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THE NATIONAL SYSTEM FOR THE PREVENTION AND
MANAGEMENT OF MARINE PEST INCURSIONS

Review of biosecurity and contaminant risks associated with in-water cleaning

Keeping marine pests out of Australian waters

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Review of biosecurity and contaminant risks associated with in-water cleaning

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Note

While every effort has been made to identify all current in-water cleaning technologies available to vessel owners and operators, some may not be contained in this review. This may be the case for overseas technologies or initiatives that are not yet published on the internet and which our points of contact for in-water cleaning technologies may not have been aware of. Some details or test results of reviewed technologies may have been deliberately kept confidential on the basis of patent or commercial development processes and were therefore not available for inclusion in this review.

Executive summary

In 1997, the Australian and New Zealand Environment and Conservation Council (ANZECC) developed the Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance (hereafter referred to as the ANZECC Code). The ANZECC Code was developed out of dual concerns over the toxic effects of antifouling biocides on the marine environment and the potential of in-water ship hull cleaning practices to facilitate the establishment of marine non-indigenous species (NIS).

The ANZECC Code describes practices that prevent the release of toxic chemicals and biofouling organisms into the marine environment. It prohibits in-water cleaning of vessels unless a permit is granted by the relevant management authority. The ANZECC Code is currently at variance with the International Convention on the Control of Harmful Antifouling Systems on Ships, ratified by Australia in 2007, because it accepts the use of tributyltin-based antifouling coatings.

Over the past decade, progress has been made internationally with the development of non-biocidal antifouling coatings and novel hull cleaning technologies that reduce the risk of releasing contaminants or biofouling organisms into the marine environment. This report represents a literature review and analysis of the benefits and risks of in-water cleaning associated with currently available cleaning technologies, and considers whether an alternative approach to the current protocols within the ANZECC Code is appropriate.The main findings of our review are as follows:

- Modern biocidal antifouling coatings use a wide range of primary and 'booster' biocides, including copper, iron, zinc, diuron, irgarol 1051 and others. There is a lack of empirical data on the effects of many biocides on marine organisms and ecosystems. However, an increasing number of studies suggest that most of the biocides used in modern antifouling coatings are highly toxic to a wide range of aquatic non-target organisms.
- Progress has been made with developing non-biocidal coating types. The currently most widely used system are fouling-release coatings that prevent the firm adhesion of biofouling organisms. Biofouling prevention of these coatings requires either fast vessel speed or regular in-water cleaning. Another emerging non-biocidal technology is mechanically resistant coatings, or surface treatment coatings. These coatings are intended to be used in combination with regular hull cleaning.

- The principal in-water hull cleaning technologies currently available or in development are systems using brush or underwater jet (hydro-blast) technology to remove biofouling from hull areas. Heat treatment and hull encapsulation are technologies currently in development. Each technology has shortcomings:
    - None of the brush-based or water jet systems reviewed are demonstrably able to remove 100 per cent of biofouling from targeted surfaces or to contain 100 per cent of the removed material. Many systems are unable to access and clean niche areas (hull recesses or protrusions). In addition, brush-based and water jet systems can be abrasive and damage antifouling coatings. These systems are currently associated with a high risk of releasing biocidal coating material and potentially NIS into the surrounding environment.
    - Heat treatment technology is being developed for proactive treatment to prevent the development of biofouling beyond the primary successional stage (microbial films and algal biofouling). Heat treatment is not available for treatment of extensive, tertiary biofouling, and is unable to treat biofouling in niche areas. This technology is also currently only available for large commercial vessels. This is a technology in development and independent evaluations of its effectiveness or effects on antifouling coatings are not available.
    - Encapsulation of vessels using plastic sheeting or specially designed envelope systems can be an effective way of killing biofouling on a vessel provided that the encapsulation system is installed correctly. This is a technology in development and independent evaluations of its effectiveness or effects on antifouling coatings are not available.
- In-water hull cleaning is generally significantly cheaper than removing a vessel from the water for cleaning. This is because of differences in the direct costs of cleaning methods and the potentially substantial indirect costs (losses in revenue) associated with shore-based cleaning of commercial vessels.
- We evaluated the environmental (biosecurity and contamination) and economic risks associated with different methods for in-water and shore-based hull maintenance based on four risk factors: biofouling origin (local or foreign), biofouling extent, antifouling coating type and cleaning method. Based on the results of our evaluation, we make the following suggestions:
    - In-water cleaning should be permissible only on vessel surfaces that are coated in non-biocidal antifouling coatings or no coating at all, and where biofouling is restricted to a slime layer (primary biofouling).

  - In-water cleaning of surfaces containing secondary and tertiary biofouling should be permissible only if the biofouling is of local origin.
  - In-water cleaning should be permissible only if the cleaning method does not damage the antifouling coating.
  - In-water cleaning of hull or niche area surfaces coated in biocidal antifouling coatings should not be permissible because commercially available in-water cleaning technologies are currently not able to capture and contain all biological and paint waste released during the cleaning process. This is a particularly high risk in instances where abrasive or high-pressure cleaning exposes older antifouling coatings that contain TBT.
  - Heat treatment and enveloping technologies are developing technologies. They should at this stage not be regarded as appropriate in-water cleaning methods because their effectiveness, associated environmental risks and impacts on antifouling coatings are not fully understood. This should be revised once conclusive and independent test results become available.
  - Biofouling often occurs principally in niche areas that are (frequently) not coated in antifouling paints. Many niche areas are important for the operation of vessels and need to be maintained. Vessel owners and operators should be encouraged or required to take proactive measures that prevent the development of mature biofouling in niche areas. This can be achieved by frequent in-water cleaning (before calcareous growths occur) and/or the use and performance monitoring of marine growth prevention systems (MGPSs).
  - The development of in-water cleaning technologies that more effectively capture biofouling and coating waste should be encouraged, as it would result in a higher level of acceptability for in-water cleaning of surfaces coated in biocidal paints and/or containing biofouling from foreign sources.
- Our evaluations of risk are intended as a starting point for discussion, and will benefit from discussion with, and feedback from, managers and stakeholders.

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1. Introduction

1.1 Background to development of the ANZECC Code

The build-up of biofouling—marine plants and animals that grow on submerged surfaces—is an impediment to efficient operation of sea-going vessels. It imposes penalties on vessel performance, fuel consumption and cooling systems (Woods Hole Oceanographic Institution 1952; Christie and Dalley 1987). Owners and operators of vessels spend significant sums of money on measures to prevent biofouling and to remove accumulated growth. Prevention is most commonly achieved through application of antifouling coatings on the vessel, which leach toxic chemicals that inhibit settlement of marine organisms. Several of these chemicals, most notably the organotin compound tributyltin (TBT), have been shown to accumulate in the marine environment and to have significant effects on non-target marine organisms (AMOG 2002).

Biofouling is also an important vector for the carriage of NIS (Carlton 2000). Recent studies suggest that vessel biofouling may rival ballast water in the diversity and number of species transported (Drake 2007) and that it may contain a larger proportion of NIS (Gollasch 2002). Therefore, removal of biofouling and/or maintenance of paint surfaces while the vessel is in the water, entail two types of environmental risk:

1. the release and accumulation in the marine environment of toxic contaminants from paint coatings
2. the release of NIS (as adults, larvae or viable gametes) into environments where they would not normally occur (Minchin and Gollasch 2003).

The ANZECC Code was released in 1997 to provide guidance to boat owners, industry and government in Australia and New Zealand on the appropriate:

- application, use, removal and disposal of antifouling coatings
- practices for in-water cleaning and maintenance of vessels.

Development of the ANZECC Code was prompted by the dual concerns (highlighted above) over the toxic effects of antifouling biocides (particularly TBT and copper-based compounds) on the marine environment and the potential to facilitate the establishment of unwanted exotic species. The ANZECC Code describes practices that should be avoided to prevent release of toxic chemicals and exotic species into the marine environment and recommends protocols to contain potentially harmful waste. It prohibits in-water cleaning of vessels except by permit.

The second part of the ANZECC Code (in-water cleaning and maintenance) only applies to commercial vessels. There appears to be no single official definition for a commercial vessel in Australia. The closest term for commercial vessel mentioned in Australia's *Navigation Act 1912* is 'trading ship', which is defined as:

> *a ship that is used, or, being a ship in the course of construction, is intended to be used, for, or in connection with, any business or commercial activity and, without limiting the generality of the foregoing, includes a ship that is used, or, being a ship in the course of construction, is intended to be used, wholly or principally for:*
>
> *a. the carriage of passengers or cargo for hire or reward; or*
>
> *b. the provision of services to ships or shipping, whether for reward or otherwise;*
>
> *but does not include a Commonwealth ship, a fishing vessel, a fishing fleet support vessel, an offshore industry mobile unit, an offshore industry vessel to which this Act applies, an inland waterways vessel or a pleasure craft.*

The ANZECC Code thus applies to merchant vessels such as bulk carriers and tankers, as well as to passenger (cruise) vessels, but not to fishing vessels or ships owned by the Australian Government. The code does allow for exemptions to be granted to commercial vessels 'under extraordinary circumstances'. In-water cleaning of sea chests, sea suction grids and propellers of commercial vessels may be permitted provided that:

- all biological material removed from these structures is captured and contained
- permission to carry out this work has been granted by the regional or local administering authority (ANZECC 1997).

In 1999, the International Maritime Organization (IMO) adopted an Assembly resolution that called on its Marine Environmental Protection Committee (MEPC) to develop a global, legally binding instrument to address the harmful effects of TBT contained in antifouling coatings (Champ 2003). These efforts resulted in the International Convention on the Control of Harmful Antifouling Systems on Ships (the AFS Convention). The AFS Convention entered into force internationally and for Australia on 17 September 2008. It is implemented in Australia through the *Commonwealth Protection of the Sea (Harmful Anti-fouling Systems) Act 2006*. The AFS Convention banned TBT-based antifouling coatings from being applied to any vessels from January 2003, and from being present on any vessels from January 2008.

Now that the AFS Convention is in force, certain sections of the ANZECC Code are at variance, as it indicates that TBT-based antifouling coatings may be used on vessels greater than 25 m in length in Australia. In recent years, there have also been significant changes within the maritime industry regarding the use of different antifouling technologies and a concomitant increase in the use of products that contain alternative biocides or technologies. Some modern paint types, such as fouling-release coatings, do not contain active biocides, but require high vessel speed or regular cleaning to provide effective protection from biofouling. The ANZECC Code currently prohibits in-water cleaning of any hull surfaces coated in antifouling paint. In-water cleaning of surfaces that lack biocides may not be associated with the pollution risks attributed to other types of paints. In addition, recent advances in in-water hull cleaning technology include the development of systems that are able to collect and retain biofouling and paint waste removed from a vessel's hull.

There is also growing acceptance of the possibility that a controlled form of in-water cleaning may create a smaller biosecurity risk than non-management of biofouling. Australia has recently developed national biofouling management guidelines for recreational, commercial (trading and non-trading) and fishing vessels, as well as the petroleum production and exploration industry (National System for the Prevention and Management of Marine Pest Incursions 2009 a,b,c,d,e). These guidelines encourage vessel owners to minimise biofouling through a high standard of vessel hygiene. In-water cleaning is strongly discouraged on the basis of the ANZECC Code. However, controlled in-water cleaning may be a viable option depending on factors such as limited availability of drydocking facilities, the origin of the biofouling, method of removal, containment and disposal and so on.

As a result, the Natural Resource Management Ministerial Council (NRMMC), which took over some of the functions of ANZECC in 2001, has agreed to a review of the ANZECC Code that includes a re-evaluation of the environmental and biosecurity risks associated with in-water cleaning of vessels.

1.2 Aims and objectives of the literature review

The objective of this literature review and analysis is to consider the benefits and risks of in-water hull cleaning, based on an understanding of current and proposed in-water cleaning techniques and technologies. The review will consider the appropriateness of protocols outlined within the ANZECC Code in the context of:

- current research and knowledge of the pollution and biosecurity risks associated with in-water vessel cleaning
- obligations under the AFS Convention
- implementation of the National System for the Prevention and Management of Marine Pest Incursions (the National System), including the recent development of national guidelines for biofouling management on vessels
- current Australian (Commonwealth, state and territory) and New Zealand processes for managing risks from marine pollutants and pests.

The particular aim of this report is to determine whether, and under what circumstances, it may be appropriate to permit in-water cleaning of vessels. To achieve this, we provide reviews of:

- developments in antifouling coatings technology, their properties and environmental effects
- developments in in-water hull husbandry technologies
- the economics of vessel hull maintenance
- current Australian and New Zealand regulatory processes to manage in-water hull cleaning.

We use these reviews to compare the relative environmental and economic risks associated with in-water hull cleaning and provide guidance as to whether and when in-water hull cleaning may be permissible.

2. Review of developments in marine antifouling coatings technology, their properties and environmental effects

The names and affiliations of individuals contacted for information presented in this section and all following sections are provided in Appendix 1.

2.1 Types of antifouling coatings and their characteristics

Antifouling coatings can be categorised into: a) those that control hull biofouling by releasing biocides and b) non-biocidal coatings, which either provide surface characteristics that inhibit the attachment and adhesion of biofouling organisms, use biocides that are not released into the water column or use natural biocides that have no contaminant effects in the marine environment (Table 2.1). In this section, we provide a review of antifouling coatings that are currently in use or in development.

Table 2.1 Antifouling coating types currently in use or in development on the global market

ANTIFOULING COATING TYPE	BIOCIDAL / NON-BIOCIDAL	MAIN BIOCIDES	MAIN USE	SERVICE LIFE*
Conventional soluble matrix	Biocidal	Traditionally copper, iron or zinc oxides (previously also arsenic and mercury)	All vessel types	CV: 48 mo RV: 24 mo
Conventional insoluble matrix/contact leaching / hard	Biocidal	Copper compound and booster biocides (usually diuron, chlorothalonil, thiram or zineb)	Commercial and recreational vessels	CV: 12-36 mo RV: 12-24 mo
Controlled depletion polymer (CDP)/ablative	Biocidal	Cuprous compound and booster biocides	Commercial and recreational vessels. Less suitable for high-speed vessels or tropical waters	CV: 36 mo RV: 24 mo
Self-polishing copolymer (TBT-free SPC)	Biocidal	Cuprous compound and booster biocides (usually 'new' biocides, including zinc pyrithione, copper pyrithione or Sea-Nine 211)	See CDP/ablative	CV: 60 mo RV: 24 mo
Hybrid coatings	Biocidal	Copper pyrithione is the most commonly used booster biocide for Hybrid SPC-CDP products	Developing technology	
Fouling-release	Non-biocidal; biofouling settlement/attachment deterrent	Biocide-free; the most successful coatings are based on silicone	High-speed vessels, or regular cleaning required	60+ mo if properly maintained
Natural biocides	Non-biocidal	Natural active compounds	Developing technology	
Biocide-free mechanically resistant	Non-biocidal; requires frequent cleaning treatment	N/A	Also referred to as Surface Treatment Coatings Increasing usage	10 years +
Biocide-free self-polishing copolymer	Non-biocidal	N/A	Developing technology	
Fibrous coatings	Non-biocidal; biofouling settlement deterrent	N/A	Developing technology – currently unproven	
Non-leaching biocidal	Non-biocidal	Toxins act on attached biofouling only, not released to marine environment	Developing technology	
Nanoparticle technology	Non-biocidal; biofouling settlement deterrent	N/A	Developing technology	
Electromagnetic and sonic deterrents	Non-biocidal; biofouling settlement deterrent	N/A	Developing technology – currently unproven	

* CV = commercial vessels
RV = recreational vessels
mo = months

2.1.1 Biocidal coatings

Antifouling coatings that contain biocides prevent or minimise biofouling growth by continuously releasing active agents from or through the coating surface. The performance, efficiency and effective life of a biocidal antifouling coating is limited by the mechanism and control of biocide release and the efficacy of the toxin. The rate of biocide delivery must be sufficient to maintain a concentration which is toxic to, or inhibits the success of, potential biofouling organisms over an extended period of time (AMOG 2002).

2.1.1.1 Conventional coatings

Biocide particles in conventional systems are physically dispersed within, or 'freely associated' with, the matrix of the antifouling coating. Seawater penetrates the surface of the coating, dissolving the biocide particles which then diffuse towards the surface and are leached (AMOG 2002). Two types of paint matrices are, or have been, employed: soluble matrix systems and insoluble matrix or contact leaching systems.
The primary biocide used in conventional coatings is usually a copper compound, combined with the secondary, 'booster' biocides diuron, chlorothalonil, thiram or zineb. Booster biocides have been developed to attain broader spectrum protection than can be achieved with a copper biocide alone (see Section 2.4).

Soluble matrix coatings

Soluble-type conventional coatings are based on a soluble resin matrix, usually rosin or a derivative of this compound. The acidic resin continuously dissolves when in contact with alkaline seawater, releasing the biocide at a constant but uncontrolled rate. The mechanical strength of this coating is poor because rosin is brittle and cracking or coating detachment may occur. For this reason, traditional soluble matrix coatings could only be applied in thin layers. Along with the constant, uncontrolled erosion and biocide release, this limited the effective life (the period over which the coating provides adequate protection against biofouling organisms) to 12 to 15 months (Almeida et al. 2007). Modern systems incorporate plasticiser into the resin, which reduces the solubility, increases the expected life span to three years and improves film-forming capacity (discussed below). Rosin also oxidises easily and is susceptible to damage by UV exposure, so rapid immersion (within 12 to 24 hours) is required after application. This characteristic also makes it an unsuitable coating for vessels that are drydocked or stored on hard-stands for extended periods. For coatings with high rosin content, high vessel speed can erode the matrix too quickly to provide an effective antifouling solution.

An additional downfall of this system is the accumulation of a thick, insoluble layer of leached materials at the coating surface. Along with deposition of cupric carbonate, a thick leached layer causes the inhibition of biocide discharge and reduced control over release rate, which declines exponentially for this antifouling system. This limits the antifouling performance and also results in increased surface roughness, which creates drag and influences vessel performance. The leached layer must be removed before recoating. Biocidal activity in stationary conditions is relatively weak, making this coating type unsuitable for slow-speed vessels or ships that remain idle for long periods (Almeida et al. 2007). Nevertheless, because of their relatively low cost, soluble matrix coatings are still commonly used on recreational vessels.

Traditionally, conventional soluble matrix coatings have incorporated copper, iron or zinc oxides, arsenic and mercury as biocides, fillers or pigments. The popularity of conventional soluble matrix coatings has declined as improved antifouling technologies have evolved and as restrictions on the use of environmentally hazardous chemicals become more stringent.

Insoluble matrix / contact leaching / hard coatings

Conventional insoluble matrix or 'contact leaching' systems are based on hard, porous resins that are insoluble and do not erode in seawater. Examples of these compounds include acrylic, vinyl, epoxy and chlorinated rubber polymers (AMOG 2002; Yebra et al. 2004). Mechanical strength is good in comparison to soluble matrix coatings, allowing thicker layers to be applied (Yebra et al. 2004) and higher concentrations of biocides to be incorporated (Almeida et al. 2007). The biocide particles near the coating surface are dissolved by seawater and released, exposing the underlying particles for subsequent release. As the process advances, seawater must penetrate deeper into the insoluble coating and the biocide particles must diffuse through the increasingly porous structure of the matrix and a thick layer of already-leached compounds.

