



**International
Standard**

ISO 20679

**Ships and marine technology —
Marine environment protection —
Testing of ship biofouling in-water
cleaning systems**

*Navires et technologie maritime — Protection de
l'environnement marin — Essais des systèmes de nettoyage des
salissures biologiques sans sortir le navire de l'eau*

**First edition
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 2, *Marine environment protection*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Like all substrates placed in coastal waters, the wetted surfaces of ships are quickly colonized by a succession of diverse sessile or sedentary micro- and macro-organisms, collectively known as biofouling.^{[1][2][3]} The adverse effects of biofouling on ships and their operations are well known and there is a long history of attempting various biofouling management approaches.^[4]

Negative impacts of biofouling on the shipping industry include:

- reduced ship performance and fuel efficiency;^{[5][6][7][8]}
- corrosion and decreased durability;^{[9][10]}
- increased greenhouse gas emissions;^{[11][12]}
- failure to meet associated legal/contractual requirements;^{[13][14]}
- increased underwater noise;^[15]
- unintended translocation of aquatic species.^{[16][17][18]}

In recent decades, the importance of ship biofouling as a pathway for invasive aquatic species translocations has become increasingly apparent.^{[17][18][19][20][21]} Entire biological communities can be moved around the world by oceangoing ships and a substantial number of species, including pathogens, can be introduced as a result.^{[22][23][24]} While not all invasive aquatic species have immediate noticeable or significant impacts, a subset of invasive aquatic species have a broad range of effects on the aquatic environment and the communities reliant upon local ecosystem services.^{[25][26][27]} Guidelines and regulations to prevent invasive aquatic species introductions via ship biofouling are beginning to emerge to protect environmental, economic, social, and cultural values (e.g. see References ^[12] ^[28] ^[29]).

The International Maritime Organization (IMO) defines antifouling systems (AFS) as various approaches used on a ship to control or prevent the attachment of unwanted organisms.^[30] The primary AFS are coatings, applied during dry-docking to surfaces below the maximum waterline of ships, which are designed to either prevent macrofouling attachment (using biocides) or reduce adhesion (foul-release) to wetted surfaces.^[31] ^[32] In some areas (e.g. Baltic Sea), non-ablative or non-polishing hard coatings are used in combination with regular cleaning as a fouling prevention strategy.^[33]

The service life of modern coatings for commercial ships is typically five years (e.g. see Reference ^[32] ^[34]). Despite substantial improvements over the past 40 years, surface coatings do not consistently prevent biofouling accumulation on all ship surfaces over the course of their service lives.^{[35][36]} Accumulations tend to occur as coatings age^{[37][38]} and when ships have extended stationary periods.^{[13][14][39][40]}

Even when antifouling coatings are used, there are also substantial areas of ships' immersed surfaces that are more prone to biofouling^{[41][42][43][44]} because they:

- cannot be painted (e.g. anodes);
- are prone to damage (e.g. bulbous bow, tug and fender points, areas below anchor chain);
- are challenging to coat (e.g. dry-dock blocking areas); or
- are sub-optimal for coating performance (e.g. gratings, rudders, propellers, and sea chests).

Given the existing limitations of coatings, especially during extended periods between dry-docking, in-water cleaning (IWC) of ship biofouling (within a coating's service life) is often required or advantageous.^[12]

IWC of biofouling – used to either maintain or reset ship immersed surfaces to a hydrodynamically smooth state – is a common approach to increase ship performance and fuel efficiency between dry-dockings.^{[8][45]} IWC is also recognized as beneficial for reducing both greenhouse gas emissions^{[11][12][46]} and biosecurity risks.^{[47][48]}

IWC systems typically involve the use of diver- or remotely-operated cleaning units (i.e. cleaning carts) that remove biofouling from hull surfaces.^{[49][50]} IWC is generally described as either proactive or reactive.^[47] Proactive IWC is the periodic removal or reduction of biofilm growth (i.e. microfouling or slime layer) on ship surfaces. Proactive IWC also removes newly settled or attached microscopic stages of macrofouling organisms, to ultimately minimize or prevent macrofouling growth.^{[47][51]} Reactive IWC is typically used to remove already established macrofouling organisms.^{[47][52]} Both proactive and reactive IWC can include debris capture, treatment and disposal.^{[48][52]}

While IWC has the potential to provide significant ship operations and biosecurity benefits, there are two main IWC processes that can result in inadvertent environmental harm:

- a) lack of, or incomplete, capture of dislodged debris by the cleaning unit; and
- b) release of untreated, or incompletely treated, effluent from debris processing.^{[47][48]}

Potential environmental impacts from these two IWC processes include:

- increased discharge of coating biocides and microplastics to ambient waters;^{[52][53][54][55]}
- release of live biofouling organisms, their propagules, or pathogens, into local habitats;^{[24][52][54]}
- diminished coating condition (e.g. dry film thickness [DFT] or scuffs and chips) that reduces antifouling performance and longevity.^{[45][56]}

Given the potential for environmental harm, independent, transparent, and predictive testing of efficacy is needed to evaluate the performance of both proactive and reactive IWC systems. Such robust and standardized testing is critical for the responsible use of IWC systems and the success of biofouling-related policies and regulations.^[48]

This document aims to provide standardized, science-based test procedures that produce the data (and level of confidence) needed by relevant stakeholders when assessing the development and use of IWC systems. This document is based on recent, related international efforts to develop IWC system testing protocols (e.g. see References [50] [57] [58]). It describes how to produce data and report on the efficacy and safety of IWC systems to clean various ship surfaces and for the capture and disposal of cleaning debris. The impartial data and reporting from testing under this document are intended to inform IWC service providers, ship operators, and relevant authorities on the performance of IWC. The procedures and methods in this document can also serve as a resource for technology developers, environmental regulators, and other stakeholders interested in the safe and effective use of IWC systems.

The methods and approaches presented in this document represent consensus among international technical experts on best scientific practices. However, it is also expected that some test methods will evolve or improve over time as collective knowledge of this complex issue grows. Performance and safety of IWC systems is context-dependent with many sources of variation across ships, environments, and associated biota. As a result, the use of this document does not guarantee that a specific IWC system will always, or under circumstances other than those used in testing, operate at the levels reported.

This document was developed so that all forms of IWC systems can be tested in a comprehensive and standardized way. However, this document also provides flexibility for conducting evaluations that are customized and appropriate for individual IWC system designs, operational requirements or limits, and providers' claims. It is expected that end-users will select appropriate aspects of this document to incorporate in any individual testing effort, depending on the specifics of the IWC system being evaluated, the function of the IWC system evaluation, and the resources available.

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Ships and marine technology — Marine environment protection — Testing of ship biofouling in-water cleaning systems

1 Scope

This document provides detailed and rigorous procedures for the independent performance testing of all forms of ship in-water cleaning (IWC), including on all types of biofouling (i.e. biofilms/microfouling and macrofouling), all external submerged surfaces (i.e. hull and niche areas), and both proactive and reactive IWC systems with or without the capture, processing, and disposal of debris. This document also includes testing protocols and describes how to produce data and report on the efficacy and safety of IWC systems to clean various ship surfaces and for the capture and disposal of cleaning debris.

The development of specific IWC performance requirements, criteria, or standards is outside the scope of this document and is the responsibility of individual authorities, agencies, or administrations. Similarly, while some methods and approaches described in this document can apply to other ship biofouling management approaches, systems designed to kill or prevent biofouling on external surfaces without removal (i.e. without in-water cleaning), and systems that remove or treat biofouling on internal surfaces (e.g. seawater pipes) or external surfaces of intricate mechanical components (e.g. external parts of propeller shaft seal), are also outside the scope of this document.

2 Normative references

There are no normative references for this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

3.1 antifouling system

AFS

coating, paint, surface treatment, surface or device that is used on a *ship* (3.18) to control or prevent the attachment of organisms

3.2 antifouling coating

surface coating or paint designed to prevent, repel, or facilitate the detachment of *biofouling* (3.3) from hull and *niche areas* (3.16) that are typically or occasionally submerged

3.3 biofouling

accumulation of aquatic organisms such as microorganisms, plants, and animals on surfaces and structures immersed in or exposed to the aquatic environment

**3.4
capture**

process of containment, collection, and removal of *biofouling* (3.3) material, debris, and *waste substances* (3.20) from surfaces during cleaning in water or in drydock

**3.5
cleaning system**

equipment used for, or the process of, removal of *biofouling* (3.3) from the *ship* (3.18) surface, with or without *capture* (3.4)

**3.6
data quality objective**

qualitative and quantitative statement that clarifies study objectives, defines the appropriate types of data and specifies the tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions

**3.7
dry film thickness**

DFT

non-destructive means to measure the total coating thickness and wear on submerged ship surfaces through repeated measures using a digital DFT sensor

**3.8
fouling rating**

FR

allocation of a number for a defined inspection area of the *ship* (3.18) surface based on a visual assessment, including a description of *biofouling* (3.3) present and the percentage of *macrofouling* (3.13) coverage

**3.9
hull area**

largest proportion of *ship* (3.18) submerged surfaces, which are relatively flat or planar locations, have well-understood hydrodynamic conditions and employ common or traditional *biofouling* (3.3) management systems (e.g. *antifouling coating* (3.2))

**3.10
independent testing organization**

independent TO

appropriately independent (e.g. with no conflicts of interest), qualified, scientific contractor accepted to conduct third-party testing

**3.11
invasive aquatic species**

non-native or non-indigenous species to a particular ecosystem that can pose threats to human, animal, and plant life, economic and cultural activities, and the aquatic environment

**3.12
in-water cleaning**

IWC

intentional removal of *biofouling* (3.3) from a *ship's* (3.18) hull or *niche areas* (3.16) while in the water

**3.13
macrofouling**

biofouling (3.3) caused by the attachment and subsequent growth of visible plants and animals on structures and *ships* (3.18) exposed to water

Note 1 to entry: Macrofouling are large, distinct multicellular individual or colonial organisms visible to the human eye such as barnacles, tubeworms, mussels, fronds/filaments of algae, bryozoans, sea squirts, and other large attached, encrusting or mobile organisms.

