biofouling management strategies. However, IWC should be conducted in a way that does not cause unintended consequences. The objective of this study was to determine if there are measurable changes to local water quality conditions as a result of proactive in-water cleaning (IWC) of microfouling or biofilms on ships' hulls.

This study was not intended as an evaluation or verification of any of the six individual participating IWC systems or service providers but rather as an assessment of some of the potential environmental impacts of the overall proactive approach. Unfortunately, only limited valid data was produced for one IWC service provider before the study was suspended.

While it is not uncommon for complicated international studies, which attempt to employ novel protocols and methods, to experience challenges and delays, several important lessons were learned through this effort, and the following recommendations are made:

A. Should a future study on quantifying the potential water quality impacts be launched in 2025, it should include all forms of IWC to avoid the complications and confusion associated with testing only proactive systems on FR < 2 (i.e., only microfouling cleaning). The goal should be to document any measurable changes to water quality parameters of concern as a result of any type of IWC system and be based on recognised international standards (e.g. ISO 20679).

B. Future Test Plans should be more detailed and prescriptive, including explicit requirements for appropriate staffing, sample collection methods, sample volumes, and sample replication.

C. Future testing should require the development of testing organization Standard Operating Procedures (SOPs) for all relevant aspects of the Test Plan and pre-testing practice trials to work through sample collection, handling, and analysis details and logistics before conducting test events.

2. Introduction

2.1 GloFouling Partnerships Project and the Global Industry Alliance

The GEF-UNDP-IMO GloFouling Partnerships Project (GFP) is a 6-year global initiative from the International Maritime Organization (IMO), in collaboration with the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF), to protect marine ecosystems from the negative effects of invasive species transferred through biofouling on ships and other marine structures. The project drives actions in developing countries through capacity building, awareness raising, and facilitating legal, policy, and institutional review.

The Global Industry Alliance (GIA) for Marine Biosafety has been established under the GEF- UNDP-IMO GloFouling Partnerships as an association of leaders from the private sector representing maritime industries, who work together with the GloFouling Partnerships to support improved biofouling management and marine biosafety initiatives. This work was commissioned by the members of the GIA, with support and oversight by GFP.

2.2 Project Background and Scope

Submerged ship surfaces are often inhabited by diverse sessile and sedentary marine organisms, which can directly impact vessel operations and increase the likelihood of non-indigenous species (NIS) establishment and impacts (e.g., Davidson et al., 2018; Tamburri et al., 2020). In-water cleaning (IWC) systems are now being incorporated into guidelines and policies to help address environmental and biosecurity risks associated with ship biofouling (e.g., Ministry for Primary Industries New Zealand, 2018; IMO Biofouling Management Guidelines, 2023).

Although IWC has long been incorporated as part of ship biofouling management strategies, it is necessary to ensure that they do not cause unintended consequences. The objective of this study, therefore, was to determine if there are measurable changes to local water quality conditions as a result of proactive in-water cleaning (IWC) of the biofouling on ships' hulls (specifically microfouling or biofilms removal) and, if so, to place the measured changes into context with known environmental safety levels/requirements. The IMO defines proactive IWC as the periodic removal of microfouling on ship surfaces to prevent or minimize attachment of macrofouling and defines microfouling as biofouling caused by bacteria, fungi, microalgae, protozoans, and other microscopic organisms that create a biofilm (IMO, 2023). This proactive removal of microfouling/biofilms (i.e., Fouling Rating [FR] of less than 2) was selected for the focus of this study because it is assumed that proactive IWC is relatively benign compared to reactive IWC of macrofouling (FR of 2 and above), with minimal if any environmental or coating impacts. However, little independent data is currently available to support this assumption.

Six IWC service providers (who were members of the GIA) agreed to participate in this study and the protocols described in the Work Plan (Appendix A) in February 2024. However, exact locations or timing could not be confirmed ahead of time due to the nature and uncertainties associated with IWC operations on active commercial ships.

Of the six service providers, four provided debris capture as part of their routine operations, whereas two did not:

a. Service providers with Debris Capture:
CleanSubsea,
ECOsubsea,
HullWiper, and
TAS Global

b. Service providers without Debris Capture:

GreenSeaIQ, and
Jotun Hull Skating Solutions

The specific testing protocols/methods are based on Tamburri et al. 2021, ACT/MERC 2022, and the draft ISO Standard 20679 (final version was released after the study was closed in December 2024). The Work Plan was developed, overseen, and coordinated by a project consultant (Mario Tamburri, the author), and testing (i.e., sample collection and analysis) was conducted by an independent testing organization, contracted by IMO (GFP) through a formal tender process.

This study was not intended as an evaluation or verification of any individual or specific IWC system or service provider but rather as an assessment of some of the potential environmental impacts of the overall approach. While the plan was to anonymize and pool all data to identify general trends in proactive IWC, limited valid data was only produced for one IWC service provider and they alone were provided their water quality data for consideration.

