Ministry for Primary Industries
Manatū Ahu Matua

Procedures for evaluating in-water systems to remove or treat vessel biofouling

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Executive Summary

Vessel biofouling is a major pathway for the introduction and spread of non-indigenous marine species. In-water systems for the removal or treatment of biofouling from vessel hulls have been proposed as a measure to manage the biosecurity risks from biofouling during the in-service operations of vessels. However, the use of these systems also carries some residual biosecurity risk that must be managed.

This document describes the (data) requirements to assess the biosecurity risks associated with the use of in-water systems to remove or treat vessel biofouling. The testing framework is based on the outcomes of a companion review of in-water systems that are currently available globally or that are in development (Morrisey and Woods 2015). This document informs the development of testing requirements and standards for the operation and performance of in-water systems to obtain Ministry for Primary Industries (MPI) approval for use in New Zealand. The testing framework will allow consenting authorities (both government and non-government) to make informed decisions regarding the biosecurity risk of in-water systems for removal or treatment of vessel biofouling.

The testing framework has been developed for three generic categories: removal ("cleaning") of vessel biofouling, treatment of vessel biofouling and filtration or treatment of removed waste. These categories and their associated performance standards are summarised below.

Table 1. Categories of in-water cleaning/treatment systems and their associated performance standards.

Category and application	Performance standard
Cleaning systems: • manual removal (e.g., by powered and non-powered hand-held tools); • mechanical removal (e.g., brush-based, cutting head, and water jet-based systems, diver-operated carts, remotely operated vehicles (ROVs) and robots).	*All visible, macroscopic biofouling shall be removed from the cleaned area*. Residual macroscopic biofouling 0.5 cm in diameter or larger is considered to represent a failure to meet the performance standard.
Treatment systems: • surface-treatment (e.g., by heat and ultrasonic); • shrouding (e.g., by encapsulation and enclosure).	*All biofouling in the treated area shall be rendered non-viable* (i.e., not capable of living and developing to reproductive maturity).
Filtration or treatment of biofouling waste (effluent) created during application of the system.	*The maximum particle size in the filtered effluent shall be 12.5 µm or all biological material must be rendered non-viable*.

The framework requires system testing to be completed on biofouling present on actual vessels and for the outcomes of the testing to be assessed against the performance standards detailed above. The tests should be realistic simulations of the intended use of the system on a vessel. Guidance is also provided on the use of test panels for preliminary system testing. Panel testing may provide useful data before committing to a vessel test (e.g., it can help to standardise elements of the test, such as the type and amount of biofouling or the type of anti-fouling coatings that the system is applied to). However, panel testing does not remove the need for testing the equipment on actual vessels.

Because different system types may be used on biofouling on different types or parts of a vessel, the requirements for vessel testing have been divided into several classes:

- systems for use on flat surfaces and the wind-and-water line;
- systems for use on flat and curved surfaces;

- systems for use on niche areas and other small or confined external structures on vessels;
- systems for use on entire vessels.

For each system category and its application, guidance is given on the requirements for:

- providing information about the system to MPI, including its:
    - method of operation and technical specifications;
    - intended application(s);
    - standard operating procedure(s);
- how the test should be conducted, including:
    - oversight by appropriately qualified personnel;
    - choice of vessels;
    - the level of replication of the test(s);
    - the environmental conditions under which the test(s) should occur;
- methods to assess system efficacy with respect to:
    - different vessel surfaces and regions;
    - different types and levels of biofouling;
    - effects on the anti-fouling coatings;
    - waste capture and treatment;
- data collection and reporting on the outcomes of the test.

The report also contains discussion on the information-base and rationale used to develop the framework and guidance on the likely costs of undertaking the tests. Templates and guidance documents are appended to assist data collection and reporting.

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Abbreviations and definitions

Anti-fouling system	A coating, paint, surface treatment, surface, or device that is used on a vessel or submerged equipment to control or prevent the attachment of organisms.
Boot-top	The area between the water lines of a vessel when fully loaded and when unloaded.
Cleaning of biofouling	The physical removal of biofouling organisms from a surface.
FR	Fouling Rating: a scale used by the US Navy to rate the type and level of biofouling present on vessels.
Independent supervisor	An appropriately qualified, scientific contractor approved by MPI to supervise the test.
LD_{100}	The acute, single dose or concentration of the treatment that is lethal to 100% of the test organisms.
Lethal agent	The method used by treatment systems to render the biofouling non-viable. This could be a biocide, de-oxygenation or a physical treatment such as elevated temperature.
LT_{100}	The period of exposure needed to achieve 100% mortality of the test organisms for a single, acute concentration or dose.
Macroscopic biofouling ("macrofouling")	Distinct multicellular biofouling organisms that are visible to the human eye, such as barnacles, tubeworms, hydroids or fronds of algae. Does not include microscopic organisms that comprise the slime layer.
Manual systems	The physical removal of biofouling organisms by hand or using small hand-held tools. Manual removal may include the use of hand-held scrapers, brushes or pads.
Mechanical systems	The physical removal of biofouling organisms using powered tools or equipment. Mechanical systems may include the use of powered rotary brushes, pads, and blades, or high-pressure water or cavitational jets and may be operated by divers or mounted on remotely operated vehicles (ROVs).
MPI	Ministry for Primary Industries.
Niche areas	Areas on a vessel that are susceptible to biofouling due to different hydrodynamic forces; susceptibility to coating system wear or damage; or being inadequately, or not, painted. They include, but are not limited to, anodes, bilge keels, sea chests, thrusters, propellers, propeller shafts, inlet gratings, and dry-docking support strips.
Non-viable	Biological material (adult, tissue or propagules) that is not capable of living and developing to reproductive maturity in the marine environment.
Propagules	Any non-adult biological material that is used for the purpose of propagating an organism to the next stage in its life cycle. May include dispersive gametes, seeds, spores or regenerative tissue.
ROV	Remotely Operated Vehicle.
Secchi depth	A Secchi disk is a weighted circular disk (20–30 cm in diameter), divided into quadrants painted alternately black and white, used to measure water transparency in bodies of water. The disk is mounted on a pole or line, and lowered slowly down through the water column. The depth at which the disk is no longer visible ("Secchi depth") is related to water colour and turbidity.

Shrouding systems	Treatments that kill biofouling organisms *in situ* by enclosing the vessel hull in an impermeable membrane to reduce or eliminate exchange of water between the enclosed area of the hull and the surrounding environment.
Slime layer	A layer of microscopic organisms, such as bacteria and diatoms, and the slimy substances that they produce.
SOP	Standard Operating Procedure: detailed, written instructions on the method of operation of the system to achieve consistency in its performance for removing or treating biofouling.
Surface-treatment systems	Treatments that are applied directly to the fouled area of the vessel to kill biofouling organisms *in situ,* but which do not remove the organisms physically. Surface-treatments may include, but are not limited to, systems that apply heat, biocides or ultrasound to biofouled areas of the vessel.
Treatment of biofouling	Systems that kill biofouling organisms *in situ*.
Viable	Biological material (adult, tissue or propagules) that is capable of living and developing to reproductive maturity in the marine environment.
Wind-and-water line	The area along the water line that is exposed or wetted by rolling or by wave action.

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1 Background

1.1 PURPOSE OF THIS DOCUMENT

This document contributes to the scientific background for approval of in-water cleaning or treatment systems under the Craft Risk Management Standard for Biofouling for Arriving Vessels and within New Zealand's domestic biofouling management approach. The document will be considered along with other information in determining proposed measures that are practical to implement and align with all applicable legislation, while ensuring the biosecurity risk does not exceed New Zealand's appropriate level of protection.

The framework and methods recommended ensure that the performance data generated will be fit for purpose, are practical and feasible to produce, and are of appropriate accuracy and precision. This document is informed by the Australian and New Zealand in-water cleaning guidelines (Department of Agriculture, Fisheries and Forestry *et al.* 2012) and the transitional facilities regulations (Ministry for Primary Industries 2013).

1.2 SCOPE OF THIS DOCUMENT

1.2.1 General scope

The development of a framework for testing in-water systems to remove or treat vessel biofouling is focussed on management of biosecurity risks, both in the testing of systems for approval and in their use once they have been approved. Chemical contamination resultant from the application of in-water systems, while also an important environmental risk, is outside the scope of this document.

The data requirements of the testing framework do not include assessment of the effects of system use on anti-fouling coatings beyond a record of any physical damage, such as scratching or polish-through. However, the evaluation test report (described in the following sections) must specify the type, age and condition of the anti-fouling coating present on the test surface.

1.2.2 Specific scope

This document describes the testing framework for the following categories of in-water removal ("cleaning") or treatment (rendering non-viable) of vessel biofouling:

- cleaning systems
    - manual removal (e.g., by powered and non-powered hand-held tools);
    - mechanical removal (e.g., brush-based, cutting head, and water jet-based systems, diver-operated carts, remotely operated vehicles (ROVs) and robots);
- treatment systems
    - surface-treatment (e.g., heat and ultrasonic);
    - shrouding (e.g., encapsulation and enclosure).

The document is intended to cover only those systems that are used to remove or treat biofouling on the external, submerged surfaces of vessels. Removal or treatment of biofouling on internal surfaces such as sea chests, seawater intakes, etc., is outside the scope of this document and will be reviewed in a separate report.

Manual and mechanical systems involve physical removal of biofouling from vessels. The manual and mechanical cleaning systems considered in this document incorporate waste collection systems (to meet the biosecurity performance standard for these types of in-water cleaning). Those systems that remove biofouling without capture are outside the scope of this document (i.e. they are not considered to meet the performance standard for removal systems).

Surface-treatment and shrouding systems kill biofouling organisms *in situ*. In general, these systems do not remove biofouling from the vessel (although movement of the vessel may cause dead biofouling to slough off).

2 Performance standards and testing requirements

2.1 PERFORMANCE STANDARDS FOR MANUAL AND MECHANICAL CLEANING

The performance standard for manual and mechanical cleaning is that all visible, macroscopic biofouling shall be removed (Morrisey and Woods 2015). For the purposes of this document, residual macroscopic biofouling 0.5 cm in diameter or larger is considered to represent a failure to meet the performance standard (Section 4.1.1).

2.2 PERFORMANCE STANDARDS FOR EFFLUENT FILTRATION

The performance standard for filtration of effluent from manual and mechanical cleaning is a maximum particle size of 12.5 µm in the filtered effluent (Section 4.1.2).

Alternative or additional treatments to filtration, such as irradiation with ultra-violet (UV) light, heat or addition of biocides, must render all biological material non-viable (see Abbreviations and definitions). However, these systems typically require prior filtration of the waste water to improve their efficacy. No treatment standard is required if waste is discharged to the sewer (with secondary treatment).

2.3 PERFORMANCE STANDARDS FOR SURFACE-TREATMENTS AND SHROUDING

The performance standard for surface-treatments and shrouding systems is that all biofouling shall be rendered non-viable (see Abbreviations and definitions).

Shrouding systems can be used in conjunction with manual removal, mechanical cleaning or surface-treatment systems to contain waste during cleaning. This may also include the addition of biocides or accelerants to enhance the efficacy of shrouding in rendering organisms non-viable. Where manual or mechanical cleaning is used, the performance standard for manual and mechanical cleaning (Section 2.1) should be applied. In all other cases, this performance standard (Section 2.3) should be used. If waste is not captured and filtered by the cleaning system, then the performance standard is that all biofouling must be rendered non-viable prior to removal of the surface-treatment or shrouding system.

2.4 TESTING REQUIREMENTS

Few mechanical or surface-treatment systems are capable of cleaning/treating all immersed, external surfaces of a vessel by themselves. Combinations of different types of systems will usually be needed to clean/treat different types of vessel surfaces. Exceptions may be the use of manual removal and hand-held tools on small vessels. However, the economic feasibility of applying such systems to reactively clean an entire small vessel is questionable when compared with the costs of hauling out and cleaning (Inglis *et al.* 2012).

Some floating dock and shrouding systems may be used to treat all immersed, external surfaces of a vessel hull (including external niche areas). These systems are currently marketed for use on small- and medium-sized vessels (generally < 20 m length) (www.fabdock.com; Aquenal Pty Ltd 2009). Wrapping systems have been trialled on vessels up to 113 m in length, however further testing is needed to demonstrate their efficacy.

Because of the differences in the way the systems are applied, there are different testing requirements for each system sub-category that take into account the specific aspects of the cleaning or treatment process. The scale and nature of testing should reflect the intended use of a given system and the equipment employed.

The general requirements for testing manual and mechanical systems, surface-treatments and shrouding systems are:

1. **Vessel testing (Section 4.1.4)**
   Testing must be completed on biofouling present on actual vessels to assess the performance of the proposed system on the different profiles and orientations of the hull. This will also incorporate the risk of material being dislodged from the hull by divers, hoses, shrouds and other parts of the equipment during set-up, cleaning and demobilisation.

   Depending on the intended use of the system, testing may include:
   - the flat sides of the hull, including the wind-and-water line;
   - curved areas, for example the turn of bilge, and angles where the orientation of the surface changes abruptly, such as the chine, keel and skegs;
   - niche areas, e.g., propellers and shafts, rudders, anodes and gratings (Section 4.1.5).

   Because testing is required on multiple examples (replicates) of each niche area, it may be necessary to test the system *on more than one vessel* if there is an insufficient number of the niche type on a single vessel. Similarly, where the system is intended for use on different types of anti-fouling coatings (e.g., self-polishing copolymer, controlled depletion polymer, fouling-release, mechanically resistant coatings) *it will be necessary to undertake separate tests on each type of coating* (however see Section 3.1.11).

2. **Panel testing (Section 4.1.6 and Appendix 9.6)**
   Given the difficulties that may be encountered by the developer in obtaining access to vessels and resource consents for testing, the preliminary testing of panels may provide useful data before committing to a vessel test. It would also provide MPI with data on system efficacy. However, testing panels alone does not meet the data requirements as testing on actual vessels must be completed (Section 4.1.6).

Vessel testing should be a realistic simulation of the intended use of the system. Consequently, the requirements for testing on vessels have been divided into the following system categories:

- systems for use on flat surfaces and the wind-and-water line;
- systems for use on flat and curved surfaces;
- systems for use on niche areas and other small or confined structures;
- systems for use on entire vessels.

Under this framework, the system developer is required to specify the category (or categories) of surface that their system is intended to be used on. The system is tested under the conditions appropriate to that category, as set out in Sections 3.2, 3.3, 3.4 and 3.5. The testing requirements for the different categories are summarised in Figure 2-1.

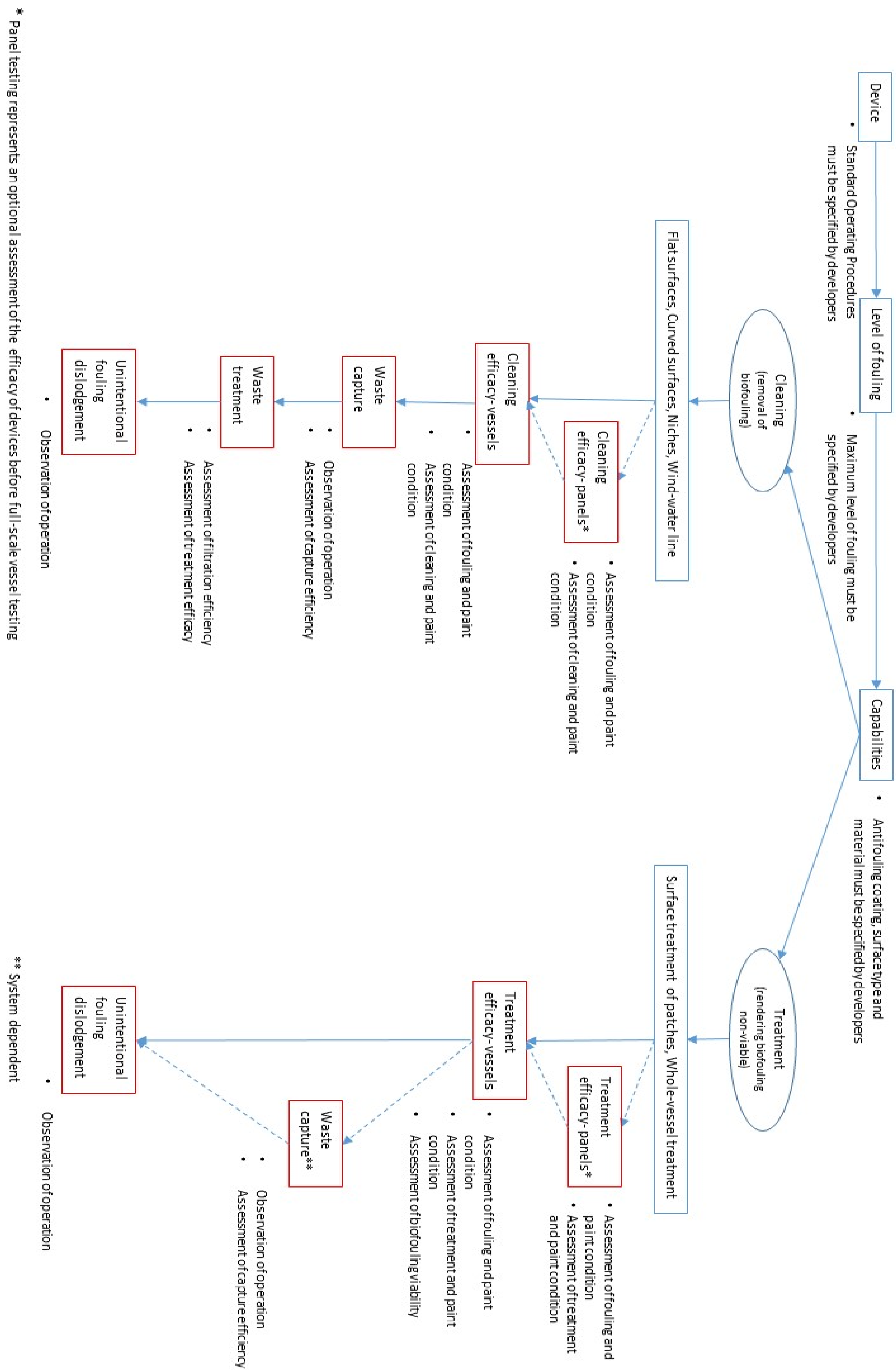

Figure 2-1. Summary of data requirements for different in-water cleaning and treatment systems.

3 Testing

3.1 GENERAL CONSIDERATIONS

3.1.1 Considerations regarding the testing of in-water systems

The following considerations must be documented by the developer and submitted to MPI with the required test data (Sections 3.2.6, 3.3.6, 3.4.6, 3.5.6 and 3.6.4):

- description and specification of the system tested:
  - mechanism of action to clean or treat biofouling;
  - equipment design;
  - method of operation;
- description of system applications:
  - the types and classes of vessel it may be applied to;
  - areas of hull and other immersed structures that the system may be used on;
  - hull materials that the system may be used on;
  - type of hull coating(s) the system is intended to be used on;
  - level and types of biofouling (slime only, soft macrofouling, calcareous macrofouling, etc.) that the system is intended to remove or treat (Section 3.1.2). The level of biofouling used to define the operation of the equipment shall be based on the US Navy fouling rating (FR) (Naval Ships' Technical Manual 2006; Appendix 9.1) and biofouling percentage cover (Floerl *et al.* 2005). The level and type of biofouling specified will depend on whether the system is intended for on-going maintenance (removal or treatment of light and moderate (soft) biofouling; FR $\leq$ 30) or emergency applications to deal with moderate (hard) and heavy biofouling (FR > 30; Section 3.1.2);
  - standard operating procedure (SOP) for the system, which must detail:
    - the mode of operation of the system, including how it will be applied;
    - the steps that will be taken to ensure that viable biofouling is not released or dislodged during mobilisation, application, and demobilisation of the system;
    - for surface-treatment and shrouding systems, the operating protocol should also specify:
      - the lethal dose (LD_{100}) and duration of treatment (LT_{100}) required to achieve 100% mortality of biofouling organisms;
    - the physical environment suitable for use of the system (e.g., alongside berth, enclosed in floating dock, open water, whether the entire fouled area of the hull must be submerged);
    - the sea and weather conditions under which the system is intended to be used (e.g., limits on current speed, wave height, water temperature, water clarity to ensure efficacy, operator safety);
- details and qualification of organisations and personnel performing and supervising the test.

The following factors shall be considered by the developer prior to testing:

- proposed test procedures, including the date and location and any modifications to the procedures set out in Sections 3.2.3, 3.3.3, 3.4.3, 3.5.3 and 3.6.3. Modifications may relate, for example, to limitations on the intended use of the system (e.g., levels of biofouling or areas of the hull that it is not intended for use on);
- the surface to be cleaned or treated:

  - type of vessel or other surface;
  - areas of the hull (flat sides, curved areas, wind-and-water line, angles, niche areas) the system will be tested on;
  - type of hull coating the system will be tested on;
  - levels and type of biofouling on the test surfaces;
  - process of preparing fouled surfaces for testing (e.g., panel immersion);
- test supervision (e.g., by appropriately qualified, independent scientists);
- operator considerations:
  - where the developer does not intend to use their own staff to operate the system during testing, detailed instructions for the system, including schematic diagrams, must be provided to the personnel performing the test. The instructions must be sufficiently detailed that testing can be done safely and in accordance with the developer's instructions and the intended use;
  - divers carrying out and observing test operations shall have communications to the surface supervisor. Those operating the system in-water shall have the means, on the system, to stop, start and manoeuvre the system, and the surface supervisor shall be able to shut down the system independently in cases of equipment or system failure;
  - testing operations must comply with safe diving codes of practice (Section 4.2.1).

3.1.2 Level and cover of biofouling on the test surface

The test surface must be fouled *to the highest level for the intended use of the system* as specified in the system description (Section 3.1.1). For the purposes of testing, four categories of biofouling are defined, based on the US Navy FR scale to define the type of biofouling (Naval Ships' Technical Manual 2006) and Floerl *et al.* (2005) to define percentage cover.

The four categories of biofouling type are:

- slime (FR 20 or less). In-water removal or treatment of slime is considered to be of low biosecurity risk and systems intended for use only on slime do not require testing under the present framework;
- moderate (soft) biofouling (FR 30, 16–40% cover);
- moderate (hard) biofouling (FR 40–80, 16–40% cover);
- heavy (hard) biofouling (FR 90 or greater, > 40% cover).

The four categories of percentage cover are:

- "light" (1–5% of the available surface);
- "considerable" (6–15%);
- "extensive" (16–40%);
- "very heavy" (41–100%), (Section 4.2.2).

For example, if the system is only intended for vessel hull maintenance, the test surface shall be fouled to no greater than US Navy FR 30 and 40% cover (Section 4.2.3; Appendix 9.1). If the system is intended for use on greater levels of biofouling, including emergency cleaning or treatment of moderate (hard) and heavy (hard) biofouling, it shall be tested on biofouling of at least FR 90 and > 40% cover.

The type of biofouling can be described in broad taxonomic and morphological categories of biofouling organisms (such as erect bryozoans, filamentous algae, and encrusting coralline algae) and can be determined by a suitably qualified independent supervisor (Section 4.2.4).