3.14

microfouling

biofouling (3.3) caused by bacteria, fungi, microalgae, protozoans, and other microscopic organisms that create a biofilm

3.15

multicomponent in-water cleaning system

multicomponent IWC system

system reliant on two or more individual components to achieve the required *in-water cleaning* (3.12)

Note 1 to entry: The use of each component shall be specified in the system standard operating procedures (SOP), e.g. the use of a hand tool for addressing *niche areas* (3.16) after the use of the main cleaning unit on hull surfaces.

3.16

niche area

subset of the submerged surface areas on a *ship* (3.18) that can be more susceptible to *biofouling* (3.3) than the main hull owing to structural complexity, different or variable hydrodynamic forces, susceptibility to *antifouling coating* (3.2) wear or damage, or inadequate or no protection by *antifouling systems* (3.1)

3.17

proactive in-water cleaning

proactive IWC

periodic removal of *microfouling* (3.14) on *ship* (3.18) surfaces to prevent or minimize attachment of *macrofouling* (3.13)

3.18

ship

vessel of any type operating in the aquatic environment, including hydrofoil boats, air-cushion vehicles, submersibles, floating craft, fixed or floating platforms, floating storage units, and floating production storage and off-loading units

3.19

reactive in-water cleaning

reactive IWC

corrective action during which *biofouling* (3.3) is removed from a *ship's* (3.18) hull and *niche areas* (3.16), either in water with *capture* (3.4) or in drydock

3.20

waste

dissolved and particulate materials or debris that can be released or produced during cleaning or maintenance, and can include biocides, metals, organic substances, removed *biofouling* (3.3), pigments, microplastics, or other contaminants that could have a negative impact on the environment

3.21

waste processing

treatment designed to remove or deactivate any particulate, dissolved material, or debris *captured* (3.4) during any form of *in-water cleaning* (3.12)

Note 1 to entry: Treatment can be a single stage such as physical separation (e.g. settling tanks, filtration, flocculation), selective media binding of compounds of concern, or disinfection of biological constituents of concern (e.g. biocides, UV, ultrasound) or a multi-staged, combined treatment approach.

4 Fundamental information needed for testing of IWC systems

4.1 Factors that can impact performance

Numerous factors can impact IWC system performance and the means by which comprehensive, standardized testing is performed.^{[48][52]} These include, but are not limited to:

- ship [e.g. type, design, coating(s), ship and coating ages, operational profile, and routes];

- biofouling (e.g. life history stage, type, coverage, location);
- environmental conditions (e.g. visibility, swell, current, ambient water quality);
- the IWC system (e.g. unique design features, operational requirements and limits, cleaning procedures); and
- IWC system operator training and experience.

4.2 Fundamental parameters

Testing IWC systems is most appropriate and informative when performed under real-world conditions. However, the cost and complexity of full-scale operations on ships can prohibit extensive experimental replication, controls, and the isolation of single factors to measure their impact on overall performance and safety. Given the complexity of these variables, it is not feasible to examine all possible factors (singularly or in combination) that can impact IWC system performance and safety. Therefore, a list of fundamental parameters that shall be either documented, characterized, or specifically tested for, as part of any independent evaluation, is provided in [Table 1](#). The listed parameters allow for linking test results to performance under specifically known (or measured) ship, biofouling, environmental, and IWC system characteristics. The experimental design and specific performance parameters for IWC system testing are described in [Clauses 5 to 9](#).

Reporting for these parameters falls into three general categories:

- Documenting: information that shall be provided either by the ship owner, operator, IWC system service provider, or all three, which appropriately describes test conditions;
- Monitoring: information that shall be observed, measured or collected (e.g. direct observations of cleaning mobilization, operations, demobilization and environmental test conditions) and reported by the independent testing organization (TO) conducting the testing; and
- Testing: factors that shall be directly targeted or manipulated as fundamental test variables (e.g. a direct test of IWC system claims).

Table 1 — Test parameters and data required to assess IWC system performance

Ship parameters	Documenting	Monitoring	Testing
Ship type/function, age, size, and design drawings, with any relevant modifications (including complexities and niche areas)	X		
Ship recent routes/voyages and operational history over at least the past 12 months (including dry-docking, long idle periods, lay-up, and repairs)	X		
<p>X Designates data or information required through documenting, monitoring, or testing for each parameter listed.</p> <p>^a 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.</p> <p>^b For example, testing the IWC system service provider's claims on coating type (biocidal or fouling release), age or damage, which can influence environmental results.</p> <p>^c For example, testing the IWC system service provider's claims on fouling type/level/location and results from recent/relevant in-water biofouling inspections.</p> <p>^d For example, testing within specifications or to limits, including fouling (e.g. type, stage, and coverage), ship (e.g. size, materials, curvature, niche areas), coating type and appropriateness for cleaning, and environmental parameters (e.g. currents and visibility).</p> <p>^e For example, testing within specifications or efficacy limits.</p> <p>^f For example, testing within specifications or limits.</p>			

Table 1 (continued)

Ship availability/access for either cleaning, testing, or both (including dates, ports, time at dock or anchorage, any access restrictions)	X		
Ship coating(s) type (or uncoated), age, expected service life, applied location, and history (including prior cleaning, damage, or repair)	X	X	X ^b
Ship fouling rating prior to testing (including type and percentage cover) and distribution on various surfaces		X	X ^c
Environmental parameters	Documenting	Monitoring	Testing
Water visibility/clarity		X	
Tides, currents, wind, and waves		X	
Water quality at location of testing and during testing, at minimum: (a) salinity, (b) temperature, (c) total suspended solids, (d) particle size distribution, (e) dissolved organic carbon, and (f) particulate organic carbon		X	
Ambient levels of biocides during testing, if applicable (e.g. background levels of copper and zinc) and other contaminants of interest (e.g. microplastics) in water column at location of testing		X	
IWC system parameters^a	Documenting	Monitoring	Testing
IWC system design and function, and IWC mobilization, operations and demobilization	X		X
IWC system specifications, requirements and limits	X		X ^d
Mode of cleaning unit operations (e.g. diver-, remotely-, or autonomously-operated)	X	X	
Mode of cleaning unit attachment to, and movement on, ship surfaces	X	X	
Operator/diver skill and experience (as described by the IWC service provider)	X	X	
<p>X Designates data or information required through documenting, monitoring, or testing for each parameter listed.</p> <p>^a 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.</p> <p>^b For example, testing the IWC system service provider's claims on coating type (biocidal or fouling release), age or damage, which can influence environmental results.</p> <p>^c For example, testing the IWC system service provider's claims on fouling type/level/location and results from recent/relevant in-water biofouling inspections.</p> <p>^d For example, testing within specifications or to limits, including fouling (e.g. type, stage, and coverage), ship (e.g. size, materials, curvature, niche areas), coating type and appropriateness for cleaning, and environmental parameters (e.g. currents and visibility).</p> <p>^e For example, testing within specifications or efficacy limits.</p> <p>^f For example, testing within specifications or limits.</p>			

Table 1 (continued)

Mode of biofouling (biofilms or macrofouling) removal (e.g. brushes, blades, or water jets, with details on type, amount, configuration)	X	X	
Rate and pattern of individual cleaning operations (e.g. speed of cleaning unit, number and overlap of passes)	X	X	X
If applicable, frequency of cleaning operations	X	X	
If applicable, debris capture methods (e.g. cleaning unit shroud and suction)	X	X	X ^e
If applicable, flow rate of debris/wastewater capture	X	X	
If applicable, debris and wastewater transport and processing (e.g. particle settlement processes, type and level of filtration/separation, secondary treatment of biological waste such as UV or chlorination, type media for removal of metals) and maximum load capacity	X	X	X ^f
If applicable, waste disposal processes (including volumes and mass)	X	X	
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	X	X	

X Designates data or information required through documenting, monitoring, or testing for each parameter listed.

^a 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.

^b For example, testing the IWC system service provider's claims on coating type (biocidal or fouling release), age or damage, which can influence environmental results.

^c For example, testing the IWC system service provider's claims on fouling type/level/location and results from recent/relevant in-water biofouling inspections.

^d For example, testing within specifications or to limits, including fouling (e.g. type, stage, and coverage), ship (e.g. size, materials, curvature, niche areas), coating type and appropriateness for cleaning, and environmental parameters (e.g. currents and visibility).

^e For example, testing within specifications or efficacy limits.

^f For example, testing within specifications or limits.

5 Test experimental design

5.1 General

The full IWC system shall be tested on a minimum of three distinct ships (i.e. $n \geq 3$). This level of replication is meant to provide fundamental information on system performance, environmental safety, and applicability across different conditions within the operational claims and parameters of the individual IWC system. A single test ship will not be able to provide multiple relevant challenge conditions for predictive IWC system testing. While such independent testing scenarios are not always possible, they represent the experimental replication required for an acceptable level of confidence in the safety and efficacy of any IWC system.

Any deviation from this design, and this document more broadly, shall be noted in test results and reporting (see [Clause 13](#)).

The test ships and conditions chosen shall capture as much relevant variability in the key parameters listed in [Table 1](#) as feasible. While the overall IWC system test unit of replication is the number of test ships (i.e. $n \geq 3$), additional sample replication within individual test trials of biofouling removal/prevention, changes to water quality, debris capture/processing, and ship coatings impacts, are provided in [Figures 1](#) and [2](#) and [Clauses 5](#) to [9](#).