2.3 Initial Challenges

It must be noted that there were extensive administrative delays in the approval of this study and in establishing contracts with both the project consultant and the testing organization, resulting in the study being initiated several months behind schedule. Due to these delays, the planned one-year study was compressed into eight months for the coordination and completion of all the sample collections and analyses for six different IWC systems (located in Europe, Asia, North America, and Africa), data analysis and presentation, and final report submission before December 24, 2024. Unfortunately, an extension of the study beyond this date was not possible due to the completion of GFP at the end of May 2025.

3. Work Completed and Observations

3.1 Initial Testing Event

On July 1, 2024, the Jotun Hull Skater was the first proactive IWC system to be tested as part of this study. The test cleaning event and water quality sampling took place at the RoRo terminal in the Port of Zeebrugge, Belgium.

Although the intention was for testing events to be attended by the project consultant (when possible), the trial was scheduled for a date they were unavailable to travel. They were, however, able to participate virtually in the Jotun communications system during cleaning and testing operations.

Unfortunately, sampling was not carried out as described in the Work Plan. The specific deviations from the Test Plan included:

a. background samples during the test cleaning event were not collected from a hose placed directly on the side of the ship at least 50 m away from any cleaning activities;

b. the cleaning unit samples and the side of the ship background samples were not collected simultaneously; and
c. the cleaning unit samples were not collected in a continuous, time-integrated way.

It was decided, therefore, that the samples collected from this first trial would not be analyzed because it was an invalid testing event.

3.1 Second Testing Event

On August 10, 2024, the GreenseaIQ was the second proactive IWC system tested at a cruise ship terminal in the Port of Miami, Florida.

The project consultant attended this testing event and provided the entity guidance on the Work Plan and sample collection.

While appropriate samples were collected (i.e., consistent with the Test Plan), there were some sample handling and analysis concerns (e.g., the use of plastic containers and insufficient analytical volume for microplastic sample analysis), and most importantly, individual samples for the various target water quality parameters were not analyzed in triplicate.

Although a minimum of three replicate (n = 3) analyses for each sample parameter is a common science best practice, it was not explicitly mentioned in the Work Plan (which formed part of the Terms of Reference [ToR] in the testing organization contract). As not mentioned in the ToR, there was no contractual obligation for the testing organization to collect sufficient volumes for triplicate analysis to be conducted nor undertake this number of replicate analyses, which in doing so would have incurred both additional costs and contract amendments. Nevertheless, this lack of replication prevented both the quantification of individual parameter analytical method variability and made it impossible to conduct any statistical comparison of water quality conditions from the background samples and those collected on the IWC unit during cleaning operations for individual testing events.

3.2 Planning for further testing events

Throughout August and September 2024, several attempts were made to schedule and conduct the water quality sampling events for the remaining four participating proactive IWC service providers. However, several logistics and scheduling challenges prevented any further testing before a decision by GIA on October 3, 2024, to suspend this study.

Specific scheduling difficulties encountered included:

a. the availability of limited testing organization staff;
b. addressing the logistic challenges associated with conducting test events when the selected test ship is offshore at anchorage (as opposed to dockside testing); and
c. ensuring test events are conducted on ship surfaces with only microfouling/biofilms

(see 4A below).

While these challenges are not insurmountable, they did limit the number of options available for test events during the condensed study schedule.

4. Lessons Learned

Although only a portion of the study was completed as described in the Work Plan, valuable experience and knowledge were gained that will help progress the safe and effective IWC of ship biofouling. The following are the three most important lessons learned from this study.

A. The 2023 IMO Biofouling Guidelines definition of proactive IWC is restricted to the removal of biofouling at FR < 2 with or without debris capture, and therefore, this study was designed to assess water quality impact during the cleaning of hull surfaces with only microfouling. However, several existing IWC systems (and four of the six participating IWC service providers) include some form of debris capture and waste processing, which means that they can operate as proactive IWC systems to remove microfouling biofilms but can also remove and capture any occasional macrofouling encountered during the same cleaning event. Therefore, the four participating proactive IWC systems service providers with capture found it difficult to identify test ships where only FR < 2 could be guaranteed during the entire test cleaning event and highlighted how FR < 2 is only operationally relevant for IWC systems without capture.

B. Given that the testing of IWC systems has not been conducted broadly or for more than a few years and that standardized testing protocols (e.g., ISO 20679) are relatively new, most testing organizations are not familiar with IWC testing logistics and objects. Furthermore, while there is a wealth of experience and knowledge in the testing of ballast water management systems, many of the approaches and methods are not necessarily transferable to the testing of IWC systems. Consistent and reliable testing that provides the appropriate data quality (including minimum replication requirements) will require 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 around the world where cleaning activities may take place.

C. The successful and timely testing of IWC systems requires a commitment and full cooperation and coordination of all involved parties. This includes the IWC service provider, independent testing organization, operator and crew of test ships, and data end-users. Given the complexity of this type of testing, all requirements, specifications, timelines, and roles/responsibilities need to be clearly delineated and agreed to, with frequent communications between all parties throughout the testing effort.

5. Recommendations

The following recommendations are based on this initial study's lessons learned and discussions with GIA and IMO GloFouling.