The effective life of the coating is reliant on a sufficiently high biocide content to ensure contact between biocide particles and seawater. As with soluble matrix conventional coatings, the rate of biocide release is not well controlled; initially high then declining rapidly, along with protection efficacy, towards the end of the effective life. After approximately two years in service, the supply of biocide is reduced to insufficient levels to diffuse to the coating surface and achieve an effective rate of biocide release (AMOG 2002). Generally, the expected effective life of traditional insoluble matrix coatings is between 12 and 24 months. Modern hard-type formulations (which are usually based on modified epoxy matrices) now provide improved control over biocide release rates, particularly for copper-based coatings, increasing the effective life expectancy to between 24 and 36 months (Altex Yacht and Boat Paint 2008, but see Finnie and Williams 2009).

A shortcoming of the insoluble matrix system is that hull surfaces become progressively roughened by the residual 'empty' coating matrix, reducing ship performance (AMOG 2002) and resulting in a weak substrate. Sealing or removal is then required before new coatings can be applied. This 'honeycomb' structure can also retain impurities from the seawater, which may block the release of biocides (Almeida et al. 2007).

An advantage of this coating type is that the hard, insoluble matrix is resilient to damage by oxidation, reducing drydocking problems (Almeida et al. 2007). Of the antifouling coatings commonly used today, hard-type coatings provide the best resistance to damage by abrasion, affording successful protection for vessels, or areas of vessels, that are subject to elevated levels of wear. It is robust enough to withstand fine sanding or burnishing and is suitable for vessels that are regularly cleaned or that frequently ground or lie on the seabed at low tide. The very slow erosion rate provides lasting protection for fast-moving vessels or those moored in areas of strong tidal flow (Altex Yacht and Boat Paint 2008).

2.1.1.2 Controlled depletion polymer / ablative coatings

Poor control over the rate of biocide release from conventional soluble matrix coatings was addressed by the development of the controlled depletion polymer (CPD) system. Physical control over dissolution is achieved by adding high-performance polymeric reinforcing resins to the soluble binding materials. These components dissolve in unison with the binder and the biocide when in contact with salt water, forming 'micro-lumps' which are removed from the coating surface via a process termed 'ablation' (AMOG 2002; Almeida et al. 2007). This mechanism provides very effective biofouling protection and, since thicker layers of CDP coatings can be applied in comparison to conventional soluble matrix systems, the effective life is increased to up to 36 months in suitable conditions.

Ablative coatings are suited to displacement vessels, including commercial ships, fishing craft and cruising yachts. The rate of ablation is excessive for high-speed vessels and the rate at which the components are released is affected by water temperature and salinity. In warm tropical, more saline waters, the coating is sloughed off too rapidly to provide adequate antifouling performance. Ablative coatings are easily damaged by abrasion and so are not suitable for vessels that are subject to mechanical wear or frequent cleaning. Traditional hull-

cleaning techniques, such as scrubbing, can damage and remove the coating and shorten the life span.

As with conventional soluble matrix coatings, the layer of leached materials emitted by CDP coatings increases with immersion time. Because the active surface layer is relatively thick, insoluble surface precipitates may form (Lewis 1998). Exposure to air during drydocking or hard-stand periods does not affect coating performance or integrity and reapplication is straightforward since the matrix build is reduced over time; however, expense may be increased by the need for a sealer coat (Chambers et al. 2006). The drying time of CDP coatings is longer than for other coating types and if the manufacturer's recommendations are not adhered to, the resultant surface may not provide consistent polishing rates or good 'self-smoothing' performance (Chambers et al. 2006).

CDP coatings provide the lowest costs per metre squared of antifouling coating and are suitable for use in low biofouling conditions or by vessels with short drydock intervals (Anderson 2006). They are widely used by pleasure vessels and small ships (Almeida et al. 2007). In comparison to other biocidal coatings, CDP systems generally require higher levels of copper compounds and booster biocides to ensure antifouling success (Almeida et al. 2007), although more recently developed coatings offer reduced copper content and emissions in an effort to provide more 'environmentally safe' products.

2.1.1.3 Self-polishing copolymer coatings

The biocides in self-polishing copolymer coatings (SPCs) are chemically bonded to the polymer backbone of the paint binder to form a copolymer, as opposed to the free association of biocides in conventional coatings. This bond is hydrolysed by contact with seawater, resulting in a soluble acidic polymer and the release of the biocide. This reaction is confined to within a few nanometres of the coating surface (AMOG 2002), resulting in comparatively very thin leached layers which remain thin even during extended periods of immersion (Anderson 1998). The active layer of the coating is continuously replaced as both the biocide and soluble polymers are released from the surface and the underlying copolymers are exposed to seawater. This provides a highly successful mechanism of controlled biocide release, providing longer effective lifetimes. This is a significant improvement over the exponential decline of biocide release rates from conventional coatings. This mechanism also produces a 'self-polishing' smoothing effect on the coating surface in proportion to vessel speed, which reduces drag and improves vessel efficiency.

When this technology was developed in the late 1960s, the organotin-based tributyltin (TBT) copolymer was identified as a highly successful toxin for use with this system, providing effective biofouling protection for at least five years. Minimised drag, extended periods between drydocking (at least five years) and significant reduced application and maintenance costs resulted in fuel savings that provided significant benefits for ship owners and the marine industry. Other advantages of this product include the ability to reapply the coating without having to remove or seal paint residues, short drying times and resistance to damage during exposure to air.

The polymer chemistry and binder composition could be modified to customise the polishing and biocide release rate to the activity and speed of different vessels, to maximise the effective life span of the coating. Slow-polishing coatings were developed for high-speed vessels and faster polishing coatings provided sufficient biocide emissions to achieve biofouling protection for slow-moving or stationary vessels (Yebra et al. 2004). These advantages all contributed to TBT-based SPCs historically dominating the antifouling coating market, with an estimated 70 per cent of all commercial shipping using this system in 1999 (Almeida et al. 2007). However, concerns about the harmful side-effects of TBT compounds on the marine environment and organisms and the consequent recent ban of its use have prompted the development of alternative TBT-free SPCs.

'New technology' TBT-free SPCs

Copper acrylate, zinc acrylate and silyl polymers have replaced TBT as the main copolymers in the next generation of SPCs. Seawater reacts with these polymers in the same way as with TBT copolymers, hydrolysing the ester linkage between the acrylic backbone polymer and the biocidal component (Anderson 1998). Thin active surfaces and minimised leached layers are achieved. This range of 'new technology' TBT-free SPCs are claimed to provide self-polishing performance, controlled biocide release rates and long-term performance comparable to TBT-SPCs. New products are marketed with effective working lives similar to TBT-SPCs (up to 60 months). Almeida et al. (2007) indicate that the maximum service life of this type of coating is usually three years, but effective life spans of up to five years have been reported.

The majority of these products are based on copper acrylate with additional booster biocides to provide protection against the full spectrum of biofouling organisms. These secondary biocides are usually 'new' biocides, including zinc pyrithione, copper pyrithione or Sea-Nine 211.

There are also concerns about the impact of many of these biocides on marine organisms and environments (see Section 2.3).

2.1.1.4 Hybrid SPC-CDP coatings

Hybrid products, which are beginning to emerge on the antifouling coating market, combine the action of multiple antifouling mechanisms, or may incorporate new components. For example, paint manufacturer Hempel has developed an alternative self-polishing mechanism based on hydrolysable zinc carboxylate salt binder technology and reinforced with microfibres to improve mechanical strength and resistance to damage (AMOG 2002).

International Coatings market an antifouling coating which combines self-polishing acrylic polymers with rosin to provide a hybrid antifouling system. Via hydrolysis of the SPC component and hydration of the rosin, this system provides antifouling performance that is midway between the highly effective SPC system and the less well controlled CDP system. The cost of applying and maintaining hybrid coatings is also intermediate. The expected effective life of this system is up to three years for vertical surfaces or up to five years for flat surfaces where biofouling is less severe. Polishing performance, film properties and control over biocide release are approximately comparable to SPC systems, but the leached layer is not as thin so antifouling performance is not as effective (although still better than CDP systems). Copper pyrithione is the most commonly used booster biocide for Hybrid SPC-CDP products, and is regarded as more effective than the secondary biocides used in CDP products (Anderson 2006).

2.1.2 Non-biocidal coatings

There is growing concern and increasing evidence that the biocides which have replaced TBT in conventional and 'new technology' antifouling coatings have detrimental effects on the marine environment and non-target organisms (Yebra et al. 2004; Evans et al. 2000). Bans and restrictions on the use of copper-based coatings are being considered in a number of places. Recent research and development efforts are therefore focused on alternative antifouling mechanisms and non-biocidal active compounds that can provide 'environmentally safe' options (AMOG 2002).

Several biocide-free systems are in development but currently the only commercially viable system that has been developed and successfully marketed is based on 'non-stick' fouling-release technology. Other alternative, non-biocidal antifouling systems, including natural biocide technology, require further development before they can be considered as commercial options.

2.1.2.1 Fouling-release, 'non-stick' coatings

The fouling-release concept was first considered in 1972, prior to the release of TBT-SPC coatings, but product development was delayed due to the success and popularity of the latter cheaper and more effective option. Restrictions on the use of TBT, along with concerns about the environmental impacts of the biocides that have replaced it, provided the impetus to develop this technology and make a practical system commercially available.

Fouling-release coating systems are, by design, 'non-stick', providing surface characteristics that aim to prevent the settlement of biofouling organisms or allow biofouling to accumulate, but cause adhesion failure as organisms grow or are subjected to water movement. The bond between the coating surface and the organism is weakened by the low surface energy and low elastic modulus of the synthetic polymers and copolymers on which these coatings are based (AMOG 2002; Holm et al. 2003). Fouling-release coatings based on fluorinated polymers and on silicone have been developed and tested, with silicone-based coatings proving the most effective. Silicon-based coatings can be applied in thicker layers than those based on fluorinated polymers, which allows the organism-to-coating bond to be fractured via a more efficient peeling action rather than shearing (Yebra et al. 2004).

Antifouling success of fouling-release coatings currently relies on vessel speed and activity to dislodge any organisms that do attach, in particular the low-profile biofilms that are formed by diatoms. Self-cleaning has been demonstrated for vessels that frequently maintain speeds between 15 and 30 knots, depending on the biofouling community (AMOG 2002; Chambers et al. 2006; Srinivasan and Swain 2007). Therefore, technology is currently best suited to fast-moving vessels, with rapid port turn-around periods and sufficient activity levels (International Coatings indicate the minimum to be greater than 7600 sea miles per month).

Fouling-release coatings applied to such vessels provide an expected effective life of five years or longer, but are more expensive to apply than other antifouling coatings (AMOG 2002). The smooth, glossy coating surface minimises surface roughness and drag, improving vessel speed and fuel consumption. This improved vessel performance may offset the higher initial cost of application; however, an efficiency penalty may exist until the accumulated biofouling communities are released from the hull (Chambers et al. 2006). A number of silicone-based fouling-release coatings are commercially available, providing a viable and

increasingly popular coating option for high-speed vessels such as fast ferries, patrol boats, high-speed catamarans and other commercial or naval vessels (AMOG 2002; Srinivasan and Swain 2007). This coating type is also suitable for aluminium hulls and components that are not compatible with metal-based coatings. concept of incorporating natural, non-toxic biocides (Yebra et al. 2004). However, these have not yet been commercialised and are not currently available to the antifouling coatings market.

Because the average recreational vessel in New Zealand and Australia is moored for 80 per cent of the year, activity levels are not sufficient to promote the self-cleaning action of fouling-release coatings. In such cases, prevention of biofouling accumulation requires regular hull cleaning. Slow-moving or predominantly static vessels coated with fouling-release paint would require frequent hull cleaning to remain biofouling free and to minimise the risk of alien species translocation (Chambers et al. 2006). Almeida et al. (2007) comment that after three years of exposure in seawater, biocide-free fouling-release coatings are hardly able to prevent the attachment of marine organisms on around 20 per cent of stationary submerged surfaces. This demonstrates the need for activity and high vessel speeds to dislodge and prevent biofouling.

Accumulated biofouling can be removed from fouling-release paints by high-pressure spraying, potentially reducing the period of time spent in drydock. Since the effluent is biocide-free it is not necessary to treat it before disposal. For vessels that are fast and active enough, drydock intervals can be flexible (up to 60 months). Maintenance and repair costs may be further reduced because only touch-ups are required up until 60 months of service, followed by only a single recoat after this period (Anderson 2006). Drydocking costs can be avoided or minimised by the employment of in-water hull cleaning methods, however silicone-based coatings are less robust than copper-based antifouling coatings and are prone to damage by traditional, abrasive in-water hull cleaning methods (Holm et al. 2003; Chambers et al. 2006). To provide for the anticipated increased use of fouling-release coatings, there is a need for the development of mechanised, non-abrasive underwater surface cleaning methods and effective cleaning regimes (Lewis 2001).

As well as being more expensive, the application of silicone-based coatings is also more complicated than for other antifouling systems, requiring specialised equipment and skilled applicators. Adhesion to the hull is poor; it cannot be successfully applied over existing coatings and requires a 'tie coat' before recoating (Yebra et al. 2004). Although biocide-free, some fouling-release coatings contain fluid additives to improve performance; these coatings may leach oils with unknown environmental effects (Yebra et al. 2004).

Research continues in attempts to improve the durability and antifouling performance of fouling-release coatings and to extend the market within the shipping industry. Recent studies are investigating the concept of incorporating natural, non-toxic biocides (Yebra et al. 2004). However, these have not yet been commercialised and are not currently available to the antifouling coatings market.

2.1.2.2 Natural biocides

Considerable effort has been put into researching the mechanisms by which many marine algae and soft-bodied invertebrates remain 'fouling-free', with the aim of identifying natural antifouling products for use as antifouling biocides (Wahl 1989; Abarzua and Jakubowski 1995; Clare 1996; Abarzua et al. 1999). Chemical defence is achieved via secondary metabolites which are either exuded by the organism or bound to its surface. These provide chemical defence against biofouling by creating unfavourable or toxic conditions which repel or inhibit biofouling organisms (AMOG 2002; Yebra et al. 2004). Inhibitory actions include prevention of attachment, metamorphosis or growth, dissolution of adhesives, interference with metabolic function or nervous pathways. Such actions result in repellent surfaces and trigger negative chemotaxis, and death via biocidal action (Yebra et al. 2004 and references therein). The key secondary metabolites that have been investigated include terpenoids, steroids, fatty acids, amino acids, heterocyclics (furans, lactones), acetogenins, alkaloids and polyphenolics.

Numerous active compounds have been identified from a variety of organisms, including sponges, algae, corals and bacteria (reviewed by Almeida et al. 2007). However, significant challenges must be overcome to formulate the biocides into a coating matrix and to ensure sufficient, but not excessive, delivery to the surface. Some experimental coatings have been developed but there are currently no commercially available antifouling systems based on natural biocides and, according to AMOG (2002), 'none are seen to become available in the foreseeable future'. A sustainable natural source of the biocide, or a man-made analogue, is required to achieve reasonable production costs, and the product must meet rigorous environmental standards to prove that it will not contribute to contamination (Yebra et al. 2004; Almeida et al. 2007).

Many secondary metabolites have been demonstrated to provide effective protection against specific organisms or types of organisms but successful antifouling systems require action against the full suite of biofouling organisms. It has been suggested that the goal of finding

natural biocides which provide broad-spectrum antifouling protection is difficult, if not unfeasible (Yebra et al. 2004).

A subcategory of natural biocides is the so-called non-toxic organic repellents, which are natural compounds that prevent larval settlement (AMOG 2002).

2.1.2.3 Biocide-free mechanically resistant coatings (with regular mechanical cleaning)

Minimised levels of biofouling, along with long intervals between costly drydocking activities, good ship performance and reduced fuel consumption, can be achieved by regular underwater hull cleaning. Several important factors determine the success of this approach:

- diligent and regular hull cleaning schedule to avoid the build-up of biofouling
- effective and affordable hull cleaning methods and equipment
- a paint type that is robust to abrasion and is non-biocidal, to minimise the emission of toxic effluent and to avoid impacts on the marine environment and non-target organisms.

It has been proposed that even if the coating is just a hard, smooth anti-corrosive paint with no antifouling properties, paint condition can be maintained and biofouling can be controlled for several years if cleaned regularly (Yebra et al. 2004). However, the use of a biofouling deterrent would provide more flexibility in the scheduling of cleaning and improved protection (AMOG 2002). As discussed in Section 3, in-water hull cleaning methods range from simple removal of biofouling by divers or diver-operated cleaning devices, through to sophisticated remote-controlled systems. Some areas of a ship's hull are difficult to access, and may be missed by automated cleaning mechanisms and require manual cleaning and/or application of an effective antifouling coating to ensure protection; these areas include bilge keels and stern and rudder arches (AMOG 2002; Yebra et al. 2004; Almeida et al. 2007). An ideal antifouling system for this scenario would be a non-biocidal fouling-release system, so that removal of biofouling is as effective and efficient as possible. However, the most effective fouling-release coatings are silicone-based and are susceptible to damage by abrasion.

An alternative antifouling system has recently been developed called 'Surface Treated Coatings' (STCs) (Van Rompay 2008). The coating is non-biocidal and is sufficiently robust to withstand regular in-water treatment. This treatment involves 'conditioning' to reduce the surface roughness of the coating and cleaning to remove any early development stage biofouling. By minimising surface roughness, the ease with which biofouling organisms can attach is reduced and drag is improved. While regular treatment with specially designed mechanised rotating brushes is required, the process is described as time-efficient and economically sound and an effective means to maintain coating integrity, improve vessel efficiency and minimise biofouling.

When conventional antifouling coatings are cleaned using in-water methods, surface roughness is increased, but cleaning and conditioning of STCs results in smoother surfaces. The highly durable matrix has provided comparatively long service lives, reduced requirements for reapplication and 'excellent antifouling protection' on test-vessels. The formulation of one commercially available STC includes glass flakes, providing a very hardwearing, resilient surface which can withstand repeated in-water cleaning treatments; tests have indicated no harmful effects after 500 treatments. This represents a significant improvement over the other commercially available non-biocidal coating type (fouling-release) which is easily damaged and can only be cleaned using soft brushes. While soft brushes can effectively remove early development biofouling such as biofilms, the removal of biofouling species that attach during extended stationary periods generally requires more abrasive techniques.

Because STCs are biocide-free, the discharge of toxins to the marine environment during in-water cleaning is allegedly eliminated. Continued testing will investigate this claim, as well as quantifying the economic and environmental benefits associated with observed fuel-efficiency improvements and the reduced risk of marine pest translocations associated with good antifouling protection (Van Rompay, 2008).

2.1.2.4 Biocide-free self-polishing coatings

This system uses the same mechanism as TBT and copper-based self-polishing coatings but uses substitute non-toxic compounds to provide a biocide-free, polishing surface which is too unstable for secure biofouling attachment. These compounds include methacrylate and several specially designed epoxies (AMOG 2002). The performance of biocide-free SPCs, tested on a variety of vessel types or as test patches on vessels, has been variable and appears to be inconclusive.