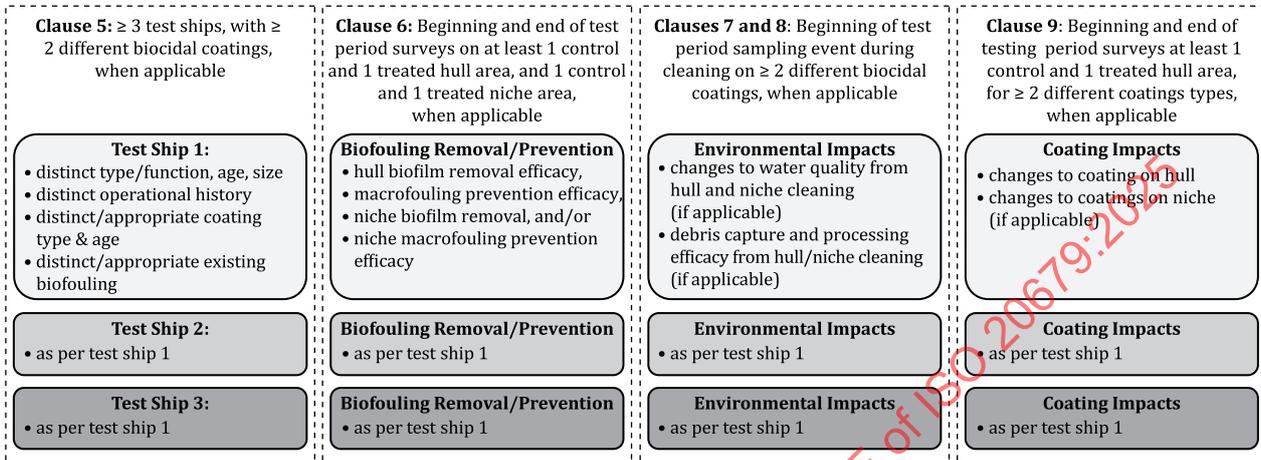


Figure 1 — Basic testing components for a proactive IWC system

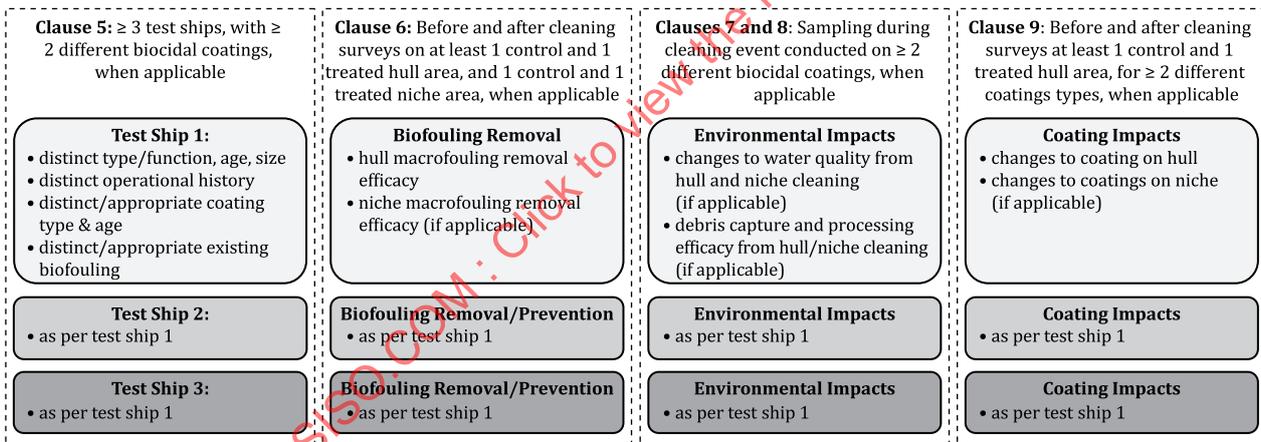


Figure 2 — Basic testing components for a reactive IWC system

The ships selected and specific tests conducted shall align with the claims of the IWC service provider. For example, if it is claimed the IWC system can be used on all coating types, then ships with different biocidal and non-biocidal coatings shall be included in testing to verify that claim. If the IWC system is claimed to be appropriate for use on large cargo ships with extensive macrofouling, then testing shall include these ship types that have close to the upper limit of biofouling type and coverage, to verify that claim. Likewise, if the IWC system is intended for use on both relatively flat hulls as well as angular niche areas, then examples of both ship surface types and distinct equipment used for different surface types shall be included in testing to verify that claim.

While it is possible that it is not feasible to directly examine all IWC service provider claims in one set of independent tests, extrapolation or prediction of performance and safety (beyond the specific conditions and parameters tested) shall be avoided.

5.2 Classification of IWC system application for testing

Test trials, on diverse replicate test ships ($n \geq 3$, varying in size, age, routes, operational profile, etc.) shall incorporate specific evaluations of performance and environmental safety (see [Figures 1](#) and [2](#) and [Clauses 6](#) to [9](#)). These shall be based on the IWC system design, function, and application, and the basic categories of key variables presented in [Table 2](#).

Table 2 — Simplified considerations for testing based on IWC system design and function

Surface type	Fouling type	Coating type	Debris capture and processing
Planar and curved hull surfaces (sides, bottom, wind-and-water line) or Angled and complex niche areas (protrusions and recesses) or All surface types	Biofilm (microorganisms) or Macrofouling (macro-organisms) or All biofouling types	Non-biocidal coatings (including non-ablative) or Biocidal coatings or All coating types	No debris capture or Debris capture and processing (waste collection, treatment, and disposal)

The following two examples in a) and b) represent experimental designs that incorporate replicate test ships and the considerations provided in [Tables 1](#) and [2](#). The fouling rating (FR) is described in [6.2](#). While such independent testing scenarios are not always possible, they represent the experimental replication needed for an acceptable level of confidence in the safety and efficacy of any IWC system. Any deviation from this design, and the document more broadly, shall be noted in test results and reporting (see [Clause 13](#)).

- a) A proactive IWC system can be tested for use only on hull surfaces with specific biocidal coatings on:
 - 1) a large, transcontinental tanker with a four-year-old biocidal coating, and a FR of 1 (with small infrequent patches of FR 2 biofouling);
 - 2) a modern roll-on/roll-off ship, just out of drydock with the same biocidal coating, and FR 0 to 1 biofouling; and
 - 3) a regional cruise ship, with a second appropriate biocidal coating, and FR 1 biofouling.
- b) A reactive IWC system, with debris capture/processing, can be tested for broad applications on:
 - 1) a large, transcontinental bulk carrier, with the same four-year-old biocidal coating on both hull and niche areas, and with biofouling ranging from FR 2 to 3;
 - 2) a regional container ship, with a one-year-old fouling release coating on the hull and a second type of biocidal coating on niche areas, and with biofouling ranging from FR 1 to 3;
 - 3) a local passenger ferry with a hard, non-biocidal coating on both hull and niche areas, and with existing biofouling of FR 2; and
 - 4) a local barge with no niche areas, a third type of biocidal coating, and with heavy biofouling ranging from FR 3 to 4.

[Clauses 6](#) to [9](#) on testing protocols and methods apply to all categories of IWC systems and applications. The exception is [Clause 8](#) (debris capture and processing), which only applies to systems that attempt debris capture/disposal or waste treatment. Additionally, where multicomponent IWC systems have been developed to clean the hull and external niches, the different primary components (e.g. different cleaning units) shall be tested to assess the complete IWC system's efficacy and safety.

Finally, since most IWC activities take place when a ship is stationary (i.e. at dock or anchorage), this document was designed around this application. The testing of IWC systems that are designed to be carried out while a vessel is underway can require modifications or adaptations to some of the methods described below in [Clauses 6](#) to [9](#). For example, water quality samples (see [Clause 7](#)) can be collected simultaneously

from the cleaning unit and a background location, with hoses and pumps from the deck of a moving test ship. Whereas before and after measures of biofouling level/extent (see [Clause 6](#)) and coatings dry film thickness (DFT) (see [Annex B](#)) can be collected from the test ship while in port just prior to, and just after, an IWC voyage. While not all aspects of this document are applicable or feasible for all possible forms of IWC, any deviation from this design shall be noted and justified in test results and reporting (see [Clause 13](#)).

5.3 Duration and extent of testing

5.3.1 General

All sampling during operational cleaning shall be conducted over at least a 90-min period, for each test event (see accommodations for smaller niche areas in [7.3](#)), with the IWC system operating in a defined cleaning mode for the conditions presented. Sampling for the various performance measures described below in [Clause 7](#) can take place in smaller designated subsections of the test ship's cleaned areas, or during a series of smaller time periods. However, at least one test trial, on one test ship, shall involve a substantial cleaning area (e.g. at least 1/3 of the test ship) over a realistic time frame (e.g. several hours), representative of the expected typical application of the IWC system being tested. Furthermore, the total area cleaned with the corresponding length of time to complete for each test trial shall be recorded and reported.

5.3.2 Proactive systems

For proactive IWC systems designed solely to periodically remove biofilms (i.e. microfouling), individual test trials (associated with a cleaning event) can take place on each replicate test ship ($n \geq 3$) during a relatively short period of a day or two. However, for proactive IWC systems that claim to periodically remove biofilms as well as incipient macrofouling, explicitly to inhibit or prevent the development of mature macrofouling growth, at least two repeated assessments over time shall be conducted. To account for the temporal aspects of proactive IWC prevention of macrofouling, the overall testing period for each replicate test ship ($n \geq 3$) shall be between 3 to 12 months, depending on the ability to document significant macrofouling growth in control locations (i.e. untreated or uncleaned areas). This window allows for an appropriate determination of IWC system performance regarding macrofouling prevention (see [Clause 6](#)). On a specific test ship, if at any point after three months of initiating the testing period it can be demonstrated conclusively that macrofouling has been established in control locations, testing can be terminated, as long as all other aspects of the planned testing are complete. Alternatively, the testing period can be extended beyond 12 months if the prevention of macrofouling as a direct result of proactive IWC cannot be unambiguously documented (e.g. little or no macrofouling growth is found in control locations). The test duration (with specific start and end dates) and a log of the test ship operations/movements during the testing period shall be included with the results.