To minimise biosecurity risk during the test, biofouling should be regionally derived[1] (Department of Agriculture, Fisheries and Forestry *et al.* 2012). To ensure this, the vessel's operational history, including biofouling management, must be known. If a vessel with regional biofouling is not available, a vessel with non-regional biofouling may only be used if the associated biosecurity risk can be shown to be minimal, for example by examining the vessel's operational and biofouling management history or by having a diver inspection of the hull. In the latter case, the costs and time delays of using a vessel with non-regional biofouling (including the costs associated with obtaining a resource consent) should be balanced against those of waiting for a suitable vessel to arrive or of relocating the system to another port where a regionally fouled vessel is available.

3.1.3 Condition of anti-fouling coating (where present)

Although assessment of the effects of the cleaning or treatment system on the anti-fouling coating falls outside the scope of this document, the test report (described in Sections 3.2.6, 3.3.6, 3.4.6 and 3.5.6) must specify the type, age and condition of the coating present on the test surface before testing. Observations of any physical damage, such as scratching or polish-through, caused to an anti-fouling coating during system operation shall also be recorded.

3.1.4 Personnel requirements for system testing

As operation of the system would typically require specific training or expertise, it is reasonable that the developer should wish to use their own staff or contractors. Therefore, operation of the system during testing may be done by the developer's staff or a contractor(s) nominated by the developer.

Independent, scientific supervision of testing is required unless the contractor nominated by the developer is from a reputed scientific provider approved by MPI for this purpose. Under no circumstance is the developer and the independent supervisor to originate from the same organisation. Any potential conflicts of interest should be disclosed prior to testing.

To protect confidentiality and intellectual property, contracts shall be drawn up between the developer, contractor(s), independent supervisors and MPI (upon receipt of the data).

3.1.5 General reporting requirements for testing

All test results shall be reported using the templates in Appendix 9.3.

Reporting of the test outcomes must include the following information (in addition to detailed results specified in the *Reporting* sections 3.2.6, 3.3.6, 3.4.6, 3.5.6 and 3.6.4):

- details of the system tested, including hull surfaces for which the system is appropriate;
- details (names and affiliations) of the personnel who operated the system;
- details (names and affiliations) of the independent supervisor of the test (if these are different from personnel carrying out the test), and any potential conflicts of interest;
- the environment (location, weather and sea conditions, depth of panels or vessel in the water, water clarity at the time of testing as Secchi depth) in which the test was done;

[1] Biofouling that has been acquired in the same location where in-water cleaning is proposed. "Regional" is as specified by the relevant local government authority in New Zealand. This category may be defined on the basis of the known distribution of established invasive aquatic species or on-going pest management, or the location of high-value environments. Such delineation is the responsibility and prerogative of the local government.

- type and size of vessel used in the test, including the material the hull was constructed from and type of anti-fouling coating (if present).

The reporting requirements described in Sections 3.2.6, 3.3.6, 3.4.6 and 3.5.6 include assessments of the amount and type of biofouling and paint condition before and after the test, and viability of biofouling organisms following application of surface-treatment or shrouding systems (Section 3.1.9; Appendix 9.2). Assessment of paint condition is based on percent occurrence (localised/scattered) of different types of damage according to the US Navy paint deterioration rating scale (Appendix 9.4).

3.1.6 Sample sizes for testing system efficacy

3.1.6.1 Systems designed to clean parts of vessels (manual or mechanical systems)

The minimum number of replicate areas of each surface type cleaned during testing of manual or mechanical systems shall be six (n = 6). After cleaning, three of the six areas will be selected randomly to analyse cleaning efficacy (Section 4.2.5).

Flat surfaces

For systems specified only for cleaning flat surfaces, six replicate areas in each of the following regions of the hull shall be cleaned (where the system has been specified by the developer as capable of cleaning):

- flat sides (n = 6);
- flat bottom (n = 6);
- wind-and-water line (n = 6).

Curved or angled surfaces

For systems specified for cleaning curved or angled surfaces, six replicate areas in each of the following regions of the hull shall be cleaned (where the system has been specified by the developer as capable of cleaning):

- curved areas of the general hull surface (e.g., turn of bilge, bow dome) (n = 6);
- angles where the orientation of the surface changes abruptly angles (e.g., chine, keel, junction of skeg and hull, bilge keels to hull) (n = 6).

Niche areas

For systems specified for cleaning biofouling on the external surfaces of niche areas, *six replicates of each type of niche area* (e.g., propellers and shafts, rudders, anodes, gratings, dry-dock support strips) shall be cleaned. *This may require more than one vessel* to obtain the necessary number of replicate niche areas to satisfy the testing requirements.

3.1.6.2 Systems designed to treat parts of vessels (surface-treatments)

The minimum number of replicate areas of each surface type treated during testing of surface-treatment systems shall be six (n = 6). After application, three of the six areas will be selected randomly to analyse treatment efficacy (Section 4.2.5).

Flat surfaces

For systems specified only for treating biofouling on flat surfaces, six replicate areas in each of the following regions of the hull shall be treated (where the system has been specified by the developer as being capable of use):

- flat sides (n = 6);
- flat bottom (n = 6);

- wind-and-water line (*n* = 6).

Curved or angled surfaces

For systems specified for treating biofouling on curved or angled surfaces, six replicate areas in each of the following regions of the hull shall be treated (where the system has been specified by the developer as capable of use):

- curved areas of the general hull surface (e.g., turn of bilge, bow dome) (*n* = 6);
- angles where the orientation of the surface changes abruptly angles (e.g., chine, keel, junction of skeg and hull, bilge keels to hull) (*n* = 6).

Niche areas

For systems specified for treating biofouling on the external surfaces of niche areas, *six replicates of each type of niche area* (e.g., propellers and shafts, rudders, anodes, gratings) shall be treated. This may require more than one vessel to obtain the necessary number of replicate niche areas to satisfy the testing requirements.

3.1.6.3 Systems designed to treat whole vessels

For systems designed to treat whole vessels, the full system must be tested on the hull of *at least three actual vessels* of the type and maximum size that the system is intended for use on (Section 4.3.1).

To assess the efficacy of shrouding and surface-treatment systems that treat an entire vessel at once, it is necessary to take into account the size of the test vessel (Table 3-1 Assessment of flat hull surfaces and the wind-and-water line will consist of replicate 1 m^2 areas of the treated hull. For curved surfaces and niches the replicates will be physically distinct surfaces or niches.

Table 3-1. Minimum number of areas required to assess the efficacy of whole vessel treatment[1].

Vessel type	TWSA[2] (m^2)	Number of 1 m^2 areas for evaluation		Number of separate curved surfaces or niches for evaluation		Total *n*
		Wind-and-water line[3]	Flat hull surfaces	Curved hull surfaces	Niches	
Yachts and other small vessels	< 80	3	3	3	3	12
Coastal fishing and other medium-sized vessels	81-1 000	6	6	6	6	24
Large merchant vessels	> 1 000	10	10	10	6	36

[1]See Section 4.2.5 for a description of how the requisite sample size was determined.
[2]Estimated Total Wetted Surface Area (TWSA).
[3]Only necessary for those systems intended to treat the wind-water line during treatment or cleaning of whole vessels.

3.1.7 Suitable vessels for testing

The vessels used in testing must fulfil the requirements for size (adequate to accommodate the number and size of test areas in relevant parts of the hull, and the number of niche areas: Section 3.1.6) and level of biofouling that the system is intended to be used on (Section 3.1.2). More than one vessel may be required to test the system on the required number of replicate areas.

The developer, or the contractor carrying out the test, shall arrange access to vessels for testing, and should use their own contacts for arranging this (Section 4.2.6). Possible options include the following:

- vessels waiting to be slipped or dry-docked;
- New Zealand Defence Force vessels;
- barge or tug companies;
- aquaculture vessels;
- fishing vessels (including laid-up vessels);
- oil and gas industry vessels.

3.1.8 Requirements for photographic and videographic recording (manual and mechanical cleaning systems)

The developer or the contractor carrying out the testing can choose whether to use video or still imaging, however the following conditions must be met. All images (video and still) must be to a resolution that allows:

- FR to be allocated in images taken prior to the cleaning;
- percentage cover of biofouling to be assessed in images taken prior to cleaning;
- all objects 0.5 cm diameter or larger to be detected and identified (to general taxonomic groups – Section 3.1.2) in images taken after cleaning;
- assessment of paint condition before and after treatment application.

Calibration objects of 0.5 cm diameter must be included in the post-cleaning video or each still photograph to allow verification that objects of this size can be identified from the images.

In addition, scale objects (such as a tape measure in videos or ruler in stills) must be included in all images, together with labels showing the date of the test, the name of the system under test, the name of the test vessel, the part of hull, the test replicate area (e.g., 1–6) and the location of still images within the test area, or the location of pass over test area if video images are not continuous for the whole area. Paired lasers mounted parallel, and a known distance apart on the video camera may be used to provide scale, but the developer or test supervisor must ensure that the light beams are suitably calibrated, are visible on the hull throughout the recording (e.g., this may not be the case in bright sunlight) and are projected onto the test surface at as close to a 90° angle as possible.

It is the responsibility of the developer or contractor to determine the swimming speed of the diver recording the video, and the size of the field-of-view in video and still images that is required to meet the above conditions. These will depend on the equipment used and the environmental conditions (particularly water clarity) at the time of testing. Swimming speed over the hull surface should not exceed 30 cm s^{-1} (0.6 kn) to prevent blurring of the image in individual frames (Section 4.2.7).

All images must be provided to MPI, together with a key explaining the text on the labels included in each image (e.g., codes for location on hull, test area number, image number) and listing any residual biofouling present in each image (in the case of post-cleaning images). A diagram must be provided showing the locations of each test area on the hull and each image within each cleaned area.

3.1.9 Requirements for assessing viability of biofouling (surface-treatments or shrouding systems)

For surface-treatment and shrouding systems, the presence of any remaining viable organisms in the treated areas, or in samples removed from them, represents a failure to meet the performance standard (Section 2.3). Viability must be assessed using both videographic (Section 3.1.9.1) and direct visual assessment (Section 3.1.9.2) after the treatment is complete.

3.1.9.1 Requirements for videographic assessment (surface-treatments and shrouding systems)

The developer or the contractor carrying out the testing must meet the following conditions. All video images must be to a resolution that allows:

- FR to be allocated in images taken prior to the treatment;
- percentage cover of biofouling to be assessed in images taken prior to treatment;
- assessment of paint condition before and after treatment (Appendix 9.4).

In addition, scale objects (such as a tape measure in videos or ruler in stills) must be included in all images, together with labels showing the date of the test, the name of the system under test, the name of the test vessel, the part of hull, the test replicate area (e.g., 1 – *n*, see Table 4-2) and the location of still images within the test area, or the location of pass over test area if video images are not continuous for the whole area. Paired lasers mounted parallel, and a known distance apart on the video camera may be used to provide scale, but the developer or test supervisor must ensure that the light beams are suitably calibrated, are visible on the hull throughout the recording (e.g., this may not be the case in bright sunlight) and are projected onto the test surface at as close to a 90° angle as possible.

It is the responsibility of the developer or contractor to determine the swimming speed of the diver recording the video, and the size of the field-of-view in video and still images that is required to meet the above conditions. These will depend on the equipment used and the environmental conditions (particularly water clarity) at the time of testing. Swimming speed over the hull surface should not exceed 30 cm s^{-1} (0.6 kn) to prevent blurring of the image in individual frames (Section 4.2.7).

Video taken to assess viability of biofouling post-treatment must be recorded as a series of video quadrats by a stationary diver to avoid confusing viability with movement of organisms caused by disturbance by the diver (Section 3.5.5).

The independent supervisor shall examine each post-treatment video to assess the viability of the remaining biofouling (Section 4.1.3). Viability will be detected in the video as active movement of organisms for feeding or other life functions (Appendix 9.2).

3.1.9.2 Visual assessment of viability (surface-treatments and shrouding systems)

Representative samples of biofouling shall be removed manually (i.e., by hand or using a paint scraper) from the treated surface taking care to ensure that the organisms and the anti-fouling coating are not damaged during removal. The samples, and adequate seawater, should be placed into labelled, sealable water-tight bags (e.g., zip-lock bags) or containers for transfer to shore. Samples must not be exposed to air or strong sunlight prior to examination on-shore, as this may confound any assessment of viability.

Each sample of biofouling collected from the treated areas shall be placed separately into a sorting tray and covered with filtered (60 µm) seawater. The types of organisms in each sample and their structural integrity (intact or exhibiting some degree of damage) shall be recorded (Appendix 9.2). Each major taxonomic group of organisms (i.e., barnacles, algae, hydroids, bryozoans, etc.) shall be sorted into separate dishes, covered with filtered (60 µm) seawater, and left undisturbed for 20–30 minutes. The organisms in each sorting dish will then be examined under magnification using either a handheld magnifying glass or a dissecting microscope for signs of active feeding or movement (Appendix 9.2). Once viability has been assessed, each taxonomic group should be removed from the water, blotted dry, and weighed (wet weight to the nearest gram) to obtain an estimate of biomass.

3.1.10 Requirements for assessing containment (shrouding systems)

Containment of treated water and material enclosed within a shrouding systems should be assessed by recording video of the exterior of the system following introduction into the shroud of a visible, non-toxic tracer dye, such as fluorescein sodium salt, Basic Blue 3 or Rhodamine WT Red (at a concentration of 4 g L^{-1} or an appropriate equivalent). Two bow-to-stern video transects (~ 1 m field of view) should be taken of the entire system following introduction of the dye. In addition, video recordings should be made of all seams, joins and obvious damage (e.g., tears or holes) to the system. Where the treatment lasts longer than 1 day, it will be necessary to repeat the assessment of containment (including re-introduction of tracer dye) immediately prior to removal of the system from the vessel.

3.1.11 System approval by coatings manufacturers

The developer must contact coating manufacturers to ensure that system application will not compromise the anti-fouling coating types it is intended for use on. Evidence of approval from the coating manufacturer(s) shall be presented to MPI as part of the data package. Preliminary guidance on the potential suitability of different systems on different coating types is given in Table 081-3-1 of the US Naval Ships' Technical Manual (2006).

It is recommended that approval by anti-fouling coatings manufacturers is completed at an early stage of system development. Failure to obtain approval from coating manufacturers will reduce the range of system applications (e.g., restricted to emergency use only).

3.1.12 System testing approval by regulatory authorities

Depending on the location in which the test is done a resource consent may be required. This is particularly so if a biocidal anti-fouling coating is present on the vessel, if biocides or chemicals are used to accelerate the treatment of biofouling following deployment of surface-treatment or shrouding systems, or if the treated cleaning effluent is to be released back into the marine environment. Obtaining this, or any other necessary approval, is the responsibility of the developer.

Where a consent is required, several test variables may reduce the biosecurity and chemical contamination risks:

- presence of regional biofouling on the hull (e.g., negligible biosecurity risk);
- collection or treatment of waste;
- amount of the hull required to test the system (e.g., chemical contamination risk from smaller test areas will be lower compared to cleaning or treating a whole vessel (Morrisey *et al.* 2013));
- effectiveness of the anti-fouling coating (e.g., aged coatings may have reduced levels of biocide and thus represent a lower chemical contamination risk than effective anti-fouling paint).

3.2 TEST PROCEDURE FOR SYSTEMS APPLIED TO FLAT SURFACES ONLY

This testing procedure is intended for manual, mechanical and surface-treatment systems that are intended to clean or treat flat hull surfaces, but which are not suitable for use on areas of strongly curved hull, angled areas of the hull or niche areas. This procedure allows for assessment of the effects of scale and environmental conditions on system efficacy, waste capture, and of dislodgement of biofouling by divers and equipment while accessing the hull.

3.2.1 Vessel selection

The system must be tested on the hull of at least one actual vessel (Section 4.3.1). The vessel used must be large enough to contain six replicate test areas in each of the following regions of the hull:

- flat sides ($n = 6$);
- flat bottom ($n = 6$);
- wind-and-water line, if the system is intended for use in this region ($n = 6$).

The size of each test area depends on the mode of system operation and the size of surface that it can be applied to effectively (see Section 3.2.3.1 and 3.2.3.2). More than one vessel will be required if sufficient numbers of replicate test areas cannot be accommodated on a single hull. Similarly, if the system is intended for use on different types of coating (e.g., fouling release, biocidal, or mechanically resistant coatings) it will need to be tested on a separate vessel for each type of coating.

The amount of biofouling required on the vessel depends on the intended use of the system (see Section 3.1.2):

- slime (FR 20 or less). In-water removal or treatment of slime is considered to be of low biosecurity risk and systems intended for use only on slime do not require testing under the present framework;
- if the system is intended to remove or treat moderate (soft) biofouling, the hull shall have macrofouling present of FR 30 and 16-40% cover;
- if the system is intended to remove or treat moderate (hard) biofouling, the hull shall have macrofouling present of FR 80 and 16-40% cover;
- if the system is intended to remove or treat heavy (hard) biofouling, the hull shall have macrofouling present of FR 90 or greater and > 40% cover.

The test areas must be fouled *to the highest level for the intended use of the system* as specified in the system description.

3.2.2 General conditions required for test implementation

The general conditions necessary for testing include:

- the hull must be low enough in the water that the wind-water line is accessible, if this region is to be included in the testing;
- the test areas shall be representative (in terms of shape and orientation) of the range of regions of the hull that the system is intended to be used on;
- the test should be conducted during periods of slack water, with current speeds of no more than 1 kn (~50 cm s^{-1}), in order to aid the independent supervisor(s) in observing system operation (Section 4.3.2);
- the test should be conducted at locations and times when water clarity (measured as vertical Secchi disk depth) is at least 2 m (Section 4.3.3).

3.2.3 Testing method

During the test, the system shall be used in the manner in which it is intended under normal operation. The system shall be separately applied to six replicate areas (Section 4.2.5) in each of the following hull regions:

- flat sides ($n = 6$);
- flat bottom ($n = 6$);
- wind-and-water line, if the system is intended for use in this region ($n = 6$).

Before testing proceeds, the independent supervisor will visually determine the biofouling rating (FR) and percentage cover of biofouling in each of the replicate areas in each hull region (Section 4.3.4). The independent supervisor will also determine the state of the anti-fouling coating (Appendix 9.4). Each test area shall be recorded by video or digital still imaging before testing for purposes of auditing the assessment of biofouling rating and cover, and coating condition (Section 3.1.8 or 3.1.9.1).

3.2.3.1 Manual and mechanical systems

The performance standard for manual and mechanical systems is that all visible macrofouling must be removed (Section 4.1.1). The equipment for capture and treatment of biofouling removed during cleaning must be operated and tested during the cleaning trials (Section 3.6). The developer may, however, choose to perform preliminary tests of cleaning ability without capture *in addition* to full testing.

On flat sides of the hull, each test area consists of at least six parallel, partially overlapping, horizontal passes of the cleaning head, and each pass must be at least four times as long as the length of the cleaning head of the system under test. At the end of each pass, the cleaning head must turn and commence the next pass in the manner that would be used in normal operation (as set out in the general reporting requirements, Section 3.1.5), with a minimum of five turns (Section 4.2.5). For systems used at the wind-and-water line, each test area should consist of at least six partially overlapping vertical passes of the cleaning head. For manual systems (e.g., scouring pads, scrapers, non-powered brushes) each test area should be at least 1 m^2 (Section 4.2.5).

3.2.3.2 Surface-treatment systems

The performance standard for surface-treatment systems is all biofouling shall be rendered non-viable (Section 2.3). Any system for capture and treatment of any biofouling dislodged during treatment must be operated and tested during the trials (Section 3.6). The developer may, however, choose to perform preliminary tests of treatment ability without capture *in addition* to full testing.

For surface-treatments, the size of the test area may vary depending on the system. Where the system involves a standardised area of treatment (such as a fixed size of heating panel), the test area should consist of at least six parallel, partially overlapping applications of the treatment. For systems that do not have a standardised area of application (e.g., cavitation guns, ultrasonic transducers) each replicate test area should be no smaller than 1 m^2 [2].

[2] For systems that do not have a standardised area of application, the size of area used in the test should first be approved by MPI following consultation with the independent supervisor.

3.2.3.2.1 Monitoring conditions achieved by the system

The independent supervisor shall measure and record the dose or concentration of the lethal agent that is achieved by the surface-treatment system during its application to a vessel. Conditions to be measured may include biocide concentration, dissolved oxygen and sulphide concentrations (where mortality is caused by deoxygenation of the water), lethal temperature, sound frequency, etc. Methods used to measure the conditions achieved should be appropriate to the system. Triplicate measurements should be taken from within the system during each application to a replicate test area.

3.2.4 Assessing system efficacy

After the system has undergone testing, images covering the entirety of each replicate test area shall be obtained by video or still photography within two days of completion of the test in accordance with the requirements specified in Sections 3.1.8 and 3.1.9.1. Video imagery will be most practical for large test areas (> 2 m^2) and is a requirement for all surface-treatment systems (Section 3.1.9.1). The images must show labels with the location of the test area on the hull and a unique image identifier. Scale objects must also be included in each image (Sections 3.1.8 and 3.1.9.1).

3.2.4.1 Manual and mechanical cleaning

The independent supervisor will randomly select the post-cleaning images from three of the six replicate cleaned areas in each hull region, and examine each image in its entirety for the presence and type of any residual biofouling 0.5 cm in diameter or larger (Section 4.1.1).

The size and type of any biofouling detected will be recorded against the image identifier (file name) and description of biofouling location within the cleaned area, namely whether it was in the general area of the pass of the cleaning head or the turning area between passes (Section 3.1.2). The independent supervisor will also describe the condition, including any damage, of the biofouling present. Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any residual macrofouling (0.5 cm in diameter or larger) in any of the cleaned areas constitutes a failure to meet the performance standard for manual and mechanical systems (Section 2.1).

Paint condition will also be assessed to identify any physical damage caused by cleaning (Appendix 9.4).

3.2.4.2 Surface-treatments

The independent supervisor will randomly select the post-treatment video from three of the six replicate test areas in each hull region, and examine each video in its entirety to assess the viability of any residual macrofouling (Section 4.1.3; Appendix 9.2).

The size and type of any viable macrofouling detected in the video will be recorded against the image identifier (file name) and a description of the location of the biofouling within the treated area (e.g., by reference to the minute and seconds in the video at which the viable biofouling is detected) (Sections 3.1.2; Appendix 9.2). The independent supervisor will also describe the general condition of the biofouling present, including signs of physical damage, morbidity and whether there are any indicators of viability (Section 4.1.3; Appendix 9.2).

The independent supervisor will take a representative sample of the treated biofouling from a minimum 25 cm^2 area within each replicate test area (Section 3.1.9). The type (i.e., taxonomic group) and condition (including viability) of biofouling observed in samples taken from each test area will be recorded against the sample identifier.

Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any viable biofouling in any of the treated areas or samples constitutes a failure to meet the performance standard for surface-treatment systems (Section 2.3).

Paint condition will be assessed to identify any physical damage caused by the treatment (Appendix 9.4).

3.2.5 Assessing containment and waste capture efficacy (see Section 3.6)

A diving observer must observe and record on video the test process, including set-up and demobilisation, to assess the amount of material dislodged from the hull outside each test area, and the amount of material removed but not captured (Section 4.3.5). The video may be recorded by the independent supervisor (using Underwater Breathing Apparatus (UBA)) or by a diver under the direction of the independent supervisor using surface-to-diver communications. When the test area includes the wind-and-water line, a video should also be taken from both in and out of the water, to assess if any biofouling is dislodged at the water-air interface.