A. Should a future study on quantifying the potential water quality impacts of IWC be launched in 2025, it should include all forms of IWC (i.e., proactive and reactive; on biofilms and macrofouling; with capture and without capture; on hulls and in niche areas) to avoid the complications and confusion associated with testing only systems on FR < 2. The goal should be to document any measurable changes to water quality parameters of concern as a result of any IWC system (which can be aided by using the relevant clauses of ISO 20679 for example) and with the appropriate reporting of:

a. system configuration, settings, and operations,
b. ship-specific parameters,
c. biofouling levels and types, and
d. environmental conditions.

B. Future Test Plans should be more detailed and prescriptive, including explicit requirements for appropriate staffing, sample collection methods, sample volumes, and sample replication.

C. Future testing should require the development of testing organization SOPs for all relevant aspects of the Test Plan, and pre-testing practice trials should be conducted with the testing organization and project consultant to work through sample collection, handling, and analysis details and logistics.

Although perhaps beyond the scope of a GIA or GFP study, a broader recommendation would be for capacity building and harmonization of IWC system testing. Training webinars and hands-on field demonstrations on the practical implementation of a recognized international standard approach (such as ISO 20679) could be conducted to build capacity and standardize processes, approaches, and methods among testing organizations. This activity could target various researchers from academia, agencies, and the private sector working on assessments of IWC but could also be open to interested IWC service providers and relevant regulatory and approval bodies.

6. Conclusions

It is not uncommon for complicated international studies, which attempt to employ novel protocols and methods, to experience challenges and delays. Although there were a series of problems in the initial phases of this study, most were resolved, and subsequent testing would have likely been successful.

However, given the firm deadline for completion of this work (by December 24, 2024) and the lessons learned to date, it was agreed to suspend this current study and reevaluate the structure and goals for the implementation of a new, related follow-on effort in 2025.

7. References

Alliance for Coastal Technologies / Maritime Environmental Resource Center (ACT/MERC), 2022. Guidelines for testing ship biofouling in-water cleaning systems. TS-788-22, CBL/UMCES 2023-017

Davidson, I. C., Scianni, C., Minton, M. S., and Ruiz, G. M., 2018. A history of ship specialization and consequences for marine invasions, management, and policy. J. Appl. Ecol. 55, 1799-1811.

International Maritime Organization (MO), 2023. Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species. International Maritime Organization: London.

International Organization for Standardization (ISO), 2024. ISO/IEC 20679, Testing of ship biofouling in-water cleaning systems.

Ministry for Primary Industries New Zealand (MPI), 2018. Craft Risk Management Standard: Biofouling on Vessels Arriving to New Zealand. CRMS – BIOFOUL. Wellington: Ministry for Primary Industries.

PPR 12/5/X, Development of Guidance on Matters Related to In-Water Cleaning, Report of the IMO Correspondence Group, Submitted by Canada to Pollution Prevention and Response Subcommittee 12th Session, 25 October 2024.

Tamburri, M.N., Davidson, I.C., First, M.R., Scianni, C., Newcomer, K., Inglis, G.J., Georgiades, E.T., Barnes, J., and Ruiz, G., 2020. In-water cleaning and capture to remove ship biofouling: An initial evaluation of efficacy and environmental safety. Frontiers in Marine Science, 7: 437.

Tamburri, M.N., Georgiades, E.T., Scianni, C., First, M. R., Ruiz, G.M., and Junemann, C.E., 2021. Technical considerations for development of policy and approvals for in-water cleaning of ship biofouling. Frontiers in Marine Science, 8, 804766.

8. Appendix A:

Work Plan
Evaluation of Possible Changes to Water Quality as a Result of Ship Microfouling Proactive In-Water Cleaning

7 November 2023

1. Background and Objectives

The GEF-UNDP-IMO GloFouling Partnerships (Project) is a 6-year global initiative from the International Maritime Organization (IMO), in collaboration with the United Nations Development Programme (UNDP) and the Global Environment Facility (GEF), to protect marine ecosystems from the negative effects of invasive species transferred through biofouling on ships and other marine structures. The project drives actions in developing countries through capacity building, awareness raising, and facilitating legal, policy, and institutional review.

The Global Industry Alliance (GIA) for Marine Biosafety has been established under the GEF- UNDP-IMO GloFouling Partnerships as an association of leaders from the private sector representing maritime industries, who will work together with the GloFouling Partnerships to support improved biofouling management and marine biosafety initiatives. This work is commissioned by the members of the GIA.

The objective of this study is to determine if there are measurable changes to local water quality conditions as a result of proactive in-water cleaning (IWC) of the biofouling on ships' hulls (specifically microfouling or biofilms) and, if so, to place changes into context with known environmental safety levels/requirements. The IMO defines proactive IWC as the periodic removal of microfouling on ship surfaces to prevent or minimize attachment of macrofouling, and defines microfouling as biofouling caused by bacteria, fungi, microalgae, protozoans, and other microscopic organisms that create a biofilm (IMO 2023). Six members of GIA, who currently provide proactive IWC services, have agreed to participate in this study using the protocols and methods provided below. The specific testing protocols/methods are based on ACT/MERC 2022 and the draft ISO Standard 20679 (currently under development). The work plan will be overseen and coordinated by a project consultant and testing will be conducted by an independent testing organization.