During the test period, the IWC system shall be operated as determined by the service provider (e.g. cleaning specified locations on the ship and at the specified frequency). All test ship routes, operations, and IWC activities (mode, frequency, locations, etc.) shall be documented and reported for at least six months prior to (when applicable) and during the testing period, as can be found in the ship's official deck log book and biofouling record book. Biofouling surveys (see [Clause 6](#)) and assessments of coating impacts (see [Clause 9](#)) shall be conducted at a minimum of two time points during the testing period: at the beginning and end. Water quality sampling for environmental impacts (see [Clause 7](#)) and debris processing (see [Clause 8](#), when applicable), shall be conducted for at least one time point (e.g. during the first cleaning at the beginning of the test period).

5.3.3 Reactive systems

Since reactive IWC is a biofouling management system designed to remove existing macrofouling, individual test trials (associated with a cleaning event) can take place on each replicate test ship ($n \geq 3$) during a relatively short period of a few days. All testing shall take place during combined, comprehensive test trials of routine IWC system activities on individual test ships (see [Clauses 6, 7, and 8](#), and where applicable, [Clause 9](#)). This allows for the appropriate assessments of test conditions, system performance, and environmental safety before, during and after IWC activities.

6 Quantification of biofouling removal and prevention

6.1 IWC systems

6.1.1 General

The primary function of all IWC systems is to prevent or remove biofouling (either biofilms, macrofouling, or both) from the submerged surfaces of ships. Therefore, quantification of ship biofouling in response to IWC is essential for any assessment of system performance. A before-after-control-impact (BACI) sampling design shall be used to quantify or estimate the change in biofouling assemblages associated with cleaning events/activities for each test ship. The BACI sampling design compares designated control (i.e. not cleaned) to treated (i.e. cleaned) test areas associated with a single cleaning event (for reactive IWC) or over time (for proactive IWC).

6.1.2 Proactive systems

To account for rapid changes in microfouling growth, IWC surveys taken before and after the biofilm removal (see proactive systems under 6.4.5) should preferably be carried out on the day of (i.e. within 12 hours of) the test cleaning event, but no more than 24 hours before or after. However, the assessments of macrofouling prevention, over 3 to 12 months, are not required to be associated with a specific cleaning event.

NOTE Surveys for coating impacts in [Clause 9](#) have different timing considerations.

6.1.3 Reactive systems

To avoid the potential influence of natural fluctuations in biofouling communities, IWC surveys taken before and after the macrofouling shall not be conducted more than three days before, or after, a test cleaning, respectively.

6.2 Fouling rating

Testing shall only be conducted on ship surfaces with a level of biofouling appropriate to the IWC system's intended use (i.e. at or just below maximum levels and to the extent possible to match the claims of the IWC service provider). There are several methods of rating ship biofouling type and percentage coverage, each having strengths and limitations. For consistency in measures of biofouling within and among tests, at minimum, the following categories of biofouling type and estimates of percentage cover shall be used (see [Table 3](#)). Other proven/accepted approaches may also be incorporated in testing, as needed.^{[59][60]} For comparative purposes, the approach chosen shall be consistent over the replicate ($n \geq 3$) test vessels.

This document uses two categories of biofouling (microfouling and macrofouling) relevant to the two fundamental types of IWC (proactive and reactive). While various ship biofouling ratings have been developed and can be successfully used in testing (e.g. see References [\[45\]](#) [\[61\]](#)), at a minimum, all assessments of the level and extent of fouling on test ships shall collect and present data in accordance with [Table 3](#), which uses the rating scale from the 2023 IMO Biofouling Management Guidelines.^[12]

Table 3 — Biofouling rating scale

Rating (FR)	Description	Macrofouling cover of area inspected
0	No fouling No visible biofouling on surfaces.	-
1	Microfouling Submerged areas are partially or entirely covered in biofilms.	-
2	Light macrofouling Presence of microfouling and multiple macrofouling patches.	1 % - 15 % of surface
3	Medium macrofouling Presence of microfouling and multiple macrofouling patches.	16 % - 40 % of surface
4	Heavy macrofouling Large patches or submerged areas entirely covered in macrofouling.	41 % - 100 % of surface

SOURCE: Based on 2023 IMO Biofouling Management Guidelines.^[12]

The presence of any observed macrofouling (≥FR 2) shall be avoided during the testing of standard proactive IWC systems. If a proactive IWC system is specifically designed to avoid unexpected macrofouling, that operational feature can be incorporated into the testing and reported. If a proactive IWC system claims to safely and effectively remove both biofilms and some minimal level of unexpected macrofouling (e.g. small rare patches of soft growth), that system shall be tested as a reactive IWC system. However, the testing of such a hybrid system for efficacy and safety in the removal and prevention of both micro- and macrofouling shall be measured over time (3 to 12 months, see 5.3.2).

For reactive IWC systems, biofouling surveys (see 6.4) shall be used to provide, at minimum, quantification of biofouling percentage cover, a coarse level of macrofouling taxonomy (e.g. barnacles, bryozoans, tubeworms, macroalgae, etc.) and, when obvious, estimates of physiological state (i.e. live or dead). However, only determinations of the presence or absence of macrofouling, irrespective of species origins or physiological state, shall be used in the testing of IWC systems. The straightforward determination of the presence or absence and magnitude of macrofouling addresses the concerns of increased ship drag and fuel consumption and the increased risk of invasive aquatic species introductions. Such determinations are also far less prone to error and uncertainties compared to attempts at appraising the origins of individual organisms and if they are alive or viable. Further, they provide a conservative and environmentally protective approach to assessing IWC systems.^[48] Residual baseplates, or basal shell material remaining after cleaning (when clearly devoid of the prior macro-organisms), shall be recorded and reported as a separate category from the biofouling described above in Table 3.

6.3 Control and treated test locations

Pairs of control and treated locations on a test ship are needed to ensure possible confounding issues are accounted for during testing. These control and treated areas shall be distinct but as similar to each other as possible (e.g. same coating type/age, depth below the surface, size, shape, and side of a ship). These locations shall also be representative of the range of surface types that the specific IWC system claims to be able to safely and effectively clean. Selection of test locations can be accomplished by the IWC service provider designating where they can and cannot clean based on the test ship design drawings and fouling type and coverage. If the service provider claims to clean only relatively flat hull surfaces, then one set of large control and treated locations (e.g. 20 m to 30 m length of the ship, from the waterline to the keel) may suffice. However, if there are claims that other surface types can be cleaned (such as the flat bottoms of the keel, rudders, and sea chest grates, etc.), then similar paired control and treated locations shall be designated for testing at a smaller appropriate scale (see 6.4). For example, to remain consistent with the BACI design, one-half of a designated niche area can be cleaned (i.e. treated) and the other half not cleaned (i.e. control), or one niche area (e.g. bow thruster) is completely cleaned and another comparable paired niche area designated as the uncleaned control (e.g. a second bow thruster). Similarly, if the IWC system claims it can be used on multiple coating types (e.g. biocidal and fouling release), paired control and treated test locations for different coating types can be designated on one individual test ship, when possible.

6.4 Biofouling survey sampling methods

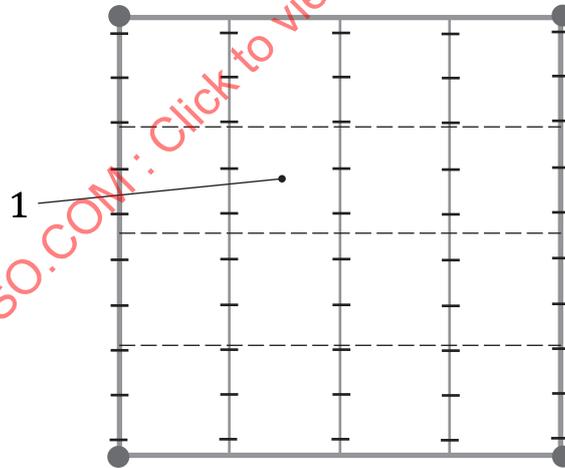
6.4.1 General

Biofouling surveys shall be designed to quantify and document both biofilms and macrofouling in the designated control and treated locations of each test ship and surface type (see [Table 2](#)). Quantitative surveys shall be conducted by trained divers, or equipment with the ability to measure and record biofouling to a level sufficient for the testing organization's data quality requirements (i.e. comprehensive, robust, and repeatable measures). While trained diver surveys have been demonstrated to provide robust and repeatable biofouling data (e.g. Reference [52]), new methods and innovations in technologies (e.g. remotely operated vehicles [ROV], autonomous underwater vehicles [AUV], and next-generation cameras, lighting, and image processing systems) can be incorporated into biofouling surveys as these new approaches are appropriately assessed for this application. Any alternative methods used for quantifying biofouling shall have a degree of rigor equal to or greater than the examples in [6.4.2](#) to [6.4.4](#).

6.4.2 Hull areas

Biofouling surveys of hulls (and other relatively flat surfaces) may use a quadrat method to delineate 1 m² plots. Each 1 m² quadrat shall be vertically divided into four bands using five equally spaced straps. Each strap shall be demarcated to create a 50-point grid (see [Figure 3](#)). Four photographic images shall be captured within each band. Each image (i.e. "sub-plot") will be 25 cm × 15 cm in size. A total of 16 sub-plots shall be imaged covering the entire area within each 1 m² plot.

Estimates of FR and percentage cover shall be made from composite photographs of each plot (see [Figure 3](#)). If poor visibility prohibits photography, the full area of sample plots shall be visually inspected using point counts as described in [6.5](#). Any additional video collected by the IWC system itself, during surveys or cleaning events, shall be provided to the testing team. An example of a dive survey scheme can be found in [Annex A](#), including the defined surface types within a single treated (i.e. cleaned) or control area as described in [Table 3](#).