For systems that use suction to capture waste, the area of effective capture around the system should be estimated by video recording the use of a visible, non-toxic tracer dye, such as fluorescein sodium salt, Basic Blue 3 or Rhodamine WT Red. During each replicate test, 50 mL aliquots of the dye (at a minimum concentration of 4 g L^{-1}) should be released slowly from a syringe at 10, 25 and 50 cm from system operation. Effective capture will be indicated by strong directional movement of the dye toward the point of suction. The independent supervisor will make visual observations of the dye movement from each position and shall ensure that the releases are recorded on video.

After completion of the trial, the video will be assessed for evidence of material being dislodged from the hull over the entire process, subsequent capture of this material, and leakage from the system itself. This assessment shall be included in the reporting template (Appendix 9.3).

Each video recording shall include a label at the start of the recording indicating the date of the test, name of the system being tested, name of the vessel, type and replicate number of the test area.

Dislodgement or discharge of macroscopic particles > 0.5 cm diameter constitutes a failure to meet the performance standard (Section 2).

3.2.6 Reporting

Using the templates in Appendix 9.3, the independent supervisor is to report each of the following:

- *general requirements*

    - a description and specification of the equipment tested (Section 3.1.1);
    - a description of the standard operating procedure (SOP) for the system (Section 3.1.1);
    - a description of how the test was undertaken, including:
        - the location, type of vessel used, hull material, surface (e.g., coating/unpainted) and environmental conditions during the test (Section 3.1.5);
        - a description of the procedures followed during set-up, testing of the system and demobilisation;
- *before cleaning or treatment*:
    - type, level (FR) and cover (%) of biofouling present in each test area;
    - presence, type and condition of anti-fouling coating;
        - the video or still image(s) on which these assessments were made are to be provided with the report;
- *during cleaning or treatment*
    - *surface-treatments*
        - the results of samples taken to monitor conditions (e.g., concentration of the lethal agent, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.2.3.2.1);
- *after cleaning or treatment*:
    - *manual and mechanical cleaning* - the amount and type of residual biofouling for each of the test areas analysed:
        - type of biofouling (Section 3.1.2);
        - number of patches and size of each patch;
        - location within the test area;
        - location of the test area on the hull;
        - relevant image identifier (file name);
        - a description of the condition of any residual biofouling;
    - *surface-treatments* - the amount and type of viable biofouling observed in video recordings of each replicate treated area selected for analysis including:
        - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);
        - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2) and their location within the test area;
        - location of the test area on the hull;
        - relevant image identifier (file name);
    - the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the selected test areas, including:
        - a description of the number, size and type of biofouling organisms (Sections 3.1.2 and 3.1.9) that exhibited indications of potential viability (Appendix 9.2);
        - relevant sample identifier (i.e., test replicate identifier);
        - location of the test replicate on the hull;
    - *all systems*:
        - the condition of the anti-fouling coating in each test area:
            - the video or still images on which these assessments were made are to be provided with the report;

- qualitative assessment of loss of material by dislodgement from the hull during set-up and demobilisation and from escape from the system during operation, based on examination of video recording (Section 3.2.5):
    - the video images from which this assessment of loss of material during the test was made are to be provided with the report;
- a description of any variations or deviations in application of the test relative to the SOP and test requirements;
- a discussion of the system efficacy, including whether the performance standard was met;
- recommendations for system or SOP improvement.

3.3 TEST PROCEDURE FOR SYSTEMS APPLIED TO FLAT AND CURVED SURFACES

This testing procedure is intended for manual, mechanical and surface-treatment systems that are suitable for cleaning or treating biofouling on both flat areas and areas of strongly curved hull, including angles where the orientation of the hull changes sharply (if the system is intended to clean or treat such areas). Flat areas of hull are not included in the testing because systems capable of use on curved areas should also be able to operate on flat areas, unless stated by the developer (Section 4.1.4).

This procedure allows assessment of effects of scale and environmental conditions on the system efficacy, waste capture, and of dislodgement of biofouling by divers and equipment while accessing the hull.

3.3.1 Vessel selection

The full system must be tested on the hull of at least one actual vessel (Section 4.3.1).The vessel used must be large enough to contain six replicate test areas in each of the following regions of the hull:

- curved portions of the sides and bottom of the hull ($n = 6$);
- angles where the orientation of the hull changes sharply, if the system is intended for use on such areas. *For each angle type* (e.g., internal angle, external angle, 90º, 45º) ($n = 6$);
- wind-and-water line, if the system is intended for use on this region ($n = 6$).

The size of each test area depends on the system and the size of surface that it can be applied to (see Sections 3.2.3.1 and 3.2.3.2). More than one vessel will be required if a sufficient number of replicate test areas cannot be accommodated on a single hull. Similarly, if the system is intended for use on different types of coating (e.g., fouling release, biocidal, or mechanically resistant coatings) it will need to be tested on a separate vessel for each type of coating.

The amount of biofouling required on the vessel depends on the intended use of the system:

- slime (FR 20 or less). In-water removal or treatment of slime is considered to be of low biosecurity risk and systems intended for use only on slime do not require testing under the present framework;
- if the system is intended to remove or treat moderate (soft) biofouling, the hull shall have macrofouling present of FR 30 and 16-40% cover;
- if the system is intended to remove or treat moderate (hard) biofouling, the hull shall have macrofouling present of FR 80 and 16-40% cover;
- if the system is intended to remove or treat heavy (hard) biofouling, the hull shall have macrofouling present of FR 90 or greater and > 40% cover.

The test areas must be fouled *to the highest level for the intended use of the system* as specified in the system description.

3.3.2 General conditions for implementing the test

The general conditions necessary for testing include:

- the hull must be low enough in the water that the wind-water line is accessible, if this region is to be included in the testing;

- the areas tested shall be representative (in terms of shape and orientation) of the range of regions of the hull that the system is intended to be used on;
- the test should be conducted during periods of slack water, with current speeds of no more than 1 kn (~50 cm s^{-1}), in order to aid the independent supervisor(s) in observing system operation (Section 4.3.2);
- the test should be conducted at locations and times when water clarity (measured as vertical Secchi disk depth) is at least 2 m (Section 4.3.3).

3.3.3 Testing method

During the test, the system shall be used in the manner in which it is intended under normal operation. The system shall be applied separately to six replicate test areas (Section 4.2.5) in each of the following hull regions:

- curved portions of the sides and bottom of the hull (n = 6);
- angles where the orientation of the hull changes sharply, if the system is intended for use on such areas. *For each angle type* (e.g., internal angle, external angle, 90^o, 45^o) (n = 6);
- wind-and-water line, if the system is intended for use on this region (n = 6).

Before testing proceeds, the independent supervisor will visually determine the biofouling rating (FR) and percentage cover of biofouling in each of the replicate areas in each hull region (Section 4.3.4). The independent supervisor will also determine the state of the anti-fouling coating (Appendix 9.4). Each test area shall be recorded by video or digital still imaging before testing for purposes of auditing the assessment of biofouling rating and cover, and coating condition (Section 3.1.8 or 3.1.9.1).

3.3.3.1 Manual and mechanical cleaning

The performance standard for manual and mechanical systems is that all biofouling must be removed (Section 2.1). The equipment for capture and treatment of biofouling removed during cleaning must be operated and tested during the cleaning trials (Section 3.6). The developer may, however, choose to perform preliminary tests of cleaning ability without capture *in addition* to full testing.

Each test area consists of at least six parallel, partially overlapping, horizontal passes of the cleaning head and each pass must be at least four times as long as the length of the cleaning head of the equipment under test. At the end of each pass, the cleaning head must turn and commence the next pass in the manner that would be used in normal operation (as set out in the general reporting requirements, Section 3.1.5), with a minimum of five turns (Section 4.2.5). For manual systems (e.g., scouring pads, scrapers, non-powered brushes), each test area should be at least 1 m^2 (Section 4.2.5).

3.3.3.2 Surface-treatment

The performance standard for surface-treatments is all biofouling shall be rendered non-viable (Section 2.3). Any equipment for capture and treatment of any biofouling dislodged during treatment must be operated and tested during the trials (Section 3.6). The developer may, however, choose to perform preliminary tests of treatment ability without capture *in addition* to full testing.

For surface-treatments, the size of the test area may vary depending on the system. Where the system involves a standardised area of treatment (such as a fixed size of heating panel), the test area should consist of at least six parallel, partially overlapping applications of the treatment. For systems that do not have a standardised area of application (e.g., cavitation guns, ultrasonic transducers) each replicate test area should be no smaller than 1 m^2 [3].

3.3.3.2.1 Monitoring conditions achieved by the system

The independent supervisor shall measure and record the dose or concentration of the lethal agent that is achieved by surface-treatment system during its application to a vessel. Conditions to be measured may include biocide concentration, dissolved oxygen and sulphide concentrations (where mortality is caused by deoxygenation of the water), lethal temperature, sound frequency, etc. Methods used to measure the conditions achieved should be appropriate to the system. Triplicate measurements should be taken from within the system during each application to a replicate test area.

3.3.4 Assessing system efficacy

After the system has undergone testing, images covering the entirety of each replicate test area shall be obtained by video or still photography within two days of completion of the test in accordance with the requirements specified in Sections 3.1.8 and 3.1.9.1. Video imagery will be most practical for large test areas (> 2 m^2) and a requirement for all surface-treatment systems (Section 3.1.9.1). The images must show labels with the location of the test area on the hull and a unique image identifier. Scale objects must also be included in each image (Sections 3.1.8 and 3.1.9.1).

3.3.4.1 Manual and mechanical cleaning

The independent supervisor will randomly select the post-cleaning images from three of the six replicate cleaned areas in each hull region, and examine each image in its entirety for the presence and type of any residual biofouling 0.5 cm in diameter or larger (Section 4.1.1).

The size and type of any biofouling detected will be recorded against the image identifier (file name) and description of location of the biofouling within the cleaned area, namely whether it was in the general area of the pass of the cleaning head or the turning area between passes (Section 3.1.2). The independent supervisor will also describe the condition, including any damage, of the biofouling present. Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any residual macrofouling (0.5 cm in diameter or larger) in any of the cleaned areas constitutes a failure to meet the performance standard for manual and mechanical systems (Section 2).

Paint condition will be assessed to identify any physical damage caused by cleaning (Appendix 9.4).

[3] For methods that do not have a standardised area of application, the size of area used in the test should first be approved by MPI following consultation with the independent supervisor.

3.3.4.2 Surface-treatments

The independent supervisor will randomly select the post-treatment video from three of the six replicate test areas in each hull region, and examine each video in its entirety to assess the viability of any residual macrofouling (Section 4.1.3; Appendix 9.2).

The size and type of any viable biofouling detected in the video will be recorded against the image identifier (file name) and a description of the location of the biofouling within the treated area (e.g., by reference to the minute and seconds in the video at which the viable biofouling is detected) (Sections 3.1.2; Appendix 9.2). The supervisor will also describe the general condition of the biofouling present, including signs of physical damage, morbidity and whether there are any indicators of viability (Section 3.1.9; Appendix 9.2).

The independent supervisor will take a representative sample of the treated biofouling from a minimum 25 cm^2 area within each replicate test area (Section 3.1.9). The type (i.e., taxonomic group) and condition (including viability) of biofouling observed in samples taken from each test area will be recorded against the sample identifier.

Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any viable biofouling in any of the treated areas or samples constitutes a failure to meet the performance standard for surface-treatment systems (Section 2).

Paint condition is also assessed to identify any physical damage caused by treatment (Appendix 9.4).

3.3.5 Assessing containment and waste capture efficacy (see Section 3.6)

A diving observer must observe and record on video the test process, including set-up and demobilisation, to assess the amount of material dislodged from the hull outside each test area, and the amount of material removed but not captured (Section 4.3.5). The video may be recorded by the independent supervisor (using Underwater Breathing Apparatus (UBA)) or by a diver under the direction of the independent supervisor using surface-to-diver communications. When the test area includes the wind-and-water line, a video should also be taken from both in and out of the water, to assess if any biofouling is dislodged at the water-air interface.

For systems that use suction to capture waste, the area of effective capture around the system should be estimated by video recording the use of a visible, non-toxic tracer dye, such as fluorescein sodium salt, Basic Blue 3 or Rhodamine WT Red. During each replicate test, 50 mL aliquots of the dye (at a minimum concentration of 4 g L^{-1}) should be released slowly from a syringe at 10, 25 and 50 cm from system operation. Effective capture will be indicated by strong directional movement of the dye toward the point of suction. The independent supervisor will make visual observations of the dye movement from each position and shall ensure that the releases are recorded on video.

After completion of the trial, the video will be assessed for evidence of material being dislodged from the hull over the entire process, subsequent capture of this material, and leakage from the system itself. This assessment shall be included in the reporting template (Appendix 9.3).

Each video recording shall include a label at the start of the recording indicating the date of the test, name of the system being tested, name of the vessel, type and replicate number of the test area.

Dislodgement or discharge of macroscopic particles > 0.5 cm diameter constitutes a failure to meet the performance standard (Section 2).

3.3.6 Reporting

Using the templates in Appendix 9.3, the independent supervisor is to report each of the following:

- *general requirements*
  - a description and specification of the system tested (Section 3.1.1);
  - a description of the standard operating procedure (SOP) for the system (Section 3.1.1);
  - a description of how the test was undertaken, including:
    - the location, type of vessel used, hull material, surface (e.g., coating/unpainted) and environmental conditions during the test (Section 3.1.5);
    - a description of the procedures followed during set-up, testing of the system and demobilisation;
- *before cleaning or treatment*:
  - location, curvature and angles of test areas;
  - type, level (FR) and cover (%) of biofouling present in each test area;
  - presence, type and condition of anti-fouling coating;
  - the video or still image(s) on which these assessments were made are to be provided with the report;
- *during cleaning or treatment*
  - *surface-treatments*
    - the results of samples taken to monitor conditions (e.g., concentration of the lethal agent, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.3.3.2.1);
- *after cleaning or treatment*:
  - *manual and mechanical cleaning* - the amount and type of residual biofouling for each of the test areas analysed:
    - type of biofouling (Section 3.1.2);
    - number of patches and size of each patch;
    - location within the test area;
    - location of the test area on the hull;
    - relevant image identifier (file name);
    - a description of the condition of any residual biofouling;
  - *surface-treatments* - the amount and type of viable biofouling observed in video recordings of each replicate treated area selected for analysis including:
    - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2) and their location within the test area;

    - location of the test area on the hull;
    - relevant image identifier (file name);
- the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the selected test areas, including:
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2);
    - relevant sample identifier (i.e., test replicate identifier);
    - location of the test replicate on the hull;
- *all systems*:
    - condition of the anti-fouling coating in each test area:
        - the video or still images on which these assessments were made are to be provided with the report;
    - qualitative assessment of loss of material by dislodgement from the hull during set-up and demobilisation and from escape from the system during operation, based on examination of video recording (Section 3.3.5):
        - the video images from which this assessment of loss of material during use was made are to be provided with the report;
    - a description of any variations or deviations in application of the test relative to the SOP and test requirements;
    - a discussion of the system efficacy, including whether the performance standard was met;
    - recommendations for system or SOP improvement.

3.4 TEST PROCEDURE FOR SYSTEMS APPLIED TO NICHE AREAS

This testing procedure allows assessment of the efficacy of manual and mechanical cleaning systems and surface-treatments designed to treat external, submerged niche areas on all vessel sizes. A separate document will address treatment of biofouling on internal surfaces such as sea chests, seawater intakes and piping, etc. Systems, such as diver-operated brushes, pads, water-jet pistols, heat boxes or cavitation guns may also be appropriate for cleaning or treating biofouling on the entire hull of small vessels.

This procedure allows assessment of effects of scale and environmental conditions on the system efficacy, waste capture, and of dislodgement of biofouling by divers and equipment while accessing the hull.

3.4.1 Vessel selection

The full system must be tested on niche areas of at least one actual vessel (Section 4.3.1). The system must be tested on six replicates of each type of external niche that it is intended to be used on. These may include, but are not limited to (Section 4.3.1):

- propellers and shafts;
- rudders and shafts;
- the keel;
- dry-dock support strips;
- gratings;
- anodes;
- stabiliser fins;
- sea chests (excluding internal spaces and pipework);
- thrusters and their tunnels.

More than one vessel will be required if six replicate test areas are not available on a single vessel (e.g., six propellers). Similarly, if the system is intended for use on different types of coating (e.g., fouling release, biocidal, or mechanically resistant coatings) it may need to be tested on a separate vessel (or area of vessel) for each type of coating.

The amount of biofouling required on the vessel depends on the intended use of the system:

- slime (FR 20 or less). In-water removal or treatment of slime is considered to be of low biosecurity risk and systems intended for use only on slime do not require testing under the present framework;
- if the system is intended to remove or treat moderate (soft) biofouling, the hull shall have macrofouling present of FR 30 and 16-40% cover;
- if the system is intended to remove or treat moderate (hard) biofouling, the hull shall have macrofouling present of FR 80 and 16-40% cover;
- if the system is intended to remove or treat heavy (hard) biofouling, the hull shall have macrofouling present of FR 90 or greater and > 40% cover.

The test areas must be fouled *to the highest level for the intended use of the system* as specified in the system description.

3.4.2 General conditions for implementing the test

The general conditions necessary for testing include:

- The test areas should be representative of the range of niches that the system is intended to be applied to;
- the test should be conducted during periods of slack water, with current speeds of no more than 1 kn (~50 cm s^{-1}), in order to aid the independent supervisor(s) in observing system operation (Section 4.3.2);
- the test should be conducted at locations and times when water clarity (measured as vertical Secchi disk depth) is at least 2 m (Section 4.3.3).

3.4.3 Testing method

During the test, the system shall be operated in the manner in which it is intended to be used during normal operation (Section 3.1.5). The system shall be separately tested on *at least six replicates of each type of external niche area that the system is intended for* (Section 4.1.5). These may include, but are not limited to:

- propellers and shafts;
- rudders and shafts;
- the keel;
- dry-dock support strips;
- gratings;
- anodes;
- stabiliser fins;
- sea chests (excluding internal spaces and pipework);
- thrusters and their tunnels.

Before testing proceeds, the independent supervisor will visually determine the biofouling rating (FR) and percentage cover in each of the replicate niche areas (Section 4.3.4). The independent supervisor will also determine the state of the anti-fouling coating (Appendix 9.4). Each test area shall be recorded by video or digital still imaging before testing for purposes of auditing the assessment of biofouling rating and cover, and coating condition (Section 3.1.8 or 3.1.9.1).

3.4.3.1 Manual and mechanical cleaning

The performance standard for manual and mechanical systems is that all biofouling must be removed (Section 4.1.1). The equipment for capture and treatment of biofouling removed during cleaning must be operated and tested during the cleaning trials (Section 3.6). The developer may, however, choose to perform preliminary tests of cleaning ability without capture *in addition* to full testing.

Each replicate external niche area is to be cleaned in its entirety.

3.4.3.2 Surface-treatment

The performance standard for surface-treatments is all biofouling shall be rendered non-viable (Section 4.1.3). Any equipment for capture and treatment of any biofouling dislodged during treatment must be operated and tested during the trials (Section 3.6). The developer may, however, choose to perform preliminary tests of treatment ability without capture *in addition* to full testing.

Each replicate external niche area is to be treated in its entirety.

3.4.3.2.1 Monitoring conditions achieved by the system

The independent supervisor shall measure and record the dose or concentration of the lethal agent that is achieved by the surface-treatment system during its application to a vessel. Conditions to be measured may include biocide concentration, dissolved oxygen and sulphide concentrations (where mortality is caused by deoxygenation of the water), lethal temperature, sound frequency, etc. Methods used to measure the conditions achieved should be appropriate to the system. Triplicate measurements should be taken from within the system during each application to a replicate test area.

3.4.4 Assessing system efficacy

After the system has undergone testing, images covering the entirety of each replicate test area shall be obtained by video or still photography within two days of completion of the test in accordance with the requirements specified in Sections 3.1.8 and 3.1.9.1. Video imagery will be most practical for large test areas (> 2 m^2) and a is requirement for all surface-treatment systems (Section 3.1.9.1). The images must show labels with the location of the test area on the hull and a unique image identifier. Scale objects must also be included in each image (Sections 3.1.8 and 3.1.9.1).

3.4.4.1 Manual and mechanical cleaning

The independent supervisor will randomly select the post-cleaning images from three of the six replicate niche areas that have been cleaned, and examine each image in its entirety for the presence and type of any residual biofouling 0.5 cm in diameter or larger (Section 4.1.1).

The size and type of any biofouling detected will be recorded against the image identifier (file name) and description of location of the biofouling within the cleaned area (Section 3.1.2). The independent supervisor will also describe the condition, including any damage, of the biofouling present. Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any residual biofouling (0.5 cm in diameter or larger) in any of the cleaned areas constitutes a failure to meet the performance standard for manual and mechanical systems (Section 2).

Paint condition will be assessed to identify any physical damage caused by cleaning (Appendix 9.4).

3.4.4.2 Surface-treatments

The independent supervisor will randomly select the post-treatment video from three of the six replicate treated niches, and examine each video in its entirety to assess the viability of any residual biofouling (Section 4.1.3; Appendix 9.2).

The size and type of any viable biofouling detected in the video will be recorded against the image identifier (file name) and a description of the location of the biofouling within the treated area (e.g., by reference to the minute and seconds in the video at which the viable biofouling is detected) (Sections 3.1.2; Appendix 9.2). The independent supervisor will also describe the general condition of the biofouling present, including signs of physical damage, morbidity and whether there are any indicators of viability (Section 4.1.3; Appendix 9.2).

The independent supervisor will take a representative sample of the treated biofouling from a minimum 25 cm^2 area within each replicate test area (Section 3.1.9). The type (i.e., taxonomic group) and condition (including viability) of biofouling observed in samples taken from each test area will be recorded against the sample identifier.

Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any viable biofouling in any of the treated areas or samples constitutes a failure to meet the performance standard for surface-treatment systems (Section 2).

Paint condition will also be assessed to identify any physical damage caused by treatment (Appendix 9.4).

3.4.5 Assessing containment and waste capture efficacy (see Section 3.6)

A diving observer must observe and record on video the test process, including set-up and demobilisation, to assess the amount of material dislodged from the hull outside each test area, and the amount of material removed but not captured (Section 4.3.5). The video may be recorded by the independent supervisor (using Underwater Breathing Apparatus (UBA)) or by a diver under the direction of the independent supervisor using surface-to-diver communications. When the test area includes the wind-and-water line, a video should also be taken from both in and out of the water, to assess if any biofouling is dislodged at the water-air interface.

For systems that use suction to capture waste, the area of effective capture around the system should be estimated by video recording the use of a visible, non-toxic tracer dye, such as fluorescein sodium salt, Basic Blue 3 or Rhodamine WT Red. During each replicate test, 50 mL aliquots of the dye (at a minimum concentration of 4 g L^{-1}) should be released slowly from a syringe at 10, 25 and 50 cm from system operation. Effective capture will be indicated by strong directional movement of the dye toward the point of suction. The independent supervisor will make visual observations of the dye movement from each position and shall ensure that the releases are recorded on video.