This study is not an evaluation or verification of any individual or specific proactive IWC system or service provider but rather it is an assessment of the environmental acceptability of the overall approach. While all data will be anonymized and pooled to identify general trends in proactive IWC, individual participating service providers will be provided their individual water quality data for consideration.

2. Description of Participating Proactive IWC Service Providers

All IWC systems participating in this study are either exclusively proactive IWC, or can be operated as proactive IWC, which is the periodic removal of microfouling on ship surfaces to prevent or minimize attachment of macrofouling. Microfouling is biofouling caused by bacteria, fungi, microalgae, protozoans, and other microscopic organisms that create a biofilm, and is categorized as a fouling rating of 0 or 1 (i.e., FR < 2). The participating proactive IWC systems are either diver or remotely operated, with some capturing and some not capturing biofouling material, debris, and waste substances released from hull surfaces during cleaning. For additional information on the six participating IWC service providers, please see Appendix A.

3. Experimental Design

3.1 Summary overview

One individual test trial each, involving assessments of ambient water quality (i.e., local background conditions) compared to water quality at the same location but in close proximity to the cleaning unit during normal hull cleaning operations, will be conducted separately for the six individual proactive IWC service providers. Each IWC service provided will arrange a single appropriate test ship for conducting their individual test trial. The biofouling level to be cleaned during these trials must be less than fouling rating 2 (as described in IMO 2023). While the individual service providers will conduct their own assessments of biofouling levels before (to ensure FR < 2) and likely after, this study will not attempt to quantify cleaning performance in any way.

Background and during a test IWC, water quality samples will be collected/analyzed for concentrations of:

- total suspended solids (TSS),
- particle size distribution (PSD),
- particulate organic carbon (POC),
- dissolved organic carbon (DOC),
- coating-associated biocides (e.g., copper and zinc), and
- microplastics (MP).

Background water quality samples will be collected at the location of the testing:

- 1 day before the cleaning trial,
- 1 hour before the cleaning trial,
- side of test ship, and > 50 meters away, during test cleaning,
- 1 hour after the cleaning trial,
- 1 day after the cleaning trial.

- IWC samples will be collected from the cleaning unit during 90 minutes or more of normal hull cleaning operations and, when applicable, samples will be collected from the influent and effluent of the debris processing unit.

- Samples will be collected/analyzed as described in ACT/MERC 2022 (draft ISO

20679).

• Relevant information on the test ship, IWC system, and the environment during testing will also be documented as described in ACT/MERC 2022 (draft ISO 20679)

Further details on relevant protocols and methods are provided below.

3.2. Fundamental information needed for testing of IWC systems

The fundamental parameters (based on ACT/MERC 2022) listed in Table 1 will be documented and reported for each test trial of this study. These parameters allow for linking test results to performance under specifically known ship, biofouling, environmental, and IWC system characteristics or conditions.

Table 1: List of fundamental parameters during IWC system testing that will be documented and reported.

Ship Parameters
Ship type/function, age, size, and design drawings, with any relevant modifications
Ship recent routes/voyages and operational history over at least the past 12 months (including dry-docking, long idle periods, lay-up, and repairs) from ship log book
Ship availability/access for cleaning and/or testing (including dates, ports, time at dock or anchorage, any access restrictions)
Ship coating(s) type (or uncoated), age, expected service life, applied location, and history (including prior cleaning, damage, or repair)
Trial area fouling rating prior to testing
Environmental Parameters
Water visibility/clarity
Tides, currents, wind, and waves
Water quality at location of testing and during testing, see below
If applicable, ambient levels of biocides during testing (e.g., background levels of copper and zinc) and other contaminants of interest (e.g., microplastics) in water column at location of testing
IWC System Parameters*
IWC system design and function, and IWC mobilization, operations and demobilization
IWC system specifications, requirements, and limits
Mode of cleaning unit operations (e.g., diver-, remotely-, or autonomously- operated)
Mode of cleaning unit attachment to, and movement on, ship surfaces
Operator/diver skill and experience (as described by IWC service provider)
Mode of biofouling (biofilms and/or macrofouling) removal (e.g., brushes, blades, or water jets, with details on type, amount, configuration, etc.)
Rate and pattern of individual cleaning operations (e.g., speed of cleaning unit, number and overlap of passes, etc.)
If applicable, debris capture methods (e.g., cleaning unit shroud and suction)

If applicable, flow rate of debris/wastewater capture
If applicable, debris and wastewater transport and processing (e.g., particle settlement processes, type and level of filtration/separation, secondary treatment of biological waste [e.g., UV or chlorination], type media for removal of metals) and maximum load capacity
If applicable, waste disposal processes (including volumes and mass)
Various pre-set modes of operations and adjustments during cleaning, including contingency plans and response to unexpected conditions (e.g., presence of macrofouling during Proactive IWC) and system failures

* Proprietary, or commercially sensitive, information on specific IWC technologies or approaches can be held confidential, provided enough basic information on system specifications, design, function, and operations are available to allow for an adequate understanding of performance and safety.