For example, test patches of biocide-free self-polishing coating on German ferries were heavily fouled by macroalgae after four months, exceeding biofouling levels on silicone-based test patches (Watermann et al. 1998). Some speed-related fouling-release was also observed. In another field trial of biocide-free SPC coatings on German coastal vessels, antifouling performance was reported to be good, particularly on high-speed vessels (Cameron 2000). A reduction in barnacle

attachment was observed, along with diminished total length of algae and ease of algal biofouling removal. Several biocide-free SPC products have been tested on deep-sea vessels. The best antifouling results (less than 20 per cent coverage by animal biofouling after 12 months) were observed on a research vessel averaging 11 knots. Higher biofouling levels (between 20 and 60 per cent) were recorded on a vessel with a lower average speed (8 knots). The performance of biocide-free SPC coatings was better than the silicone-based coatings that were also tested on the same vessels (Watermann et al. 2001).

One biocide-free, non-metallic and non-toxic coating has been made commercially available by Lotréc AB in Sweden. During the 2000 boating season, 'LeFANT' was extensively tested by over 5000 yachts in Holland, Germany, Austria and Sweden, with reports of 'outstanding results'. This product is yet to be tested in high-biofouling environments and some doubts have been expressed about its likely performance (AMOG 2000).

2.1.2.5 Fibrous coatings

Fibre-flocked coatings are an innovative attempt to provide surface characteristics that inhibit the settlement or adhesion of biofouling organisms. By applying an adhesive coating, followed by a layer of electrostatically charged microfibres which lie perpendicular to the hull, a three-dimensional 'furry' surface is created. The movement of the fibres in response to water currents, even when the boat lies idle in port, prevents the attachment of some biofouling organisms (AMOG 2002).

Fibre length has been demonstrated to determine antifouling performance and the types of biofouling organisms that are deterred. For example, the control of fouling by hydroids and barnacles has been achieved by fibres longer than 1 mm; however, mussels, ascidians and algae were more effectively controlled by shorter fibres. Protection against the settlement of 'hard' biofouling organisms has been demonstrated, but control over 'soft' biofouling organisms is not good (Yebra et al. 2004). Achieving broad-spectrum antifouling protection using fibres may therefore prove to be challenging. A major disadvantage is the increased drag that is a consequence of the rough surface (Almeida et al. 2007) and there is doubt about fouling-release properties (Yebra et al. 2004). A known disadvantage of fibrous coatings is their high application costs (only via trained specialists) and susceptibility to damage (the surface cannot be recoated).

2.1.2.6 Non-leaching biocidal coatings

This concept, suggested and investigated by Clarkson and Evans (1993), involves biocides that are confined to the coating surface and that exert a toxic effect on biofouling organisms that contact or become attached to the surface. The biocides are not leached into the marine environment. This is an attractive idea because, if feasible, this approach would require only small amounts of biocides and environmental impacts would be minimised. However, investigations into potential compounds and mechanisms have proved unsuccessful and, until the current state of knowledge is improved, this technology remains only a concept (AMOG 2002).

2.1.2.7 Nanoparticle technology

Researchers are currently investigating nanoparticle technology and photocatalytic reactions as a novel non-biocidal antifouling solution. The concept builds on existing technologies which use the semi-conducting oxide titanium oxide (TiO_2) to treat waste water, purify air, provide anti-bacterial surfaces and self-cleaning properties for windows and coatings. When TiO_2 is exposed to ultraviolet light, it undergoes a photocatalytic reaction which results in the production of potent oxidants at the surface. These oxidants have the potential to break down any organic matter that is attached to the surface, before decomposing without negative impacts on the surrounding environment.

The effectiveness of this technology on submerged marine antifouling is currently being evaluated via laboratory-based tests, with some promising preliminary results emerging, including inhibition of diatom fouling and larval bryozoan settlement. Remaining developments include tailoring the reaction to operate in low light conditions and incorporating the nanoparticles into ‘commercially relevant paint formulations’ for industry field testing, and evaluating of long-term performance (Dupree 2008).

2.1.2.8 Electromagnetic and sonic deterrents

The concept of creating unsuitable settlement conditions for biofouling by using electromagnetic or sonic deterrents has been proposed and tested, but neither can currently provide broad-spectrum or long-term biofouling protection (AMOG 2002). Systems under development include units that emit electromagnetic impulses or low frequency sound waves to set up a micro-thin layer of rapidly moving water, thus deterring the attachment of biofouling organisms.

Another approach involves electrolytical generation of chlorine or hypochlorous ions via minor differences in potential between an electrically conductive paint and the vessel’s hull (Hare 2000). Growth of marine organisms has been demonstrated to be inhibited by sufficiently high concentrations of hypochlorous ions (Nishi et al. 1992). This system has been tested on the hull of a small ship and a tug, with effective antifouling protection observed over several months. A major advantage

offered by this technology is that the system can be switched on when in biofouling-conducive environments like harbours, or when travelling at slow speeds, but remain off when the risk of biofouling is low. However, before this technology can be applied to larger ships, several important areas need to be addressed, including durability, performance, effective application, practicality and the risk of producing halogenated by-products (AMOG 2002).

Other mechanisms for biofouling protection currently under investigation and testing include electrochemical oxidisation of intracellular substances, continuous anodic polarisation and high-frequency alternating currents which interfere with cell membrane potential (AMOG 2002).

2.2 Main uses of coating types

Ablative antifouling coatings are used by the majority of New Zealand-based and Australian-based recreational craft and by the global commercial fleet. However the use of fouling-release paints on commercial vessels is increasing.

2.3 Primary biocides

2.3.1 Copper and copper compounds

The restrictions on the use of, and the recent ban of, TBT-based antifouling coatings have driven research and development of alternative, TBT-free biocides. Today copper and copper compounds, specifically cuprous oxide, cuprous thiocyanate and copper metal, have replaced TBT as the most commonly used and effective primary biocides in commercially available antifouling coatings (Voulvoulis et al. 2002; Srinivasan and Swain 2007). Of these, cuprous oxide is the most widely used due to its low cost and ability to provide relatively broad-spectrum antifouling protection. Cuprous oxide has a corrosive effect on aluminium and, therefore, copper thiocyanate is preferred for use on aluminium-hulled vessels or components, including stern drives (AMOG 2002).

The effective life of TBT-free and cuprous oxide-free antifouling coatings is shorter than that of cuprous oxide-based paints, seldom providing more than two years of protection. This can be attributed to the superior control over toxin release rates achieved by cuprous oxide-based coatings. The technology for leaching control of non-copper biocides is still being developed.

2.3.2 Zinc oxide

Zinc oxide is commonly used in copper-based coatings as a filler or extender, reducing the amount of more costly copper compounds required for effective antifouling performance. Zinc oxide also provides some beneficial biofouling protection qualities (AMOG 2002).

2.4 Booster biocides

Copper-based biocides provide effective antifouling protection against the majority of biofouling organisms, but cannot successfully control several important biofouling species which exhibit physiological tolerance to copper (Harino 2004). These include the algal genera *Enteromorpha* and *Ectocarpus*, and the diatom *Achnanthes* (Voulvoulis et al. 2002). In a review of the occurrence and effects of antifouling coating booster biocides, Konstantinou and Albanis (2004) indicated that 18 compounds are used worldwide as antifouling biocides. The most commonly used compounds included, at that time, irgarol 1051, diuron, Sea-Nine 211, dichlofluanid, chlorothalonil, zinc pyrithione, TCMS (2,3,3,6-tetrachloro-4-methylsulfonyl) pyridine, TCMTB [2-(thiocyanomethylthio) benzothiazole], and zineb. Other important compounds include dithiocarbamates maneb, thiram and ziram (AMOG 2002).

The function and performance of these booster biocides can range from specific protection against diatom slimes (thiram and nabam) or macroalgae (irgarol 1051) via photosynthesis inhibition, through to protection against a broad spectrum of biofouling organisms provided by chlorothalonil and Sea-Nine 211 (AMOG 2002 and references therein). Many of these biocides have been, or are, used as agricultural pesticides, fungicides and herbicides (Voulvoulis et al. 1999; Harino 2004), with documented harmful side-effects for humans and non-target species. Concerns that some may have adverse environmental effects (Scarlett et al. 1999; Madsen et al. 2000; Voulvoulis et al. 2000) has led some countries to restrict or ban their use (Srinivasan and Swain 2007). The persistence and impact of booster biocides in the marine environment and on non-target organisms are discussed in later sections of this review.

The antifouling coatings and biocidal constituents that are currently registered and approved for use in New Zealand by the Environmental Risk Management Authority (ERMA) and in Australia by the Australian Pesticides and Veterinary Medicines Authority (APVMA) in Appendix 1.

2.5 Risks to marine environments posed by biocides and potential for exacerbation of risk through in-water cleaning

Along with providing effective control of a broad spectrum of biofouling organisms, an ideal antifouling agent should:

- be rapidly degraded to non-toxic derivatives once released into the marine environment
- be minimally toxic to, or not bioaccumulate within, non-target organisms
- be quickly partitioned to reduce bioavailability (Jacobson 1998).

Despite more than a century of research effort there are still few effective antifouling biocides with the ideal combination of physical, chemical and toxicological properties that can address these conflicting requirements (i.e. toxicity to diverse biofouling species but not to non-target species) (AMOG 2002).

The available information on the occurrence, fate, toxicity and environmental effects of copper and booster biocides has been reviewed and assessed by Voulvoulis et al. (1999, 2002). These authors, along with several others (e.g. Evans 2000; Thomas et al. 2001; Yebra et al. 2004) comment that there is a paucity of data and information available and that the current knowledge about toxicity, sub-lethal effects and environmental persistence is incomplete. Accurate risk assessments are required to gauge and regulate the potential effects of these compounds, but these assessments are difficult and are compromised by the lack of published toxicity data (Voulvoulis et al. 1999; Evans et al. 2000). The available information indicates that many booster biocides are highly toxic to both target and non-target species. This is to be expected given their origins as agricultural biocides and their inclusion as active ingredients in antifouling coating formulations.

Several studies have collected and reviewed data on the occurrence of copper and booster biocides in coastal waters (e.g. Voulvoulis et al. 2000; Thomas et al. 2001; Srinivasan and Swain, 2007). Diuron and irgarol 1051 were found at concentrations above the limits of detection in areas of high boating activity in the United Kingdom by Thomas et al. (2001). Irgarol 1051 has been detected in water samples from southern England, the Mediterranean Sea, Denmark, Japan and Queensland (Australia), at concentrations that may be high enough to cause damage to a range of non-target organisms, including microalgae, endosymbiotic corals, seagrasses and, therefore, herbivorous mammals such as dugongs (Evans et al. 2000 and references therein).

Concerns are growing about the effect of copper-based antifouling coatings on the marine environment. In areas of high boating activities, elevated concentrations of copper have been detected. This scenario is likely to continue and increase as more vessels employ copper-based biofouling control in the wake of the TBT ban (Srinivasan and Swain 2007). Copper naturally occurs in the marine environment and is an essential nutrient for organism growth, but elevated concentrations can have harmful effects on marine algae and animals (Voulvoulis et al. 1999). The most toxic form of copper is the free copper ion, which is quickly bound or chaelated by organic ligands in the marine environment, effectively minimising the bioavailability and reducing concentrations to non-toxic levels. Both copper and zinc have been observed to affect the growth, feeding and development of marine invertebrates and plankton (Johnson et al. 2007 and references therein).

Synergistic interactions between copper and some booster biocides have been detected, raising concerns about additive effects and potential impacts on the marine environment. For example, the dithiocarbamates maneb and ziram have been observed to form lipophilic complexes with copper. These complexes reduce the toxic threshold concentrations by one and two orders of magnitude, respectively, in a toxicity test for the ciliate *Colpidium campylum* (Voulvoulis et al. 1999).

The biodegradation of booster biocides, once released into the marine environment, varies considerably. For example, Sea-Nine 211 is reported to be readily biodegradable, whereas diuron and irgarol 1051 are considered non-biodegradable and may be expected to accumulate in the environment (Voulvoulis et al. 1999; Evans et al. 2000; AMOG 2002 and references therein). Irgarol 1051 and other booster biocides are considered non-biodegradable due to their toxicity and ability to persist once they break down (Voulvoulis et al. 1999). Pyrithione compounds are broken down rapidly but it has been hypothesised that they may accumulate in sediments (Yebra et al. 2004). Dichlofluanid is relatively insoluble in water and may also potentially bioaccumulate by becoming associated with particulate matter (Thomas et al. 2001).

Voulvoulis et al. (2002) attempted to use available information to conduct a comparative assessment of several commonly used booster biocides. The results indicated that irgarol 1051 and diuron may have serious consequences for aquatic organisms and their use should only be permitted after further toxicity studies. Zinc pyrithione and zineb were considered comparatively less harmful to the environment. The authors commented that the 'risk associated with the use of TCMS pyridine, TCMTB and even dichlofluanid should be well established before their use is permitted, as they all demonstrate similar

environmental characteristics as TBT'. Application of the 'precautionary principle' concerning the use of TBT-substitute booster biocides has been recommended due to the reported (and potential) occurrences, toxicity and persistence of these compounds in the marine environment (Voulvoulis et al. 2002).

Active agents contained in antifouling coating formulations are registered and regulated in many countries. Documented toxicity and environmental chemistry information is collected and the environmental impact of each compound is evaluated, categorised and regulated accordingly. In New Zealand, ERMA <http://www.ermanz.govt.nz> provides public access to this information via a chemical classification information database. In Australia, the same function is carried out by APVMA. The relevant information about the environmental persistence of approved antifouling biocides and their documented toxicity to aquatic organisms is summarised in Table 2.2.

2.5.1 Likely effect of traditional in-water hull cleaning (mechanical) on performance and/or biocide release rate of different paint types

Traditional in-water hull cleaning practices involve the mechanical removal of biofouling using abrasive devices, including brushes and scrapers. Insoluble / hard matrix conventional coatings are the most robust of the biocidal antifouling coatings available. This type of paint is often used by craft that are frequently cleaned, such as racing yachts that are often wiped clean of biofouling and lightly sanded or burnished before races to achieve minimum drag. It is also used in areas of high wear, such as the loading zone of fishing vessels, because of its resistance to damage by abrasion. Most types of traditional in-water hull cleaning techniques will not damage this type of coating, although scrapers and very coarse nylon brushes may have a harmful effect, especially if used frequently.

Ablative coatings are designed to slough off layers of matrix and biocides as water moves over the hull surface, providing a self-polishing mechanism to maintain hull smoothness. This process also promotes self-cleaning by presenting an unstable, biocidal surface for biofouling organisms. A side-effect of this sloughing effect is that the coating surface is prone to damage or excessive ablation by even gentle wiping with a cloth. Cleaning with abrasive tools such as brushes and scrapers would quickly damage the coating, removing layers of paint and rapidly depleting the biocidal content. Fouling-release coatings are also sensitive to damage by abrasion (Almeida et al. 2007) and it is complicated and expensive to repair this coating type.

Schiff et al. (2004) measured the emission of dissolved copper from three types of antifouling coatings used by recreational vessels, quantifying the rate of passive leaching and toxin release caused by cleaning activities. Two commercially available conventional (contact leaching) coatings were tested in the study, along with a biocide-free Teflon^{TM} coating. The biocide-based coatings contained cuprous oxide as the primary biocide, in an insoluble matrix of either modified epoxy or hard vinyl enhanced with Teflon^{TM}.

Under normal environmental conditions, the modified epoxy and hard vinyl coatings passively leached 4.3 and 3.7 µg of dissolved copper/cm^2/day (monthly averaged rate), respectively. Following non-abrasive hand cleaning, the release rate from the modified epoxy coating averaged twice the daily baseline rate (8.6 µg/cm^2/event) over the duration of the response to cleaning. The flux recorded for hard vinyl coatings was 3.8 µg/cm^2/event. When subjected to abrasive cleaning methods, the concentration of dissolved copper emitted by the modified epoxy coating increased two-fold but the same treatment did not generate any significant increase in emissions from the hard vinyl coating. One day after the cleaning activities, the rate of passive leaching peaked (18 and 15 µg/cm^2/day, respectively), decreasing three-fold within three days then asymptotically returned to the baseline rate. This rate reduction was attributed to the development of biofilms, which are known to sequester biocides released from the antifouling coating beneath them (Yebra et al. 2004).

Table 2.2 Summary of toxicity and environmental risk associated with antifouling coating biocides approved for use in Australia and New Zealand.

Information obtained from the New Zealand Environmental Risk Management Authority (ERMA) and the Australian Pesticides and Vetinary Medicines Authority.

			TOXICITY TO:				
BIOCIDE	**BIODEGRADATION**	**BIOACCUMULATION**	**Fish**	**Algae**	**Crustacean**	**Other marine organisms**	**Humans**
Cuprous oxide (Copper (I) oxide, Cu2O, Dicopper monoxide)	**Degrades into copper ions, which are NOT rapidly degradable;** may cause long-term adverse effects in the aquatic environment	no data	**Very ecotoxic;** toxicity reported for Arctic grayling (LC50, 0.003 mg/l)	**Very ecotoxic;** toxicity reported for green alga *Selenastrum capricornutum* (EC50 POP DEC, 0.03 mg/l)	**Very ecotoxic;** toxicity reported for Daphnid (LC50, 0.005 mg/l)		Acutely toxic and harmful to target human organs or systems if ingested orally or inhaled, irritating to the eye
Copper thiocyanate (Thiocyanic acid, copper (1+) salt)	no data	no data	**Very ecotoxic;** toxicity reported for Rainbow / Donaldson trout, *Oncorhynchus mykiss* (LC50 mortality, 0.031 mg/l)		**Very ecotoxic;** toxicity reported for water flea *Daphnia magna* (EC50 intoxication, 0.020 mg/l)		Acutely toxic (oral, dermal, inhalation) and harmful to human target organs or systems (oral)
Chlorothalonil (Tetrachloroisophthalonitrile 1,3-Benzenedicarbonitrile, 2,4,5,6-tetrachloro-)	**NOT rapidly degradable;** degrades rapidly (half-life = 4 to 150 hours) but degradation metabolites are persistent and ecotoxic (half-life is >30 days)	**NOT bioaccumulative;** BCF = 264, log Kow = 2.88	**Very ecotoxic;** toxicity reported for Rainbow / Donaldson trout, *Oncorhynchus mykiss* (LC50, 0.0076 mg/l)	**Very ecotoxic;** toxicity reported for the green alga *Selenastrum capricornutum* (EC50, population decrease, 0.17 mg/l)	**Very ecotoxic;** acute and chronic toxicity reported for the water flea *Daphnia magna* (EC50, 0.059 mg/l; 0.032 mg/l)		Acutely toxic (inhalation), contact sensitiser, suspected human carcinogen, toxic to human target organs or systems (oral), corrosive to ocular tissue
Copper pyrithione	Data inaccessible						
Dichlofluanid	**Rapidly degradable;** Dichlofluanid hydrolysis very rapidly to dimethylphenylsulfamid (DMSA) which is not ecotoxic and is not considered persistent	**NOT bioaccumulative;** BCF value suggests that bioconcentration in aquatic organisms may be an important fate process. Dichlofluanid is less soluble than diuron and irgarol 1051 and this may allow association with particulate matter and result in bioaccumulation (AMOG 2002)	**Very ecotoxic;** acute and chronic toxicity reported for Rainbow trout, *Oncorhynchus mykiss* (LC50, 0.05 mg/l; NOEC, 10 mg/l)		**Very ecotoxic**		Acutely toxic (oral, inhalation), irritating to eye, midly irritating to skin, contact sensitiser, harmful to human target organs or systems (oral)

Table 2.2 Summary of toxicity and environmental risk associated with antifouling coating biocides approved for use in Australia and New Zealand. Continued

Information obtained from the New Zealand Environmental Risk Management Authority (ERMA) and the Australian Pesticides and Vetinary Medicines Authority.