After completion of the trial, the video will be assessed for evidence of material being dislodged from the hull over the entire process, subsequent capture of this material, and leakage from the system itself. This assessment shall be included in the reporting template (Appendix 9.3).

Each video recording shall include a label at the start of the recording indicating the date of the test, name of the system being tested, name of the vessel, type and replicate number of the test area.

Dislodgement or discharge of macroscopic particles > 0.5 cm diameter constitutes a failure to meet the performance standard (Section 2).

3.4.6 Reporting

Using the templates provided in Appendix 9.3, the independent supervisor is to report each of the following:

- *general requirements*

- a description and specification of the system tested (Section 3.1.1);
  - a description of the standard operating procedure (SOP) for the system (Section 3.1.1);
  - a description of how the test was undertaken, including:
    - the location, type of vessel used, hull and niche area material, surface (e.g., coating/unpainted) and environmental conditions during the test (Section 3.1.5);
    - a description of the procedures followed during set-up, testing of the equipment and demobilisation;
- *before cleaning or treatment*:
  - type, level (FR) and cover (%) of biofouling present in each test area;
  - presence, type and condition of anti-fouling coating or uncoated surface:
    - the video or still image(s) on which these assessments were made are to be provided with the report;
- *during cleaning or treatment*
  - *surface-treatments*
    - the results of samples taken to monitor conditions (e.g., concentration of the lethal agent, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.4.3.2.1);
- *after cleaning or treatment*:
  - *manual and mechanical cleaning* - the amount and type of residual biofouling for each of the niche areas analysed:
    - type of biofouling (Section 3.1.2);
    - number of patches and size of each patch;
    - location within the test area;
    - location of the test area on the hull;
    - relevant image identifier (file name);
    - a description of the condition of any residual biofouling;
  - *surface-treatments* - the amount and type of viable biofouling observed in video recordings of each replicate treated area selected for analysis including:
    - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2) and their location within the test area;
    - location of the test area on the hull;
    - relevant image identifier (file name);
  - the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the selected test areas, including:
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2);
    - relevant sample identifier (i.e., test replicate identifier);
    - location of the test replicate on the hull;
  - *all systems*:
    - condition of the anti-fouling coating or surface in each test area;
      - the video or still images on which these assessments were made are to be provided with the report;

- qualitative assessment of loss of material by dislodgement from the hull during set-up and demobilisation and from escape from the system during operation, based on examination of video recording (Section 3.4.5):
    - the video images from which this assessment of loss of material during the test was made are to be provided with the report;
- a description of any variations or deviations in application of the test relative to the SOP and test requirements;
- a discussion of the system efficacy, including whether the performance standard was met;
- recommendations for system or SOP improvement.

3.5 TEST PROCEDURE FOR SYSTEMS APPLIED TO ENTIRE VESSELS (SHROUDING AND SURFACE-TREATMENT)

Shrouding techniques (including encapsulation) involve enclosing the vessel hull in an impermeable membrane to reduce or eliminate water exchange between the area immediately around the hull and the surrounding water. This can result in the death biofouling organisms by depriving them of oxygen, food and light (Morrisey and Woods 2015). Mortality of biofouling can be hastened inside the shroud by addition of biocides, oxygen-scavenging compounds or freshwater. Alternatively, shrouds may be used as an enclosure to contain waste removed by other systems (e.g., manual and mechanical cleaning) that are applied to the vessel inside the shroud. Surface-treatments also kill biofouling organisms *in situ*, through direct application of a lethal agent (e.g., heat, biocides, freshwater, ultra-sound, etc.) to the organisms.

This testing procedure allows the efficacy assessment of systems designed to treat the biofouling *in situ* on entire vessels. The procedure allows assessment of effects of scale and environmental conditions on treatment efficacy. Where applicable, any equipment for capture or treatment of biofouling during or following system application must be operated and tested during the cleaning trials (Section 3.5). This includes manual or mechanical cleaning systems that may be used within a shroud to clean an entire vessel.

3.5.1 Vessel selection

The full system must be tested on the hull of *at least three actual vessels* of the type and maximum size that the system is intended for use on (Section 4.3.1). The vessels used must be large enough to contain the number of hull, wind-and-water line, and external niche areas required to assess system efficacy (refer to Section 3.5.3). Niche areas can include structures such as:

- propellers and shafts;
- rudders and shafts;
- the keel;
- dry-dock support strips;
- gratings;
- anodes;
- stabiliser fins;
- sea chests (excluding internal spaces and pipework);
- thrusters and their tunnels (Section 4.3.1).

A separate document will address treatment of biofouling on internal surfaces such as sea chests, seawater intakes and piping, etc. (see Section 1.2).

The amount of biofouling required on the vessel depends on the intended use of the system:

- slime (FR 20 or less). In-water removal or treatment of slime is considered to be of low biosecurity risk and systems intended for use only on slime do not require testing under the present framework;
- if the system is intended to remove or treat moderate (soft) biofouling, the hull shall have macrofouling present of FR 30 and 16-40% cover;
- if the system is intended to remove or treat moderate (hard) biofouling, the hull shall have macrofouling present of FR 80 and 16-40% cover;
- if the system is intended to remove or treat heavy (hard) biofouling, the hull shall have macrofouling present of FR 90 or greater and > 40% cover.

The test areas must be fouled *to the highest level for the intended use of the system* as specified in the system description.

3.5.2 General conditions for implementing the test

The performance standard for surface-treatment and shrouding systems is that all biofouling must be rendered non-viable (to the requirements detailed in Section 4.1.3). Biofouling rendered non-viable does not have to be removed. Where the system uses manual or mechanical cleaning within a shroud, the performance standard will be that all visible macrofouling must be removed (Section 4.1.1). Any equipment for capture and treatment of biofouling removed during cleaning must be operated and tested during the testing (Section 3.6). The developer may, however, choose to perform preliminary tests without capture *in addition* to full testing.

The general conditions necessary for testing include:

- the full system must be tested on the hull of *at least three actual vessels* of the type and maximum size that the system is intended for use on (Section 4.3.1);
- vessels selected to assess system efficacy should have the range of areas intended for treatment and may include the wind-and-water line, hull and niches present on the hull;
- vessels selected to assess system efficacy must be representative of the type and amount of biofouling that the system is intended to be used on;
- tests of the system should be conducted during periods of slack water, with current speeds of no more than 1 kn (~ 50 cm s^{-1}), in order to aid the independent supervisor(s) in observing system operation (Section 4.3.2);
- the tests should be conducted at locations and times when water clarity (measured as vertical Secchi disk depth) is at least 2 m (Section 4.3.3).

3.5.3 Testing method

During the test, the system shall be used in the manner in which it is intended under normal operation. To examine the efficacy of systems for use on whole vessels, the system must be tested on *at least three vessels*. The required number of replicate 1 m^2 areas for assessment for vessels of various sizes is specified in Table 3-1. Replicate 1 m^2 area should be selected randomly from each distinct hull area (i.e., wind-and-water line, flat hull, curved surfaces) and each type of niche area. Niche areas may include (but are not limited to):

- propellers and shafts;
- rudders and shafts;
- the keel;
- dry-docking support strips;
- gratings;
- anodes;
- stabiliser fins;
- sea chests (excluding internal spaces and pipework);
- thrusters and their tunnels.

Before testing proceeds, the independent supervisor will visually determine the biofouling rating (FR) and percentage cover in a minimum of six 1 m^2 areas selected randomly from each distinct hull area (i.e., boot-top, flat hull, curved surfaces and niches). The independent supervisor will also determine the state of the anti-fouling coating (Appendix 9.4). Each test area shall be recorded by video or digital still imaging before testing for purposes of auditing the assessment of biofouling rating and cover, and coating condition (Section 3.1.8 or 3.1.9.1).

3.5.3.1 Monitoring conditions achieved by the system

The independent supervisor shall measure and record the dose or concentration of the lethal agent that is achieved within the shroud or surface-treatment system during its application to a vessel. Conditions to be measured may include biocide concentration, dissolved oxygen and sulphide concentrations (where mortality is caused by deoxygenation of the water), lethal temperature, sound frequency, etc. Methods used to measure the conditions achieved should be appropriate to the system.

Triplicate measurements should be taken from at least three different locations within the containment system. The measurements must also be repeated at three intervals:

- immediately after the containment system is in place;
- mid-way through the treatment;
- immediately prior to removal of the containment system.

The location of each measurement must be recorded.

3.5.4 Assessing containment and waste capture efficacy (see Section 3.6)

A diving observer must observe and record on video the test process, including set-up and demobilisation, to assess the amount of material dislodged from the hull and the amount of material removed but not captured. The video may be recorded by the independent supervisor (using Underwater Breathing Apparatus (UBA)) or by a diver under the direction of the independent supervisor using surface-to-diver communications.

A diving observer must observe and record on video any leakage from the shrouding or treatment system (Section 3.1.10).

After completion of the trial, the video will be assessed for evidence of material being dislodged from the hull over the entire process, capture of this material, and leakage from the shroud or surface-treatment system. This assessment shall be included in the reporting template (Appendix 9.3).

Each video recording shall include a label at the start of the recording indicating the date of the test, name of the system being tested, name of the vessel, type and replicate number of the test area.

Leakage from the shrouding or treatment system or dislodgement of any macroscopic particles > 0.5 cm diameter during system set-up, cleaning or demobilisation represents a failure to meet the performance standard (Section 2).

3.5.5 Assessing surface-treatments and shrouding efficacy

The independent supervisor will examine the post-treatment video (i.e., after surface-treatment or removal of the shrouding) from each replicate assessment area in its entirety to determine the viability of any residual biofouling (Section 4.1.3; Appendix 9.2).
The size and type of any viable biofouling detected in the video will be recorded against the image identifier (file name) and a description of the location of the biofouling within the treated area (e.g., by reference to the minute and seconds in the video at which the viable

biofouling is detected) (Sections 3.1.2; Appendix 9.2). The independent supervisor will also describe the general condition of the biofouling present, including signs of physical damage, morbidity and whether there are any indicators of viability (Section 4.1.3; Appendix 9.2).

The independent supervisor will take a representative sample of the treated biofouling from a minimum 25 cm^2 area within each replicate 1 m^2 assessment area (Section 3.1.9).
The type (i.e., taxonomic group) and condition (including viability) of biofouling observed in samples taken from each test area will be recorded against the sample identifier.

Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any viable biofouling in any of the evaluation areas or samples constitutes a failure to meet the performance standard for surface-treatment or shrouding systems (Section 2).

The efficacy of manual or mechanical cleaning applied within a shrouding system should be assessed according to Sections 2, 3.2.4 and 3.2.4.1.

Paint condition will also be assessed to identify any physical damage caused by system deployment or removal of shrouding (Appendix 9.4).

3.5.6 Reporting

Using the templates in Appendix 9.3, the independent supervisor is to report each of the following:

- *general requirements*
  - a description and specification of the system (Section 3.1.1);
  - a description of the standard operating procedure (SOP) for the system (Section 3.1.1);
  - a description of how the test was undertaken, including:
    - the location, type of vessel used, hull material, surface (e.g., coating/unpainted) and environmental conditions during the test (Section 3.1.5);
    - a description of the procedures followed during set-up, testing of the system and demobilisation;
- *before treatment (or cleaning)*:
  - type, level (FR) and cover (%) of biofouling present in each test area;
  - presence, type and condition of anti-fouling coating or uncoated surface:
    - the video or still image(s) on which these assessments were made are to be provided with the report;
- *during treatment (or cleaning)*:
  - *surface-treatments/shrouding*
    - the results of samples taken to monitor conditions (e.g., biocide concentration, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.4.3.2.1);
- *after treatment (or cleaning)*:

- *surface-treatments/shrouding* - the amount and type of viable biofouling observed in video recordings of each replicate treated area selected for analysis including:
    - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2) and their location within the test area;
    - location of the test area on the hull;
    - relevant image identifier (file name);
- the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the selected test areas, including:
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2);
    - relevant sample identifier (i.e., test replicate identifier);
    - location of the test replicate on the hull;
- *manual and mechanical cleaning* - the amount and type of residual biofouling for each area analysed:
    - type of biofouling (Section 3.1.2);
    - number of patches and size of each patch;
    - location within the test area;
    - location of the test area on the hull;
    - relevant image identifier (file name);
    - a description of the condition of any residual biofouling;
- *all systems*:
    - condition of the anti-fouling coating or surface in each test area;
        - the video or still images on which these assessments were made are to be provided with the report;
    - qualitative assessment of loss of material by dislodgement from the hull during set-up, demobilisation (where cleaning used) and from leakage from the system during operation, based on examination of video recording (Section 3.4.5):
        - the video images from which this assessment of loss of material during the test was made are to be provided with the report;
    - a description of any variations or deviations in application of the test relative to the SOP and test requirements;
    - a discussion of the system efficacy, including whether the performance standard was met;
    - recommendations for system or SOP improvement.

3.6 TEST PROCEDURE FOR WASTE TREATMENT SYSTEMS

Waste treatment is a requirement for systems that do not render fouling non-viable (e.g., manual and mechanical cleaning systems) or discharge waste into the sewer (with secondary treatment). Before in-water cleaning waste can be discharged back into the environment any propagules must be removed or rendered non-viable. The performance standard for filtration of effluent from manual and mechanical cleaning is a maximum particle size in the filtered effluent of 12.5 µm (Section 4.1.2). Alternative or additional treatments to filtration, such as irradiation with ultra-violet (UV) light, heat or addition of biocides, must render all biological material non-viable (Section 4.1.3).

The volume of waste material removed from a hull during cleaning, together with water entrained with it by the waste capture process, is likely to be very large. Lewis (2013) estimated that a volume of 350 000 L of effluent was generated from cleaning a 45 m vessel using a brush cart fitted with a suction system for waste capture. The large volume of waste places great demands on effluent treatment systems, creating the risk of failure in terms of discharge of untreated or partially treated waste during the treatment process, or of inadequately treated final effluent.

Removal of biological material from the effluent may involve some form of filtration. The most likely cause of failure of filtration systems is overloading due to the volume of effluent and the concentration of particles larger than the filter pore size. Overloading may cause effluent to bypass the filter and overflow back into the environment, or cause the filter to rupture. It is therefore important that the capacity of the filtration system is matched to the rate of delivery of effluent.

As a further safeguard of effluent quality, the final effluent may be treated by a secondary process (e.g., UV light, heat or a biocide) before discharge into the environment. Discharge of biocides may require a resource consent, and obtaining this or any other necessary approval is the responsibility of the developer (Section 3.1.12).

An alternative option for waste treatment is to discharge cleaning waste to the sewer (with secondary treatment). No treatment standard is required in this case. Discharge of liquid trade wastewater to sewer systems will normally require a registration or resource consent, and obtaining this or any other necessary approval will be the responsibility of the developer.

The system for capture and treatment of biofouling removed must be operated and tested during the cleaning trials. The developer may, however, choose to perform preliminary testing of systems without capture *in addition to* full testing.

3.6.1 Vessel selection

Whether testing of the waste treatment system is done as part of the testing of the overall cleaning process or as a separate exercise, the same considerations for the selection of suitable vessels for cleaning apply (Sections 3.2.1, 3.3.1, 3.4.1 and 3.5.1).

3.6.2 Test conditions

Whether testing of waste treatment system is done as part of the testing of the overall cleaning process or as a separate exercise, the same considerations for test cleaning apply (Sections 3.2.2, 3.3.2, 3.4.2 and 3.5.2).

3.6.3 General conditions for implementing the test

The developer shall provide a standard operating procedure (SOP) for the waste capture and treatment systems, including the frequency of changing or cleaning filters and filter cartridges to prevent system overload. The independent supervisor shall audit the use of the waste treatment system during the test against this SOP. The parts of the waste treatment system above the water surface shall be monitored for leaks or overflows. A log of system performance shall be kept, noting any problems, including blocked or ruptured filters and leaks.

The efficacy of waste filtration shall be assessed by separately re-filtering samples of the final effluent obtained from each of the test area replicates through filters with a pore size less than 12.5 µm (e.g., Whatman No. 1 (11 µm) or No. 40 (8 µm)). Triplicate 200 mL samples shall be taken from the first effluent produced at an appropriate time after the start of cleaning and at two subsequent times during the cleaning process, one approximately halfway through and one at the end. The sampling times during the cleaning process should be recorded. Each sample shall be filtered and the filter discs microscopically examined (Section 4.4.1) to determine the presence of objects larger than the pore size of the allowed standard (Sections 2.2 and 4.1.2).

In systems where the effluent is treated to kill propagules, rather than filtered to remove them, the viability of organisms or propagules in the effluent shall be assessed. Triplicate 200 mL samples shall be taken from the first effluent produced after the start of cleaning and at two subsequent times during the cleaning process. The sampling times during the cleaning process should be recorded. Each sample shall be filtered and the filter discs microscopically examined to determine the presence and structural integrity of objects larger than the pore size of the allowed standard (Section 4.4.2).

For all systems, it will be 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 running aliquots of dye through the system at appropriate times (Section 4.4.1).

3.6.4 Reporting

The independent supervisor shall provide an assessment of how the waste treatment system was operated against the SOP, identifying any deviations from the prescribed method and their consequences for meeting the performance standard.

The assessment report will list any problems recorded in the performance log and will provide recommendations on any improvements that could be made in the procedure based on the outcomes of the trial. The performance log shall be included in the report as an appendix.

The report shall also state how many particles larger than the performance standard were present in the samples of the final effluent. The results of the assessment of viability (structural integrity) of biological material present in the effluent shall also be presented.

Using the templates in Appendix 9.3, the independent supervisor is to report each of the following:

- *general requirements*
  - a description and specification of the system tested (Section 3.1.1);
  - a description of the SOP for the system (Section 3.1.1);
  - a description of how the test was undertaken, including:

    - the procedures followed during set-up, system operation, monitoring and demobilisation;
    - the performance of the system, including any deviations from the prescribed SOP;
- the results of monitoring the effluent stream, including:
    - the number, size and (where possible) identity of particles > 12.5 µm in dimension; or
    - the viability of biological material in the effluent;
- a discussion of the system efficacy, including whether the performance standard was met;
- recommendations for system or SOP improvement.

4 Rationale for the framework development

4.1 PERFORMANCE STANDARDS AND TESTING REQUIREMENTS

4.1.1 Minimum practicable detectable size of residual biofouling (0.5 cm)

The potential size of fragments of viable residual biofouling occupies a continuum from microscopic to macroscopic and includes fragments of colonial organisms and microscopic life stages of larger, solitary adults, such as the gametophyte of *Undaria pinnatifida*. Consequently, a minimum, practical detectable size must be specified. A minimum dimension (diameter or length, according to patch shape) of 0.5 cm has been chosen because this is representative of the size of individuals of common calcareous biofouling organisms, such as barnacles and tubeworms that are visible to the naked eye.

4.1.2 Maximum particle size in treatment system filtered effluent (12.5 µm)

This maximum particle size is a compromise between minimising the biosecurity risk from effluent discharged to the environment and what is practically achievable. A previous review of the pore size of filters required to remove propagules from effluent from land-based hull-cleaning facilities recommended a pore size of 60 µm because smaller propagules were unlikely to survive after discharge (McClary and Nelligan 2001). However, Morrisey *et al.* (2013) suggested that survival of smaller propagules was more likely in the case of in-water cleaning because the receiving environment was likely to be more benign. The IMO Ballast Water Convention Regulation D2 has performance standards of 50 µm and 10 µm[4], and the Australia and New Zealand's Anti-fouling and In-water Cleaning Guidelines (Department of Agriculture, Fisheries and Forestry *et al.* 2012) state that "(i)n-water cleaning technologies should aim to, at least, capture debris greater than 50 µm in diameter". Although Morrisey *et al.* (2013) suggested a pore size of 2 µm to eliminate biosecurity risk, 12.5 µm is more realistic with current systems, as indicated by recent testing in Western Australia (Lewis 2013). Systems capable of filtering to 10 µm or smaller are technically possible, but their effectiveness has yet to be demonstrated in this context.

4.1.3 Viability of treated biofouling organisms

A viable biofouling organism (adult or propagule) is defined as one that is potentially capable of living and developing normally in the marine environment. This simply means that the organism has survived the treatment process and is in a condition that could *potentially* allow it to grow or produce offspring. The likelihood that populations will establish successfully in New Zealand waters from surviving biofouling is uncertain as it is influenced not just by the physiological condition of the organism, but also by the suitability of the local environment and interactions with resident biota (competitors, predators and parasites).

It is difficult to determine if a biofouling organism is alive, moribund or dead following treatment (e.g., physically intact, non-motile organisms such as macroalgae or sponges). Further, many marine species (particularly macroalgae and clonal invertebrates) are able to regenerate from very small fragments. A precautionary approach is, therefore, needed to assess viability. Unless an organism can be confidently determined to be non-viable (dead), it should be classified as being 'viable'. Organisms that are moribund (i.e., dying/near death, but which still show signs of mobility or fecundity) must still be regarded as potentially viable.

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[4] IMO Resolution MEPC.173(58) Guidelines for Ballast Water Sampling (G2), available at www.imo.org/blast/blastDataHelper.asp?data_id=23757&filename=173(58).pdf

In situ photography or videography of treated macroscopic biofouling provides a guide to the viability of biofouling organisms. Loss of colour (i.e., pigmentation) or mobility can indicate death, but neither is definitive. Also, in structurally complex biofouling assemblages, cryptic organisms may survive in the interstices formed by other biofouling organisms. For this reason, assessment of video and samples of residual biofouling are needed to determine the efficacy of the treatment system.

Susceptibility of individual organisms to surface-treatments and shrouding systems (including the addition of biocides or accelerants) may vary considerably. For example, calcareous organisms, such as bivalves and barnacles, may have considerably greater tolerance of prolonged treatment at greater intensity than soft-bodied organisms (Forrest *et al.* 2007; Brook 2015). Moreover, some organisms that appear to be dead, at least superficially, may still be viable (e.g., Morris and Carman 2012). For these reasons, microscopic examination of representative biofouling samples is necessary immediately following application of the surface-treatment and shrouding systems to reliably assess the viability of biofouling organisms.

Despite the difficulties in determining viability, a pragmatic approach is recommended that uses *in situ* and laboratory assessments of physiological condition as surrogates for more complex tests of viability. The appended guide for assessing the viability of macroscopic biofouling organisms (Appendix 9.2) is modified from Woods *et al.* (2007), and draws upon other studies that have used pragmatic assessments of biofouling organism viability (i.e., Coutts and Forrest 2005; Forrest and Blakemore 2006; Blakemore and Forrest 2007; Locke *et al.* 2009; Dunmore *et al.* 2011; McCann *et al.* 2013).

Although propagules (e.g., eggs, larvae, spores or fragments) released from biofouling organisms during the treatment may be viable, they should be contained by the shroud or surface-treatment system and treated during operation. It is not technically feasible to distinguish them in the water column from the propagules released by organisms in the surrounding environment. For this reason, attempting to assess their viability in the water column is not recommended.