Key

1 sub-plot

NOTE A total of 16 sub-plots (bounded by the dashed lines between bands) can be photographed or 50-point counts defined. Circles represent magnets to attach the quadrat for sampling.

Figure 3 — Example of a quadrat frame containing four survey bands used to survey each 1 m² plot

Condition of hull surfaces shall be captured using video, digital still imaging, or visual observations stratified by the surface types. Within each surface type of interest (e.g. based on IWC service provider claims), divers shall evaluate at least six randomly placed 1 m² plots.

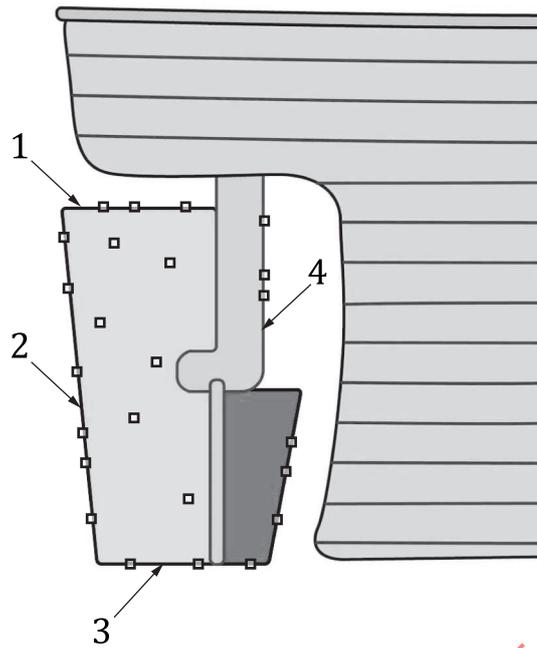
NOTE This requirement corresponds with the recommendations in Morrisey et al. (2015)^[50] and Tamburri et al. (2020).^[48]

If the IWC system is claimed to clean angled surfaces (edges), linear transects along edges shall be photographed immediately adjacent to the edge (i.e. not a full 1 m² quadrat around the edge, but a single 25 cm x 1 m band centred along the edge). See [Annex A](#) for an example of surveying biofouling on three surface types.

6.4.3 Niche areas

For relatively small niche areas (e.g. paired control and treated small gratings), quantification of biofouling in the entire test areas is recommended. For larger niche areas, representative quadrat sub-sampling can be needed. While there is no requirement for specific quadrat sizes or shapes (e.g. square, rectangular, circular), the sampling design for niche areas shall be standardized to provide comparable data across tests and replicate ships. Therefore, quadrats or even transect samples can be fit to the niche area shape and size. Sampling and replication approaches can be scaled down appropriately for use on smaller niche areas (e.g. Reference [\[50\]](#)). For example, quadrats of 0,01 m² have been employed successfully for the quantification of biofouling percentage cover and composition in ship niche areas (e.g Reference [\[62\]](#)). Sampling can also be further stratified into sub-niche areas. For example, rudders can be divided into trailing edge, bottom edge, leading edge, hinge gap, and side face (see [Figure 4](#)), or thrusters can be divided into rim, grate, tunnel, and mechanism case.^[63]

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Key

- 1 top edge
- 2 trailing edge
- 3 bottom edge
- 4 leading edge

NOTE 1 In this example, one side face of the rudder can be treated (i.e. cleaned) and the other designated as the control. The randomized three to six replicate plots within each sub-niche area of the rudder are designated by different sample squares.

NOTE 2 This figure is not to scale.

Figure 4 — Pictorial representation of delineating a treated or control niche area and sub-niche areas

6.4.4 Hull and niche areas

Differences in biofouling percentage cover and biofouling composition shall be determined among areas sampled using appropriate statistical analysis (e.g. non-parametric Kruskal-Wallis tests and PERMANOVA test, respectively^[52]). If macrofouling is found to be rare or extremely patchy, well-described and accepted methods for lower-resolution video transects examining larger areas can be considered in addition to the methods described here.

Qualitative biological samples may also be collected at the end of the sampling period to provide better determinations of the dominant macrofouling taxa present. However, these samples shall only be collected in a way that does not influence any testing assessments of biofouling or coating conditions.

6.4.5 Proactive systems

In addition to the presence, level, and percentage cover of biofilms measured at the beginning and end of each test ship's testing period, an assessment shall also be conducted to qualitatively estimate the efficacy of biofilm removal at least once, on the hull of each test ship. The assessment consists of two surveys:

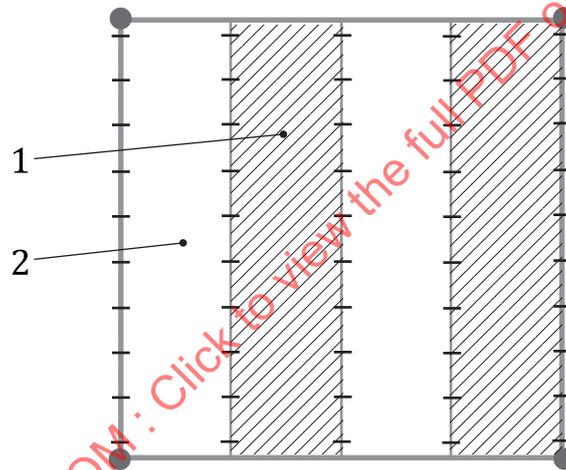
- one pre-cleaning survey shall occur within 12 hours before in-water cleaning begins; and
- one post-cleaning survey shall occur within 12 hours after in-water cleaning ends.

The two surveys shall:

- a) be conducted in a location on the test ship that is scheduled to be cleaned; and
- b) consider the different surfaces that the IWC system can clean.

A survey within the predesignated treated test area is recommended, but not required. Quadrats of 1 m² that are randomly placed on the test surface shall be used to document the biofilm in the designated area, with at least 12 replicates sampled before and 12 replicates sampled after cleaning activities. After the quadrat is attached to the hull, the biofilm from two of the four quadrat bands shall be removed (see [Figure 5](#)).

Existing biofilm shall be removed using one or more clean sponges per wiped band. This will enable a visual comparison of biofilm on the ship surface to a set standard/baseline (bare surface) in a photo comparison. The single-use sponge(s) per band shall be photographed for observations of any collected biofilm material. The biofilm within each plot will be documented by taking at least three randomly placed photographs of a small 25 cm × 25 cm sub-section. For a direct comparison, each image shall capture both wiped (cleaned by hand) and unwiped (undisturbed) spaces side-by-side (see [Figure 5](#)). Once the plot has been photographed, the quadrat shall be removed from the surface and placed at another location (selected at random) within the designated area on the ship's surface and the survey repeated. This method has been designed for relatively flat hull surfaces. If the proactive IWC system is claimed to clean angled surfaces (edges) and other niche areas, modifications to the method can be made, such as linear transects along edges or scaling down to appropriate dimensions and image number.



Key

- 1 quadrat band to be wiped clean
- 2 quadrat band that is not wiped

NOTE 1 Biofilm cover determined by using percentage cover visual estimates and fouling ratings within the four bands.

NOTE 2 Two quadrat bands (0,25 m² each) are wiped with a sponge to remove biofilms. Side-by-side photos compare wiped versus unwiped sections. The biofilm cover is determined within four bands.

Figure 5 — Examples of a 1 m² quadrat used to determine biofilm cover

While individual proactive IWC systems can put forward claims with respect only to biofilm removal efficacy, or only to macrofouling prevention efficacy, it is recommended that testing of both indicators of performance be included for comprehensive, standardized testing.

NOTE These indicators are the presence or absence of biofilms before and after cleaning events, and the presence or absence of macrofouling growth over time.

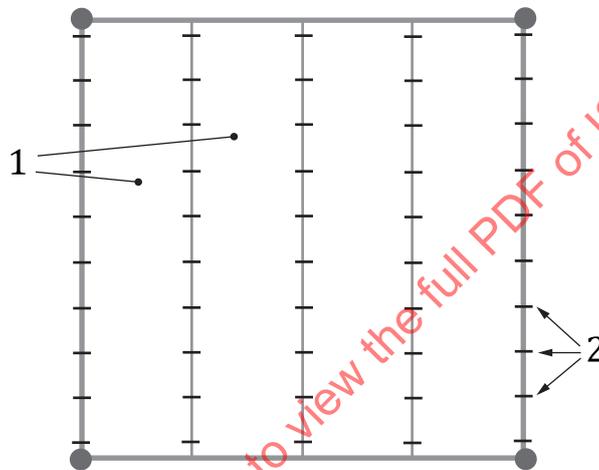
6.5 Dive survey sampling method during low visibility

6.5.1 Hull areas

In low visibility conditions, when still images are unreliable for biofouling surveys, an in situ method shall be used. Similar, comparable analyses (for quantifying biofouling type and extent) can be conducted directly by the diver, rather than during post-dive image analysis (e.g. see Reference [52]). For each hull area sampled, 1 m² quadrats shall be placed in the test areas for at least 6 plots per surface type. The quadrats shall be used to determine biofouling cover (biofilm and macrofouling) by:

- using a point count method of the 50 evenly spaced points delineated on the bands of the 1 m² area;
- using percentage cover visual estimates within each of the four bands (see Figure 6).

Biofouling shall be identified to FR rating as described in 6.2. Divers shall use data sheets and dive slates to record data in the field. After a quadrat is positioned, one diver can use an underwater light to illuminate the sampling area while the other records the data.



Key

- percent cover bands
- points

Figure 6 — Example of a 1 m² quadrat used to determine biofouling cover in low visibility conditions

Differences in biofouling percentage cover obtained from point counts shall be determined among the areas sampled (i.e. before and after, treated and control locations, by surface type) using appropriate statistical analysis (e.g. non-parametric Kruskal-Wallis tests and PERMANOVA test).

To the extent possible, supporting example photographs or videos, or both, of the areas surveyed with the low visibility method shall also be collected. Other low-visibility biofouling survey methods, such as photographs using a camera water-box system on relatively flat surfaces, [64][65] can be considered for use once appropriately assessed for this application.