BIOCIDE	BIODEGRADATION	BIOACCUMULATION	TOXICITY TO:				
			Fish	Algae	Crustacean	Other marine organisms	Humans
Diuron	**NOT rapidly degradable;** if released into water, diuron is expected to adsorb to suspended solids and sediment based on the range of Koc values. Diuron is 67–99 % degraded in 10 weeks under aerobic conditions by mixed cultures isolated from pond water and sediment	**NOT bioaccumulative**; an estimated BCF of 64 was calculated for diuron, using a log Kow of 2.68. Carp *(Cyprinus carpio)* exposed for six weeks to diuron had experimental BCF values ranging from 3.4 to 4.9 (0.5 mg/l exposure) and <3-74 (0.05 mg/l exposure). **Low-to-moderate potential for bioconcentration**	**Very ecotoxic;** acute toxicity reported for Cuthroat trout (LC50, 1.4 mg/l); chronic toxicity reported for Fathead minnow (LOEC, 0.0618 mg/l)	**Very ecotoxic;** toxicity reported for green alga *Selenastrum capricornutum* (EC50, 0.0024 mg/l)	**Very ecotoxic;** acute toxicity reported for *Daphnia pulex* (EC50, 1.4 mg/l); Chronic toxicity reported for *Daphnia magna* (LOEC, 0.2 mg/l)		Acutely toxic if ingested orally, irritating to the eye, suspected human reproductive or developmental toxicants, toxic to human target organs or systems
Irgarol 1051	**NOT rapidly degradable;** 'fairly persistent in water.' No hydrolysis in fresh or salt water. The US Environmental Protection Agency considered the aqueous photolysis to be stable, with a half-life ranging from 35.9 to 84.8 days. Anaerobic and aerobic aquatic metabolism considered stable. Adsorption/desorption studies on clay loams indicated half-lives of 502–548 days, and 820–956 days on sandy loam	**NOT bioaccumulative;** Kow = 8912 (so bio-accumulation may occur). A whole-body bio-accumulation factor (BCF) = 160x was determined for bluegill sunfish, however depuration (removal of impurities) was rapid when exposure was ceased	**Very ecotoxic;** acute toxicity reported for Rainbow / Donaldson trout *Oncorhynchus mykiss*, (LC50 Mortality, 0.75 mg/l); chronic toxicity reported for Rainbow trout (NOEL, 0.004 mg/l)	**Very ecotoxic;** acute toxicity reported for green alga *Selenastrum capricornutum*, (LC50 intoxication, 0.00147 mg/l); chronic toxicity (NOEC, 0.0008 mg/l)	**Very ecotoxic;** acute toxicity reported for water flea, *Daphnia magna*, (EC50 intoxication, 5.3 mg/l); chronic toxicity (NOEL, 0.56 mg/l)	**Very ecotoxic;** toxicity reported for American or Virginia oyster, *Crassostrea virginica*, (LC50 intoxication, 3.2 mg/l)	Acutely toxic if ingested orally, irritating to the eye, contact sensitiser
Mancozeb	**NOT rapidly degradable;** Mancozeb degrades rapidly but the metabolites are persistent and toxic	**NOT bioaccumulative;** BCF = 2.1, log Kow = 1.33, potential for bioconcentration in aquatic organisms is low	**Very ecotoxic;** acute toxicity reported for Rainbow trout, *Salmo gairdneri* (LC50, 0.46 mg/l); chronic toxicity reported for Fathead minnow, *Pimephales promelas* (NOAEC, 0.00219 mg/l)	**Very ecotoxic;** toxicity reported for the green alga, *Selenastrum capricornutum* (EC50, 0.047 mg/l)	**Very ecotoxic;** acute and chronic toxicity reported for the water flea *Daphnia magna* (EC50, 0.073 mg/l; NOAEC, 0.0073 mg/l)		Irritating to the eye, contact sensitiser, harmful to human target organs or systems (oral)

Table 2.2 Summary of toxicity and environmental risk associated with antifouling coating biocides approved for use in Australia and New Zealand. Continued

Information obtained from the New Zealand Environmental Risk Management Authority (ERMA) and the Australian Pesticides and Vetinary Medicines Authority.

			TOXICITY TO:				
BIOCIDE	**BIODEGRADATION**	**BIOACCUMULATION**	**Fish**	**Algae**	**Crustacean**	**Other marine organisms**	**Humans**
Octhilinone (isothiazolone biocide)	**NOT readily biodegradable;** very little information available on environmental fate of Octhilinone, but in general isothiazolone biocides typically biodegrade very rapidly with half-lives of <26 hours	**NOT bioaccumulative**	**Very ecotoxic;** acute toxicity reported for Rainbow trout, *Oncorhynchus mykiss* (LC50, 0.047 mg/L); chronic toxicity reported for Fathead minnow, *Pimephales promelas* (NOEC, 0.0085 mg/l)		**Very ecotoxic;** toxicity reported for the water flea *Daphnia magna* (EC50, 0.180 mg/l)		Acutely toxic (oral, inhalation, dermal), contact sensitiser, corrosive to dermal and ocular tissues
Sea-Nine 211 (isothiazolonone biocide) Synonoms: DCOI, Kathon 5287	**Rapidly degradable;** degraded extremely rapidly in aquatic microcosms with a half-life of less than an hour. The degradation metabolites of Sea-Nine 211 are 4–5 orders of magnitude less toxic than the parent compound due to the cleavage of the isothiazolinone ring and degradation by microorganisms to open-ring structures. This provides an effective mechanism of detoxification	**NOT bioaccumulative;** og Kow = 2.8, Log Pow = 2.8, BCF = 13	**Very ecotoxic;** acute and chronic toxicity reported for Rainbow trout, *Oncorhynchus mykiss* (LC50, 0.0027 mg/l; NOEL, 0.0018 mg/l)	**Very ecotoxic;** acute and chronic toxicity reported for the green alga, *Selenastrum capricornutum* (EC50, 0.032 mg/l; NOEL, 0.0075 mg/l)	**Very ecotoxic;** acute and chronic toxicity reported for the Mysid, *Mysidopsis bahia* (LC50, 0.0047 mg/l; NOEL, 0.0016 mg/l)		Acutely toxic if inhaled, contact sensitiser, corrosive to dermal and ocular tissues
TCMTB (2-(Thiocyanomethylthio) benzothiazole)	**Rapidly degradable;** TCMTB biodegrades in less than 5 days	**NOT bioaccumulative;** measured whole fish BCF = 230	**Very ecotoxic;** acute toxicity reported for Chinook salmon, *Oncorhynchus tshawytscha* (LC50, 0.0073 mg/l); chronic toxicity reported for Rainbow trout, *Oncorhynchus mykiss* (NOEC, 0.00034 mg/l)		**Very ecotoxic;** toxicity reported for the water flea, *Daphnia magna* (EC50, 0.023 mg/l)		Acutely toxic if inhaled or ingested orally, irritating to the skin, contact sensitiser, corrosive to ocular tissues and harmful to target organs or systems (oral)

Table 2.2 Summary of toxicity and environmental risk associated with antifouling coating biocides approved for use in Australia and New Zealand. Continued

Information obtained from the New Zealand Environmental Risk Management Authority (ERMA) and the Australian Pesticides and Vetinary Medicines Authority.

BIOCIDE	BIODEGRADATION	BIOACCUMULATION	TOXICITY TO:				
			Fish	Algae	Crustacean	Other marine organisms	Humans
Thiram	**NOT rapidly degradable**	**NOT bioaccumulative;** experimental BCF values suggest that bioconcentration of thiram will be low in aquatic organisms	**Very ecotoxic;** toxicity reported for (common mirror carp), *Cyprinus carpio* (LC50, 0.0003 mg/l)	**Very ecotoxic;** toxicity reported for the green alga, *Selenastrum capricornutum* (EC50, 0.045 mg/l)	**Very ecotoxic;** toxicity reported for Mysid (LC50, 0.0033 mg/l)		Acutely toxic (oral, inhalation), irritating to eye, midly irritating to skin, contact sensitiser, harmful to human target organs or systems (oral)
Tolyfluanid	**NOT rapidly degradable;** Tolyfluanid degrades rapidly (undetectable concentrations by 14 days after treatment), but the primary degradation product partitions preferentially to the water phase, has long half-life (persistent) and is toxic	log Kow = 3.9 (borderline for classification as bioaccumulative under HSNO, limit = 4.0), but rapid breakdown in soil and metabolism / excretion by animals, so not considered to pose a significant risk of bioaccumulation	**Very ecotoxic;** acute and chronic toxicity reported for Rainbow trout (LC50, 0.05 mg/l; NOEC, 0.0031 mg/l)	**Very ecotoxic;** toxicity reported for *Scenedesmus subspicatus* (EC50, 4.2 mg a.i./l)	**Very ecotoxic;** acute and chronic toxicity reported for *Daphnia* (EC50, 0.57 mg/l ; NOEC, 0.01 mg/l)		Acutely toxic (inhalation, oral), irritating to the skin and eye, contact sensitiser, toxic to human target organs or systems (inhalation), harmful to human target organs or systems (oral)
Zinc pyrithione ('Zinc Omadine', ZPT)	**Rapidly degradable;** Degrades rapidly in natural seawater, but may persist in darker waters. Half-life under aerobic conditions (combined water and sediment) = 21 hours; under anaerobic conditions the half-life = 0.5 hour. Degradation products are several orders of magnitude less toxic than the parent compound. Elemental zinc resulting from the degradation of zinc pyrithione is persistent, but bioavailability to aquatic organisms is greatly affected by a number of factors	**NOT bioaccumulative;** Log Kow = 0.97	**Very ecotoxic**	**Very ecotoxic**	**Very ecotoxic**		Acutely toxic if inhaled, irritating to the skin, suspected human reproductive or developmental toxicant, toxic to human target organs or systems (oral), corrosive to ocular tissue

Table 2.2 Summary of toxicity and environmental risk associated with antifouling coating biocides approved for use in Australia and New Zealand. Continued

Information obtained from the New Zealand Environmental Risk Management Authority (ERMA) and the Australian Pesticides and Vetinary Medicines Authority.

			TOXICITY TO:				
BIOCIDE	**BIODEGRADATION**	**BIOACCUMULATION**	**Fish**	**Algae**	**Crustacean**	**Other marine organisms**	**Humans**
Zineb	**NOT rapidly degradable;** Koc values ranging from 308 to 1168 indicate that Zineb is expected to adsorb to sediment and suspended solids in water. Hydrolysis half-lives for zineb in relation to pH are nine minutes at pH 3.8, 6.5 hours at pH 5.7, 96 hours at pH 7.0, and 405 hours at pH 8.0	**NOT bioaccumulative;** an estimated BCF of two was calculated for zineb, using a log Kow of 1.3. **Low potential for bioconcentration in aquatic organisms.** The BCF of Zineb in Golden Ide (*Leuciscus idus melantus)* after three days and algae (*Chlorella fuscavar vacuolata*) after one day was <10 and 170, respectively	**Very ecotoxic;** acute toxicity reported for the Guppy, *Poecilia reticulata*, (LO50 Mortality, 7.2 mg/L); chronic toxicity reported for Rainbow / donaldson trout, *Oncorhynchus mykiss* (LOEC Mortality, 0.18 mg/l)		**Very ecotoxic;** toxicity reported for water flea *Daphnia magna* (LC50, 0.97 mg/l)	**Very ecotoxic;** dramatic development modifications (spicule formation abnormalities) observed for embryos of the sea urchin, *Paracentrotus lividus*, when exposed to 0.4 ug/mL zineb solution for 48 hours. Evidence of abnormal differentiation of fertilised eggs	Contact sensitiser
Ziram	**NOT rapidly degradable**	**No bioaccumulation expected in aquatic organisms**	**Very ecotoxic;** toxicity reported for Fathead minnow (LC50, 0.008 mg/l)	**Very ecotoxic;** Pseudokirchneriella subcapitata (EC50, 0.067 ppm)	**Very ecotoxic;** acute toxicity reported for mysid, *Americamysis bahia* (LC50, 0.014 mg/l); chronic toxicity reported for the water flea, *Daphnia magna* (EC50, 0.011 mg/l)		Acutely toxic (inhalation, oral), midly irritating to the skin, irritating to the eye, contact sensitiser, harmful to human target organs or systems (oral)

BCF = bioconcentration factor; LC50 = lethal concentration which kills 50% of the sample population; EC50 = concentration which induces a response half-way between baseline and maximum; NOAEC = no observed adverse effect concentration; NOEL = no observable effects limit; LOEC = lowest observed effect concentration; log Kow = octanol-water partition coefficient.

3. Review of developments in in-water cleaning technology

3.1 Background to in-water cleaning and motivation for development of effective and efficient treatment technologies

The frequency of drydocking of large commercial vessels is principally based around the scheduled survey requirements of the IMO conventions relating to safety and environment protection (that apply technical standards for the design, construction, equipment and operational discharges). In addition, there are numerous technical codes and resolutions associated with these conventions.

The administration offering vessel registration is referred to as the 'flag state' and holds the responsibilities and obligations imposed by the international conventions for ships entitled to fly its flag. To achieve this, most flag states delegate some or all of these functions to 'recognised organisations' which are most commonly classification societies. Such societies have developed large networks of worldwide resources to enable them to carry out delegated tasks. However, even when delegating these functions, the flag state, as the signatory to the international convention, retains ultimate responsibility. Most commercial vessels (94 per cent) operating internationally are subject to surveys undertaken by several societies that are part of the International Association of Classification Societies (IACS) (for a detailed list of global classification societies see IACS 2006).

Classification society rules include requirements for periodic hull surveys, in accordance with the IMO conventions, to ensure safety and structural integrity of vessels, but do not currently include obligations to address biofouling. Generally, survey schedules consist of annual in-water surveys and five-yearly shore-based surveys, with some variation between classification societies and vessel classes. Because opportunities for drydocking are usually limited and costly, commercial vessels only drydock in accordance with survey requirements, which include those to renew the antifouling coatings (Takata et al. 2006). Recreational vessels generally do not engage classification societies, and the frequency with which they are removed from the sea for maintenance and antifouling is generally at the owners' discretion or determined by the need for repairs.

Most vessel types develop biofouling assemblages between scheduled drydockings. This can occur on general hull areas but is especially predominant in locations that either protrude from, or are recessed into, the hull ('niche' areas). These areas may include irregular surfaces and hard-to-access crevices. The presence of niche areas varies with vessel type. The most common niche areas are:

- sea chests and their gratings
- internal seawater systems
- seawater inlet pipes
- cathodic protection anodes
- sonar domes and transducers
- echo sounders and velocity probes
- drydocking support strips
- propeller and shaft
- bow and stern thrusters (including thrusters tunnels)
- retractable propulsion units
- bilge keels
- cooling and propulsion scoops
- rudder, including hinges and stocks
- stabiliser fins.

For detailed descriptions of these niche areas refer to Coutts (1999), Taylor and Rigby (2002) and ASA (2007).

Niche areas are particularly prone to biofouling because they are often not coated in antifouling paint (e.g. propellers, rudder stocks), are protected from water flow and turbulence (e.g. thruster tunnels) or overexposed to water flow and turbulence (e.g. sea chest gratings). Biofouling of general hull areas and some niche areas can have significant effects on vessel performance. The presence of extensive biofouling on a vessel can decrease its speed and fuel efficiency to such an extent that the vessel needs to burn an extra 10–195 tons of fuel oil to maintain design speed and trading schedules (Munk 2006).

The need to reduce the effects of biofouling on vessel performance can be assessed via on-board tests such as the Computerised Analysis of Ship Performance (CASPER Rigby and Taylor 2002; Munk 2006) and/or diver inspections. It is often not economically feasible or logistically possible for vessel owners and operators to remove a vessel from the water to address hull and niche biofouling outside the regular service schedule. In-water cleaning represents a convenient and affordable option for vessels of all types and sizes. For a large ship, the increase in thrust resulting from regular propeller polishing can save up to five tons of fuel oil per day, and the reduced hull friction after comprehensive hull cleaning can save more than 10 tons of fuel oil per day (Munk 2006). Traditional methods used for in-water cleaning are generally simple and based on mechanical (abrasive) removal of biofouling. However, efforts and regulations aimed at reducing pollution and biosecurity risks have provided an incentive for the development of a diverse range of in-water hull cleaning technologies.

3.2 Current technologies for in-water vessel husbandry

In-water hull maintenance technologies currently available or in development can be separated into two categories: technologies that remove biofouling organisms from targeted hull areas; and technologies that prevent or kill biofouling organisms in target areas but do not actively remove them. Both categories of treatment are discussed below with reference to each technology's availability, specificity (vessel type and/or hull or niche area), effectiveness, impact on antifouling coating surfaces, ability to capture biological and paint material removed from the treatment area, recommended frequency of application and ease of use. Summaries are provided in Table 3.1.

3.2.1 Technologies that remove biofouling organisms from targeted areas

3.2.1.1 Manual scrubbing or brushing

Manual scrubbing or brushing of fouled surfaces is typically used on small vessels such as recreational yachts and motor launches. Depending on the nature of the biofouling (slime/biofilm vs encrusting organisms), cloths, brushes or plastic/metal scraping devices are used by a diver, snorkeler or surface-based person to remove biofouling organisms (Figure 3.1). Manual cleaning is common on recreational vessels in Australia and New Zealand. Of the 137 recreational vessel owners surveyed by Floerl (2002) in Queensland, 53 per cent indicated that they use manual in-water cleaning to reduce biofouling between antifouling coating renewal intervals. Similarly large proportions of domestic (59 per cent, N = 899) and international yachts (66 per cent, N = 182) surveyed in New Zealand reported undertaking manual hull cleaning (Floerl, unpublished data 2004; Floerl et al. 2008).

It is likely that during in-water cleaning by snorkelling or scuba, not all organisms are removed from a hull. For example, the owners of 40 international yachts surveyed by Floerl et al. (2008) in New Zealand reported that they had manually cleaned their hulls by snorkelling

or swimming around the boats within the three weeks prior to being surveyed. However, between one and 15 biofouling species, including NIS, were observed on 32 (80 per cent) of these vessels, suggesting that some organisms were missed during the cleaning process, particularly from deeper or cryptic hull locations. These findings are supported by a recent study of the effectiveness of in-water cleaning using handheld brushes. Davidson et al. (2008) measured the extent and diversity of biofouling assemblages on the rudder, propeller, stern tubes and struts of an obsolete commercial vessel before and after cleaning had taken place. The cleaning operation, carried out by a commercial hull cleaning company using scuba, removed most of the biofouling biomass, but approximately 40 per cent of the species identified prior to cleaning were still present in treated areas after it had been completed (Davidson et al. 2008).

During manual hull cleaning, organisms removed from hull and niche areas are generally not captured and are left to settle on the seabed below or are transported to adjacent areas by currents (Hopkins and Forrest 2008). The effect of manual cleaning on the performance of antifouling coatings varies between cleaning methods and paint types. In some scenarios, such as when stiff brushes are used to remove biofouling from soft paint types (e.g. fouling-release coatings), the scrubbing process can gouge and abrade the paint layer to the extent that future biofouling protection is compromised (Holm et al. 2003). In contrast, *gentle* removal of slime and minor biofouling from non-biocidal fouling-release paints preserves optimal performance and helps prevent the build-up of more developed, encrusting biofouling assemblages.