4.1.4 Vessel testing

Systems designed for cleaning or treating general hull surfaces vary in scale with the size of vessel that they are intended to be used on, from small, brush-based robots for recreational vessels to larger, diver operated or remotely controlled carts and remotely operated vehicles (ROV) for large commercial vessels. Other than size, however, there is no inherent difference among the surfaces that all of these systems are designed to clean or treat. Consequently, they may all be tested on any size of vessel large enough to provide suitably sized areas (Sections 3.2.3, 3.3.3 and 3.4.3). Special considerations may apply where systems are only intended for use on particular types of coating or types of hull material that may only be found on certain size categories of vessel.

Systems designed to treat whole vessels are also an exception. Due to problems likely to be encountered in scale-up, the full system must be tested on vessels of the maximum size and type that the system is intended for use on.

4.1.5 Niche areas

Systems specific to cleaning or treating structurally complex parts of the hull, or areas that are otherwise difficult to access, generally involve smaller, often hand-operated tools, such as diver operated brushes, water jet and cavitational jet pistols, small brush carts, ROVs and robots. In some cases, these systems may also be suitable for cleaning or treating the entire hull of small vessels. However, the test conditions will, to some extent be determined by the specific design of the system and the types of niches they are intended for use on. Because different types of niches (e.g., propellers and shafts, rudders and shafts, anodes, gratings, etc.) have different shapes and characteristics, a system designed for one type of niche may not be as effective on others. Separate tests are required to assess the efficacy of the system on each type of niche area.

4.1.6 Panel testing

Panel testing does not allow system assessment under realistic conditions relating to the scale and structural complexity of the working environment and the associated logistical problems. Examples of the latter are the presence of hoses dragging across the hull and dislodging material, and the need to manoeuvre the system and equipment among different parts of the hull. However, panels may provide a medium for preliminary system testing (Appendix 9.6).

4.2 GENERAL CONSIDERATIONS

4.2.1 Safe diving codes of practice

Health and safety considerations for the system operators and assessors are of primary importance, but are beyond the scope of this document. Information pertaining to occupational diving in New Zealand is available from WorkSafe New Zealand: http://www.business.govt.nz/worksafe/notifications-forms/registrations/occupational-diving.

4.2.2 Level of biofouling on the test surface

The US Navy fouling rating (FR) is more widely used (for example, in the testing of anti-fouling coatings) than the biofouling levels of Floerl *et al.* (2005) for defining level of biofouling. However, the FR system does not incorporate percentage cover as this is assessed separately as a continuous variable for characterising biofouling (Naval Ships Technical Manual 2006). Therefore the FR system has been integrated with the percentage cover categories of Floerl *et al.* (2005).

4.2.3 Level of biofouling for hull maintenance

Fouling > FR 30 (i.e., hard biofouling) indicates that the vessel’s anti-fouling coating has failed or that its operational profile is not appropriate for the type of anti-fouling applied. Although hull maintenance of vessels with FR 40 or 50 may be justifiable on biosecurity grounds, depending on the percentage cover, the type of process required to remove hard biofouling may compromise the anti-fouling coating and there will be a higher risk of chemical contamination of the environment than when cleaning or treating soft biofouling (see Morrisey *et al.* 2013).

4.2.4 Type of biofouling

Assessing the type of biofouling provides a context for the test and the performance of the system under test, and for use in assigning the conditions under which a system has approval. A high level of taxonomic resolution is unnecessary for this and, being a specialised task for many taxa, would cause unwarranted expense and delay in reporting.

4.2.5 Sample sizes for efficacy testing

The probability that any residual areas of biofouling larger than 0.5 cm will be detected in a survey of the cleaned area will depend upon the size of the cleaned area (A) and the proportion of it that is sampled in the survey (i.e., $\frac{\hat{a}}{A}$, where $\hat{a}$ is the area included in the survey sample). Because the criterion for failure is so small, a large proportion of the cleaned area must be sampled to have high confidence of detecting residual biofouling. For very large values of A (e.g., where all, or a significant proportion of a large vessel is cleaned), this will require very intensive survey effort to determine if the standard is met.

To illustrate this point, Table 4-1 provides a guide to the number of sample units (e.g., photo quadrats or transects) of different sizes that would be required to detect system failure (i.e., at least one sample unit containing biofouling > 0.5 cm diameter) in cleaned areas of between 2 to 16 m^2 with 80% and 90% confidence. In this example, system failure is defined as the presence of any residual biofouling > 0.5 cm diameter in one or more sample units within the cleaned area. The statistical rationale for these calculations is described in Appendix 9.5. As a rule of thumb, 80% or more of the cleaned area would need to be sampled (i.e., $\frac{\hat{a}}{A} \geq 0.8$) to detect a failure with 80% confidence. Where a very small sample unit is used, a large number of samples will be required to achieve high confidence of detecting failure.

Table 4-1. Numbers of sample units (quadrats or transects) of four sizes (0.04, 0.25, 1 and 2 m^2) required to detect residual biofouling in four sizes of cleaned area (2, 4, 8 and 16 m^2) to achieve $\boldsymbol{P(x \geq 1)}$ = 0.8 and 0.9†.

Sample unit size (m^2)	Prob. of detecting residual biofouling	Area cleaned (m^2) 2	4	8	16
0.04	0.8	40	80	160	320
	0.9	45	90	180	360
0.25	0.8	7	13	26	52
	0.9	8	15	29	58
1.00	0.8	2	4	7	13
	0.9	2	4	8	15
2.00	0.8	1	2	4	7
	0.9	1	2	4	8

†Assumes sampling is done without replacement and that the presence of biofouling in a sample unit is observed without error.

For these reasons, an approach is recommended that:

- prescribes a minimum size of unit area to be cleaned or treated on a vessel, relative to the size of cleaning head (or treatment applicator);
- requires a minimum number (n = 6) of replicate areas to be cleaned (or treated) on a vessel;
- assesses a random sub-sample (n = 3) of cleaned/treated areas for residual/viable biofouling to ensure that the samples evaluated are representative of how normal cleaning (or treatment) operations will be undertaken;
- large sample units (video transects or a mosaic of still imagery, where practicable) are used to census the area tested in trials of patch cleaning or treatment by manual, mechanical or surface-treatment.

Test cleaning or treatment of a few, small areas of hull may not provide realistic estimates of the probability of residual or viable biofouling if the operator allocates more effort and attention to cleaning the test areas than they would during normal operations (for example, to maximise the apparent system efficacy). For this reason, the operators are required to clean or treat a large number of areas (six) from which three are randomly selected by the independent supervisor for examination. Having to clean or treat a large number of areas reduces the risk that the operator will focus unrealistic effort on each.

The size of each cleaned area has been specified to include a reasonable number (five) of turns of the cleaning head because it is more likely that biofouling will be missed by the head when it is manoeuvring at the end of each straight pass along the hull than during a straight pass. For surface-treatments the area of treatment will depend on the system. Some systems (e.g., heated panels) will have a fixed area of treatment. In these cases, the size of the test area should be scaled in a manner that is analogous to mechanical cleaning (i.e., at least six parallel, partially overlapping applications of the treatment).

For manual cleaning systems (such as handheld scouring pads or scrapers, with waste capture systems) the cleaning head is likely to be small (for example, the largest pad approved in the Naval Ships' Technical Manual (2006) is 15 x 30 cm). Defining the size of the test area in terms of the size of the cleaning tool may not provide an adequate test of biofouling removal or of waste collection. It is, therefore, more appropriate to specify an area to be test cleaned and 1 m^2 is considered large enough to reduce the risk that the operator will focus unrealistic effort on each test area.

A pragmatic approach was also taken to specifying the minimum number of samples needed to assess the efficacy of whole vessel treatment by shrouding or surface-treatment. Recognising that the power of the evaluation will depend on the proportion of the treated area that is sampled, it was initially specified that a minimum proportion (5%) of the fouled wetted surface area of the vessel should be included in the assessment. This would ensure consistency across vessels of various sizes. However, as Table 4-2 demonstrates, this sample criterion resulted in very small (inadequate) replication for small vessels – particularly when the test percentage cover of fouling was low – and very large (impractical) sample sizes for heavily-fouled merchant vessels. The sample sizes specified in Table 3-1 are a compromise between the necessity to scale the assessment for vessels of different sizes and the practicality of undertaking the assessment at reasonable cost.

Table 4-2. Minimum number of 1 m^2 areas required to assess cleaning (or treatment) efficacy when based on a sample criterion of 5% of the fouled total wetted surface area (TWSA).

Vessel type	Mean TWSA (m^2)	Biofouling cover (%) 1-5	6-15	16-40	41-100
Yachts and other small vessels	68	1	1	2	4
Coastal fishing and other medium-sized vessels	790	2	6	16	40
Large merchant vessels	6 000	15	46	122	306

4.2.6 Sources of vessels for testing

Sources of vessels have not been specified because the willingness of the potential providers of test vessels may vary over time or between representatives of each category (for example, different fishing vessels). Furthermore, developers are likely to have a network of contacts and sources of their own.

4.2.7 Requirements for photographic and videographic recording of tests

The suggested maximum swimming speed is based on recently published values for diver swimming speeds during video transect studies (e.g., Holmes *et al.* 2013, Mallet and Pelletier 2014), and the authors' experience.

4.2.8 System approval by coatings manufacturers

Systems may damage coatings that have active biocides or non-toxic fouling release or mechanically resistant (hard) properties. For these reasons, developers should test their system on the coatings they are intended for use on and seek approval from the coating manufacturers. Damage to coatings may be less important in the case of emergency application to a heavily fouled vessel because the coating has clearly failed and will require replacement.

4.3 TESTING OF SYSTEMS

4.3.1 Vessel selection/number of vessels tested

For testing systems on flat or curved surfaces, where the vessel is large enough to accommodate the required number of replicate test areas it is acceptable to conduct testing on a single vessel. More than one vessel would be required when the hull is not large enough to accommodate the required number of replicate test areas.

Differences among vessels in the material of the hull and of the anti-fouling coating will be at least partly obscured by the layer of biofouling, particularly for heavily fouled vessels. However, if the system is intended for use on different types of coating (e.g., fouling release, biocidal, or mechanically resistant coatings) *it will need to be tested on a separate vessel for each type of coating*. This is because the ease of biofouling removal and potential for coating damage will vary among coating types.

Any damage to the hull material or the anti-fouling coating caused by system application is outside the scope of the present document (and should be addressed during system development rather than system testing at this advanced stage of development).

Different types of external niche areas may require different system types or may influence the efficacy of a single system type. Because of this, it is necessary to test a system on multiple examples of each type of niche area that it is intended to be used on. To obtain sufficient numbers of replicates, it may be necessary to test the system on more than one vessel or to select a vessel that is likely to have multiple examples of each type of niche area. Similarly, if the system is intended for use on different types of coating (e.g., fouling release, biocidal, or mechanically resistant coatings) it will need to be tested on a separate vessel (or part of a vessel) for each type of coating.

For systems designed to treat whole vessels, the full system must be tested on the hull of *at least three actual vessels* of the type and maximum size that the system is intended for use on. This is to provide sufficient replication to evaluate the efficacy of application under different conditions and on different vessels.

4.3.2 Test conditions – current speed

Faster current speeds make it more difficult for the assessor to move around the application area, and any material knocked off the hull or not captured may be carried away from the hull before the independent supervisor is able to see or video it. Strong currents are also likely to make system set-up, deployment and handling, and demobilisation more difficult, increasing the risk that material will be dislodged. System testing should be conducted during periods of slack water, with current speeds of no more than 1 kn (~ 50 cm s^{-1}), in order to aid the independent supervisor(s) in observing system operation. Whether the system can be applied safely in faster current speeds (i.e., without additional hazard to biosecurity or human health) will, to some extent, depend on the system and the ability of the operator. As guidance it is suggested that systems should be approved for operation only at current speeds $\leq$ 2 kn (~ 1 m s^{-1}). Current speed may be estimated by releasing a 50 mL aliquot of a non-toxic tracer dye (at a minimum concentration of 4 g L^{-1}) and recording its movement over a fixed distance (e.g., 3 m) or by use of current meters or an acoustic Doppler current profiler.

4.3.3 Test conditions – water clarity

Tests should, where possible, be done in water clarity of 2 m or greater Secchi disk reading. Although divers can detect some macro-organisms reliably at visibility < 1 m Secchi disk (Gust *et al.* 2006; Inglis *et al.* 2008), the resolution of the video and still images may be compromised. In poor visibility, it will also be more difficult for the independent supervisor to see or video material knocked off the hull during set-up or escaping from the cleaning head/treatment apparatus which may be carried away from the hull. Long-term median Secchi depth at 11 ports and marinas around New Zealand (NIWA and MPI unpublished data from Marine High Risk Site Surveillance) ranged from 0.9–3.2 m, with all but Lyttelton, Nelson and Opua > 2 m, suggesting that most ports would provide suitable conditions.

4.3.4 Testing method

This is to confirm that the FR and percentage cover of biofouling comply with the requirements set out in Section 3.1.2 for the system under test. This provides context for system efficacy and the conditions for which it shall be approved. Each test area is photographed (video or still) in its entirety to allow auditing of the FR and percentage cover allocation, and assessment of anti-fouling coating condition. This information also provides a context for the test.

4.3.5 Assessing containment and waste capture efficacy

A qualitative method of assessment was chosen to assess the waste capture efficacy and accidental dislodgement of biofouling because these aspects of system application are significantly dependent on the skills and motivation of the operator. Operators may, for example, minimise efforts to collect and record material dislodged from the hull and maximise efforts to recover material escaping from the cleaning head in order to exaggerate the efficacy of the cleaning operation. Therefore, it is proposed that video recording of the testing process be used to record material dislodged or escaping capture. Large amounts of dislodged or escaped material will be detected by both qualitative and quantitative methods of assessment. Although small amounts of material may not be noticed by the assessor or recorded by the video, the power of quantitative methods to measure them (such as collecting water samples at increasing distances from the test area) is also likely to be small because of background variation in, for example, concentrations of suspended sediments.

4.4 WASTE CAPTURE AND TREATMENT SYSTEMS

4.4.1 Testing method – efficacy of waste filtration

A magnification of up to 400 times is sufficient to see objects of 12.5 µm diameter.

It will be necessary to allow sufficient time between the start of cleaning of each section of hull and the collection of effluent samples to allow residual effluent in the system to be flushed through. This can be determined by running aliquots of dye through the system at appropriate times.

4.4.2 Testing method – viability of organisms or propagules in waste effluent

First and Drake (2013) noted that “with the suite of approaches currently available, it is not possible to determine the viability of organisms rapidly, that is, within minutes of collecting a ballast water sample. Measurements of the photosystem integrity via variable fluorescence and the presence of adenosine triphosphate (ATP) are currently the most promising for rapidly estimating concentrations of living cells in compliance testing of ballast water discharges; however, extensive validation is required to verify the applicability of these approaches for the complexity of real world samples”. Given the lack of appropriate methods, it is proposed that structural integrity of organisms and propagules be used as an indicator of viability as per First and Drake (2013) (Appendix 9.2).

5 Feasibility and costs of testing

5.1 GENERAL FEASIBILITY CONSIDERATIONS

5.1.1 Systems applied to flat surfaces only, flat and curved surfaces, and niche areas

The main limitation for testing systems is likely to be the availability of a vessel of suitable size and with adequate biofouling, particularly for assessing efficacy on flat and curved surfaces. For example, the size of the vessel must be matched to the size of the cleaning equipment to ensure the appropriate number of turns and passes can be made (Section 3.1.6). Similarly, it may be necessary to use more than one vessel to test the equipment on the required number of replicate areas (particularly niche areas; Section 3.4.1). It may also be difficult to locate vessels with the appropriate level of biofouling to test the system. In the case that a vessel cannot be located with high levels of biofouling (i.e., FR 40 or greater), the system will only be approved to the level of biofouling tested. Arrangements to locate vessels appropriate for each test will need to be made well in advance of testing.

A resource consent may be required if testing involves cleaning a hull coated with anti-fouling paint (or use of a biocide in shrouding systems). There may also be concerns over the potential release of biosecurity contaminants if the vessel has spent time outside the testing location since any previous hull maintenance.

It may be possible to clean small vessels inside a floating dock or other shrouding device to minimise biosecurity and chemical contamination risks (e.g., to assist resource consenting) and to assess the amount of uncaptured waste more easily. Health and safety procedures for diver operated cleaning systems in this situation will need to consider the elevated dangers of an enclosed environment and the potential for concentration of anti-fouling biocides, where applicable. Water pumped out of the dock as cleaning effluent must be periodically or continually replaced to prevent the volume that the divers are working in from becoming progressively smaller, and thus possibly presenting a hazard.

Unless the vessel undergoing testing will be dry-docked afterwards or the hull is heavily fouled (indicating failure of the anti-fouling coating), the owners of vessels used in the test are likely to require evidence that the procedure will not compromise anti-fouling or anti-corrosion coatings or damage the hull in other ways. The developer should obtain these assurances from paint manufacturers before testing (Section 3.1.11).

For feasibility and cost considerations pertinent to panel testing, refer to Appendix 9.6.

5.1.2 Waste capture and treatment systems

Collection of the samples from the final effluent should be straightforward.

Discharge of liquid trade wastewater to sewer systems will normally require a registration or consent (Section 3.1.12).

5.2 COSTS

The costs incurred during testing of in-water systems under realistic operating conditions are likely to be highly variable. Some indicative costings are provided that could be associated with such testing (Table 5-1). In producing these costings, a minimum of two separate sources for the cost of each test item have been averaged. The main assumption is that test cleaning would involve one day for assessing *in situ* cleaning efficacy (Table 5-1). For shrouding systems (i.e., encapsulation and enclosure systems such as floating docks), test cleaning may involve multiple days for implementation and assessment. Specific costing assumptions are listed in the Table notes.

Table 5-1. Indicative costs associated with the testing of in-water systems under realistic operating conditions.

Test item	Indicative cost (NZ$)
Vessel berth/wharf face (20–100 m length)	$65–350 per day
Site power/generator	$50/$525 per day[1]
Crane truck/forklift (< 5 tonne)	$1 408/$800 per day[2]
Encapsulation (wrapping) < 12 m vessel/> 12 m vessel	$200–500/$100–160 per lineal m of vessel[3]
Enclosure (floating dock, shroud) (15–25 m vessel)	$12 000 – 45 000[4]
Dive contractor	$1 960 per day[5]
Scientific contractor (field)	$4 800 per day[6]
Scientific contractor (report)	$14 250[7]
Waste disposal	$5 per kg of solids[8]

Notes

1 For example, 32-amp power cables, power transformer, splitter box or 250-KvA generator. Excludes power/fuel costs.

2 Based on hourly rates of $176 (truck)/$100 (forklift) per hour (includes driver) for an 8-hour day.

3 Based on using a thin plastic silage-type wrapping (e.g. “Oceanwrap”). Cost is inclusive of wrapping time by divers. Integrated Packaging Group provide a similar product (SilaWrap, 25 μm thick, 0.5 m width x 300 m length rolls) at ~ $18 per roll. Where integrity of thin plastic silage-type wrapping is at risk (e.g., tearing of wrap through sharp biofouling organisms or the surrounding environment), thicker encapsulation materials such as ripstop canvas or woven polyester fabric with a flexible PVC coating can be utilised. For example, the Canvas Company has ripstop PVC products (Genlon 400, 600 and Trident Ripstop PVC) in widths 1.8–2 m at $21–40 per lineal m.

4 Based on IMProtector and FAB Dock options. Such units are not usually available for hire. Options (at extra cost) for such units include: water or air pumps, heavy-duty PVC floors (for long-term *in situ* use), and inflatable pontoon bridges for sectioning off larger docks for smaller vessels or to allow staff better/safer access when working on vessels. Customised units for vessels > 6 m in length can be commissioned.

5 Based on a single three-diver commercial team for an 8-hour day at $245 per hour. Travel time/costs to/from test location additional. Does not include sampling materials/sundries that may need to be purchased (e.g., sampling quadrats, mesh bags etc.). Assumes one day to conduct *in situ* testing of the system.

6 Based on a four-person science provider team to ensure independence of testing. This team comprises a three-person in-water field team (one diver, one standby diver and one surface support/skipper) to assess *in situ* system efficacy (via videoing of system in operation for waste capture, knocking off of biofouling, efficacy of waste treatment system etc.), and one person assessing the efficacy of the waste treatment system, for a 7.5-hour day at $160 per hour, averaged across Technician/Scientist classifications. Travel time/costs to/from test location additional. Does not include sampling materials/sundries that may need to be purchased (e.g., sampling quadrats, mesh bags etc.). Assumes one day to assess *in situ* efficacy.

7 Based on a single science provider for a 7.5-hour day at $190 per hour for a Senior Scientist to spend a total of 10 days on project set-up/management, client liaison, and reporting (including internal peer-review of report) pertinent to the testing framework.

8 Based on disposal to landfill by approved waste transporter/handler as industrial/contaminated waste. Minimum weight requirements for collection and disposal by commercial waste companies may apply. Conditional upon Resource Management Act 1991 (RMA) and Hazardous Substances and New Organisms Act 1996 (HSNO). Waste could be regarded as industrial/contaminated waste due to possible anti-fouling coating contamination, and inherent biological material.

6 Look-up guide to testing requirements

Table 6-1. Comparison of test requirements for each in-water system category and indicative costs related to the level of testing required. Indicative costs are based upon Table 5-1 and Table 9-4.

		Testing requirements					Likely costs			
System category	Sub-category	Biofouling cover before	Biofouling cover after	Biofouling viability	Anti-fouling coating condition	Waste capture/ treatment	Niche testing only[5]	Flat and curved surface testing[6]	Whole vessel testing[7]	Panel testing[8]
Manual/mechanical	Hand-held manual/ mechanical	✓	✓	✗	✓	✓	$14 850-16 218	$18 412-19 780	$21 975-23 343	$86 930-89 096
	Diver operated brushcart/ contactless	✓	✓	✗	✓	✓	n/a	$18 412-19 780	$21 975-23 343	$86 930-89 096
	ROV brushcart	✓	✓	✗	✓	✓	n/a	$16 452-17 820	$20 015-21 383	$86 930-89 096
	High-pressure water jet/ Cavitation jet	✓	✓	✗	✓	✓	$14 850-16 218	$18 412-19 780	$21 975-23 343	$86 930-89 096
Surface-treatment	Heat treatment	✓	✗	✓	✓	✗	$14 850-16 218	$18 412-19 780	$21 975-23 343	$86 930-89 096
	Ultrasonic	✓	✗	✓	✓	✗	$14 850-16 218	$18 412-19 780	$21 975-23 343	$86 930-89 096
Shrouding	Encapsulation	✓	✗	✓	✓	✗	$13 090-14 758	$18 612-20 280	$22 175-23 843	$86 930-89 096
	Enclosure	✓	✗	✓	✓	✗	$24890-59 258	$28 452-62 820	$32 015-66 383	$86 930-89 096

[5] Scientific contractor (reporting) component estimated at 50% of that required for whole vessel testing based upon fewer test replicates
[6] Scientific contractor (reporting) component estimated at 75% of that required for whole vessel testing based upon fewer test replicates
[7] Scientific contractor (reporting) component estimated at full cost as in Table 5-1 (10 days)
[8] Scientific contractor (reporting) component considered to be the same as that required for whole vessel testing due to high test replicate numbers

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9 Appendices

9.1 FOULING RATINGS FOR US NAVAL SHIPS

Sourced from *Naval Ships' Technical Manual (2006), Chapter 081, Waterborne underwater cleaning of Navy ships, Revision 5. S9086-CQ-STM-010.*

PROGRESSIVE FOULING PATTERNS
081-1.2.1 GENERAL. The biological biofouling of Navy ships is a recurring process following identifiable patterns of growth. Relatively few types of organisms are responsible for hull biofouling and they tend to develop in the order listed in paragraphs 081-1.2.2.1 through 081-1.2.2.3 (depending on geographical locality).