6.5.2 Niche areas

The quantification of biofouling in niche areas can be particularly challenging under low visibility conditions. As described above in 6.4.3, quadrats and transect samples can be fit to the niche area shape and size, and sampling approaches can be scaled down appropriately for use on smaller niche areas. [50] However, the determination of type and extent of biofouling in niche areas shall only be conducted if the appropriate level of data quality can be confirmed (e.g. low visibility biofouling surveys of hull areas [52]).

6.6 Environmental characteristics to quantify

Table 4 lists the minimum background environmental characteristics that shall be observed or measured and reported during biofouling surveys.

Table 4 — Environmental characteristics recorded during biofouling dive surveys

Environmental characteristic	Method of measurement
Water temperature	Single or multiparameter instrument/thermometer
Salinity	Single or multiparameter instrument/salinity meter
Water clarity/turbidity	Secchi disc 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 ^[66]
Air temperature	Thermometer or data from a nearby weather station
Weather	Visual observations (precipitation, cloud cover, etc.)

NOTE Additional measures (e.g. water dissolved oxygen and pH) can be informative or required to test provider claims, and can be added as needed.

7 Quantification of changes to water quality

7.1 Water quality measures as proxies for broad environmental impacts

7.1.1 General

All testing is expected to be coordinated with local, regional, or national authorities, as such entities can have specific water quality standards or threshold requirements regarding the release of contaminants (i.e. chemical, physical, and biological) during IWC. As these standards can vary greatly among locations, all testing of IWC systems shall report total or absolute values (e.g. means and standard deviations) of the measured water quality parameters (see 7.2) during and adjacent to IWC activities (see 7.3). Those values shall also be compared statistically (e.g. Student's *t*-test) for significant differences from ambient or background ranges of the same parameters at the location of testing.

7.1.2 Proactive systems

For each of the replicate test ships ($n \geq 3$), samples shall be collected and analysed as part of at least one specific cleaning trial at the beginning (time zero or beginning of testing) of the test period. For each ship, the water quality sampling shall be repeated during trials for hull and niche, and coating type (i.e. biocidal coating and non-biocidal coating) cleaned. For systems that clean biocidal coatings, a minimum of two distinct biocidal coating types shall be tested (e.g. a different biocidal coating on two of the test ships) and samples analysed for all relevant biocides and co-biocides (i.e. secondary or “booster” biocides).

7.1.3 Reactive systems

Samples shall be collected and analysed during trials for each of the replicate test ships ($n \geq 3$) and repeated for each surface type (e.g. hull and niche) and coating type (i.e. biocidal coating and non-biocidal coating) cleaned. For systems that clean biocidal coatings, a minimum of two distinct biocidal coating types shall be tested and samples analysed for all relevant biocides/co-biocides.

7.2 Water quality parameters to quantify

Environmental impacts from IWC include potentially unacceptable changes to local water quality and sediment conditions (due to the release of biocides and other substances from coatings) and the potential

release of live organisms. At a minimum, the parameters specified in [Table 5](#) shall be analysed in triplicates ($n \geq 3$) from each collected water quality sample, as practical, measurable, and conservative proxies for environmental impact.^[48]

Table 5 — Water quality parameters measured for IWC systems

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.
Total and dissolved biocide(s) (e.g. copper- and zinc-based compounds) associated with the test ship coating, when applicable	Measure of possible biocide release from ship coating, when applicable.
Microplastics (MP) Nanoplastics (NP)	Measure of possible polymer release from ship coating.

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

To the extent possible, certified or validated analytical methods are expected to be used for the parameters in [Table 5](#). [Table 6](#) provides a few examples of such methods. However, other recognized methods can be used if they meet the data quality requirements of the testing organization.

NOTE Such alternative methods can include ISO standards, ASTM standards, or documents from the European Chemicals Agency.

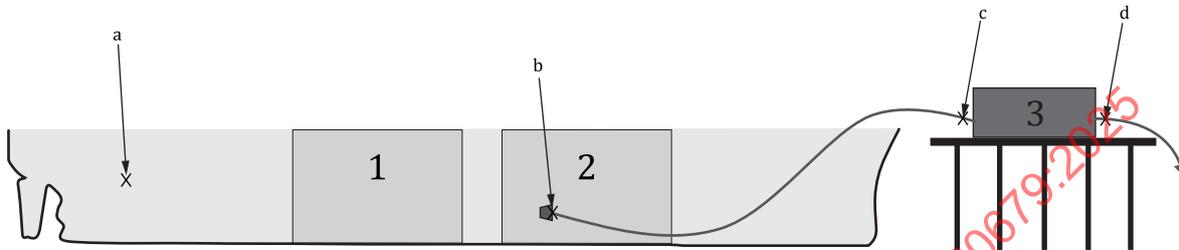
Any analytical method used is expected to be either validated or accepted, or both, by the relevant IWC approval or permitting authority.

Table 6 — Sample type and examples of accepted analytical methods for measuring water quality parameters

Sample type	Analytical method	Method detection limit	Quality assurance reporting limit
TSS	SM2540D ^[68] EPA 160.2 ^[69]	2,4 mg TSS/l	2,4 mg TSS/l
POC	EPA 440.0 ^[70]	0,063 3 mg C/l	0,063 3 mg C/l
DOC	SM5310B/C ^[71] EPA 440.0 ^[70]	0,16 mg/l DOC	0,50 mg/l DOC
PSD	ISO-13322-1 ^[72]	> 10 – 1 000 µm	> 10 – 1 000 µm
Particulate and Dissolved Copper (Cu)	EPA 200.8 ^[73] EPA 6020A ^[74]	0,1 µg/l	0,5 µg/l
Particulate and Dissolved Zinc (Zn)	EPA 200.8 ^[73] EPA 6020A ^[74]	Dissolved 0,5 µg/l Particulate 0,1 µg/l	Dissolved 1,0 µg/l Particulate 1,0 µg/l
Microplastics (MP) Nanoplastics (NP)	ISO 24187 ^[75]		

7.3 Water quality sample collection

Discrete and continuous, time-integrated water samples shall 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 at the test ship's surface. This station shall be ≥ 50 m away from, and clearly not impacted by the test cleaning activities (e.g. located at mid-depth, up current, or opposite side of the test ship). The second station shall 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 (see [Table 7](#)). At both stations, during each test trial, a series of three sequential and continuous time-integrated samples shall be collected simultaneously over at least a 90-min sampling period (see [Figures 7](#) and [8](#)).



Key

- 1 control area
- 2 treated area
- 3 debris treatment unit, if applicable
- a Continuous, time-integrated background sample during cleaning (mid-depth).
- b Continuous, time-integrated cleaning unit sample during cleaning.
- c Continuous, time-integrated influent to debris processing unit sample during cleaning.
- d Continuous, time-integrated effluent from debris processing unit sample during cleaning.

NOTE 1 Debris processing and effluent impacts are described in [Clause 8](#) of this document.

NOTE 2 This figure is not to scale.

NOTE 3 This figure does not include the discrete samples of background conditions taken before and after a test trial at the same location.

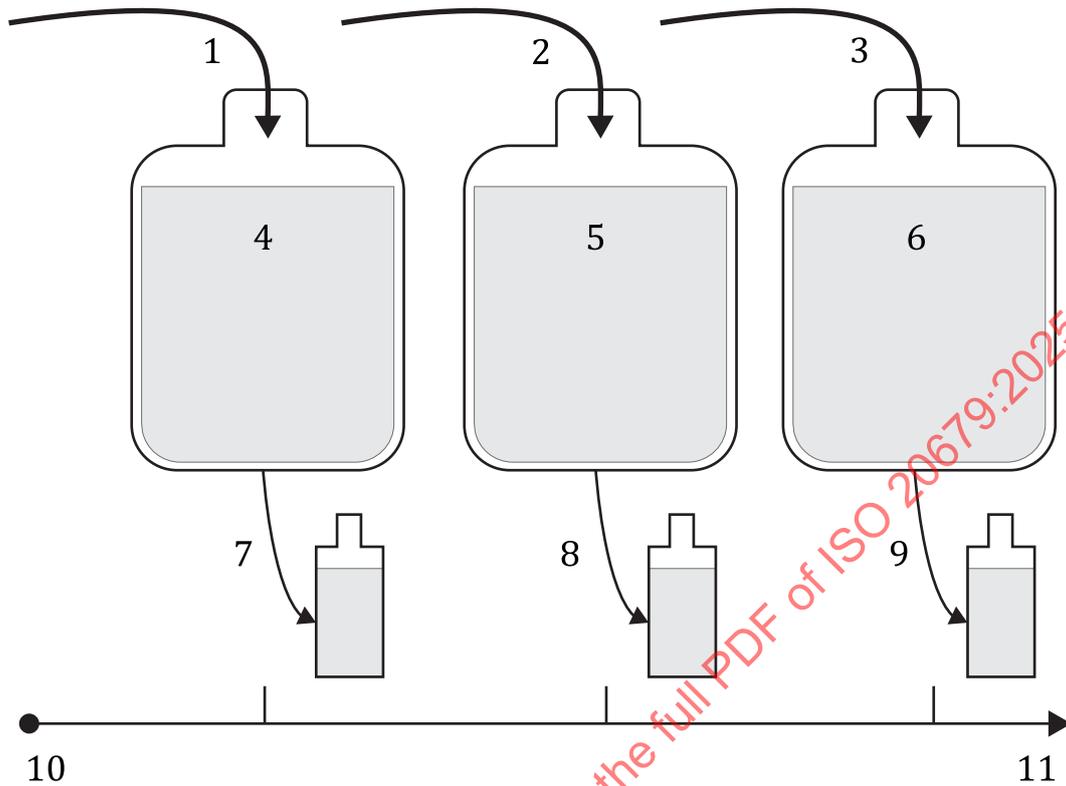
Figure 7 — Pictorial representation of water quality sampling locations during a test cleaning event

It is not always 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 testing organization shall 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 background (i.e. ambient water) and the second on the cleaning unit, shall be collected with the appropriate pump and hose systems (e.g. with sufficient power and flow rates) into a series of sample collection containers or carboys. Care shall be taken to ensure sampling equipment and methods do not introduce artifacts (e.g. sample contamination with metals or polymers), including appropriate controls and blanks (see [Clause 10](#)). Both 90-min (or more) continuous time-integrated sample events (for background and cleaning unit) shall then be divided into three 30-min (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 (see [Figure 8](#) and [Table 8](#)).