3.3. Duration and extent of testing

Water quality parameters will be evaluated once for each participating IWC system, over a three day period. Ambient background samples will be collected on Days 1, 2, and 3, whereas test ship background and cleaning unit samples will be collected only on Day 2 during test trial cleaning event. Each individual test trial will be conducted over at least a 90-minute hull cleaning event, with the IWC system operating in a normal, defined cleaning mode for the conditions presented. 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 a smaller time period (minimum 90-minutes) of a full cleaning event.

3.4. Quantification of changes to water quality

All testing will be coordinated with local, regional, or national authorities, as necessary, as such entities may have specific water quality standards or threshold requirements regarding the release of contaminants (chemical, physical, and biological) during IWC. As these standards can vary greatly among locations, all testing of IWC systems will report total or absolute values (e.g., means and standard deviations) of the measured water quality parameters (described below) during and adjacent to IWC activities. Those values will also be compared to identify differences from ambient or background ranges of the same parameters at the location of testing.

3.5. Water quality parameters to quantify

Environmental impacts from IWC include potentially unacceptable changes to local water quality and sediment conditions (due to release of biocides and other substances from coatings) and the potential release of live organisms. Table 2 lists the parameters that will be analyzed (from collected water quality samples) as practical, measurable, and conservative proxies for environmental impact (Table 5; Tamburri et al. 2021; ACT/MERC 2022).

Table 2: Water quality parameters to be measured for IWC systems and their purpose.

Parameter	Purpose

Total suspended solids (TSS)	Represents the mass of particulate material, in background water and water near cleaning activities, which will include possible biofouling organisms, coating material, and IWC associated fragments.
Particle size and distribution (PSD)	Indicative of the type/characteristics of the solid material found in TSS analyses.
Particulate organic carbon (POC) Dissolved organic carbon (DOC)	Indicative of the amount of biological material present.
Test ship coating total and dissolved biocide(s) (e.g., copper- and/or zinc-based compounds), when applicable	Measure of possible biocide release from ship coating, when applicable.
Microplastics (MP)	Measure of possible polymer release from ship coating.

The appropriate volumes, for all subsamples and various analyses, will be placed in suitable, cleaned bottles (e.g., glass containers and sample bottles for assessment of MP/NP). All sample bottles will be labeled with unique identification numbers prior to sampling. To ensure analytical validity, all samples will be stored and transported within the appropriate time, temperature, and light requirements.

To the extent possible, certified, standardized, and/or validated analytical methods will be used. Table 3 provides a few examples of analytical methods that may be employed. However other accepted methods approved for use by ISO, European Chemicals Agency, American Society for Testing Materials, and others could be used if they meet the testing organization data quality requirements.

Table 3: Sample type and examples of accepted analytical methods (and limits of detection) for measuring water quality parameters.

Sample Type	Analytical Method	Method Detection Limit	QA Reporting Limit
TSS	SM208 E, SM2540D, EPA 160.2	2.4 mg TSS/L (2019)	2.4 mg TSS/L (2019)
POC	EPA 440.0	0.0633 mg C/l (2019)	0.0633 mg C/l (2019)
DOC	SM5310B/C	0.16 mg/L DOC (2019)	0.50 mg/L DOC (2019)
PSD	ISO-13322-1	>10 – 1000 µm (2020)	>10 – 1000 µm (2020)
Particulate and Dissolved Copper (Cu)	EPA 200.8/EPA 6020A	0.1 µg L^{-1} (2018)	0.5 µg L^{-1} (2018)
Particulate and Dissolved Zinc (Zn)	EPA 200.8/EPA 6020A	Diss. 0.5 µg L^{-1} Part. 0.1 µg L^{-1} (2018)	Diss. 1.0 µg L^{-1} Part. 1.0 µg L^{-1} (2018)

Microplastics (MP)	ISO/DIS 24187, ASTM D83302-20		

3.6. Water quality sample collection

Discrete and continuous, time-integrated water samples will be collected at two stations for every IWC system test trial (i.e., during a cleaning event). One of the two stations is designated for measuring background/ambient conditions adjacent to the test ship. This station will be at ≥ 50 meters away from, and clearly not impacted by, the test cleaning activities (e.g., mid-depth or at least 1 m below the surface, up current, and/or opposite side of the test ship). The second station will be directly on the IWC system's cleaning unit, at a point designated as the most likely to be the greatest source of possible environmental release. At both stations, during each test trial, a series of three sequential, continuous time-integrated samples will be collected simultaneously over at least a 90-minute sampling period (Figure 1 and 2).