During an experimental evaluation of in-water cleaning practices, Floerl et al. (2005) observed recruitment of biofouling organisms on surfaces where some organic tissue remained after manual removal (by scraping) of biofouling. Therefore, once biofouling of a hull surface has begun, manual cleaning by scrubbing or brushing may be required at intervals of one to several months to prevent the re-establishment of biofouling assemblages.

Manual scrubbing and brushing is a widely used practice and is often undertaken by the vessels' owners or crews, at no cost other than the price for the brushes and scrapers (A$25). The cost for commercial manual in-water cleaning for recreational yachts and launches is approximately A$240 plus GST for a 12 m vessel such as a standard sailing yacht, including general hull and all niche areas.

Figure 3.1 Manual hull scrubbing by diver

(Image: C. H. Smith Marine)

3.2.1.2 Diver-operated rotating brush systems

The most common system used for in-water cleaning of larger commercial vessels is diver-operated rotating brushes. They generally consist of a treatment unit that houses one or several brushes that are rotated by a hydraulic motor. Treatment units range in size from handheld systems approximately 30 cm in diameter to large, self-propelled systems such as submersible cleaning and maintenance platforms (SCAMPs) with a diameter of 1.8 m (Davidson et al. 2008; Hopkins et al. 2008; Figure 3.2). Generally, different types of brushes are used depending on the type of biofouling. Nylon brushes may be used to remove slime, algae and soft-bodied organisms, while steel brushes or abrasive discs are used to remove hard calcareous organisms (Figure 3.2 e, f). Attending divers can usually vary the rotating speed of the brush to suit the type of biofouling. Standard operating speeds range from 400 to 700 rpm (Hopkins et al. 2008).

Rotating brush systems are generally able to remove biofouling from flat or slightly curved areas such as general hull surfaces and propellers (small brush units only) but are not suited for treating cryptic or structurally complex niche areas (Davidson et al. 2008; Hopkins et al. 2008; Figure 3.2 a). Large, self-propelled systems are able to clean up to 1000 m^2 of hull area per hour and treat an entire merchant vessel (hull areas, propeller and rudder) within a period of 48 to 72 hours (according to Triton Diving Services Ltd <www.tritondivingservices.com>; Lufesa Divers <www.lufesa.com>; Underwater Services International <www.hullcleaning.com>).

The effectiveness of rotating brush systems in completely removing biofouling from targeted areas appears limited. In 2006, a SCAMP unit was used to remove biofouling assemblages from an obsolete commercial vessel prior to its final voyage to a ship-breaking facility. The vessel had been inactively moored for 13 years and featured extensive biofouling assemblages. The SCAMP system achieved a 5.75-fold increase in exposed hull area. However, following the cleaning operation, 21.8 per cent of the entire hull area was still covered in biofouling assemblages and, depending on hull region, 40–60 per cent of the species recorded prior to cleaning were still present

and, presumably, viable (Davidson et al. 2008). Two custom-built, handheld rotating brush systems evaluated in New Zealand by Hopkins et al. (2008) were found to be effective at treating surfaces with low to moderate levels of biofouling that had developed over a period of approximately six months. In such conditions, the rotating brush systems removed > 80 per cent of organisms in the treatment areas. However, the systems were less effective at removing mature assemblages that had developed over a period of 12 months and that contained robust calcareous organisms. In such conditions, up to 50 per cent of calcareous tubeworms, as well as oysters and barnacles, were not removed by the rotating brushes and remained intact and (presumably) viable. Effectiveness of rotating brush systems also varies between operators.

Most commercially used rotating brush systems, including the SCAMP units described above, do not capture biofouling and paint waste generated by the cleaning process. However, the two handheld units developed in New Zealand as part of a Ministry of Agriculture and Forestry – Biosecurity New Zealand (MAFBNZ) research project were fitted with shrouds and suction hoses and designed to capture and contain any paint material or biofouling removed from a hull surface, with the aim to reduce the risk of pollution and the introduction or spread of NIS.

On average, 95 per cent of the biofouling material that was removed by the brushes was captured by the suction system and contained safely for disposal as landfill (Hopkins et al. 2008). However, the 5 per cent of material lost to the environment contained a wide range of intact organisms that included mussels, barnacles, worms, bryozoans, hydroids and ascidians. Containment of biofouling waste was worst on curved surfaces, where the shrouds did not seal the treated areas and a larger proportion of material escaped into the surrounding environment. Niche areas such as sea chest gratings were inaccessible to the rotating brushes.

The action of the brushes also resulted in significant abrasion of the antifouling coating covering the treatment surfaces. During treatment of a fishing vessel coated in antifouling paint, the water surrounding the treatment area became visibly discoloured. A large quantity of paint particles were captured by the suction system, but particles < 60 µm in size (as well as several measuring > 0.5 mm) were released into the environment during the cleaning process (Hopkins et al. 2008).

A handheld device similar to those evaluated by Hopkins et al. (2008) was developed by a UK-based company specialising in underwater maintenance technology (Bohlander 2009). The unit has been designed for propeller polishing and is able to collect and retain fouling waste via a shrouded brush head and a companion filtration unit. The company claims that the system is able to collect and retain 75 per cent of the fouling removed from propellers; however, no test results are available to confirm this (Bohlander 2009).

The cost for in-water cleaning using brush systems depends on:

- the number of divers, and amount of topside equipment and support personnel required
- the type of brush system used
- the size of the vessel
- the areas targeted for cleaning.

In New Zealand and Australia, an approximate price for propeller polishing on merchant vessels ranges from A$4500–10 000 depending on vessel size. Cleaning of sea chest grates (not involving removal of the grate and cleaning of the inside of the chest) generally ranges from A$4000–6000. A Norwegian company estimates that the average price of hull cleaning using brush systems is approximately US$5 per m^2. For a 150 m vessel with approximately 3500 m^2 wetted hull area this would amount to approximately A$25 000. Estimates for costs of in-water cleaning in the US ranged between US$10 000 and US$30 000.

Specialised remotely operated vehicle (ROV) technology has been developed for automated in-water hull maintenance and inspections of US Naval ships. The Automated Hull Maintenance Vehicle (AHMV) is a 'free-swimming' ROV, operating and navigating autonomously without the need for divers. The unit addresses the expense and environmental implications of traditional diver-operated cleaning equipment that discharge toxin-laden effluent into the marine environment, along with biofouling debris and potentially non-indigenous species. Biofouling is cleaned from the hull using rotating brushes incorporated into the unit and the debris is collected by a vacuum-sealed mantle that surrounds the AHMV. Particulate matter is transported to the surface for processing and disposal, and particles > 20 µ are removed from the effluent via filters.

Additionally, video and digital camera equipment provides documentation of hull biofouling and, along with probes and sensors, hull and coating condition (e.g. coating thickness and integrity, corrosion and hull damage). This information can be used to prioritise maintenance work. Navigation around the hull along pre-planned tracks is optimised by the use of sonar technology and an acoustic tracking system, which is especially useful in low-visibility conditions. This system is expected to save the US Navy, or other

sectors of the commercial shipping industry, 10 per cent on fuel-costs, and will facilitate compliance with existing and anticipated hull cleaning regulations.

We were unable to obtain detailed information on test results of this unit, particularly on the AHMV's effectiveness at removing biofouling from targeted areas and at collecting and containing biofouling and paint waste. The AHMV has been further developed and upgraded; however, no information has been made available to date for inclusion in this report.

As part of the same program, the US Navy has contracted the development of another in-water hull maintenance system, the Advanced Hull Cleaning System (AHCS), described by Bohlander (2009). The AHCS consists of two components, the diver-operated Advanced Hull Cleaning Vehicle (AHCV, Model MK-1C) and a wastewater management unit (WMU). The entire AHCS occupies two 16 m trailers. The purpose of the AHCS is to provide in-water cleaning services that include the capture and containment of fouling waste and toxic paint material arising from the treatment. Bohlander (2009) describes the AHCS as being able to reduce the solids content of the treatment effluent to < 5 mg/l of fouling waste and < 1 mg/l of copper. However, no test results or specific information are available to evaluate the effectiveness of the system to remove light, moderate or heavy fouling assemblages. The AHCS is unable to access and clean fouling from structurally complex niche areas (Bohlander 2009). The present version represents a prototype in its test phase and is unavailable for commercial use.

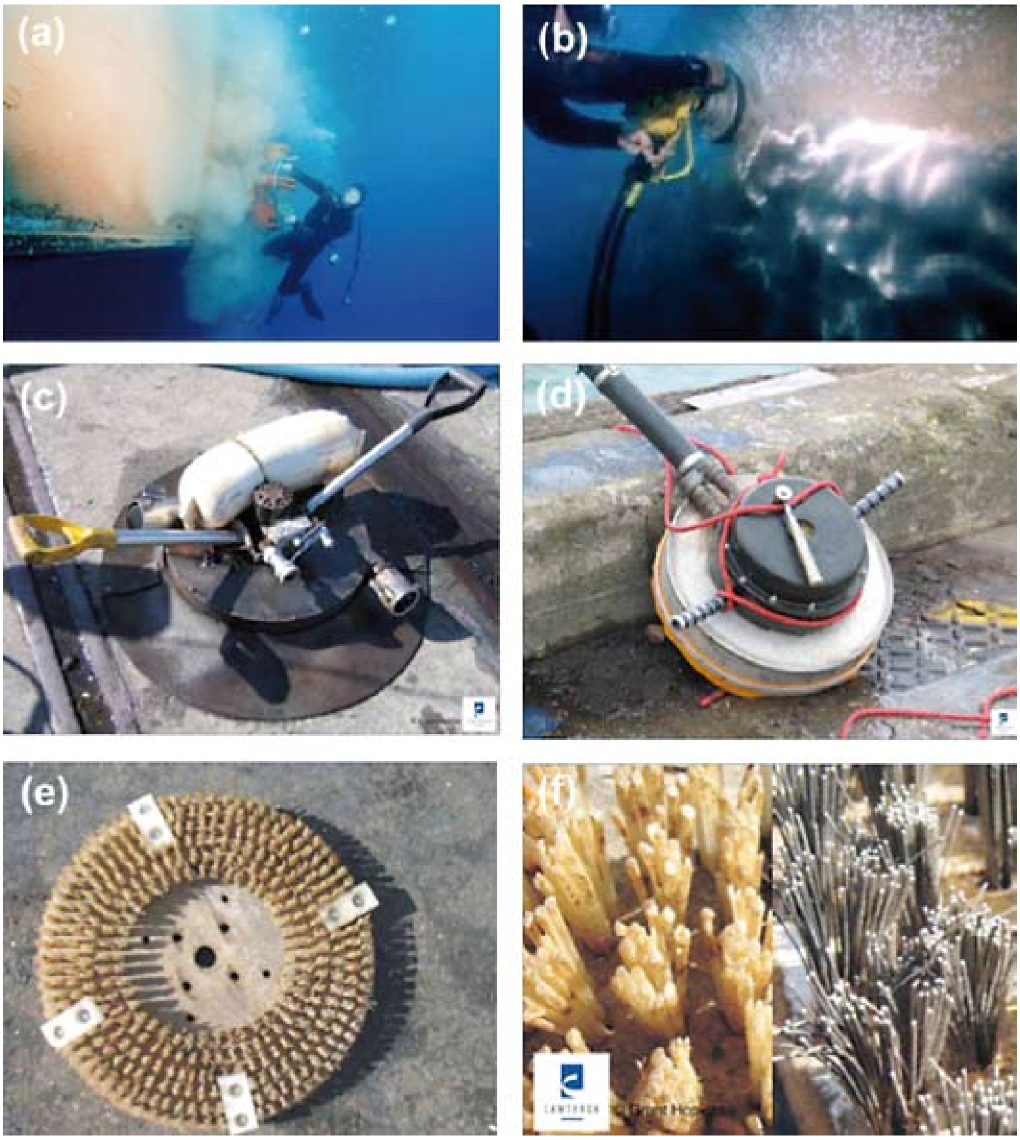


Figure 3.2 Diver-operated rotating brush systems

(a) Large rotating system used on flat hull area (source: Triton Diving Services Ltd.)

(b) Smaller brush system for propeller cleaning (source: Triton Diving Services Ltd.)

(c) and (d) Rotating brush systems evaluated by Hopkins et al. (2008). These systems are capable of capturing biofouling waste

(e) Rotating brush unit

(f) Nylon (left) and steel bristles (right) on rotating brush systems

Images (c–f) used with permission from Cawthron Institute and MAF Biosecurity New Zealand.

3.2.1.3 Underwater suction devices

A custom-built underwater suction or vacuum device was built by a New Zealand company under contract to the New Zealand Ministry of Fisheries to remove a biofouling pest, the colonial ascidian *Didemnum vexillum*, from the hull of a commercial barge and the seabed below the vessel (Coutts 2002). The underwater vacuum system consisted of a diver-operated hydraulic cutter and vacuum head for collection and containment of the biological material removed from targeted areas, and a three-stage filtration system on an adjacent support vessel. The original vacuum cutting head was not effective at removing the *D. vexillum* colonies, and was replaced by a simple nozzle that could be operated by a diver and that proved to be an effective method for removing the ascidian from the barge and adjacent seabed (Figure 3.3 a, b). All vacuumed material was passed through a 50 µm mesh filter. Larvae of *D. vexillum* are approximately 300 µm in size, meaning that no viable propagules were discharged into the sea via the filtration effluent (Figure 3.3 c).

Overall, the system was effective in removing the ascidian *D. vexillum* from the infested barge. A total of 473 kg of ascidian wet weight (an estimated 80 per cent of the total biomass on the barge) was removed from the 72 x 23 m hull in just two days (Coutts 2002). The captured material was successfully filtered to 50 µm at a flow rate of 270 l/min, with no detected accidental release of propagules into the surrounding water.

The all-inclusive cost (labour and materials) to remove *D. vexillum* from the New Zealand barge was approximately A$10 000. This figure does not include the cost of developing and trialling the system (A$80 000) (Coutts and Forrest 2007).

As a tool for in-water hull cleaning, this system has a number of limitations. The most obvious one is its high level of specificity. The suction device appears effective at removing soft-bodied organisms that extend from their attachment surface, such as large ascidians and, presumably, erect sponges and some species of macroalgae. Because the study described by Coutts (2002) focused on *D. vexillum* and did not aim to clean a targeted surface of all biofouling, the general effectiveness of this method in removing biofouling assemblages is not known. However, observations made by the field teams suggest that the system in its present configuration is not effective at removing firmly attached organisms such as barnacles, tubeworms and cementing bivalves.

An additional problem associated with the device was clogging of the nozzle or the suction hose. Clogging of the nozzle by large clumps of biofouling occurred occasionally and was easily cleared by the divers. However, deeper clogging of the hose required reverse-flushing of the system, during which fragmented material and potentially viable propagules were expelled back into the surrounding water and could not be captured by the dive team (Coutts 2002). This limitation may be overcome by fitting a filtering device (such as a fine mesh bag) to the nozzle during reverse-flushing.

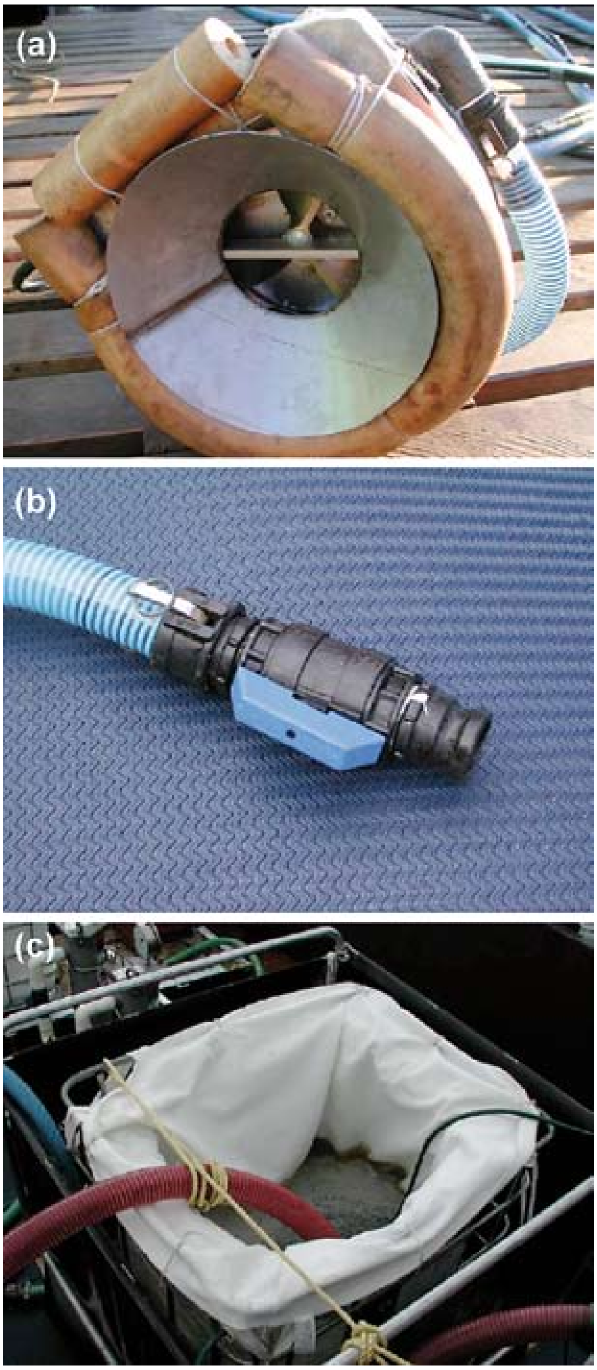


Figure 3.3 Suction technology for in-water cleaning

(a) Vacuum cutter head developed to remove the ascidian *Didemnum vexillum* from a New Zealand barge. The vacuum cutter head could not be easily operated by a diver.

(b) The suction nozzle used in place of the cutter head proved to be effective at removing the ascidian from the barge's hull.

(c) Image of one of the three stages during which the suction effluent was filtered to a size of 50 μm.

Images: New Zealand Diving and Salvage Ltd., used with permission from MAF Biosecurity New Zealand.

3.2.1.4 Underwater pressure cleaning (water-jet)

Some research has examined the use of high-pressure underwater jets (hydro-blast) for in-water hull cleaning. An advantage of this technology is its minimal impact on antifouling coatings if an appropriate water pressure is used. Brush-based cleaning technology is associated with a high risk of abrading and permanently damaging antifouling coating layers below targeted biofouling organisms. The use of cleaning jets can have a less abrasive effect if appropriate water pressure and cleaning current angle are used, or an equally abrasive effect when pressure is too high. Even when low pressure is used, the removal of biofouling, surface deposits and leached paint layers still results in the release of biocide and toxic coating material into the surrounding environment.

Since 2000, an Italian company has developed and subsequently marketed a system called Cavi-Jet. This patented technology uses water pressures of up to 2175 psi to create a cavitating jet of water with microscopic gas and steam bubbles, which collapse when touching the surface treated. This results in a micro-explosion with a pressure of up to 2 million psi at the treatment point <http://www.cavi-jet.purotecnica.com/3/index.html>. Rust and biofouling are destroyed during this process. Cavi-Jet is being offered for hull-cleaning purposes in a range of systems from handheld, pistol-like units to treat rounded or cryptic niche areas such as rudder and propeller shafts and thrusters tunnels to diver-operated vehicles that can treat up to 1500 m2 of algal biofouling per hour and up to 600 m2 of calcareous (e.g. barnacle) biofouling (Figure 3.4).