Three appropriately sized sample containers for each sequential sample shall 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 l to 40 l) over a 30-min sampling period. After the first container is filled (at the 30-min mark), the hose can be moved to the second container, and then to the third container at the 60-min mark (see [Figure 8](#)). Each sample container shall then be uniformly mixed prior to sub-sampling for analysis of specific water quality parameters (see [7.2](#)).

While 90 minutes (or more) is typically required for IWC of large areas of a ship's hull, smaller niche areas can take far less time. When possible, at least a single 30-min continuous, time-integrated sample shall be collected (for background and cleaning unit) to assess discharges during niche area cleaning.



Key

- 1 hose in first container for replicate 1
- 2 move hose to second container for replicate 2
- 3 move hose to third container for replicate 3
- 4 0-30 minutes
- 5 30-60 minutes
- 6 60-90 minutes
- 7 mix and subsample
- 8 mix and subsample
- 9 mix and subsample
- 10 trial start (0 min)
- 11 trial end (90 min)

Figure 8 — Representation of three replicate, continuous, sequential, time-integrated water quality samples, at each sample location, during a test cleaning event

Table 7 — Description of minimum 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 at the ship's surface	≥50 m upstream of system	One per test ship and per test cleaning location on the test ship > 90-min samples ^a	Three at minimum intervals of: 0 min to 30 min 30 min to 60 min 60 min to 90 min
Potential environmental release from cleaning unit during cleaning	On IWC system cleaning unit	One per test ship and per test cleaning location on the test ship > 90-min samples ^a	Three at minimum intervals of: 0 min to 30 min 30 min to 60 min 60 min to 90 min

^a Sampling duration can be reduced for niche areas, dependent on size of area being cleaned.

As water quality conditions will vary over time at a single location (e.g. based on season, tides, storms, and local ship traffic), ambient background water quality shall also be characterized by discrete sampling at the testing location before and after a test cleaning event. This background station shall be located near the test ship or test berth/anchorage, 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. At a minimum, one discrete sample shall be collected one hour prior to the test cleaning event and a second discrete sample collected one hour after the completion of the test cleaning event. Additional background samples (e.g. a day before and a day after the test cleaning event), and existing local water quality data, can also provide additional information on ranges of background water quality parameters (i.e. independent of IWC) but are optional.

7.4 Environmental characterization

During all sampling for water quality, background environmental characteristics shall be observed or measured and reported in accordance with 6.6 and Table 5.

8 Quantification of debris processing and effluent

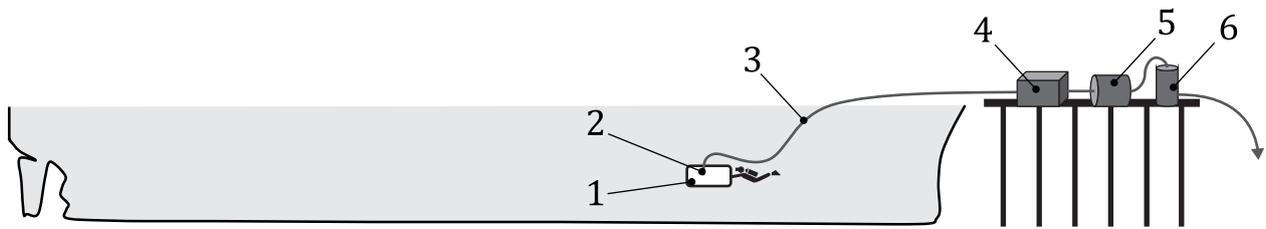
8.1 Overview

This clause describes methods for:

- 1) quantifying debris processing efficacy; and
- 2) identifying potential changes to water quality from debris processing effluent.

Therefore, this clause 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 7 and 9. 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.

It is possible that some IWC systems include only 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). 8.2 and 8.3 do not apply to such IWC systems, as the discharge from this approach can be assessed with targeted sampling, as described in Clause 7.



Key

- 1 debris containment shroud
- 2 suction to entrain debris
- 3 suction hose to transport debris
- 4 physical separation unit
- 5 disinfection unit
- 6 selective media separation unit

SOURCE: Reference [67], reproduced with the permission of the authors.

NOTE Debris processing depicted in this figure involves physical separation, disinfection, and selective media separation.

Figure 9 — Example of a proactive or reactive IWC system with debris capture and processing

8.2 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) shall be sampled. Sampling shall be conducted using a series of sequential, continuous time-integrated water samples as part of any IWC system test (see Figure 8). 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.^[48] Therefore, the priority assessment of environmental impacts shall be a statistical comparison of:

- a) effluent water quality parameters versus simultaneous measures of background (i.e. ambient) water conditions;
- b) discrete background samples collected before and after test cleaning events (see 7.2).

For each test area cleaned during each test trial, simultaneous, continuous time-integrated samples shall be collected:

- c) at a suitable influent sample port; and
- d) at a suitable effluent sample port (i.e. to produce representative samples).

Sampling shall occur over at least a 90-min period for a hull cleaning event and shall target at least 30 min for a niche area cleaning event. Again, both 90-min continuous time-integrated sample locations (influent and effluent) shall then be divided into three 30-min sequential samples (see Figure 8) to provide sample replication and insights into possible temporal changes in water quality. Care shall be taken to ensure sampling equipment and methods do not introduce artifacts (e.g. sample contamination with metals or polymers), including appropriate controls and blanks (see Clause 10).

For most IWC systems tested, it is necessary to allow sufficient time between the start of the cleaning of each section of the hull and the collection of samples of effluent to allow residual effluent in the system to be flushed through. This can be determined by calculating the volume of water required to flush the residual effluent or by running aliquots of an environmentally safe dye (e.g. rhodamine or fluorescein) through the system at appropriate times.

The three appropriately sized sample containers shall 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 l to 40 l) over a 30-min sampling period. After the first container is filled (at the 30-min mark), the hose can be moved to the second container, and then to the third container at the 60-min mark (see [Figure 8](#) and [Table 8](#)). Each sample container shall be uniformly mixed prior to sub-sampling for analysis of specific water quality parameters (see [Table 8](#)).

Table 8 — Minimum 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 ship	Processing unit influent	One per test ship and per each test cleaning location on test ship > 90-min samples ^a	Three at minimum intervals of: 0 min – 30 min 30 min – 60 min 60 min – 90 min
Potential environmental release from debris processing unit	Effluent release point	One per test ship and per each test cleaning location on test ship > 90-min samples ^a	Three at minimum intervals of: 0 min – 30 min 30 min – 60 min 60 min – 90 min

^a Sampling duration can be reduced as needed, dependent on size of area being cleaned.

8.3 Water quality parameters to quantify

Discharge of debris processing effluent shall be assessed through a direct statistical comparison of the same water quality parameters (e.g. TSS, PSD, POC, DOC, biocides, MP, and NP) in effluent water and in background water, as described in [7.2](#). Samples shall be collected and analysed at minimum in triplicate ($n \geq 3$) for each parameter during test trials.

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

To the extent possible, certified or validated analytical methods are expected to be used for the parameters in [Table 5](#). The sample analytical method used for [Clause 7](#) shall be the same as those employed for [Clause 8](#) for the testing of an individual IWC system. [Table 6](#) provides a few examples of analytical methods that can be employed. However, other recognized methods can be used if they meet the data quality requirements of the testing organization.

NOTE 1 Any analytical method used is expected to be either validated or accepted, or both, by the relevant IWC approval or permitting authority.

The IWC system service provider shall 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 shall be audited against this SOP. The parts of the waste treatment system above the water surface shall be monitored for leaks, overflows, or alarms. A log of system operations/performance shall be kept, noting any problems, such as blocked or ruptured filters, or leaks. Contingency plans to manage the risks and rectify system failures shall be included in the SOPs. Video recordings (of five minutes or more) of the debris processing unit operations and functioning (e.g. control panel, solid waste separation and collection, effluent discharge) shall be captured at the beginning, middle, and end of each test trial as supporting documentation of service provider claims.

Some IWC system debris processing units can include an effluent disinfection stage to kill or render organisms “non-viable” prior to environmental release. Where this is the case, additional data shall be collected to document the proper dose and operations of the disinfection process (including neutralization, if applicable), rather than measuring or estimating live or viable organisms.^[48] Measured water quality

values (see 7.2) will also provide fundamental insight into the possible effluent release of macro-organisms of concern.

NOTE 2 Very few, if any, particles >10 µm in size can indicate reduced biosecurity risk from macro-organisms.

The IWC system provider shall supply details of the disinfection method employed (e.g. UV, heat, biocide) and existing data to verify its efficacy on various aquatic organisms (including propagules and pathogens) that can be found within the effluent. This shall include results of pre-treatment of the effluent (e.g. filtration to a specified size) required to achieve an efficacious secondary process. Efficacy can be deduced from scientific literature demonstrating doses known to effectively treat ship's ballast water, effluent from land-based aquaculture or seafood processing facilities, or municipal wastewater.^[24]

During each IWC system test, it shall 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 shall 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 discharged during a test cleaning trial shall be either documented or reported, or both, 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.