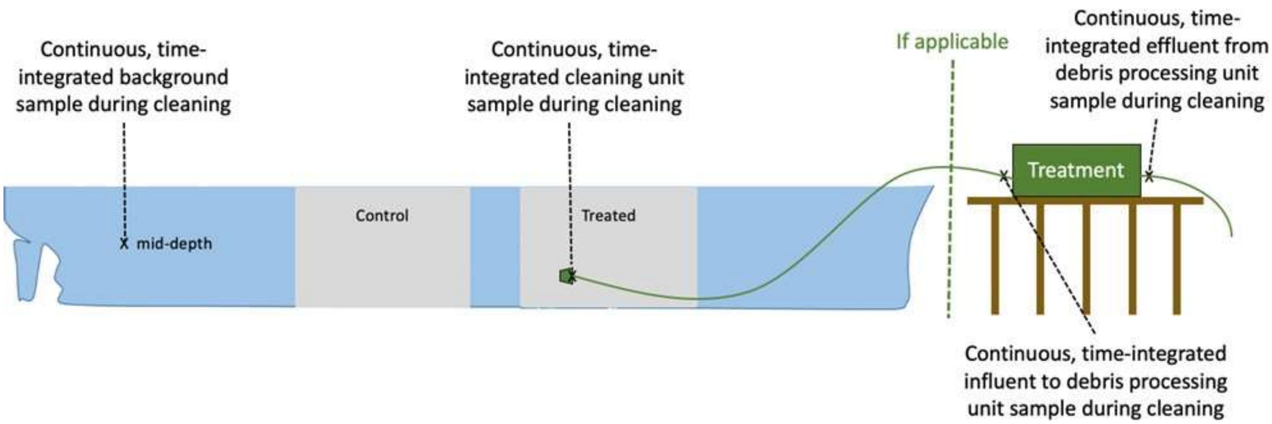

Figure 1: Pictorial representation (not to scale) of water quality sampling locations during a test cleaning event. Debris processing and effluent impacts are described below. Not pictured are the discrete samples of background/ambient conditions taken before and after a test trial at the same location and please note that no Control site is required for this study.

It may not always be possible to identify—and position a single sample collection point on—the part of the IWC system cleaning unit with the largest potential for environmental release. The project consultant and testing organization will work with the IWC system service provider to understand the cleaning unit design and operations (e.g., computational fluid dynamics models or video assessments of debris plumes) to optimize sample collection point placement to the extent possible.

Both samples, one for ambient/background and second on the cleaning unit, will be collected with the appropriate pump and hose systems (e.g., sufficient power and flow rates) into a series of sample collection containers or carboys. Care will be taken to ensure sampling equipment and methods do not introduce artifacts (e.g., sample contamination with metals or polymers). Both 90-minute (or more) continuous time-integrated sample events (background and cleaning unit) will then be divided into three 30-minute (or more) sequential samples. This provides a level of sample replication and insights into possible temporal changes in water quality during a test cleaning event.

Three appropriately sized sample containers for each sequential sample will be placed at the end of the sampling hose for both the background and cleaning unit and filled sequentially at a standardized flow rate suitable to collect the needed analytical volumes (e.g., 20 to 40 L) over a 30-minute sampling period. After the first container is filled (at the 30-minute mark), the hose can be moved to the second container, and then to the third container at the 60-minute mark (Figure 2). Each sample container will then be uniformly mixed prior to sub-sampling for analysis of specific water quality parameters.

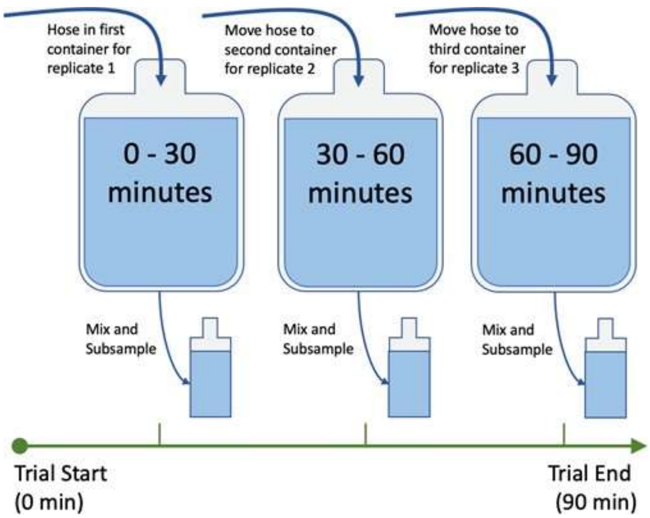

Figure 2: Pictorial representation of three-replicate, continuous, sequential, time-integrated water quality sampling, at each sample location, during a test cleaning event.

Table 4: Description of water quality sample collection during an individual IWC system test trial.

Purpose	**Station**	**Number of sample events**	**Number of continuous samples per event**
Background or ambient conditions during cleaning	≥ 50 m upstream of system	1 per test ship and per each test cleaning location on test ship > 90-minute samples*	3 intervals of: 0-30 minutes 30-60 minutes 60-90 minutes
Potential environmental release from cleaning unit during cleaning	On IWC system cleaning unit	1 per test ship and per each test cleaning location on test ship > 90-minute samples*	3 intervals of: 0-30 minutes 30-60 minutes 60-90 minutes

As water quality conditions will vary over time at a single location (e.g., based on season, tides, storms, local ship traffic), ambient background water quality will also be characterized by discrete sampling at the testing location before and after a test cleaning event (Table 5). This background station will be located near the test ship or test berth/anchorage location, at an appropriate depth (e.g., mid-depth of the test ship), and collected using a water sampling device such as a van Dorn or Niskin bottle, or rapid pump sampling system.