According to the company, Cavi-Jet is able to remove any level of biofouling and 'clean the hull to bare metal', depending on the type and power of pump used to generate the cleaning jet. Cavi-Jet systems can be accommodated and operated from a dockside trailer or small support vessel. The company is now in the process of developing a waste capture system called the Cavi-Jet Net. The net is installed at the bottom of a ship receiving treatment and waste material removed during the operation is left to sink through the water column and settle into the net. Cavi-Jet technology is not currently for sale. Instead, the company operates via partnering with commercial dive companies to offer fleet service agreements to shipping companies.

Figure 3.4 Cavi-Jet hull cleaning devices

Cavi-Jet hull cleaning devices

Top: twin self-propelled cleaning unit for in-water cleaning of smooth hull surfaces.

Bottom: Cavi-Jet pistol for cleaning of cryptic or rounded/irregular niche areas (left) and combined Cavi-Jet/grinding device for propeller polishing (right). All devices are diver-operated.

Image: company website <www.cavi-jet.purotecnica.com>.

A Norwegian company has recently developed an automated underwater cleaning vehicle called the CleanROV (Figure 3.5). The CleanROV manoeuvres around the submerged parts of a vessel's hull using thrusters, cameras and a positioning system. CleanROV is designed to clean large, flat surfaces with a curvature of > 2 m in diameter and preliminary (and unpublished) test results indicate an effectiveness of close to 100 per cent in removing biofouling from such areas. CleanROV is not able to clean niche areas such as propellers, rudders, thrusters or similar irregular structures. CleanROV was designed to treat biofouling assemblages at early stages of development (e.g. algal growth and small barnacles) and the developers offer fleet service agreements involving multiple treatments per year. The ROV is not intended for use on heavily fouled ships, as the principal objective of the system is to preserve or reinstate the performance of a ship's antifouling coating.

Biofouling is removed from hull surfaces using an underwater high-pressure water-blast. The power of the water-blast is varied depending on the type of antifouling coating on the hull (e.g. silicone-based paints require gentler treatment) and has a range of 725–5800 psi. The removed biofouling material is captured via a vacuuming system and pumped into a filter unit. The company estimates that approximately 98 per cent of all removed biofouling material is captured and contained during this process. However, supporting documentation was not supplied and no information is available on the particle sizes that can be captured by the system (e.g. macrofouling waste vs larvae). Apparently, extensive testing in collaboration with several major antifouling coating manufacturers (Jotun, Hempel, International) has been undertaken. Results (which were not available to us) indicate that the water-blasting action of CleanROV has no negative effect on the performance of antifouling coatings, including biocide-free silicon-based products. This is seen as its principal advantage over more abrasive techniques such as rotating brushes.

CleanROV is able to clean approximately 800–1000 m^2/hr and the time to clean a vessel of approximately 140 m in length and 8 m in draft is approximately five hours, including preparation and setup. A support vessel with two to three personnel, an enclosed cabin for the instruments and approximately 50 m^2 deck space is required to operate CleanROV. The cost for cleaning is between A$9.50 /m^2 and A$15 /m^2 depending on vessel size (please note that these price estimates were provided in early 2009). Reduced rates are available for customers entering fleet service agreements and services are currently offered around Norway, in the Skagerak and in Algeciras, Spain. Operations in the United Arab Emirates and Singapore are in development.

Figure 3.5 CleanROV, an automated hull cleaning vehicle

Image supplied by R. Anderson, CleanHull AS.

Another European initiative is HISMAR (Hull Identification System for Marine Autonomous Robotics), an ongoing European Union funded project to develop a robotic hull inspection and maintenance platform. HISMAR is a multifunctional robotic device which will be able to perform specific inspection or maintenance tasks such as structural integrity monitoring of the ship's hull or cleaning operations using water-jet technology. HISMAR is being developed by a consortium of 10 partner institutions from eight countries, led by the University of Newcastle (UK). A prototype robot has been developed and is currently undergoing laboratory testing. However, according to information presented in Bohlander (2009), the development of HISMAR is significantly behind schedule and in need of additional funding for completion and sea testing.

HISMAR has a 1.2 m wide enclosed cleaning head that comprises a pivoted high-pressure (up to 2900 psi) spray cleaning unit. This unit enables the robot to treat biofouling while moving in either a forward or backward direction (Figure 3.6). The system is being developed to treat light-to-moderate biofouling, with the overall objective being to prevent the build-up of heavy biofouling on ships' hulls through regular cleaning operations. HISMAR's design is aimed particularly at the new generation of fouling-release coatings (see Section 2) and its variable cleaning pressure will allow it to be used for treating surfaces coated in either soft or hard variations of this paint type without damaging them.

The HISMAR robot is able to be steered around a ship's hull via joystick from an attending support vessel, or able to move independently using an on-board optical dead reckoning system (ODRS) and a magnetic landmark recognition system (MLRS). ODRS and MLRS produce a map of the ship's hull that allows HISMAR to locate navigational landmarks in a 2D reference frame by detecting surface and subsurface features of the hull. HISMAR is designed to move around a hull at approximately 0.48 m/s, and is attached via a system of magnets strong enough to hold the robot's weight above and below the waterline of a hull.

The robot has been designed to clean approximately 80 per cent of a vessel's submerged surface area. While HISMAR's principal focus is to clean biofouling from the vertical sides and the flat keel bottom of ships, its hinged cleaning head allows it to effectively operate on surfaces with a limited extent of curvature, such as the bow and stern regions of a vessel. However, HISMAR is not able to clean biofouling from most niche areas, including sea chest gratings, rudder and rudder stock, lateral fins, thrusters pods and tunnels.

HISMAR's envisaged suction extraction system collects wastewater and cleaning debris using a high-powered eductor pump. Waste material is extracted at a rate of 80 l/min. Test results (not made available to us) suggest that the waste extraction system built into the fully sealed cleaning head is able to collect and contain at least 95 per cent of the material removed by the cleaning operation; however, no information was provided on the range of particle sizes that are effectively captured and retained.

The project team envisages development of a debris separation system, which would allow for the majority of the cleaning water to be returned to the harbour or reused in the cleaning process. During a separate project, designs have been developed for a two-stage separation

tank with increasingly finer filters, designed to collect most of the larger debris pieces. A pump will be connected to the second stage of the settling tank and force the waste water through a cyclone filter arrangement. This process is intended to remove all debris particles down to 5 μm. Following filtration, the team envisages using UV light or heat to kill any organisms that survived the previous treatment process, before discharging the filtrate into the sea or diverting it back to HISMAR's cleaning head. However, the development team is also considering a design that would be used when treating vessels coated in biocide-based antifouling coatings. In this scenario, filtered water would not be immediately discharged but instead collected and treated or disposed of onshore, depending on the nature and concentration of biocides in it.

Once operational, HISMAR will be able to clean a vessel's hull above and below the waterline (thus independent of loading operations), as well as when the vessel is in drydock. The robot's operation underwater will not require the assistance or presence of divers. However, a surface-based team of three to five people is required to operate and monitor HISMAR and the waste collection system. The robot can be deployed from the ship's deck, bunker doors, an adjacent support vessel or wharf. HISMAR is not in commercial operation yet, but the cleaning costs for a 30 000 DWT vessel (approx 180 m in length) are estimated to be around A$52 000. Once commercialised, the purchase price of HISMAR is estimated to be between A$520 000 and A$625 000 per robot. No published test results on the performance of HISMAR are available.

Figure 3.6 Pre-production image of HISMAR

Source: HISMAR (2008)

3.2.2 Technologies designed to kill but not remove biofouling

Several approaches to in-water hull cleaning are available that do not rely on abrasive action to remove biofouling organisms. Instead, these technologies are aimed at killing biofouling organisms without actively removing them. Once killed, soft-bodied organisms will eventually fall off the hull, while cemented taxa are likely to remain attached and contribute to frictional resistance.

3.2.2.1 Heat treatment

Heat is widely known as a method for killing larval, juvenile or adult life-history stages of marine organisms. Various forms of heat shock have been used to remove biofouling infestations in the cooling systems of power plants, epibionts on aquaculture and mariculture species, viable organisms in ships' ballast water systems and benthic populations of marine NIS (Wotton et al. 2004; Aquenal 2007; Stuart et al. 2008).

'Hot water box' to eradicate Undaria pinnatifida from a ship wreck

In 2000, the high-profile invader *Undaria pinnatifida* (Japanese kelp) was found on the hull of a fishing trawler that sank in shallow coastal waters off New Zealand's Chatham Islands (Wotton et al. 2004). Under contract to the Ministry of Fisheries, a commercial diving company developed two techniques to kill *Undaria* plants growing on the vessel's hull. The first was a 'hot water box', developed to treat general hull areas. The hot water box consisted of a wooden box whose single open side was placed onto the vessel's hull. Foam seals on the sides created a closed system inside the box, which contained heating elements. These elements were powered by a generator on an attending support vessel and heated the water inside the box to a temperature of 70 ^{0}C within a period of 15 minutes. The area covered by the box was then subjected to the heated water for a period of 10 minutes, which demonstrably killed any sporophytes of *Undaria* present in the treatment area (Wotton et al. 2004).

The second method consisted of an adapted Petrogen oxy-gasoline cutting torch, which was used to kill *Undaria* plants via heat in areas that could not be sealed by the hot water box (e.g. openings and gratings in the hull). The cleaning operation lasted four weeks and successfully removed *Undaria* from the wreck. A post-treatment survey conducted 18 months later found no surviving *Undaria* sporophytes. It is unknown what effect the hot water box and Petrogen torch had on the antifouling coating of the vessel. The cost of eradicating *Undaria* from the sunken trawler was A$306 000 (Wotton et al. 2004).

Steam sterilisation tool to kill *Undaria pinnatifida* plants on natural and artificial substrates

A similar system was developed by New Zealand's Department of Conservation as an incursion response tool for *Undaria* on natural substrates around southern New Zealand. This technology did not heat seawater adjacent to the treatment area but instead delivered either freshwater or steam heated by a surface-based industrial steam cleaner to the seabed, where it was applied to the treatment area via a silicone cone 30 cm in diameter.

In 2006, Golder Kingett Mitchell Ltd. evaluated the effectiveness of this technology in killing marine sessile organisms on a range of natural and artificial substrata (Stuart et al. 2008). Water that was heated to 54.8 ^{0}C (average temperature across replicate trials of 42.4 ^{0}C) and then applied to a smooth target area containing *Undaria* gametophytes (microscopic juvenile stage) for 10 seconds, resulted in approximately 44-fold lower survivorship of gametophytes than a control treatment. The same treatment decreased the abundance of small plantlets 17-fold. When the heat treatment was applied to diverse biofouling assemblages on floating pontoon surfaces (maximum temperature 53.8 ^{0}C; average 35.1 ^{0}C), average survivorship of organisms present in the treatment area decreased from 99.3 per cent (control) to 16.6 per cent. Mortality was highest among soft-bodied organisms and lowest for calcareous species such as bivalves and barnacles (Stuart et al. 2008).

Stuart et al. (2008) concluded that the heat treatment system as tested was not effective enough to kill organisms in the field using a single treatment. The system was found to be most reliable on flat surfaces where the silicone cone could be sealed against the treatment area. On irregular surfaces, or on surfaces with extensive and structurally complex biofouling assemblages, the failure of the cone to seal the unit against the substratum resulted in a loss of heated water and lower treatment temperatures for targeted organisms. This resulted in lowered and highly variable rates of mortality (Stuart et al. 2008). However, the rapid heat-up time per unit of treatment area (25–35 seconds to get to 50 ^{0}C) is a promising feature if a better seal can be provided.

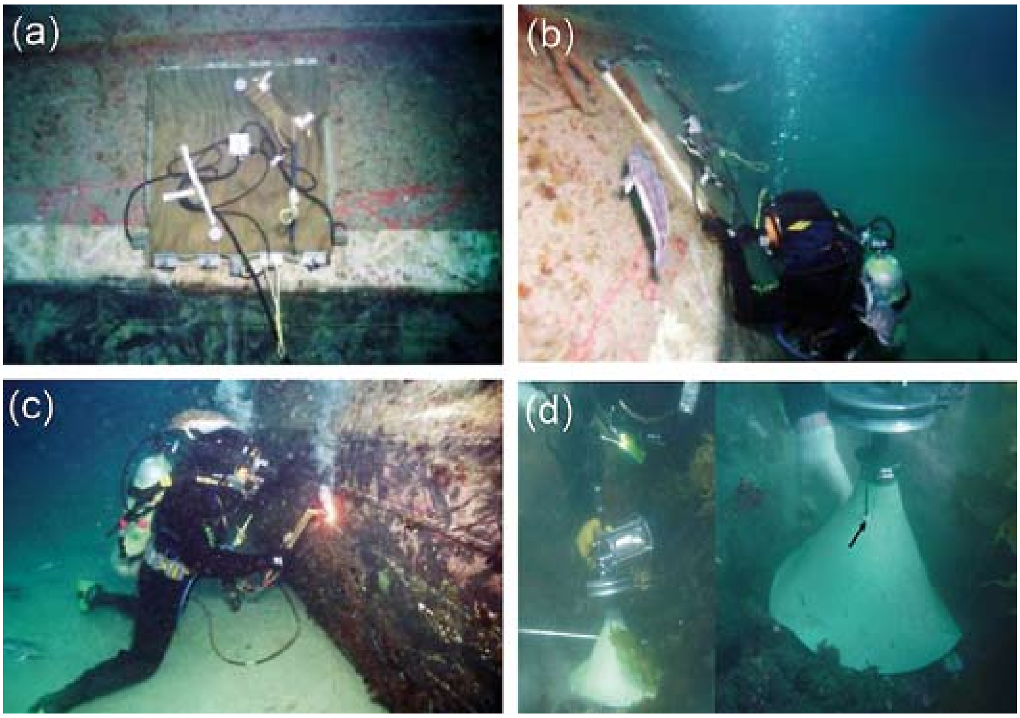


Figure 3.7 Heat treatment systems developed in New Zealand

(a) and (b) 'Hot water box' developed to remove the kelp *Undaria pinnatifida* from a sunken trawler in the Chatham Islands.

(c) The Petrogen heat torch being used to kill Undaria on irregular or angular hull surfaces.

Images by New Zealand Diving and Salvage Ltd, used with permission from MAF Biosecurity New Zealand.

(d) The heat treatment cone developed by the Department of Conservation and evaluated by Stuart et al. (2008).

Image: Golder Associates, used with permission from MAF Biosecurity New Zealand.

Hull heat treatment technology

An Australian company is in the process of commercialising heat treatment technology, aimed at preventing the development of mature biofouling assemblages on those areas of ships where biofouling results in the greatest fuel penalties. The company's Hull Surface Treatment (HST) system is a non-chemical, non-abrasive process to kill and remove marine slime (biofilm) and algal biofouling from ships, hulls. Similar to the system used to eradicate *Undaria* from the sunken trawler in the Chatham Islands, HST relies on thermal shock (i.e. the exposure of biofouling organisms to lethal water temperatures in an enclosed treatment system). It is important to note that HST is aimed at preventing the development of complex biofouling assemblages by targeting and removing earlier stages of the biofouling sequence (biofilm and algal biofouling). It was not developed to kill and remove complex existing biofouling assemblages such as those containing mature barnacles, tubeworms and bivalves.

The HST system consists of a 'thermal applicator' (current prototype dimensions are 2.5 x 1.5 m) that is lowered from an attending support vessel (12 m in length) and that attaches to a vessel's hull via patented technology involving a magnetic mechanism (Figure 3.8). The hull areas and biofouling enclosed within the thermal applicator are then exposed to water at a temperature of 50 ^{0}C, supplied via a diesel-powered boiler unit on the support vessel above. The exposure time is approximately four seconds, which was found to be sufficient to effectively kill algal growth and recently settled barnacles. Following this exposure, the thermal applicator automatically changes position via a system of roller wheels.

The applicator is initially positioned at the water surface and automatically moves vertically down the hull to the bilge keel. Once there, the support vessel shifts its position along the vessel's hull and the thermal applicator automatically self-centres and conducts the next, adjacent vertical treatment transect. No divers are required for HST treatment, meaning that this technology is independent of water clarity and quality. Three surface personnel are required to operate the support vessel and on-board HST equipment.

HST does not remove biofouling organisms from the hull but simply kills them. Dead material either falls off the hull following treatment or is dislodged by turbulence and water drag when the vessel departs from the port. HST is claimed to not remove or damage the antifouling coating underneath the targeted biofouling. However, independent test results on the long-term performance of different antifouling coating types following the application of HST are not currently available for verification. The company envisages HST for use on vessels' hulls every four to six months, which was shown during research and development and commercial trials (four vessels) to prevent the development of biofouling assemblages beyond the early stages of slime and algal growth. HST was not designed to treat vessels containing extensive biofouling assemblages.

The current HST system can treat general hull areas from the water line to the bilge keel. This includes niche areas such as sea chest gratings and outflow/intake pipe openings. However, the HST system is not able to treat flat bottom keels, rudders and propellers. The time taken to apply HST treatment to a 200 m vessel is 16 hours (two eight hour shifts) with a single HST unit, or a single 12 hour shift using one unit on each side of a vessel's hull. The current target market for HST is large commercial vessels, on a contractual basis. The system is not currently available for preventing biofouling on smaller vessels such as sailing and motor yachts.

The company has released news of a second system that is designed to remove biofouling from niche areas inaccessible to the HST unit described above. The HST Niche applicator (HSTNA) is a lightweight, portable and diver-operated device able to effectively negotiate the various shapes and angles associated with oil rigs, off-shore structures, sea chests, bow thrusters, rope guards, sea inlet pipes and overboard discharge. This process is identical in terms of the patented technology established for the HST system; however, the company claims that HSTNA is capable of killing even structurally complex (tertiary biofouling) assemblages. No test results are currently available.

The design of the handheld application allows the divers to vary the water treatment temperature from 50 to 90 ^{0}C. The developers have carried out testing and believe the unit operates effectively. However, formal test results are unavailable at this point. Because this information was only made public at the final editing stage of this report, HSTNA has not been included in the risk evaluation described in Section 5 of this report.