081-1.2.2 TYPES AND CATEGORIES OF FOULING. The types of biofouling are separated into soft, hard, and composite categories. Soft biofouling typically algae, slime and grasses, has less of an effect on the coating systems and the performance of the ship than hard biofouling[9]. Hard biofouling is more tenacious having a calcareous structure which may become detrimental to the performance of the ship and coating systems. Composite biofouling includes both hard and soft biofouling organisms and is extremely detrimental to the ship's performance and coating and machinery systems.

081-1.2.2.1 SOFT FOULING. The dominant organisms in this stage of biofouling are slime and grass.

081-1.2.2.1.1 SLIME. Formation of slime is the first step in the biofouling process. Almost any object immersed in seawater rapidly accumulates a coating of slime, consisting of bacteria, fungi, protozoa, and algae. Bacteria frequently are attached within one-half hour of wetting the surface, and slime can often be felt by hand within an hour. The coating of slime is smooth and generally follows hull contours.

081-1.2.2.1.2 GRASS AND OTHER SOFT FOULING. Grass is a form of multicellular green and brown algae. It forms most heavily near the water-line, where adequate light is available for photosynthesis. It is less evident as depth increases, and the dominant colour changes from green to brown.

081-1.2.2.2 HARD FOULING. The dominant forms of hard biofouling are barnacles (usually acorn) and tubeworms (serpulids). Some underwater components, such as the bare metal of a propulsor, can experience severe conditions where a combination of biofouling (hard and soft) and calcareous deposits can form.

081-1.2.2.2.1 BARNACLES. Acorn barnacles have conical hard shells with jagged tops.

081-1.2.2.2.2 TUBEWORMS. Tubeworms form intertwined tubes lying along or projecting out from the hull.

081-1.2.2.2.3 CALCAREOUS DEPOSITS. A result of an active cathodic protection system is the deposition of magnesium and calcium carbonate on bare metal surfaces. The bare nickel-aluminum-bronze-surfaces of a propulsor are highly susceptible to a uniform accumulation of calcareous deposit. The thickness will depend upon the time from the last cleaning and the

[9] Nevertheless, even low-form algal biofouling can cause a significant increase in frictional drag and therefore, affect vessel performance and operational cost (Schultz *et al.* 2011).

functionality of the cathodic protection system and although usually more fragile than biological hard-fouling, can still be tenacious and difficult to remove.

081-1.2.2.3 COMPOSITE FOULING. In advance stages of biofouling, mature barnacles and tubeworms may be present along with calcareous bivalve organisms such as mussels or oysters, or hydroids with calcareous cellular structure such as coral or anemones. In advanced stages of biofouling, the ship will be affected by slime, grass, barnacles, and tubeworms. In addition, this stage of biofouling will include soft shell-less animal forms, such as hydroids, anemones, and tunicates (sea squirts).

081-1.2.3 FOULING RATING (FR). The fouling rating scale (Table 081-1-1) describes the 10 most frequently encountered biofouling patterns in order of increasing severity. Representative photographs of each biofouling pattern are provided in Figure 081-1-1.

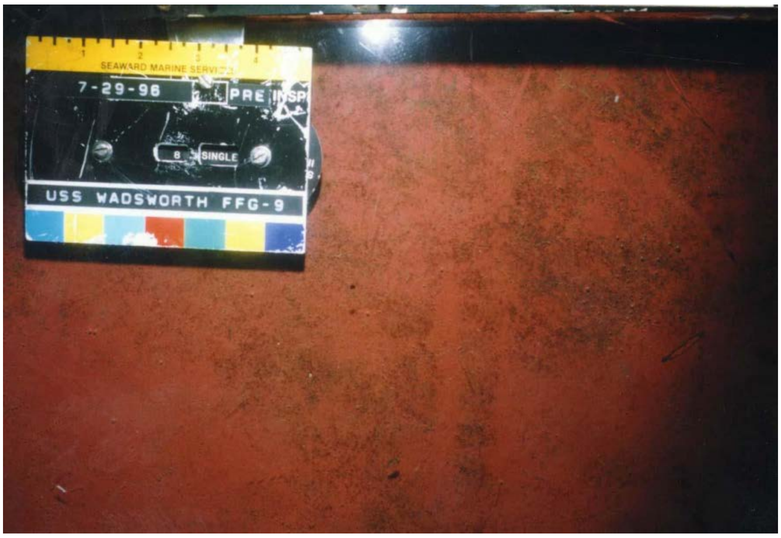
081-1.2.4 FOULING RATING (FR) SCALE. A rating number has been assigned to each of the 10 biofouling patterns on a scale of 0 to 100 in 10-point increments. The lowest number represents a clean hull and the higher numbers represent biofouling organism populations of increasing variety and severity.

081-1.2.5 FOULING PERCENTAGES. The biofouling percentage quantifies the density of biofouling which covers a particular component or area of the hull (i.e., rudder, strut, propeller, stern, port side bow, starboard mid ship, sea chest, etc.).

Table 9-1 Fouling ratings (FR) in order of increasing severity.

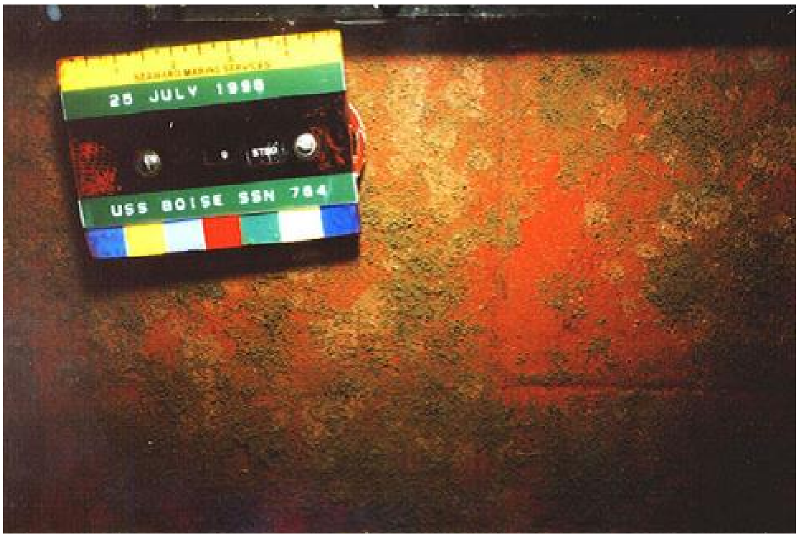
Type	Fouling rating (FR)	Description
Soft	0	A clean, foul-free surface; red and/or black anti-fouling paint or a bare metal surface.
Soft	10	Light shades of red and green (incipient slime). Bare metal and painted surfaces are visible beneath the biofouling.
Soft	20	Slime as dark green patches with yellow or brown coloured areas (advanced slime). Bare metal and painted surfaces may by obscured by the biofouling.
Soft	30	Grass as filaments up to 3 inches (76 mm) in length, projections up to ¼ inch (6.4 mm) in height; or a flat network of filaments, green, yellow, or brown in colour; or soft non calcareous biofouling such as sea cucumbers, sea grapes, or sea squirts projecting up to 1/4 inch (6.4 mm) in height. The biofouling cannot be easily wiped off by hand.
Hard	40	Calcareous biofouling in the form of tubeworms less than ¼ inch in diameter or height.
Hard	50	Calcareous biofouling in the form of barnacles less than ¼ inch in diameter or height.
Hard	60	Combination of tubeworms and barnacles, less than ¼ inch (6.4 mm) in diameter or height.
Hard	70	Combination of tubeworms and barnacles, greater than ¼ inch in diameter or height.
Hard	80	Tubeworms closely packed together and growing upright away from surface. Barnacles growing one on top of another, ¼ inch or less in height. Calcareous shells appear clean or white in colour.
Hard	90	Dense growth of tubeworms with barnacles, ¼ inch or greater in height; Calcareous shells brown in colour (oysters and mussels); or with slime or grass overlay.
Composite	100	All forms of biofouling present, soft and hard, particularly soft sedentary animals without calcareous covering (tunicates) growing over various forms of hard growth.

Figure 9-1. Guide of typical fouling ratings (FR) in order of increasing severity (22 images).



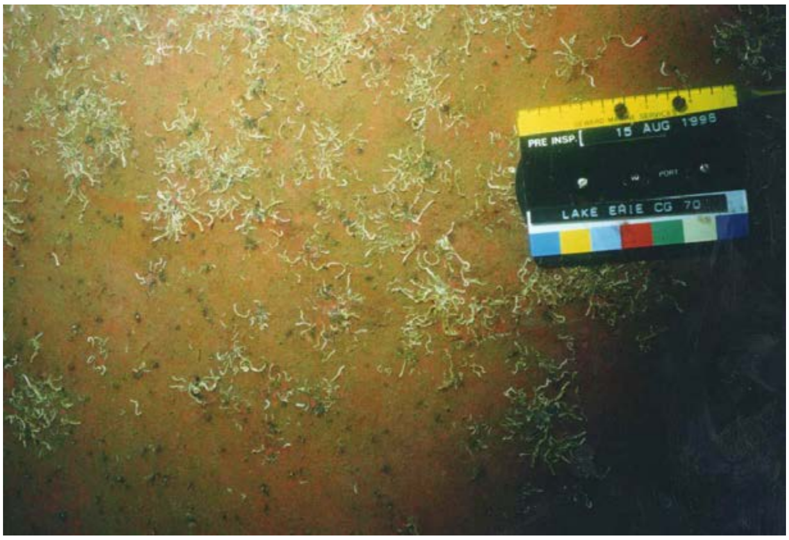
FR-10, over 30 percent of area.

FR-10, over 100 percent of area.

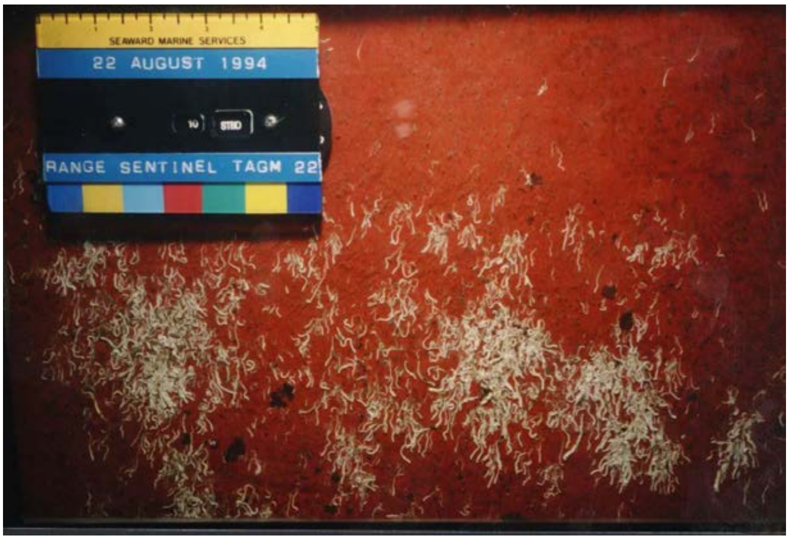


FR-20, over 80 percent of area.

FR-30, over 40 percent of area.

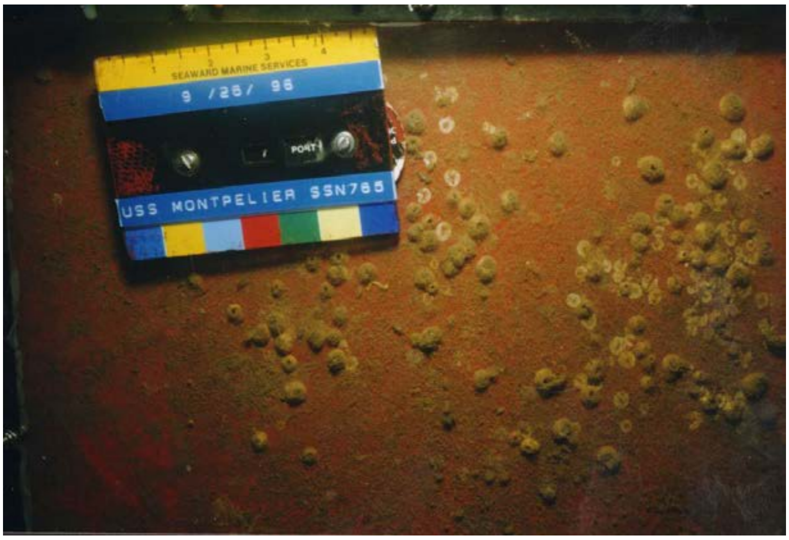


FR-40, over 20 percent of area.



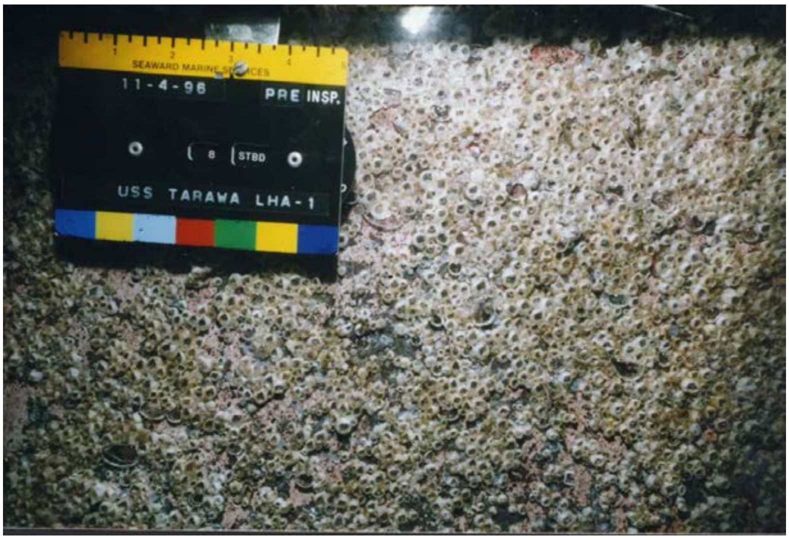
FR-40, over 30 percent of area.

FR-40, over 90 percent of area.



FR-50, over 20 percent of area.

FR-50, over 40 percent of area.

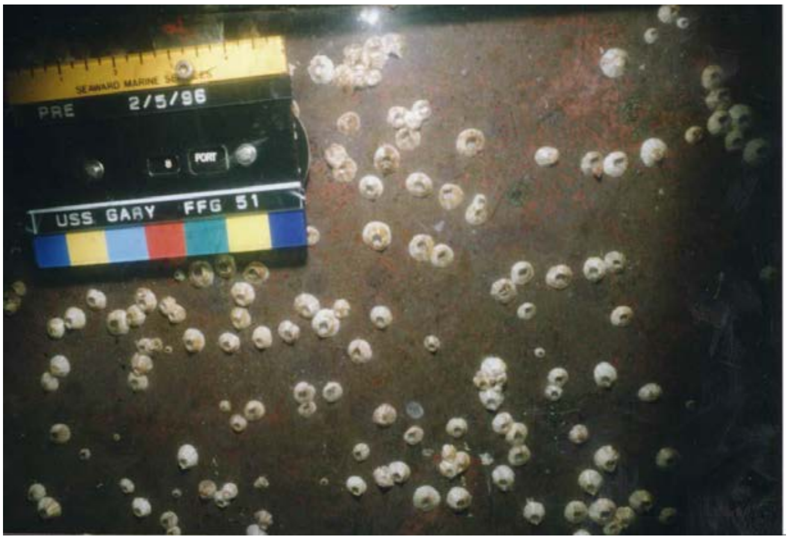


FR-50, over 100 percent of area.

FR-60, over 15 percent of area.

FR-60, over 20 percent of area.

FR-60, over 90 percent of area.



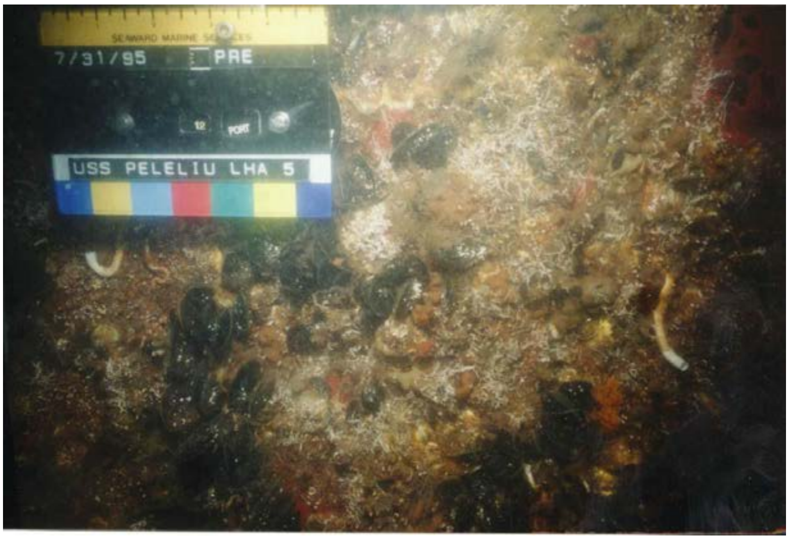
FR-70, over 20 percent of area.

FR-70, over 80 percent of area.

FR-80, over 60 percent of area.

FR-80, over 80 percent of area.

FR-80, over 90 percent of area.



FR-90, over 90 percent of area.

FR-90, over 90 percent of area.

FR-100, over 50 percent of area.

FR-100, over 100 percent of area.

9.2 GUIDELINES FOR ASSESSING VIABILITY OF MACROSCOPIC BIOFOULING ORGANISMS

These guidelines are modified from Woods *et al.* (2007), and draw upon other studies that have use pragmatic assessments of the viability of biofouling organisms (i.e., Coutts and Forrest 2005; Forrest and Blakemore 2006; Blakemore and Forrest 2007; Locke *et al.* 2009; Dunmore *et al.* 2011; McCann *et al.* 2013). Note that indicators related to the desiccation of organisms are not relevant here as biofouling organisms will be wet from in-water sample collection.

Table 9-2: Indicators of the viability of different types of biofouling organisms.

Type of biofouling organism	Indicators for potential viability	Indicators for non-viability
Sessile taxa		
Barnacles	• Structure: all shell plates present and intact, opercular plates present. • Feeding/movement: feeding structures (cirri) protrude out of the test and perform sweeping feeding movements. Or: opercular shells closed by muscular action. Feeding or respiration currents visible.	• Structure: shell/opercular plates and/or feeding structures (cirri) broken or missing. • Feeding/movement: feeding structures visible but motionless and slack, and/or no reaction when touched. No feeding or respiration currents visible.
Bivalves	• Structure: both shells present and intact. • Feeding/movement: shells may be locked by muscular action. Shells may also be open (feeding), exposing mantle tissue and siphons (or gaps in mantle), but will close when touched (reaction). Feeding or respiration currents visible.	• Structure: one shell missing or one/both shells significantly cracked or fragmented. • Feeding/movement: shells open but no reaction to touch. No feeding or respiration currents visible.
Encrusting bryozoans	• Structure: colony/fragment contain several intact zooids, and natural colour (pigmentation). • Feeding/movement: filtering apparatus (lophophore) protrude through opening in zooid. Feeding or respiration currents visible.	• Structure: all zooids damaged/smashed, no soft tissues visible or tissues decomposing. Complete loss of pigmentation. • Feeding/movement: zooids' soft tissues and/or feeding structures may be visible but no movement or reaction to touch. No feeding or respiration currents visible.
Erect bryozoans	• Structure: colony/fragment contain several intact zooids, and natural colour (pigment). • Feeding/movement: filtering apparatus (lophophore) protrude through opening in zooid. Feeding or respiration currents visible.	• Structure: all zooids damaged/smashed, no soft tissues visible or tissues decomposing. Complete loss of pigmentation. • Feeding/movement: feeding structures may be visible but no movement or reaction to touch. No feeding or respiration currents visible.
Colonial ascidians	• Structure: Colony/fragment in reasonable 'shape', not entirely crushed, and natural colour (pigmentation). Several polyps intact. • Feeding/movement: inhalant and/or exhalant siphons open, but close when touched. Feeding or respiration currents visible.	• Structure: Shredded or crushed so that badly damaged, no soft tissues visible or tissues decomposing. No polyps visible (polyps may have 'popped out' from mechanical pressure on colony). Complete loss of pigmentation. • Feeding/movement: siphons open but no reaction to touch. No feeding or respiration currents visible.
Solitary ascidians	• Structure: test (body) intact, no holes or gashes, not crushed flat or severely deformed, and natural colour (pigmentation).	• Structure: test badly damaged, crushed or deformed. Branchial basket exposed and/or damaged, gut system protruding from test, no soft tissues

Type of biofouling organism	Indicators for potential viability	Indicators for non-viability
	• Feeding/movement: inhalant and/or exhalant siphons open, but close when touched. Or: siphons closed and resistant to opening. Feeding or respiration currents visible.	visible or tissues decomposing. Complete loss of pigmentation. • Feeding/movement: Siphons open, but no reaction to touch. No feeding or respiration currents visible.
Hydroids	• Structure: body reasonably intact, feeding polyps (often at distal ends of braches) present and natural colour (pigmentation). • Feeding/movement: feeding tentacles exposed. Feeding or respiration currents visible.	• Structure: All polyps damaged/smashed, no soft tissues visible or tissues decomposing. Complete loss of pigmentation. • Feeding/movement: feeding structures may be visible but no movement or reaction to touch. No feeding or respiration currents visible.
Tube-building polychaetes	• Structure: generally intact (body usually within tube), not crushed, no holes or gashes, and natural colour (pigmentation). Care needed, as regeneration from lesser fragmentation is possible with some taxa. • Feeding/movement: worm retracts into tube when touched, and/or feeding structures (tentacular crown) visible and moving. Feeding or respiration currents visible.	• Structure: tube missing, loss of tentacular crown, body badly crushed or lacerated, no soft tissues or tissues decomposing. Complete loss of pigmentation. • Feeding/movement: feeding structures may be visible, but no movement or reaction to touch. No feeding or respiration currents visible.
Sponges	• Structure: fragments retain natural colour, firm texture (don't fall apart). Sponges retain a "fleshy/translucent/shiny" appearance. Look for "translucent" tissue between fibres. • Feeding/movement: extremely difficult to observe. Feeding or respiration currents visible.	• Structure: colony/fragment faded and bleached, falling apart. Complete lack of pigmentation. Sponge a mass of golden fibres/hair-like structures without "translucent fleshy tissue" between the fibres, or decomposing tissues. • Feeding/movement: extremely difficult to observe. No feeding or respiration currents visible.
Macroalgae	• Structure: whole plant or fragments not crushed and natural colour (pigmentation). • Feeding/movement: n/a	• Structure: badly crushed or fragmented with complete loss of pigmentation. • Feeding/movement: n/a
Motile taxa		
Crabs	• Structure: several missing limbs no problem unless all are gone. Carapace intact. Natural colour (pigmentation). • Feeding/movement: movement or reaction to touch. Eyes/sensory organs in head region moving. Respiration currents visible.	• Structure: all, or nearly all limbs missing. Carapace significantly damaged (e.g., large holes or parts missing). Complete loss of pigmentation. • Feeding/movement: no movement or reaction to touch. No respiration currents visible.
Molluscs (gastropods, nudibranchs, chitons)	• Structure: body intact (gastropod snails: shell present), and natural colour (pigmentation). • Feeding/movement: movement or reaction to touch.	• Structure: body significantly damaged, crushed or lacerated. Complete loss of pigmentation. • Feeding/movement: no movement or reaction to touch.
Sea stars/brittle stars	• Structure: basal disc or parts of it present (can regenerate). Body (or whatever's present) has natural shape, not crushed, and natural colour (pigmentation). • Feeding/movement: movement or reaction to touch.	• Structure: arm-only without part of basal disc (can't regenerate), body significantly damaged, crushed or lacerated. Complete loss of pigmentation.