8.4 Solid waste disposal

For each test cleaning trial, the total wet mass, volume or both of solid waste material removed during debris processing shall be quantified and characterized to the extent possible. This shall also be directly linked to the total area and duration of the specific cleaning event, as well as the type and abundance of biofouling on the surface before cleaning. All documentation associated with the appropriate disposal of solid waste shall also be reported, including the results of any analyses of the waste material itself. While waste disposal requirements are determined by each port or local jurisdiction, proof of compliance shall be provided.

9 Quantification of IWC impact on ship coatings

Observations of coating physical condition on various ship surface types before and after cleaning shall be recorded (e.g. through photos, videos, or both) and reported. For comparative purposes, the approach chosen shall be consistent over the replicate ($n \geq 3$) test ships and incorporate existing approaches for coating assessments (e.g. the Paint Deterioration Rating Scale specified in Reference [76]). These observations of coating physical condition can be conducted as part of the biofouling surveys described in Clause 6, noting considerations for proactive IWC systems. Observations regarding the physical condition of the coating can include, but are not limited to, visible scratches, brush marks, paint flakes, pitting, bare metal/polish through, and blemishes. See Annex B for an optional quantitative estimate of the potential IWC system impacts on ship coatings.

10 Data management

10.1 System for data management

10.1.1 General

A formal system for managing data should be implemented, which encompasses and traces the path of the data from their generation to their final use or storage. For example, from field measurements and sample collection/recording through transfer of data to computers (laptops, data acquisition systems, etc.), laboratory analysis, data validation/verification, quality assessments, and reporting of data of known quality to the clients and sponsors. The system should also include control mechanisms for detecting and correcting errors.

10.1.2 Data quality objectives

Data quality objectives (DQO) are qualitative and quantitative statements that clarify study objectives, define the appropriate types of data and specify the tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. DQOs are typically expressed in terms of acceptable uncertainty associated with a point estimate at a desired level of statistical confidence. Only data that meet or exceed these criteria can be deemed valid.

For example, the development of DQOs can follow the EPA Guidance for the Data Quality Objectives Process,^[77] or a similar accepted framework.

10.1.3 Data quality indicators

Data quality indicators (DQIs) are supported by measurement quality objectives (MQOs). During test planning, DQIs should be considered and specific MQOs are set to ensure that data are of appropriate quality for their intended use. The traditional DQIs considered are:

- accuracy, which is a measure of the closeness of a measured value to the true value;
- precision, which is a measure of the repeatability of a measurement;
- bias, which is the systematic or persistent distortion of a measurement process that causes error in one direction;
- representativeness, which describes how well the data reflect the actual conditions;
- comparability of data that are of a recognized quality, and can be validly applied by external users;
- completeness, which describes whether valid data are produced for all the submitted samples, or just some fraction thereof; and
- sensitivity, which describes the lowest measure, or increment of measurement, that a technique can detect.

Examples of approaches to determining DQIs include the EPA's Guidance for Quality Assurance Project Plans^[70] and Guidance for the Data Quality Objectives Process.^[77]

10.2 Data recording and archiving

Various types of data are acquired and recorded electronically or manually during testing by the staff of the testing organization. Sample collection data (e.g. date, time, and location of collected samples) and analytical data should be recorded manually or electronically using a method that preserves unique identification, and longevity, and ensures accuracy, traceability, and integrity of the data. All documentation should be:

- made promptly at the time of observation;
- accurate, legible, permanent, clear, and complete;
- dated and initialled by the responsible personnel; and
- copied, scanned, or photographed.

Chain-of-custody forms may be used as needed.

10.3 Data analysis

10.3.1 Overview

Data analysis is the process of systematically applying statistical and logical techniques to describe and illustrate, condense, summarize, and evaluate data. An essential component of ensuring data integrity is the accurate and appropriate analysis of field samples and laboratory measurements of environmental and

technology performance variables. Examples of relevant data analysis are described by Tamburri et al. (2020).^[52]

10.3.2 Quality assurance and quality control

There is potential for variability in any sample collection, analysis, or measurement activity. Field variability generally contributes more than laboratory variability. Total study error can result from among sampling unit variability, and within-sampling-unit variability.

Quality assurance (QA) measures undertaken to ensure the reliability of the data collected include duplicate sampling, replicate analysis, calibration and maintenance procedures, schedules, and standards (if applicable) for all equipment used in the test. Quality control (QC) measures are actions to ensure that defined standards are met in the analysis of data. These measures should be measurement or method-specific and are defined within the relevant SOP. Field QC samples collected should include equipment blanks, trip blanks, field blanks, field duplicate samples, and matrix spike/matrix spike duplicate samples. Routine procedures for laboratory QC include daily instrument calibrations, efficiency, and background checks, and standard tests for precision and accuracy.

Examples of QA/QC measures can be found in Reference [\[80\]](#) and the EPA Guidance for Quality Assurance Project Plans.^[78]

10.3.3 Measurement uncertainty

Measurement uncertainty should be reported when:

- it is relevant to the validity or application of the test result;
- instructed by a client; or
- the uncertainty affects compliance to a specification limit.

The IWC testing process can have uncertainties associated with factors such as equipment calibration, operator skill, sample variation, and environmental factors. It is not necessary to calculate measurement uncertainty for standard analytical methods that specify limits to the values of the major sources of uncertainty of measurement and the form of presentation of calculated results. For other methods, the combined standard uncertainty can be calculated as described in documents such as ISO/IEC Guide 98-1.

11 Quality assessments

11.1 Fundamental principles

Quality assessments (QA) include technical audits and data quality assessments. The assessment process includes the following requirements:

- assessments are performed by the QA Manager, who is independent of direct responsibility for the performance of the test;
- each assessment is fully documented;
- each assessment shall be responded to by the appropriate level of the testing team;
- quality assessment reports require a written response by the person performing the inspected activity and acknowledgement of the assessment by the test lead; and
- corrective action shall be documented and approved on the original assessment report, with a detailed narrative in response to the assessor's finding.

11.2 Technical audits

11.2.1 Overview

Technical audits are systematic and objective examinations of test implementation to determine whether data collection activities and related results comply with the test protocol, are implemented effectively, and are suitable to achieve its data quality goals. Audits of tests shall include technical system audits (TSA) and audits of data quality (ADQ).

11.2.2 Technical system audit

A TSA is a thorough, systematic, and qualitative evaluation of the sampling and measurement systems associated with testing. The objective of the TSA is to assess and document the conformance of on-site testing procedures with the requirements of the test protocol, published reference methods, and associated procedures. The TSA assesses test facilities, equipment maintenance and calibration procedures, reporting requirements, sample collection, analytical activities, and QC procedures. Both laboratory and field TSAs may be performed following the EPA Guidance on Technical Audits and Related Assessments for Environmental Data Operations,^[78] or a similar accepted framework.

11.2.3 Audit of data quality

An ADQ is a quantitative evaluation of the test data. The objective of the ADQ is to determine if the test data were collected according to the requirements of the test protocol and associated procedures and to verify whether the data were accumulated, transferred, reduced, calculated, summarized, and reported correctly. The ADQ assesses data accuracy, completeness, quality, and traceability.

The ADQ shall be conducted by the QA Manager and can follow procedures found in the US EPA's Guidance on Technical Audits and Related Assessments for Environmental Data Operations,^[79] or a similar accepted framework.

11.3 Data quality assessment

The Data Quality Assessment (DQA) is a scientific and statistical evaluation of validated data to determine if the data are of the right type, quality, and quantity to support conclusions on the performance of the IWC systems tested. The DQA process includes consideration of:

- soundness: the extent to which the scientific and technical procedures, measures, and methods employed to generate the information are reasonable for, and consistent with, the intended application;
- applicability and utility: the extent to which the information is relevant for the intended use;
- clarity and completeness: the degree of clarity and completeness with which the data, assumptions, methods, and quality assurance, employed to generate the information are documented; and
- uncertainty and variability: the extent to which the variability and uncertainty (quantitative and qualitative) in the information or in the procedures, measures, and methods are evaluated and characterized.

A DQA may be conducted as described in the EPA Guidance for Data Quality Assessment: Practical Methods for Data Analysis,^[82] or a similar accepted framework, and include:

- data verifications;
- data validations; and
- data usability assessment.

11.4 Non-conforming work and corrective action

Non-conforming work can occur during various stages of testing (e.g. incorrect following of documented test procedures, use of uncalibrated test equipment, lack of staff supervision or training, errors in the test report). Procedures shall be established for the control of non-conforming work. and ensure that:

- the responsibilities and authorities for the management of non-conforming work are designated and actions (including halting of work and withholding of test reports, as necessary) are defined and taken when non-conforming work is identified;
- an evaluation of the significance of the non-conforming work is made, including criteria;
- corrective actions are taken immediately, together with any decision about the acceptability of the non-conforming work;
- where necessary, the client is notified and work is recalled;
- the responsibility for authorizing the resumption of work is defined; and
- all actions are recorded and become part of the permanent project file.

An example of a corrective action procedure is presented in the US EPA's Control of Nonconforming Work.^[83]

11.5 Audit reporting

The QA Manager is responsible for all audit reports. These written reports focus on whether the test activities and related analytical results:

- comply with the test plans and related SOPs;
- are implemented effectively; and
- are suitable to achieve data quality goals.

An audit report usually consists of:

- an introduction describing the date, location, purpose, and scope of the audit;
- a detailed account of the findings and their basis;
- conclusions, including a discussion of any findings requiring corrective action; and
- recommendations (if requested) for resolving problems that affect quality.

Findings of audit results can generally be divided into three categories:

- noteworthy practices or conditions;
- observations, which are neither positive nor negative; and
- non-conformances, which are deviations from standards and documented practices (e.g. test plans, SOPs, reference methods).

Non-conformances can be divided into two subcategories:

- deficiencies, which adversely impact the quality of results; and
- areas of concern, which do not necessarily (but could) result in unacceptable data.

12 Human health and environmental safety

The IWC service provider and personnel of the testing organization are expected to follow standard laboratory and field work safety procedures, abide by all health and safety legislation in the location of