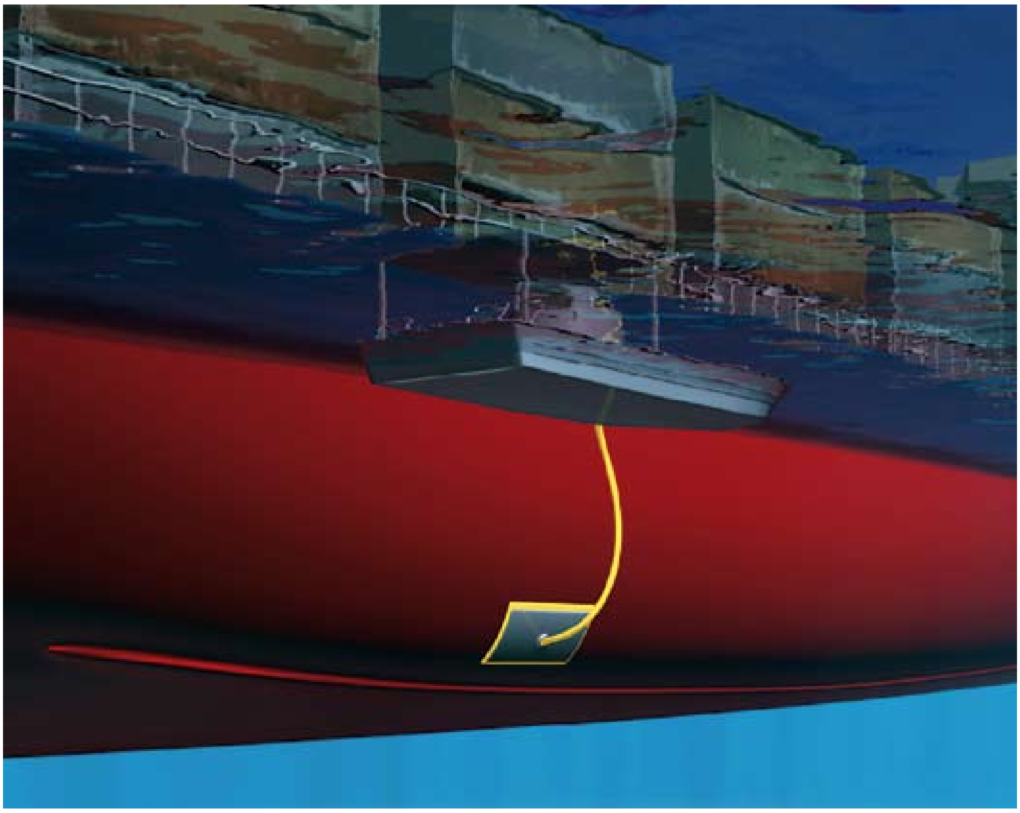


Figure 3.8 HST treatment of a large commercial vessel

The treatment unit is controlled from an attending support vessel and moves vertically from the waterline to the bilge keel. No divers are required for this operation.

Illustration reproduced with permission of Commercial Diving Services Pty Ltd.

Heat treatment of ships' sea chests

Sea chests are recesses built into the hulls of large vessels and are used to supply water to the vessels' cooling, ballasting and fire fighting systems. Sea chests can harbour diverse assemblages of sessile and mobile marine organisms, and have been identified as a major vector for the introduction and transport of marine NIS (Dodgshun and Coutts 2002; Coutts et al. 2003).

The use of heat sterilisation for treating ships' sea chests is currently being investigated in New Zealand as part of a research program funded by the Foundation for Research, Science and Technology (Effective management of marine biodiversity and biosecurity program (C01X0502)). The work is a collaboration between the Cawthron Institute, the University of Canterbury's Department of Mechanical Engineering, and Pacifica Shipping (Bell et al. 2008). The team has developed a laboratory-based, life-sized sea chest model and developed a mechanism that floods a sea chest with hot water generated using excess heat given off by the ship's engine. Based on a literature review on the thermal tolerances of marine organisms, a temperature of 60 ^{0}C, maintained over several hours, was identified as sufficient to sterilise the sea chest (i.e. kill all resident organisms).

The prototype is being used to calibrate models of heat treatment for different sea chest sizes and configurations and to undertake experiments on treatment efficacy. An internal water temperature of 50 ^{0}C was achieved in the experimental unit when the sea chest gratings (flush with hull surface) were facing downwards, as convection served to contain the hot water within the sea chest. However, when the sea chest gratings were oriented sideways, hot water escaped through the grating and resulted in insufficient heating of the water inside the sea chest.

The development team recommended that the installation of grating covers during the sterilisation treatment would mean that temperatures of at least of 60 ^{0}C can be achieved (Bell et al. 2008). The team further recommended that the hot water pumped into the sea chest should have a temperature of 90 ^{0}C and be supplied at a rate that fills the sea chest in no more than one hour to minimise the amount of heat lost through the sea chest walls (Bell et al. 2008). As this work is currently in development, the treatment is not yet commercially available. The longer-term effect of high water temperatures on the performance of different antifouling coating types has not been examined.

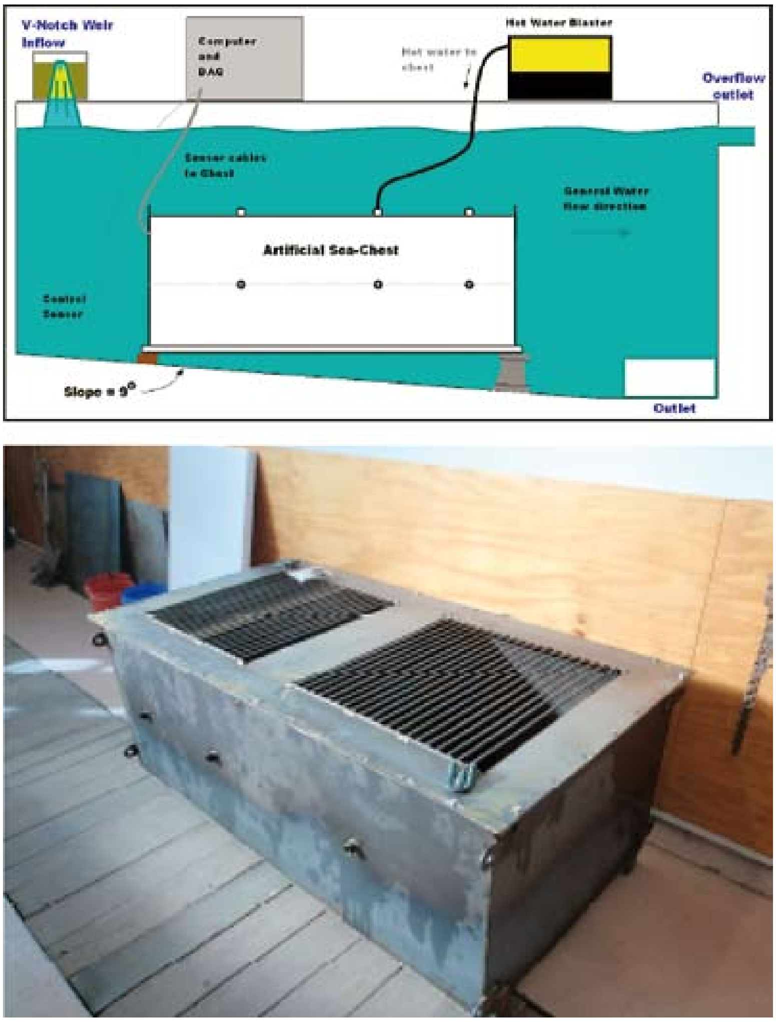


Figure 3.9 The sea chest sterilisation model developed by the University of Canterbury

Top: Illustration of the laboratory-based sea chest model and source of hot water.

Bottom. The experimental sea chest as developed by the university's mechanical workshop.

Image reproduced with permission from the University of Canterbury.

3.2.2.2 Encapsulation technologies

A promising alternative technology for killing marine biofouling organisms is the use of impermeable barriers. The underlying objective of this technology is to isolate and kill targeted organisms by depriving them of essential resources such as light, oxygen and food. Mortality may be accelerated by adding chemical agents (Coutts and Forrest 2005). Several methods have been used, including wrapping or encapsulating permanent structures (e.g. pontoons and pilings) or vessels in polyethylene plastic, or surrounding them in specially designed envelope systems.

Bottom Liner

Encapsulation technologies are specifically designed to contain and kill existing biofouling assemblages. Bottom Liner is a product made and marketed by a company based in Long Beach, California, USA. Bottom Liner creates a self-contained 'pool' that isolates a vessel from the surrounding water. It is intended as a technology to *prevent* the development of hull-fouling assemblages by isolating the hull from the surrounding water and propagules. Bottom Liner is permanently installed at a vessel's berth, and specifically designed to be used on recreational vessels residing at floating marina berths. We were unable to obtain quotes, test results or information on the availability of Bottom Liner in Australasia <www.bottomliner.com>.

IMProtector™

A Tasmanian company is developing a mobile encapsulation tool that quarantines and kills biofouling on vessel hulls. The IMProtector™ can be applied within minutes of a vessel arriving in port, on a vessel at anchor, alongside a wharf or in a marina berth. If installed properly, it causes no physical damage to the vessel's antifouling coating. This method has the potential to treat niche areas of a vessel, including through-hull fittings, saltwater systems such as toilets and cooling systems, and around propellers and rudder. The IMProtector does not actively remove biofouling from a hull.

The unit can be deployed by two people on the surface (no diving needed) and a small dinghy to enclose and secure a 15 m vessel for treatment in less than 45 minutes. Material detaching from the hull during treatment is retained inside the unit and can be pumped out, treated to a desirable level and then disposed of in an appropriate manner before releasing the vessel. Removal of the unit can be completed by two people using a small dinghy in 15 minutes.

Three prototypes have been built to date. Two cater for vessels of loaded waterline length up to 15 m and draught up to 2.5 m. The third caters for vessels of loaded waterline length up to 18 m and draught up to 5 m and was specifically built to treat suspected irregular entry vessels in northern Australia. The company is also investigating units for larger vessels, including dredges, barges, marina pontoons, oil rigs and ships, and marine infrastructure of all types.

Several treatment options are available depending on the degree of biofouling and the time available. The 'set-and-forget' method involves leaving the vessel encapsulated and allowing the enclosed water to become anoxic. Preliminary (in-house) research indicates that mobile fauna are killed within 24 hours and complete mortality of all taxa occurs between four and nine days. In-house research is underway to assess the rate of mortality when low concentrations of environmentally benign chemicals are used to treat an encapsulated vessel. The addition of biocides to encapsulated vessels is currently not a registered antifouling method with the APVMA.

The cost to treat a vessel using the 'set–and-forget' approach will be up to A$24 000 depending on vessel size. The use of chemical additives to obtain a 24-hour treatment will incur an additional cost (please note that these cost estimates were provided in early 2009). The cost of purchasing a unit is likely to range between A$6000 and A$250 000 depending on vessel size.

Treatment of *Didemnum vexillum* and *Styela Clava* in New Zealand via encapsulation

As part of an eradication program for the nuisance ascidian *Didemnum vexillum* in New Zealand, the species was removed from 27 vessels, ranging in size from seven to 30 m, that were moored in Queen Charlotte Sound (Pannell and Coutts 2007). This was achieved using a 'set-and-forget' encapsulation technology that consisted of surrounding each vessel with a custom-shaped sheet of polyethylene silage cover (Figure 3.10). Acetic acid was added to the entrapped water between hulls and plastic sheets to create a 5 per cent working concentration of acetic acid. Vessels were left encapsulated for seven days. This treatment was found to be 100 per cent effective for killing *D. vexillum* on targeted vessel hulls (Pannell and Coutts 2007; Coutts and Forrest 2007). When the sheets were removed, the acetic acid and biofouling material that had dropped off the hulls were left to naturally degrade in the surrounding marine environment. The cost for the encapsulation amounted to approximately A$460 per vessel.

A similar encapsulation technique was used to kill *D. vexillum* on pontoons and pilings in the same geographical area. Encapsulation of these structures was achieved by wrapping them in impermeable plastic sheets. An incubation period of one month was found to be effective at killing *D. vexillum*. The treatment process was significantly accelerated through the addition of acetic acid (5 per cent working concentration) which generally achieved total mortality of *D. vexillum* within 48 hours (Pannell and Coutts 2007).

In a study using the same encapsulation technique on pontoons in an Auckland marina, Coutts and Forrest (2005) achieved 100 per cent mortality of the invasive clubbed tunicate *Styela clava* following exposure to one per cent acetic acid for 10 minutes, or following encapsulation (without the addition of chemicals) for a period of six days. An exposure time of 20 minutes in one per cent acetic acid resulted in almost

complete mortality of non-target biofouling taxa, with the exception of oysters (*Crassostrea gigas*) and calcareous tubeworms (*Pomatoceros terraenova*) (Coutts and Forrest 2005). The use of chlorine was less effective than acetic acid in accelerating mortality.

Figure 3.10 Encapsulation of recreational and commercial vessels of 7–30 m in length in the Marlborough Sounds, New Zealand

Image: Diving Services New Zealand, reproduced with permission from MAF Biosecurity New Zealand.

Encapsulation of a large naval vessel in New Zealand

In 2007, MAF Biosecurity New Zealand trialled the encapsulation technique described above on a 113 m long naval frigate (the *Canterbury*) prior to the vessel being deliberately sunk and turned into a dive site. This operation required the assistance of divers and surface-based workers in a support vessel. Encapsulation of the frigate took 1.5 days and was achieved using 125 μm thick plastic sheeting and 'belly ropes' that secured the plastic against the hull of the vessel (Figure 3.11). During the encapsulation process the plastic sheet tore in several places and had to be repaired by divers. The sheet was left in place for a period of 11 days (including the installation time), after which a 30 m long tear in the material was discovered caused by contact with the adjacent wharf (Golder Associates 2008). The plastic material was removed from the water using a 25 ton lift.

During the treatment process, water samples were taken and analysed for dissolved oxygen, ammoniacal nitrogen and nitrate. Oxygen levels in the encapsulated water decreased after the second day of the treatment, but then increased in proportion to the amount of damage recorded in the wrap as this allowed seawater to leak into the capsule. Likewise, ammoniacal nitrogen concentration levels had risen slightly on the third day but then dropped, coinciding with the increasing damage to the wrap. Diver observations indicated that mortality of biofouling organisms had commenced in those parts of the vessel that were largely unaffected by damage to the capsule. The study was considered a successful trial for encapsulation of large vessels, provided an effective seal can be achieved by the encapsulation material (Golder Associates 2008). The cost associated with the encapsulation of the naval frigate was approximately A$14 000.

Figure 3.11 The New Zealand naval frigate Canterbury encapsulated in plastic

Image: Diving Services New Zealand, reproduced with permission from MAF Biosecurity New Zealand.

Table 3.1 Summary of available in-water hull husbandry technologies

	AVAILABILITY	EASE OF USE	SUITABLE FOR TREATING HULL AREAS?	SUITABLE FOR TREATING NICHE AREAS?	EFFECTIVENESS	EFFECT ON ANTIFOULING COATING	ABILITY TO CAPTURE PAINT AND BIOFOULING WASTE	COMMENTS
Manual scrubbing / brushing	Widely available.	Simple, can be done without specialised equipment.	Yes	Yes	Varies—evidence that private and professional cleaning often result in incomplete biofouling removal.	Potential for damage to coatings.	Generally no.	Predominantly used on recreational and small commercial vessels.
Rotating brushes	Commercial services widely available.	Requires divers and support vessel.	Yes	Unsuitable for some niche areas.	No proven ability to remove all biofouling species from a vessel.	High potential for damage to coatings.	Generally no. Current technology to capture and retain waste requires improvement.	Regarded as a 'destructive' method by paint manufacturers.
Underwater suction devices	Custom-built in New Zealand, not widely available.	Requires divers, support vessel and filtration plant.	Yes but only soft-bodied organisms.	Unsuitable for some niche areas.	Proven effective for soft-bodied, large ascidians. Ineffective for cementing taxa.	Unknown – not examined	Very good capture and retention, but expulsion of waste during reverse-flushing when system clogged.	Highly specific to soft-bodied taxa, but could be modified to treat wider range of biofouling. Efficient.
Underwater pressure cleaning	Limited commercial services available.	Depending on system, may require divers. All systems require surface support team and filtration plant.	Yes	CleanROV and HISMAR: No. Cavi-Jet: Yes (handheld system only).	Not formally evaluated. Manufacturers/ developers admit <100% effectiveness.	Unknown – not examined. Potential for damage under high water pressures	CleanROV and HISMAR: Yes but not independently tested or still in development. Cavi-Jet: currently none.	Promising technology but requires independent evaluation.
Heat treatment	Currently being commercialised.	Requires surface staff and support vessel. Sea chest sterilisaton requires retro-fitting systems to existing vessels.	Yes. However, only intended to treat early algal and slime biofouling.	Unsuitable for most external niche areas. However, sea chest treatment achievable—in development. HST technology for treating niche areas currently in development.	Each system effective at killing target biofouling but lacks ability to kill non-target biofouling, heavy biofouling (HST) or niche areas.	Unknown – not examined	Not required.	Promising technology but requires further development and independent evaluation.
Encapsulation	Restricted availability.	Some products require divers while others do not.	Yes	IMProtector: yes, including internal seawater systems.	Potentially very high.	Unknown – not examined.	Yes	Promising technology but requires further development and independent evaluation.

4. The economics of vessel hull maintenance

The global ban on the use of organotin-based antifouling coatings raised concerns that use of less-effective products might increase the incidence and intensity of biofouling on vessels worldwide, with concomitant increases in fuel consumption and the spread of marine NIS (Nehring 1999; Champ 2000). It was suspected that this would require an increase in the frequency of hull maintenance. However, as discussed in Section 2, modern non-TBT coatings are able to achieve a performance similar to that of the banned TBT-based coatings.

The recommended intervals for antifouling coating renewal vary between vessel types and with the type of antifouling coating used. Especially in the case of commercial vessels, dry-dockings are usually scheduled according to vessel survey requirements (Table 4.1). Recommended service lives are not always adhered to by commercial and recreational vessel owners and operators. This is illustrated by the results of a Ministry of Agriculture and Forestry Biosecurity New Zealand (MAFBNZ) research project conducted in 2004–08. This research determined the hull maintenance and travel history of 496 recreational and commercial vessels (including tankers, cargo carriers, roll on, roll off vessels, container ships, passenger ships and other types of merchant vessels) (Inglis et al. 2008). When vessels were grouped by antifouling coating type, up to 40 per cent of commercial vessels and up to 20 per cent of recreational vessels surveyed had an antifouling coating age that, at the time of sampling, exceeded the manufacturer's recommended service life by up to three years (Table 4.1).

As discussed in Section 3, regular renewal of a vessel's antifouling coating is unlikely to prevent the development of biofouling in niche areas. Some niche areas are very important for the performance of a vessel, such as propellers (loss in speed and fuel efficiency), sea chests (water intake, fire fighting equipment), or sonar domes and transducers (navigation). These niche areas are often not coated in antifouling paint. The speed at which they will be colonised by biofouling will vary with latitude, salinity and the vessel's activity level. Commercial diving operators in temperate and subtropical latitudes recommend that niche area cleaning is carried out every six to eight months, and that it definitely should be carried out every 12 months. This represents approximately two to three times the frequency of antifouling coating renewal.

In the sections below, we review the costs associated with in-water and shore-based maintenance for recreational and commercial vessels.

Table 4.1 Major antifouling coating types and their recommended service lives for large (commercial) and small (recreational) vessels

Information on RSL provided by Altex Coatings New Zealand. Also shown are the proportions of 496 commercial and recreational vessels sampled in New Zealand (a MAFBNZ initiative) whose antifouling coating age exceeded the recommended service life. For each vessel type and paint type, the proportion of vessels that had received in-water cleaning (IWC) since the last antifouling coating renewal is indicated.

	LARGE COMMERCIAL VESSELS (FAST-MOVING, REGULAR ACTIVITY)	RECREATIONAL VESSELS (SLOW-MOVING, IRREGULAR ACTIVITY)
Conventional biocidal coating[1]	RSL: 36–48 months Sample size (*n*) = 1 Exceeded by 0% IWC: none	RSL: 24 months *n* = 10 Exceeded by 20% IWC: 90%
Controlled depletion polymer[2]	RSL: 36–60 months *n* = 11 Exceeded by 0% IWC: 12.5%	RSL: 24 months *n* = 27 Exceeded by 8% IWC: 68.2%
Biocide-based self-polishing copolymer[3]	RSL: up to 60 months *n* = 134 Exceeded by 40% IWC: 6.7%	RSL: 18 months *n* = 45 Exceeded by 3% IWC: 51.5%
Fouling-release coating[4]	RSL: 30-60 months *n* = 16 Exceeded by 6% IWC: none	*n* = 5 IWC: 60%

1 Estimated service life based on copper-based paints at four coats for commercial and two coats for recreational vessels, at 100 µm dry film thickness (DFT) per coat.