Table 5: Description of background water quality sampling before and after an individual IWC system test trial. Background sampling will be designed to capture, to the extent possible, the range of relevant ambient water quality parameters at the testing location.

Timing relative to IWC system test	Number of samples
One day before Three different times (at least 2 hours apart)	3
One hour before	1
One hour after	1
One day after Three different times (at least 2 hours apart)	3

3.7. Quantification of Debris Processing and Effluent

This section describes methods for: 1) quantifying debris processing efficacy; and 2) any potential changes to water quality from debris processing effluent. Therefore, it only applies to IWC systems that attempt some form of debris capture and treatment or removal. Debris processing can include treatments such as particle settling, filtration, flocculation, selective binding media (e.g., to remove metals), and disinfection treatments (e.g., UV, heat, chlorination), as depicted in Figures 3. The waste processing units for the majority of existing IWC systems that are designed to capture, process, and dispose of biofouling and coating debris are located above the water surface on support boats, barges, or dockside. Some IWC systems may only include a simple form of debris capture as part of the submerged cleaning unit (e.g., coarse filtration with periodic emptying of nets above the surface). This section does not apply to such IWC systems.

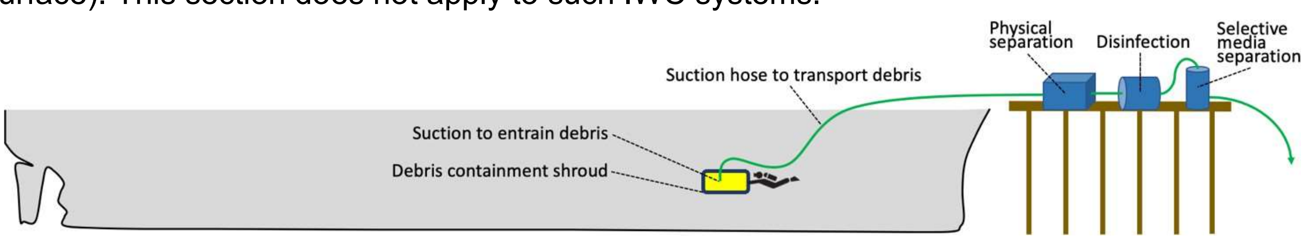

Figure 3: Pictorial representation of a Proactive or Reactive IWC system with debris capture and debris processing, involving physical separation, disinfection, and selective media separation.

3.8. Sampling the debris processing unit

To estimate biofouling and coating related waste processing efficacy, the debris processing unit influent (i.e., water and material entering the unit) and effluent (i.e., water and material released from the unit back into the environment) will be sampled. Sampling will be conducted using a series of sequential, continuous time-integrated water samples as part of any IWC system test (Figure 2). While percent reductions (i.e., effluent compared to influent) in various water quality parameters can provide insight on the performance of the debris processing unit, they do not allow for an appropriate assessment of possible effluent impacts on local waters (Tamburri et al. 2021). Therefore, the priority assessment of environmental impacts will be a comparison of: 1) effluent water quality parameters versus simultaneous measure of background/ambient conditions; and 2) discrete background samples collected before and after test cleaning events.

For each test trial, simultaneous, continuous time-integrated samples will be collected: 1) at a suitable influent sample port; and 2) at a suitable effluent sample port (i.e., to produce representative samples). Sampling will occur over at least a 90-minute period for a hull cleaning event and target at least 30-minutes for a niche area cleaning event. Again, both 90-minute continuous time-integrated sample locations (influent and effluent) will then be divided into three 30-minute sequential samples (Figure 2) to provide sample replication and insights into possible temporal changes in water quality. Care will again be taken to ensure sampling equipment and methods do not introduce artifacts (e.g., sample contamination with metals or polymers).

The three appropriately sized sample containers will be placed at the end of the sampling hose and filled at a standardized flow rate suitable to collect the needed analytical volumes (e.g., 20 to 40 L) over a 30-minute sampling period. After the first container is filled (at the 30-minute mark), the hose will be moved to the second container, and then to the third container at the 60- minute mark (Figure 2 and Table 6). Each sample container will be uniformly mixed prior to
sub-sampling for analysis of specific water quality parameters (Table 3).

Table 6: Description of water quality sample collection for testing IWC system debris processing unit.

Purpose	Station	Number of sample events	Number of continuous samples per event
Quantify the captured dissolved and particulate material removed from vessel	Processing unit influent	1 per test ship and per each test cleaning location on test ship > 90-minute samples*	3 intervals of: 0-30 minutes 30-60 minutes 60-90 minutes
Potential environmental release from debris processing unit	Effluent release point	1 per test ship and per each test cleaning location on test ship > 90-minute samples*	3 intervals of: 0-30 minutes 30-60 minutes 60-90 minutes

3.9. Water quality parameters to quantify

The appropriate volumes, for all subsamples and various analyses, will be placed in suitable, cleaned bottles (e.g., glass containers and sample bottles for assessment of MP/NP). All sample bottles will be labeled with unique identification numbers prior to sampling. To ensure analytical validity, all samples will be transported and stored within the appropriate times, temperatures, and light requirements. The same certified, standardized, and/or validated analytical methods employed for background and cleaning unit samples will again be used for waste processing influent and effluent samples.