Type of biofouling organism	Indicators for potential viability	Indicators for non-viability
		• Feeding/movement: no movement or reaction to touch.
Amphipods/isopods/tanaids etc.	• Structure: exoskeleton intact. Several missing limbs no problem unless all or nearly all are gone. Natural colour (pigmentation). • Feeding/movement: visible movement/reaction, especially feeding limbs will beat if submerged and alive. Feeding or respiration currents visible.	• Structure: Exoskeleton damaged (e.g. large holes or parts missing). All or nearly all limbs or feeding structures missing. Complete loss of pigmentation. • Feeding/movement: No movement or reaction to touch. No feeding or respiration currents visible.
Errant polychaetes	• Structure: generally intact, not crushed, no holes or gashes. Care needed, as regeneration from lesser fragmentation is possible with some taxa. Natural colour (pigmentation). • Feeding/movement: movement or reaction to touch.	• Structure: body badly crushed or lacerated. Complete loss of pigmentation. • Feeding/movement: no movement or reaction to touch.

9.3 TEMPLATES FOR REPORTING TEST RESULTS

9.3.1 Example report template

Title

Executive Summary

Introduction

System description and specifications (see Section 3.1.1)
This section should include information on:

- the system(s) and its mechanism of action;
- system design;
- general method of system operation.

Description of the system application (see Section 3.1.1)
This section should include information on:

- the types and classes of vessel that the system may be applied to;
- the areas of hull and other immersed structures that the system may be used on;
- hull or niche area materials that the system may be used on;
- type of hull coating(s) the system is intended to be used on;
- level and types of biofouling that the system is intended to remove or treat.

Standard operating procedures (SOP) for systems cleaning or treating biofouling (see Section 3.1.1)
This section should include detailed information on:

- how the system is used;
    - for surface-treatment and shrouding systems, this should include describing the lethal dose (LD_{100}) and duration of treatment (LT_{100}) required to achieve 100% mortality of biofouling organisms;
- steps taken to ensure that viable biofouling is not released or dislodged during system set-up, application and demobilisation;
- the physical environment suitable for system application (e.g., alongside berth, enclosed in floating dock, open water, whether the entire fouled area of the hull must be submerged);
- sea and weather conditions under which the system is intended to be used (e.g., limits on current speed, wave height, water temperature, water clarity to ensure efficacy, operator safety).

SOP for waste capture and treatment (if applicable) (see Section 3.6)
This section should include detailed information on:

- the operation of the waste capture and treatment system, including:
    - the volumes of liquid and solid waste material that the system is designed to handle;
    - the frequency of changing or cleaning filters and filter cartridges to prevent system overload;
    - the fate of the liquid and solid waste streams.

Methods

Test conditions

This section should include detailed information on:

a) Vessel testing (see Sections 3.2.6, 3.3.6, 3.4.6, 3.5.6)

- the date and location of the test(s) and the environmental conditions at the time, including;
  - water clarity (Secchi depth);
  - current and tide conditions;
  - wind direction and speed;
  - sea state;
- the vessel(s) used in the test, including its:
  - size length/tonnage;
  - design and construction materials;
  - anti-fouling coating type(s);
- the areas of the hull and other immersed structures that the test was carried out on, including;
  - the location of test areas on the vessel;
  - the fouling rating (FR) and percentage cover of biofouling in each of the replicates test areas;
  - the condition of the anti-fouling coatings in the test areas;
- how the system was applied to the test areas/vessel, including:
  - any variations or deviations in application of the test relative to the SOP and test requirements;
- methods used by the test supervisor to observe and record the application of the system(s) for containment and waste capture (Sections 3.2.5, 3.3.5, 3.4.5, 3.5.4).

b) Waste treatment systems (see Sections 3.2.5, 3.3.5, 3.4.5, 3.5.5 and 3.6)

- a description of how the test was undertaken, including:
  - the procedures followed during system set-up, operation, monitoring and demobilisation, including:
    - any variations or deviations in application of the test relative to the SOP and test requirements;
  - the methods used to monitor the effluent stream, including:
    - the number, size and (where possible) identity of particles > 12.5 µm in dimension; or
    - the viability of biological material in the effluent.

c) Panel testing (if applicable) (see Section 4.1.6 and Appendix 9.6)

- the date and location of the test(s) and the environmental conditions at the time, including:
  - water clarity (Secchi depth);
  - current and tide conditions;
  - wind direction and speed;
  - sea state;
- the design of the panel test, including:
  - the size and numbers of panels used;
  - the type(s) and condition of anti-fouling coatings present on them;
  - the type, level (FR) and cover (%) of biofouling present on each test panel;
  - the experimental set-up;
  - how the system was applied to the panels;
- how the system was applied to the test areas/vessel, including:

    - any variations or deviations in application of the test relative to the SOP and test requirements;
- methods used by the test supervisor to observe and record the application of the system(s) for containment and waste capture (Sections 3.2.5, 3.3.5, 3.4.5, 3.5.4).

Personnel involved in the test

- details and qualification of organisations and personnel performing and supervising the test (Section 3.1.4).

Results

This section should include detailed information on:

a) All systems
  - any loss of material by dislodgement from the hull or niche areas during system set-up and demobilisation and from escape during system application, based on examination of video recording (Section 3.2.5);
  - the condition of the anti-fouling coating in each test area or panel.

b) Vessel Testing
    a. Manual and mechanical cleaning
  - the amount and type of residual biofouling for each of the test areas analysed:
    - type of biofouling (Section 3.1.2);
    - number of patches and size of each patch;
    - location within the test area;
    - location of the test area on the hull;
    - relevant image identifier (file name);
    - a description of the condition of any residual biofouling.

    b. Surface-treatments
  - the results of samples taken to monitor conditions (e.g., biocide concentration, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.2.3.2.1);
  - the amount and type of viable biofouling observed in video recordings of each replicate treated area selected for analysis including:
    - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2) and their location in within the test area;
    - location of the test area on the hull;
    - relevant image identifier (file name);
  - the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the selected test areas, including:
    - a description of the number, size and type of biofouling organisms (Sections 3.1.2 and 3.1.9) that exhibited indications of potential viability (Appendix 9.2);
    - location of the test replicate on the hull;
    - relevant sample identifier (i.e., test replicate identifier);

c. Shrouding systems

- the results of samples taken to monitor conditions (e.g., biocide concentration, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.2.3.2.1);
- the amount and type of viable biofouling observed in video recordings of each replicate treated area selected for analysis including:
  - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);
  - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2) and their location in within the test area;
  - location of the test area on the hull;
  - relevant image identifier (file name);
- the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the selected test areas, including:
  - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2);
  - location of the test replicate on the hull;
  - relevant sample identifier (i.e., test replicate identifier).

c) Waste treatment systems

- the performance of the equipment, including any deviations from the prescribed SOP;
- the results of monitoring the effluent stream, including:
  - the number, size and (where possible) identity of particles > 12.5 µm in dimension; or
  - the viability of biological material in the effluent.

d) Panel testing (if applicable) (see Appendix 9.6.6)

- *manual and mechanical cleaning*
  - the amount and type of residual biofouling on each of the test panels:
    - type of biofouling (Section 3.1.2);
    - number of patches and size of each patch;
    - location within the test area;
    - relevant image identifier (file name);
    - a description of the condition of any residual biofouling;

- *surface-treatments and shrouding systems*
  - the results of samples taken to monitor conditions (e.g., concentration of the lethal agent, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.4.3.2.1);
  - the amount and type of viable biofouling observed in video recordings of each replicate test panel including:
    - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);

        - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability Appendix 9.2) and their location on the panel;
        - relevant image identifier (file name);
    - the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the test panels, including:
        - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2);
        - relevant sample identifier (i.e., test replicate identifier).

Discussion and conclusions

This section should include detailed discussion of:

- system(s) efficacy, including:
    - whether the system met the performance standard(s);
- the effects of any variations or deviations in application of the test relative to the SOP(s) and test requirements that may have affected system performance;
- any recommendations for system improvement, its SOP or in the test requirements.

Appendices

This section should include:

- copies of any approvals or consents required to undertake the test, including:
    - approval of the system by manufacturers of anti-fouling coatings (see Section 3.1.11);
    - approval by regulatory bodies for in-water testing of the system (see Section 3.1.12);
- a copy of the performance log kept during testing of the waste treatment system (see Section 3.6.4);
- copies of the completed data templates (see Section 9.3.2);
- copies of video or still images on which assessments were made during the test(s) and an associated index of the images and sample identifiers.

9.3.2 Example data reporting templates

9.3.2.1 General data requirements (all in-water system categories)

Pre-test reporting					
Pre-test details		Environmental conditions		Vessel/panel characteristics	
Date of test:		Secchi depth[2]:		Vessel name:	
System developer:		Current and tide state[3]:		Size length/tonnage:	
Type of system:		Wind direction/speed:		Hull materials:	
Removal method[1]:		Sea state[4]:		Paint type:	
System operator company/personnel:					
Location of test:		Test conditions			
Supervising company:		Hull surface type(s):			
Supervising personnel:		Biofouling rating and cover:			

	System testing											
Test areas[5]	Size of cleaned /treated area (m^2)	Location on vessel	Test surface[6]	Test surface sub-category[7]	Initial biofouling cover	Initial biofouling type[8]	Image identifiers (file name)[9]	Pre-test paint condition[10]	Post-test paint condition[10]	Residual biofouling cover (%)[11]	Residual biofouling type[12]	System testing description[13]
1												
2												
3												
4												
5												
6												

9.3.2.2 Assessments of containment and capture efficacy

Efficacy of containment and capture of biofouling			
(a) General requirements (all system categories)[14]			
Stage of operations	Amount of biofouling dislodged (estimate)	Cause of dislodgement (description)	Video identifier (file name and time stamp)
Set-up / Mobilisation			
De-mobilisation			
(b) Additional requirements for manual, mechanical and surface-treatment systems[14]			
Stage of operations	Amount of biofouling dislodged (estimate)	Cause of dislodgement (description)	Video identifier (file name and time stamp)
Test areas[5]			
1			
2			
3			
4			
5			
6			
(c) Additional requirements for shrouding systems[15]			
Stage of operations	Transect No.	Evidence of dye leakage or damage to shroud (description)	Video identifier (file name and time stamp)
Commencement	1		
Date:	2		
	Other		
Completion	1		
Date:	2		
	Other		

9.3.2.3 Monitoring conditions achieved by surface-treatment or shrouding systems[16]

Conditions achieved in surface-treatments and shrouding systems					
Lethal Agent[17] :___________					
	LD_{100}:_________	LT_{100}__________			
Date / Time	Location on vessel	Monitoring location	Replicate number	Sample identifier	Measurement (e.g., concentration; temperature)
1		1	1		
1		1	2		
1		1	3		
1		2	1		
1		2	2		
1		2	3		
1		3	1		
1		3	2		
1		3	3		
2		1	1		
2		1	2		
2		1	3		
2		2	1		
2		2	2		
2		2	3		
2		3	1		
2		3	2		
2		3	3		
3		1	1		
3		1	2		
3		1	3		
3		2	1		
3		2	2		
3		2	3		
3		3	1		
3		3	2		
3		3	3		

9.3.2.4 Analysis of viability of treated biofouling using video imagery

Viability of macroscopic biofouling organisms estimated from videography						
	Pre-treatment			Post-treatment		
Test areas[5]	Image identifier(s)	Percentage of viable biofouling organisms[18]	Notes on condition of biofouling	Image identifier(s)	Percentage of viable biofouling organisms[18]	Notes on condition of biofouling
1		Taxonomic group 1 – Taxonomic group 2 – etc.			Taxonomic group 1 – Taxonomic group 2 – etc.	
2						
3						
4						
5						
6						

9.3.2.5 Analysis of viability in samples of treated biofouling

Viability of macroscopic biofouling organisms estimated within samples taken from treated test areas				
Test areas[5]	Sample identifier	Biomass (g) of each taxonomic group of biofouling organisms	Number and size of viable organisms from each taxonomic group of biofouling organisms[19]	Notes on the condition of the biofouling
1		Taxonomic group 1 – Taxonomic group 2 – etc.	Taxonomic group 1 – Taxonomic group 2 – etc.	
2				
3				
4				
5				
6				

Notes on the data templates

1 Specific details on the system's mechanism for removing biofouling (e.g., nylon brush, cavitation, cutting blade, water jet, etc.).

2 The Secchi disk is a weighted circular disk (20–30 cm in diameter), divided into quadrants painted alternately black and white, used to measure water transparency in bodies of water. The disk is mounted on a pole or line, and lowered slowly down through the water column. The depth at which the disk is no longer visible (= Secchi depth) is related to water colour and turbidity.

3 Relative assessment of current by divers. Tidal state derived from authoritative source pertinent to location of testing, e.g., New Zealand Nautical Almanac (http://www.linz.govt.nz/sea/nautical-information/new-zealand-nautical-almanac-nz204/nautical-almanac-extracts).

4 Douglas Sea Scale (Table 9-3). Adapted from World Meteorological Organization, http://www.wmo.int/pages/prog/amp/mmop/faq.html (accessed 4/11/2014). Note: Direction of both wind-sea and swell should also be recorded (if present).

5 Number of test areas will vary in accordance with the size of the vessel. See Sections 3.1.6 and 4.2.5.

6 Flat surface, curved surface or niche area.

7 For curved surfaces, must specify the type of angle or surface. For niche areas, must specify the type of niche area.

8 Fouling type should be assessed using the fouling ratings for US Naval Ships (Appendix 9.1).

9 All images and videos must be made available, and all must be accounted for.

10 Paint condition should be assessed using the paint deterioration rating scale (Appendix 9.4).

11 Residual biofouling cover should be assessed using the methods described in Sections 3.1.2, 4.1.1, 4.2.2 and Appendix 9.1.

12 Residual biofouling type should be assessed using methods described in Sections 3.1.2, 4.2.4, and Appendix 9.1.

13 Number of passes and turns made with the system, and whether the specified number of passes/turns was completed (if this wasn't possible, reason/s why must be provided).

14 Estimates of the amount of biofouling dislodged from the vessel during system operation should be made using the methods described in Sections 3.2.5, 3.3.5, 3.4.5, and 3.5.4.

15 Assessment of leakage from the shroud and damage to its integrity should be made using the methods described in Section 3.1.10.

16 Monitoring of conditions achieved by surface-treatment and shrouding systems should conducted according to the methods described in Sections 3.2.3.2.1, 3.3.3.2.1, 3.4.3.2.1, and 3.5.3.1.

17 The lethal agent is the method used to render the biofouling non-viable as specified in the SOP. This could be a biocide, de-oxygenation or a physical treatment such as elevated temperature. Values for the lethal dose (LD_{100}) of the agent and duration of treatment required at that dose to achieve 100%

mortality (LT_{100}) should also be specified in the SOP. The dose achieved during treatment should be expressed in the same measurement units as the LD_{100}.

18 Estimate of percent viability for each taxonomic biofouling group obtained from image/video analysis (see Section 3.1.9.1 and Appendix 9.2).

19 Number of viable organisms from each taxonomic biofouling group recorded in samples taken following completion of the treatment (see Section 3.1.9.2 and Appendix 9.2).

Table 9-3. Douglas Sea Scale (adapted from World Meteorological Organization).

State of the sea (wind sea)		
Degree	Wave height (m)	Description
0	0 (no wave)	Calm (glassy)
1	0–0.1	Calm (rippled)
2	0.1–0.5	Smooth (wavelets)
3	0.5–1.25	Slight
4	1.25–2.5	Moderate
5	2.5–4	Rough
6	4–6	Very rough
7	6–9	High
8	9–14	Very high
9	> 14	Phenomenal

Swell		
Degree	Swell wave length (m)/height (m)	Description
0	0/0	No Swell
1	< 100/< 2	Very low (short and low wave)
2	> 200/< 2	Low (long and low wave)
3	< 100/2–4	Light (short and moderate wave)
4	100–200/2–4	Moderate (average and moderate wave)
5	> 200/2–4	Moderate rough (long and moderate wave)
6	< 100/> 4	Rough (short and heavy wave)
7	100–200/> 4	High (average and heavy wave)
8	> 200/> 4	Very high (long and heavy wave)
9		Confused (wavelength and height indefinable)

9.4 SUMMARY GUIDE FOR ASSESSING DAMAGE TO ANTI-FOULING COATINGS

Sourced from *Naval Ships' Technical Manual (2006), Chapter 081, Waterborne underwater cleaning of Navy ships, Revision 5. S9086-CQ-STM-010.*

081-1.4 PAINT DETERIORATION RATING (PDR) SCALE

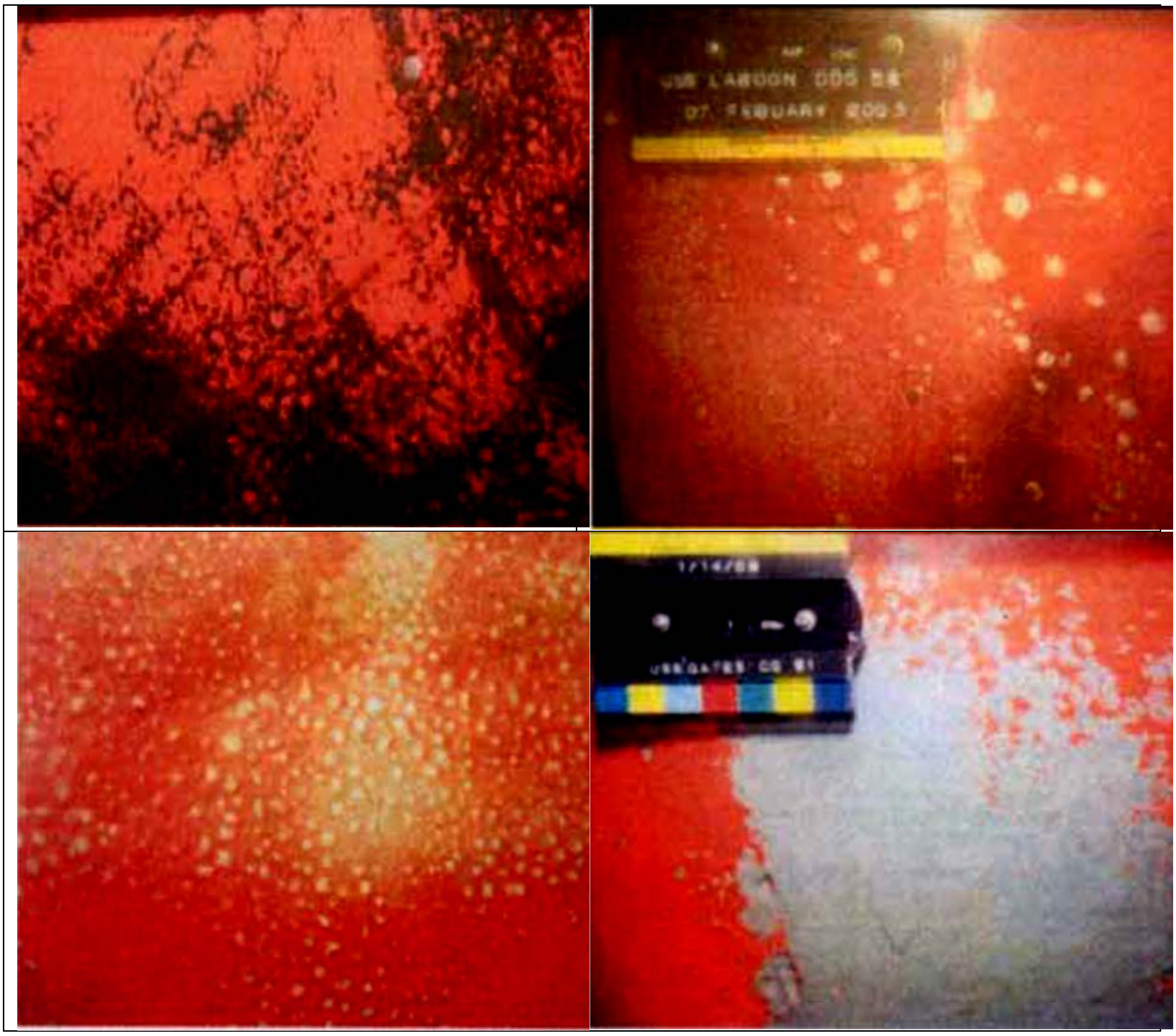
081-1.4.1. The paint deterioration ratings describe the hull coating condition and assigns a numerical rating of increasing severity on a scale from PDR-10 to PDR-100 in 10-point increments. Figure 081-1-2 provides photographs representing this scale. The first three ratings (PDR-10 through PDR-30) represent anti-fouling painted surface appearances associated with normal physical wear due to underwater cleaning action or hydrodynamic effects. The rating of PDR-40 is significant in that it indicates either excessive cleaning actions or blistering due to internal failure of the paint system. Such blisters are not the result of cleaning, but may not be noticed until after a cleaning operation. Failure at the anti-corrosive/anti-fouling interface results in a softer blister (PDR-40) which is more likely to be broken by cleaning. Relatively hard blisters (PDR-50) which have survived cleaning indicate a probable failure at the anti-corrosive/steel interface. Subsequent ratings of PDR-60 to PDR-100 indicate advancing deterioration of the entire anti-corrosive/anti-fouling paint system. Whenever a rating of PDR-40 or higher is found over a substantial portion of the hull, consult paragraphs 081-2.1.8 and 081-2.1.8.1 before planning any future hull cleaning actions.

Figure 9-2. Paint deterioration ratings (PDR) (11 images).

PDR-10. Anti-fouling paint intact, red in colour or with mottled pattern of light and dark red (no brush swirl marks).

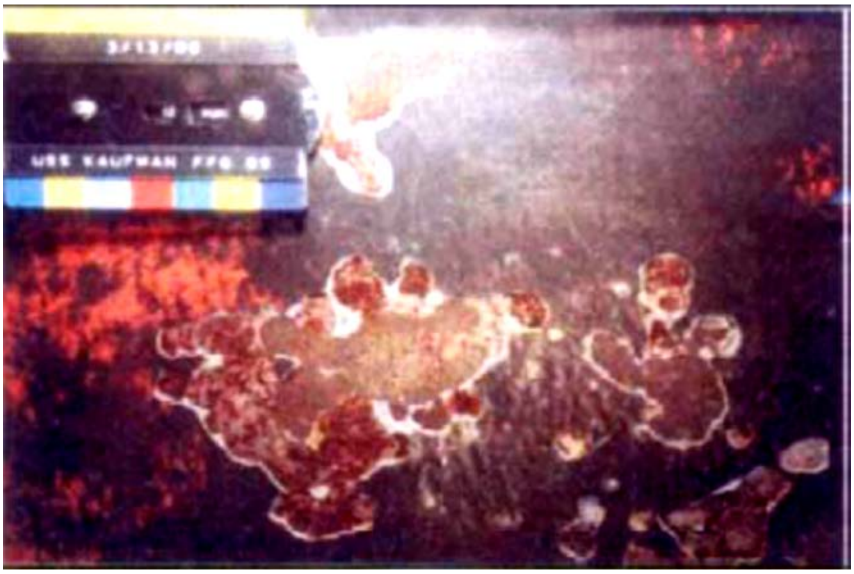
PDR-20. Anti-fouling paint missing from edges, corners, seams, welds, rivets or bolt heads to expose anti-corrosion paint.

PDR-30. Anti-fouling paint missing from slightly curved or flat areas to expose underlying anti-fouling or anti-corrosion paint or an anti-fouling paint with visible brush swirl marks within the outermost layer; not extending into any underlying layers of paint.



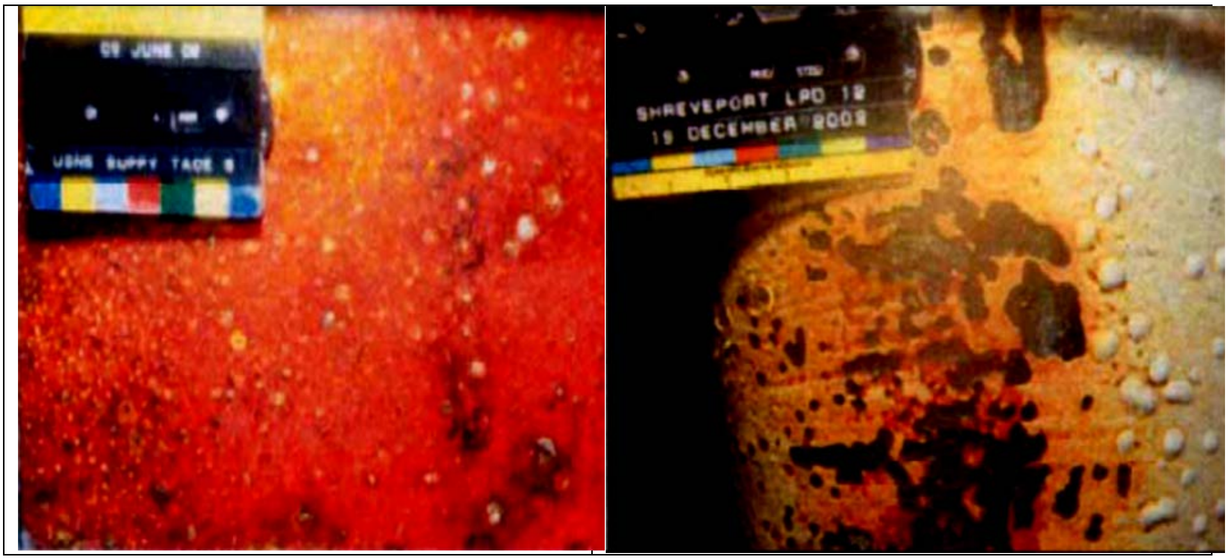
PDR-40. Anti-fouling paint missing from intact blisters to expose anti-corrosion paint or an anti-fouling coating with visible brush swirl marks exposing the next underlying layer of anti-fouling or anti-corrosion paint.

PDR-50. Anti-fouling blisters ruptured to expose anti-corrosion paint.



PDR-60. Anti-fouling/anti-corrosion paint missing or peeling to expose steel substrate, nor corrosion present.

PDR-70. Anti-fouling/anti-corrosion paint removed from edges, corners, seams, welds, rivets or bolt heads to expose steel substrate with corrosion present.



PDR-80. Ruptured anti-fouling/anti-corrosion blisters on slightly curved or flat surfaces with corrosion or corrosion stains present.

PDR-90. Area corrosion of steel substrate with no anti-fouling/anti-corrosion paint cover due to peeling or abrasion damage.

PDR-100. Area corrosion showing visible surface evidence of pitting, scaling and roughening of steel substrate.

9.5 ESTIMATING THE NUMBER OF SAMPLES NEEDED TO DETECT FAILURE OF CLEANING

The Hypergeometric Distribution can be used to estimate the probability of an event when a sample is taken without replacement from a finite population (i.e., where the sample forms a reasonable proportion of the population and the outcomes in successive sample units are dependent). Using this distribution, the probability of detecting x quadrats with biofouling in them in a sample of n quadrats is given by the equation:

$$P(x) = \frac{\binom{k}{x}\binom{N-k}{n-x}}{\binom{N}{n}},$$

where

x = the number of quadrats with biofouling in the sample;
k = the number of quadrats with biofouling in the cleaned area;
n = the number of quadrats in the sample;
N = the total number of quadrats in the cleaned area.

The probability of no quadrats containing biofouling in a sample of n is, therefore, calculated as:

$$P(x = 0) = \frac{\binom{k}{0}\binom{N-k}{n}}{\binom{N}{n}},$$

Thus, the probability of obtaining one or more quadrats in the sample that contain biofouling is given by:

$$P(x \geq 1) = 1 - P(x = 0).$$

9.6 TESTING USING PANELS

9.6.1 General considerations

Panel testing is not a mandatory requirement for system testing and approval. However, panel testing allows the system performance to be assessed on standardised levels of biofouling and on biofouling organisms with different strengths of attachment. It is most relevant to manual and mechanical systems that involve physical removal of biofouling. However, test panels may also be used to evaluate the efficacy of surface-treatment and some shrouding systems, particularly for range-finding studies to determine the intensity and duration of treatment that is needed to achieve the performance standard (e.g., Piola and Hopkins 2012). Panel testing also allows a level of replication and assurance that may be difficult to achieve using actual vessels due to availability.

Panel testing *does not remove the requirement for testing on actual vessels* because it does not allow system assessment under realistic conditions relating to the scale and structural complexity of the working environment and the associated logistical problems. These may include dislodgement of material by dragging hoses or other equipment across the hull and the need to manoeuvre the system among different parts of the vessel. Panel testing can also be relatively expensive (Section 9.6.7) because of the costs of materials, manufacture and preparation (including painting and development of biofouling).

Advantages of panel testing include:

- panels can be used to test most system types for manual, mechanical, surface-treatment and shrouding of biofouling, from handheld tools to larger brush carts, ROVs and robots;
- panels can be deployed within field or laboratory test systems to determine the efficacy of surface-treatments or lethal agents on different groups of biofouling organisms;
- panels are readily accessible and available, and can be used as a stepping stone to full testing on vessels when access to actual vessels is limited and spread over long periods of time;
- high levels of replication and repeatability are possible;
- fouling can be developed at the testing location, reducing the biosecurity risk of testing;
- different types of coating(s) can be incorporated into tests, providing information in support of approval for use from coating manufacturers (though manufacturers may have their own testing requirements);
- if biocide-free coatings are used, no biocide is released during cleaning, facilitating or avoiding the need for resource consent;
- panels can be used to test part or full systems (including waste collection system), to allow staged development of in-water systems.

Because it is not a mandatory requirement, testing on panels can be done with or without independent scientific supervision. However, the results will not be taken into account by MPI unless an independent, suitably qualified supervisor is present.

This section provides technical guidance for undertaking system testing using panels.

9.6.2 General conditions for implementing the test

9.6.2.1 Manual and mechanical cleaning

The performance standard for manual and mechanical systems is that all biofouling must be removed (to the requirements detailed in Section 2.1).

The conditions necessary for testing manual and mechanical systems include:

- each panel shall be large enough to accommodate at least two passes of the cleaning head with turns at the end of each pass (at least one turn), and each pass shall be at least two times the length of the cleaning head;
- the panel must be low enough in the water that the wind-water line is accessible, if this region is to be included in the testing;
- test cleaning should be carried out during periods of slack water, with current speeds of no more than 1 kn (~ 50 cm s^{-1}), in order to aid the independent supervisor(s) in observing cleaning operations (Section 4.3.2);
- test cleaning should be done at locations and times when water clarity (measured as vertical Secchi disk depth) is at least 2 m (Section 4.3.3).

9.6.2.2 Surface-treatments

The performance standard for surface-treatments is that all biofouling shall be rendered non-viable (Section 2.3).

The conditions necessary for testing surface-treatment systems include:

- each panel shall be large enough to accommodate at least two, partially overlapping applications of the surface-treatment;
- the panel must be low enough in the water that the wind-water line is accessible, if this region is to be included in the testing;
- testing should be conducted during periods of slack water, with current speeds of no more than 1 kn (~ 50 cm s^{-1}), in order to aid the independent supervisor(s) in observing system operations (Section 4.3.2);
- testing should be conducted at locations and times when water clarity (measured as vertical Secchi disk depth) is at least 2 m (Section 4.3.3).

9.6.2.3 Shrouding systems

The performance standard for shrouding systems is that all biofouling shall be rendered non-viable (Section 2.3).

The conditions necessary for testing shrouding systems include the following:

- each panel should be able to be covered by a shroud and treated independently of other panel and treatment replicates;
- the panel must be low enough in the water that the wind-water line is accessible, if this region is to be included in the testing;
- the method in which the shroud is used to enclose each panel should accurately replicate the intended treatment for vessels;
- testing should be conducted during periods of slack water, with current speeds of no more than 1 kn (~50 cm s^{-1}), in order to aid the independent supervisor(s) in observing system operations (Section 4.3.2);
- testing should be conducted at locations and times when water clarity (measured as vertical Secchi disk depth) is at least 2 m (Section 4.3.3).

9.6.3 Testing method

Depending on the proposed end-use of the system, panels must be prepared sufficiently in advance to allow the appropriate levels of biofouling to develop (this may require panels to be deployed at three different times, one for moderate soft biofouling, one for moderate hard biofouling and one for heavy hard biofouling) (see Section 3.1.2):

- slime (FR 20 or less). In-water removal or treatment of slime is considered to be of low biosecurity risk and systems intended for use only on slime do not require testing under the present framework;
- if the system is intended to remove or treat moderate (soft) biofouling, the panel shall have macrofouling present of FR 30 and 16-40% cover;
- if the system is intended to remove or treat moderate (hard) biofouling, the panel shall have macrofouling present of FR 80 and 16-40% cover;
- if the system is intended to remove or treat heavy (hard) biofouling, the panel shall have macrofouling present of FR 90 or greater and > 40% cover.

The panels should be composed of a rigid material, such as steel, aluminium or glass-reinforced plastic to replicate that of a vessel hull.

The panels should be submerged in seawater to allow biofouling to develop to the level appropriate for the intended use of the system under test (moderate (soft), moderate (hard) or heavy (hard)). It is noted that the appropriate duration of deployment required for biofouling to develop cannot be predicted in advance because biofouling development varies with location, season and other factors. As a guide, moderate biofouling is likely to take several months to develop (e.g., Hopkins *et al.* 2008). The developer should ensure that the required levels of biofouling are achieved.

Panels should be attached to a solid structure in a way that allows the system under test to be operated in its intended manner.

The panel should be submerged to a depth that allows the system to be operated as intended, taking into consideration what is being tested. For example, panels intended to test the efficacy of cleaning at the air-water interface (i.e., wind-and-water line) will obviously be at a shallower depth than those that are not.

Before the test begins, the independent supervisor should determine the biofouling rating and percentage cover in each of the replicate panels (Section 3.1.2 and Appendix 9.1). The independent supervisor should also determine the state of the anti-fouling coating (Appendix 9.4). Each panel should be recorded by video or digital still imaging before testing (Section 3.1.8) for purposes of auditing the assessment of biofouling rating and cover and coating condition.

9.6.3.1 Manual and mechanical cleaning

For testing manual and mechanical systems, one set of six panels should be coated with a non-biocidal, anti-corrosive coating (abrasion-resistant and strong biofouling attachment) and a second set of six with (non-biocidal) foul-release coating system (abrasion-susceptible, weak biofouling attachment).

For manual and mechanical systems, the six replicate panels of each paint type should be cleaned in the manner in which the system is intended to be used on an actual vessel. The cleaning head should make at least two partly overlapping passes across the panel with at least two turns at the end of each pass, consistent with the proposed use of the system.

9.6.3.2 Surface-treatment and shrouding systems

For surface-treatment and shrouding systems that use biocides or other lethal agents (e.g., heat, deoxygenation, etc.), panel tests should be designed to determine the acute, single dose or concentration of the treatment that is lethal to 100% of the test organism(s) (LD_{100}) and the period of exposure (LT_{100}) needed to achieve 100% mortality at the at the test concentration or dose. Sixteen test panels should be coated with a non-biocidal, anti-corrosive coating. One set of four panels should be exposed to the treatment for the duration it is intended to be used on an actual vessel or part of a vessel. A second set of four panels will be exposed for half the duration intended and a third set of four panels will be exposed to the treatment for twice the duration intended. The remaining set of panels will not be treated and will serve as a control for natural mortality of the organisms during the test.

9.6.4 Assessing system efficacy

After cleaning or treatment, each of the panels should be videoed or photographed, covering the entire test area. As stipulated in Sections 3.1.8 and 3.1.9.1, the images must show labels with the location of the cleaned or treated area on the panel and of the image within the test area. Scale objects must also be included in each image (Section 3.1.8).

9.6.4.1 Manual and mechanical systems

The independent supervisor should randomly select the post-cleaning images from three of the six replicate cleaned panels coated with each paint type, and examine each image in its entirety for the presence and type of any residual biofouling 0.5 cm in diameter or larger (Section 4.1.1).

The size and type (Section 3.1.2) of any biofouling detected should be recorded against the image identifier (file name) and description of location of the biofouling within the cleaned area, namely whether it was in the general area of the pass of the cleaning head or the turning area between passes. The independent supervisor should also describe the condition, including any damage, of the biofouling present. Information will be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Appendix 9.3), or to a paper version and later transferred to an electronic version.

The presence of any residual biofouling (0.5 cm in diameter or larger) in any of the cleaned areas constitutes a failure to meet the performance standard (Section 2).

Paint condition should also be assessed to identify any physical damage caused by cleaning (Appendix 9.4).

9.6.4.2 Surface-treatment and shrouding systems

The independent supervisor should examine each post-treatment video to assess the viability of the remaining biofouling (Section 4.1.3). Viability will be detected in the video as active movement of organisms for feeding or other life functions (Appendix 9.2). The size and type (Section 3.1.2) of any viable biofouling detected should be recorded against the image identifier (file name) and a description of location of the biofouling within the treated area (e.g., by reference to the minute and seconds in the video at which the viable biofouling is detected).

The independent supervisor should remove a randomly selected 25 cm^2 area of biofouling from each test panel. Samples should be removed manually (i.e., by hand or using a paint scraper) taking care to ensure that the organisms are not damaged during removal. The samples should be placed into labelled, sealable water-tight bags (e.g., zip-lock bags) or containers for transfer to shore. Samples must not be exposed to air and strong sunlight prior to examination on-shore, as this may confound any assessment of viability.

The independent supervisor should examine the samples of biofouling removed from the test panels for signs of viability (Appendix 9.2). The presence of any viable biofouling organisms on any of the panels treated for the intended period or longer constitutes a failure to meet the performance standard (Section 2.3).

Paint condition should also be assessed to identify any physical damage caused by the treatment (Appendix 9.4).

Information should be recorded directly to an electronic spreadsheet (e.g., Microsoft Excel) version of the data sheet template (Section 9.3.2), or to a paper version and later transferred to an electronic version.

9.6.5 Assessing containment and waste capture efficacy

A diving observer must observe and record on video the test process, including set-up and demobilisation, to assess the amount of material dislodged from the hull outside each test area, and the amount of material removed but not captured (Section 4.3.5). The video may be recorded by the independent supervisor (using Underwater Breathing Apparatus (UBA)) or by a diver under the direction of the independent supervisor using surface-to-diver communications. When the test area includes the wind-and-water line, a video should also be taken from both in and out of the water, to assess if any biofouling is dislodged at the water-air interface.

For systems that use suction to capture waste, the area of effective capture around the system should be estimated by video recording the use of a visible, non-toxic tracer dye, such as fluorescein sodium salt, Basic Blue 3 or Rhodamine WT Red. During each replicate test, 50 mL aliquots of the dye (at a minimum concentration of 4 g L^{-1}) should be released slowly from a syringe at 10, 25 and 50 cm from system operation. Effective capture will be indicated by strong directional movement of the dye toward the point of suction. The independent supervisor will make visual observations of the dye movement from each position and shall ensure that the releases are recorded on video.

For shrouding or treatment systems applied to whole vessels, a diving observer must observe and record on video any leakage from the (Section 3.1.10).

After completion of the trial, the video will be assessed for evidence of material being dislodged from the hull over the entire process, subsequent capture of this material, and leakage from the system itself. This assessment shall be included in the reporting template (Appendix 9.3).

Each video recording shall include a label at the start of the recording indicating the date of the test, name of the system being tested, name of the vessel, type and replicate number of the test area.

Leakage from the shrouding or treatment systems or dislodgement of any macroscopic particles > 0.5 cm diameter during system set-up, operation or demobilisation represents a failure to meet the performance standard (Section 2).

9.6.6 Reporting

Using the templates in Appendix 9.3, the independent supervisor should report on each of the following:

- *general requirements*:
  - including panel material and environmental conditions during the test (Section 3.1.5);
- *before cleaning or treatment*:
  - type, level (FR) and cover (%) of biofouling present on each test panel;
  - type and condition of anti-fouling coating;
    - the video or still image(s) on which these assessments were made are to be provided with the report;
- *during cleaning or treatment*:
  - *surface-treatments and shrouding systems*
    - the results of samples taken to monitor conditions (e.g., concentration of the lethal agent, temperature, oxygen and sulphide levels) achieved during the treatment, including where and when the samples were taken and the total duration of treatment (Section 3.4.3.2.1);
- *after cleaning or treatment*:
  - *manual and mechanical cleaning* - the amount and type of residual biofouling on each of the test panels:
    - type of biofouling (Section 3.1.2);
    - number of patches and size of each patch;
    - location within the test area;
    - relevant image identifier (file name);
    - a description of the condition of any residual biofouling;
  - *surface-treatments and shrouding systems*- the amount and type of viable biofouling observed in video recordings of each replicate test panel including:
    - a description of the general condition of the biofouling present, including signs of physical damage, change in pigmentation and morbidity (Appendix 9.2);
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability Appendix 9.2) and their location on the panel;
    - relevant image identifier (file name);
  - *surface-treatments and shrouding systems*- the amount and type of viable biofouling recorded in each replicate sample of biofouling removed from the test panels, including:
    - a description of the number, size and type of biofouling organisms (Section 3.1.2) that exhibited indications of potential viability (Appendix 9.2);
    - relevant sample identifier (i.e., test replicate identifier);
  - *all systems*:
    - condition of the anti-fouling coating or surface on each test panel;
      - the video or still images on which these assessments were made are to be provided with the report;

- qualitative assessment of loss of material by dislodgement from the panel during the test, based on examination of video recording (Section 3.4.5):
  - the video images from which this assessment of loss of material was made are to be provided with the report;
- discussion of system efficacy including whether the system met the relevant performance standard (see Sections 2.1 and 2.3);
- recommendations for system or SOP improvement.

9.6.7 Feasibility and costs

Testing on panels is relatively easy to set up because it is not dependent on the availability of suitably fouled vessels. Testing can be done in locations, such as marinas, that are suitably sheltered and close to facilities (e.g., power, land access, waste disposal). Maximal control of test conditions is possible and replication is relatively easy and cheap.

However, planning must be done months in advance to allow plates to develop the required biofouling in time for testing.

Panels should also replicate the conditions encountered on the hull (i.e., they should not move or flex during application of cleaning systems). Therefore, consideration should be given to their attachment to supporting structures.

The main disadvantage of testing on panels is the lack of realism in the scale and complexity of the surface being tested.

Costs incurred during the efficacy testing of in-water cleaning/treatment and capture systems using panels are likely to be highly variable (Table 9.2). A minimum of two separate sources for the cost of each test item have been averaged. The main assumption is that, given the number of replicate test panels, *in situ* testing could take a minimum of two days to complete. Specific costing assumptions are listed in the Table notes. Costs associated with shrouding (Table 5-1) are not included as these systems are less likely to be used in panel testing.

Table 9-4. Indicative costs associated with the testing of in-water testing of cleaning/treatment and capture efficacy utilising paint panels under realistic operating conditions.

Test item	Indicative cost (NZ$)	Units	Total cost
Test panels (n = 36)[1]	$61 200	1	$61 200
Vessel berth/wharf face (20–30 m length)	$65 per day	2	$130
Site power/generator	$50/$525 per day[2]	2	$100/$1 050
Crane truck/forklift (< 5 tonne)	$1 408/$800 per day[3]	2	$2 816/$1 600
Dive contractor	$1 960 per day[4]	2	$3 920
Scientific contractor (field)	$4 800 per day[5]	2	$9 600
Scientific contractor (report)	$14 250[6]	1	$14 250
Waste disposal	$5 per kg of solids[7]	1	$5 per kg of solids

Notes

1 Thirty-six test panels (4 m long x 1.2 m wide) at $1 700 per panel. Panel cost includes panel material (e.g., steel), preparation (e.g., sandblasting and primer) and anti-fouling coatings. Six replicate panels for two types of anti-fouling coating and three levels of biofouling for each coating type.

2 For example, 32-amp power cables, power transformer, splitter box or 250-KvA generator. Excludes power/fuel costs.

3 Based on hourly rates of $176 (truck)/$100 (forklift) per hour (includes driver) for an 8-hour day.

4 Based on a single three diver commercial team for an 8-hour day at $245 per hour. Travel time/costs to/from test location additional. Does not include sampling materials/sundries that may need to be purchased (e.g., sampling quadrats, mesh bags etc.).

5 Based on a four-person science provider team to ensure independence of testing. This team comprises a three-person in-water cleaning/treatment field team (one diver, one standby diver and one surface support/skipper) to assess *in situ* efficacy (via videoing of the system in operation for waste capture, knocking off of biofouling, efficacy of waste treatment system etc.), and one person assessing the efficacy of the waste treatment system, for a 7.5-hour day at $160 per hour, averaged across Technician/Scientist classifications. Travel time/costs to/from test location additional. Does not include sampling materials/sundries that may need to be purchased (e.g., sampling quadrats, mesh bags etc.).

6 Based on a single science provider for a 7.5-hour day at $190 per hour for a Senior Scientist to spend a total of 10 days on project set-up/management, client liaison, and reporting (including internal peer-review of report) pertinent to the testing framework.

7 Based on disposal to landfill by approved waste transporter/handler as industrial/contaminated waste. Minimum weight requirements for collection and disposal by commercial waste companies may apply. Conditional upon Resource Management Act 1991 (RMA) and Hazardous Substances and New Organisms Act 1996 (HSNO). Waste could be regarded as industrial/contaminated waste due to possible anti-fouling coating contamination, and inherent biological material.