The individual IWC system service providers will also supply a standard operating procedure (SOP) for the debris processing unit, including the frequency of activities (e.g., changing or cleaning of filters and filter cartridges) to prevent failure of the unit. The use of the debris processing unit during the test will be audited against this SOP. The parts of the waste treatment system above the water surface will be monitored for leaks, overflows, or alarms log of system operations/performance will be kept, noting any problems, such as blocked or ruptured filters, or leaks. Contingency plans to manage the risks and rectify system failures should be included in the SOPs.

Some IWC system debris processing units may include an effluent disinfection stage to kill or render organisms “non-viable” prior to environmental release. Where this is the case, additional data will be collected to document the proper dose and/or operations of the disinfection process, rather than measuring or estimating live or viable organisms (see Tamburri et al. 2021). During each individual IWC system trial, it will be confirmed that the treatment system is meeting specifications (e.g., concentration, time, temperature) via independent observations or measurements, as appropriate. A log of disinfection system operations/performance will also be kept, noting any problems with these systems. Methodologies will vary depending on the type of treatment system.

The total volume of wastewater produced, processed, and/or discharged during a test cleaning trial will be documented/reported and linked directly to the total area and duration of the cleaning event. This can be estimated via repeated measurements using a flow meter attached to the system or through siphoning off the flow for direct volumetric measures under timed conditions.

3.10. Solid waste disposal

For each test cleaning trial that includes capture, the total wet mass and/or volume of solid waste material removed during debris processing will be quantified and characterized to the extent possible. This will also be directly linked to the total area and duration of the specific cleaning event. All documentation associated with the appropriate disposal of solid waste will also be reported. While waste disposal requirements are determined by each port or local jurisdiction, proof of compliance will be provided.

3.11. Environmental characteristics to quantify

In conjunction with all test trials, the background environmental characteristics listed in Table 7 will be observed or measured and reported during all sample collection events. This will provide insight into environmental conditions during testing.

Table 7: Environmental characteristics to be recorded during test trials.

Environmental characteristic	Method of measurement

Water temperature	Single or multiparameter instrument/thermometer
Salinity	Single or multiparameter instrument/salinity meter
Water clarity/turbidity	Secchi disc and/or turbidity sensor
Wind speed and direction	Hand-held anemometer or a nearby weather station
Current speed and direction	Current meter
Tide	Local tide tables and visual observations
Sea state	Beaufort scale (www.weather.gov/pqr/beaufort)
Air temperature	Thermometer or data from a nearby weather station
Weather	Visual observations (precipitation, cloud cover, etc.)

4. Evaluation Schedule

Note that the schedule below is provisional. Dates indicate expected deadlines and may vary.

Activity	Q4 2023	Q1 2024	Q2 2024	Q3 2024	Q4 2024
Project plan sign-off	30 Oct				
Designation of testing organization		31 Jan			
Confirmation of sampling dates		31 Mar			
Sampling			1 May	31 Jul	
1st draft of report				15 Sep	
Comments to report				30 Sep	
Final version of report					31 Oct
Publication					24 Dec

5. Data Management and Quality Control / Quality Assurance

The selected testing organization will follow all internal, documented best practices for data management and testing QA/QC (e.g., ISO/IEC 17025). The work conducted, and data produced, by the testing organization will be overseen and audited by the project consultant. Details are available upon request.

6. Roles and Responsibilities

Participating IWC service providers will:

- Review and agree to this work plan;
- Identify the primary points of contact for this study, an appropriate test ship and location for their individual test trial;
- Meet with the project consultant and testing organization to address all logistic details;
- Prior to testing, provide the project consultant with all relevant documentation described above;
- Facilitate appropriate sample collection and perform the IWC on the designated test ship;
- Work on site with the test team to ensure all activities take place safely and

successfully; and

- Review and agree to a final report.

Project consultant will:

- Draft the study work plan;
- Serve as the primary project point of contact for participating IWC service providers, and the testing organization;
- Coordinate the testing schedule in consultation with the testing organization, test ship, and IWC service providers;
- Confirm all required documentation is received prior to testing;
- Oversee testing organization activities and analyses;
- Work with the testing organization on data analysis and presentation;
- Draft a study report for review; and
- Submit a final report.

Testing organization will:

- Review the study work plan;
- Conduct all sample collection and analyses, as described in the final work plan;
- Provide all data collected to the project consultant;
- Assist the project consultant in data analysis and presentation; and
- Assist the project consultant in drafting and reviewing the final study report.

7. References

International Maritime Organization (2023). Guidelines for the Control and Management of Ships' Biofouling to Minimize the Transfer of Invasive Aquatic Species. International Maritime Organization: London.

International Organization for Standardization (ISO). 2017. ISO/IEC 17025, General Requirements for the Competence of Testing and Calibration Laboratories

Tamburri, M.N., Georgiades, E.T., Scianni, C., First, M. R., Ruiz, G.M., and Junemann, C.E. (2021). Technical considerations for development of policy and approvals for in-water cleaning of ship biofouling. Frontiers in Marine Science, 8, 804766.

———