2 Estimated service life based on copper-based paints at five coats for commercial and two coats for recreational vessels, at 100 µm DFT per coat.

3 Estimated service life based on non-copper paints (most usual formula) at three coats for commercial and recreational vessels, at 100 µm DFT per coat.

4 Estimated service life based on a total DFT of 300–400 µm DFT. Only suitable for vessels travelling at approx. 25 knots and more or less continuously. Unsuitable for recreational yachts who spend 50–80% of time inactive.

4.1 Shore-based maintenance

Vessel maintenance out of the water can have a range of dimensions that include biofouling-related maintenance, surveys required by classification societies and structural and non-structural repairs. In this review, only maintenance related to biofouling is considered. It generally comprises some or all of the following activities (Woods et al. 2007):

- removal of vessel from water (yachts: travel lift; large vessels: slipway or drydock)
- hull cleaning by water-blast (including all niche areas such as propellers, rudder and stock)
- opening and cleaning of sea chests (large ships)
- surface preparation for painting
- application of primer/anticorrosive coatings (if required) and new antifouling coating.

Depending on vessel type and operation, these activities may be carried out by the vessel owner or professional contractors. For example, many marinas offer hard-stand areas where yachts are hauled out of the water, cleaned via water-blast and then 'stored' in a work area at a daily charge, where their owners can carry out their own hull maintenance (e.g. preparing and re-painting the hull). The situation is more complex for larger commercial ships, whose off-service periods may represent financial loss to their operators. Large ships are normally removed from the water via slipways or drydocks and any cleaning and painting work is done by commercial contractors. The demand for such facilities is generally high and a quick turn-around is required to minimise economic losses arising from the vessels' inactivity. As a result, different types of maintenance (e.g. cleaning, surface preparation and painting) are generally carried out simultaneously by independent contractors who invoice a ship's agent independently.

In the comparison of costs associated with in-water and shore-based biofouling maintenance outlined below, we focus on the removal of vessels from the water in combination with high-pressure hull cleaning. Many vessel owners or operators combine removal of the vessel from the water and cleaning with a renewal of the antifouling coating system. This procedure is an extra dimension of ship maintenance. In this review, we compare the costs of in-water and shore-based hull cleaning, and present the costs for antifouling coating application as additional information during our review and in the appendices.

4.1.1 Costs for recreational vessels

Owners of recreational vessels are generally able to choose between performing hull maintenance, such as paint application, themselves or using commercial services. Generally, removal from the water and operation of the water-blaster is done by professional operators for occupational health and safety reasons. The cost for having a small vessel (examples here use a length of 12.5 m) removed from the water and having the hull and niche areas cleaned using high-pressure water-blast is approximately A$575 (Table 4.2; mean figure based on quotes obtained from three Australia-wide operations). Costs for smaller or larger yachts can be calculated using information provided in Appendix 2. Subsequent renewal of the antifouling coating by the owner is associated with an additional cost of approximately A$500–1200, or can be carried out professionally for approximately A$1200–1900 depending on paint type.

Table 4.2 Approximate costs for shore-based biofouling removal on recreational vessels

Prices exclude GST.

	12 M YACHT, HAUL-OUT AND CLEANING
Removal from and return to water	A$475
Water-blasting	A$100
Cost for biofouling removal	**A$575 (1 day)**
Additional cost for antifouling (by owner)	A$500–1200
Additional cost for antifouling (professional service)	A$1200–1900

4.1.2 Costs for commercial vessels

Larger ships such as container vessels, tankers, ferries, passenger carriers and cargo carriers are generally removed from the water for marine survey or when repairs are required. In Australia and New Zealand, slipways are able to remove vessels of up to approximately 60 m in length from the water via wheeled undercarriages and powerful winches. Larger ships are removed from the water in drydocks, lockable basins into which vessels are manoeuvred and which are subsequently pumped empty (see Taylor and Rigby 2001; Woods et al. 2007). The costs of services such as drydock or slipway hire, professional cleaning crews for water-blasting and painting, charges for water usage, waste removal and treatment and other associated activities vary greatly between facilities and countries. New Zealand's drydocks can accommodate vessels of up to 170 m in length, while drydocking facilities exist in Australia for vessels exceeding 200 m in length, although their availability is limited.

An indicative charge for removing medium-sized ships (25–60 m in length) from the water and cleaning them via water-blast is approximately A$3000–12 200 (Table 4.3). In addition to this, the vessels will lose one to two days of operating revenue. The application of antifouling coating following cleaning is associated with an approximate cost of A$6600–25 000 for paint and application, and an additional two to three days of lost operating revenue. The charges for slipway facilities are based on quotes obtained from a single Australian facility. The prices shown in Table 4.3 do not include revenue losses arising from travel to the slipway facility or waiting times.

Charges associated with drydocking and biofouling removal in drydocks are considerable. New Zealand is known for relatively cheap vessel maintenance services for both recreational and commercial vessels (Inglis and Floerl 2002). The cost for drydocking and cleaning a vessel using high-pressure water-blast (8000 psi) at a New Zealand drydock catering for vessels up to 104 m in length or 6000 gross tonnes, ranges from A$9000–29 300 depending on vessel size (Table 4.4). The additional application of antifouling coating is associated with an additional A$36 000–89 500 depending on vessel size (Table 4.4; Appendix 2).

Information on the cost of drydocking, cleaning and antifouling of large ships in Australia was obtained from several shipowners' associations and the antifouling coating industry (Appendix 2). The information provided in Table 4.5 represents the average figures for drydocking, cleaning and antifouling costs obtained from these sources. Depending on vessel length, drydocking and biofouling removal from hull and niche areas (including sea chests) is associated with a cost of A$26 000 (smaller vessels up to 50 m in length) to A$195 000 (ships over 200 m), plus one to three days of lost revenue. Antifouling coating renewal is associated with an additional cost of approximately A$30 000 (smaller vessels up to 50 m in length) to A$425 000 (ships over 200 m), plus an additional three to seven days of lost revenue (observed drydocking periods are often longer than these estimates, but this is often caused by repair activities being done while a vessel is out of the water).

Table 4.3 Approximate cost of shore-based biofouling removal on medium sized commercial vessels at slipway facilities

We have also estimated the time (in days) that is required for the treatment and provide this with the treatment costs as it represents a commercial loss to a vessel. Prices exclude GST.

	25 M VESSEL	40 M VESSEL	60 M VESSEL
Removal from and return to water	A$1050	A$3200	A$7200
Shipyard charge	A$181	A$420	A$1050
Water-blast charge	A$375	A$750	A$1125
Sea chest cleaning	–	–	A$500
Equipment	A$300	A$450	A$750
Labour	A$1050	A$1575	A$1575
Waste levy	A$15	A$15	A$15
Cost for biofouling removal	**A$2900 + 1 day**	**A$6400 + 1 day**	**A$12 200 + 2 days**
Additional cost for antifouling	A$6600 + 2 days	A$15 500 + 2 days	A$25 000 + 3 days

Table 4.4 Charges for drydock hire and services for large ships at a New Zealand drydock

We have also estimated the time (in days) required for the treatment and provide this with the treatment costs as it represents a commercial loss to a vessel. Prices exclude GST.

	25 M VESSEL	40 M VESSEL	60 M VESSEL
Drydock hire	A$2950 (2 days)	A$43 500 (2.5 days)	A$7000 (3.5 days)
Access equipment	A$2150	A$3900	A$13 350
Hull cleaning	A$1450	A$2260	A$3900
Sea chest cleaning	A$500	A$500	A$1000
Water charge	A$1450	A$1450	A$2600
Waste removal	A$485	A$970	A$1455
Cost for biofouling removal	**A$8980 + 1 days**	**A$13 430 + 2 days**	**A$29 300 + 3 days**
Additional cost for antifouling	A$35 500 + 3 days	A$56 600 + 5 days	A$89 500 + 7 days

Table 4.5 Approximate charges for drydock hire and hull cleaning in Australia

Quotes obtained from Shipping Australia Limited and the Australian Shipowners Association. We have also estimated the time (in days) required for the treatment and provide this with the treatment costs as it represents a commercial loss to a vessel. Prices exclude GST.

	VESSELS APPROX. 50 M IN LENGTH	VESSELS APPROX. 100 M IN LENGTH	VESSELS – 200 M IN LENGTH
Drydock hire	A$3000 (1 days)	A$20 000 (2 days)	A$60 000 (3 days)
Access equipment	A$7500	A$30 000	A$42 500
Cleaning (water-blast)	A$5500	A$18 000	A$65 000
Sea chest cleaning	A$2400	A$2400	A$2400
Waste removal	A$8000	A$15 000	A$25 000
Cost for biofouling removal	**A$26 400 + 1 day**	**A$85 4000 + 2 days**	**A$195 000 + 3 days**
Additional cost for antifouling	A$30 000 + 3 days[a]	A$149 000 + 5 days[a]	A$425 000 + 7 days[a]

[a] Includes cost of extended drydock hire.

4.2 In-water maintenance

In Australia and New Zealand, the ANZECC Code in its current form prohibits in-water cleaning of surfaces coated in antifouling paint on commercial vessels, although the way that the code is (or is not) enforced varies between states and territories (Section 6). Services for cleaning general hull surfaces (e.g. vertical sides and keel) using diver-operated brush-vehicles or SCAMP systems are thus unavailable; these hull locations need to be cleaned either in drydock or in overseas ports where regulations allow for the activity. However, a range of commercial dive companies around Australia and New Zealand offer cleaning services for niche areas that are generally not coated in antifouling paint, such as sea chests, propellers, transducers and sonar domes, as well as comprehensive hull cleaning for recreational vessels.

Below we describe the costs associated with these in-water hull maintenance services, as well as those that kill but do not actively remove biofouling from treated surfaces.

4.2.1 Costs for recreational vessels

Technologies currently available for treating biofouling assemblages on recreational vessels such as sailing yachts and motor launches include brushing/scrubbing by divers, and encapsulation techniques such as plastic wrapping. The cost to kill biofouling organisms on a vessel of approximately 12.5 m in length in Australia or New Zealand is A$240–500 (Table 4.6). However, Johnson et al. (2007) report the price for in-water cleaning of 12.5 m recreational yachts around San Diego, USA, at around US$50 (A$70).

Table 4.6 Approximate cost of in-water hull treatment for recreational vessels in Australian dollars

Estimates are made for a vessel of approximately 12.5 m in length. Prices exclude GST.

	MANUAL BRUSHING / SCRUBBING	ENCAPSULATION
Hull areas treated?	Yes	Yes
Niche areas treated?	Yes	Yes
Biofouling removed from vessel?	Yes	No
Time required	1–3 hours	24 hours–4 days
Approx. cost	**A$240**	**A$300–500**

4.2.2 Costs for commercial vessels

In this section we consider technologies that are currently available, or in the process of being developed, for treating biofouling assemblages on commercial vessels. They include the use of diver-operated brush or water-blast systems, underwater robots using water-blast or heat treatment technology, and encapsulation with plastic sheeting. We do not consider technologies such as the steam sterilisation tool developed by New Zealand's Department of Conservation or the suction device developed by New Zealand Diving and Salvage, as these systems were developed for specific, project-based applications and are not available for commercial use. In Table 4.7 we have combined the indicative costs for in-water cleaning services made available to us by the various companies, development teams, commercial dive operators and the literature. Where multiple cost estimates were available (e.g. for the price of diver operated brush systems), we combined these to derive an average figure.

The approximate cost of in-water removal of biofouling from all hull and niche areas of a 50 m long ship range from A$10 500 to A$27 000, plus one to two days of lost revenue. For larger vessels, these costs increase to A$21 000–42 000, plus two to five days of lost revenue (100 m vessels); and A$65 000–92 000, plus three to five days (200 m vessels); (Table 4.7). In-water technologies based on water-blast (HISMAR, CleanROV) and heat treatment (HST) are unable to treat niche areas (at the time of finalising this report). To remove all biofouling from a vessel's submerged surface area, additional methods (most likely the widely available rotating brush systems) have to be used to treat niche areas (Table 4.7).

The use of encapsulation technologies to kill biofouling assemblages can be several times cheaper than other available technologies for any vessel size. Financial savings are particularly significant if the treatment is enhanced through the use of chemicals. However, encapsulation is a technology in development and not currently readily available. In addition, the addition of biocides to the encapsulated water is not a registered antifouling method and (depending on the substances added) may not be legal. Also encapsulation does not remove biofouling organisms from hull surfaces. While perished soft-bodied biota may eventually drop off the hulls, calcareous taxa such as barnacles, bivalves and tubeworms are likely to remain attached to the hull. Encapsulation is unlikely to solve the issues of hull resistance and resulting fuel penalties.

Table 4.7 Ability and cost of currently available in-water hull maintenance technology for treating biofouling in hull and niche areas of large commercial vessels

We have also estimated the time (in days) that is required for the treatment and provide this with the treatment costs as it represents a commercial loss to a vessel. All prices exclude GST. Estimates of time taken to clean a vessel will depend on the size of the team. Our estimates are based on a standard commercial team of five (including surface support and dive staff).

	ROTATING BRUSH SYSTEMS	WATER-BLAST ROBOT SYSTEMS	HEAT TREATMENT ROBOT SYSTEM	ENCAPSULATION[d]
Can treat hull areas? **Cost (A)**	Yes (A$7 /m^2)[a] A$6500 (50 m ship) A$15 400 (100 m ship) A$56 000 (200 m ship)	Yes[c] A$8300–13 800 (50 m ship) A$20 700–26 000 (100 m ship) A$72 000–76 000 (200 m ship)	Yes 50 m ship: unknown 100 m ship: unknown A$70 500 (200 m ship)	Yes—entire vessel treated
Can treat niche areas?	Yes[b]	No	No	Yes—entire vessel treated
Cost for cleaning individual niche areas:				
Sea chests	A$2000–4000 (50 m ship) A$2000–5000 (100 m ship) A$2000–6000 (200 m ship)	Cost as for rotating brush systems	Cost as for rotating brush systems	
Propeller and shaft	A$1050–5000 (50 m ship) A$1600–7500 (100 m ship) A$2100–10 000 (200 m ship)	Cost as for rotating brush systems	Cost as for rotating brush systems	
Rudder and shaft	A$1600–4000 (50 m ship) A$1800–4000 (100 m ship) A$2000–5000 (200 m ship	Cost as for rotating brush systems	Cost as for rotating brush systems	
Sonar domes and transducers	A$1600–4000 (50 m ship) A$1600–4000 (100 m ship) A$1600–4000 (200 m ship)	Cost as for rotating brush systems	Cost as for rotating brush systems	
Thrusters	A$3200–4000 (50 m ship) A$4000–5000 (100 m ship) A$4800–6000 (200 m ship)	Cost as for rotating brush systems	Cost as for rotating brush systems	
Combined cost for all niche areas in single operation (B)	A$4000–13 000 (50 m ship) A$5300–16 000 (100 m ship) A$9300–21 800 (200 m ship)	Cost as for rotating brush systems	Cost as for rotating brush systems	
Biofouling removed from vessel?	Yes	Yes	Yes (removal via drag upon departure)	No—requires additional treatment
Approx. total cost 50 m ship (A+B)	**A$10 500–19 500 + 1-2 days**	**A$12 300–26 800 + 1 day**	**Currently unknown**	**A$2000–7000 + 1-5 days**
Approx. total cost 100 m ship (A+B)	**A$20 700–31 400 + 3 days**	**A$26 000–42 000 + 2 days**	**Currently unknown**	**A$7000–14 000 + 1-5 days**
Approx. total cost 200 m ship (A+B)	**A$65 300–77 800 + 4-5 days**	**A$81 300–97 800 + 3 days**	**A$79 800–92 300 + 3 days**	**A$14 000–24 000 + 1-5 days**

a Average international price of A$7 /m^2 calculated from estimates supplied by several parties.

b Assumes use of small, handheld rotating or manual brush systems.

c Approximate cost per metre squared supplied by the HISMAR and CleanROV development teams.

d Estimate assumes an encapsulation unit is already installed at the location. The lower cost estimate includes set-and-forget treatment, while the higher estimate includes the addition of chemicals to kill all biofouling within 24 hours

4.3 Summary of relative costs of in-water and shore-based hull maintenance

The costs for in-water and shore-based hull maintenance obtained during this study are indicative only, as there is large variation in rates charged by providers of these services. However, several important trends emerge.

1. The cost of in-water cleaning of hull and niche areas using technologies that remove biofouling organisms from a hull (i.e. brushes, water-blast, also HST) is generally lower than the cost for removing a vessel from the water for cleaning only. However, because of variation in the rates different operators charge for the same service, the relative difference in cost between in-water and shore-based water cleaning is also variable. Nevertheless, in-water cleaning is between 10 to 50 per cent cheaper for recreational vessels than removal of biofouling out of the water. For commercial vessels of 50–200 m in length, a comprehensive in-water hull clean using a combination of brushes and/or underwater jets and/or heat treatment is 35–65 per cent cheaper than biofouling removal at a slipway or drydock. This difference in cost may further increase when indirect costs such as losses in revenue are incorporated. In-water cleaning is slightly faster, especially when general hull areas are cleaned by a robot while divers treat niche areas. However, a vessel can incur significant financial losses if the next drydock is several days' sailing distance away. For example, the nearest drydock available to a vessel residing at Port Dampier is located on Australia's East coast (eight days' sailing distance) or in Indonesia (four days' sailing distance). Travel times to drydocking facilities, and potential waiting times can add considerably to the cost of shore-based hull maintenance. In contrast, in-water operations can generally proceed while a vessel is loading or unloading, minimising financial losses.

2. The effectiveness of in-water cleaning operations that remove organisms from treated surfaces is likely to be lower than that of cleaning activities out of the water. All in-water maintenance technologies reviewed in Section 3 are either unable to treat niche areas (e.g. heat treatment, robotic underwater jet systems) or are unable to capture and retain all of the biofouling material removed during the treatment process (e.g. rotating brush systems). Importantly, the effects of unproven technologies, in particular heat treatment and encapsulation, on the integrity of different antifouling coatings are currently not understood.

3. Depending on vessel size, the use of encapsulation technologies is three to five times cheaper than in-water cleaning methods that remove biofouling from hulls, and 3.5–14 times cheaper than shore-based cleaning. Encapsulation is a developing technology. If reliable systems can be developed, encapsulation may be able to achieve 100 per cent mortality of biofouling organisms—including those inside sea chests and internal seawater systems. However, encapsulation is unlikely to be highly valued by the shipping industry, as it does not remove biofouling and therefore has a less noticeable effect on speed and fuel consumption. We were unable to obtain quotes for the disposal of vessel encapsulation material (plastic sheets) and associated biofouling waste. If encapsulation is used, this cost needs to be added to the treatment.

4. The majority of hull maintenance cost lies with the renewal of the antifouling coating. In the case of commercial vessels, antifouling coating treatments are generally two to four times the cost of in-water or shore-based biofouling removal. Depending on vessel size, renewal of the antifouling coatings (labour and materials) can add A$35 000–425 000 to the cost for hull cleaning, as well as several extra days of lost revenue for the vessel. This highlights the feasibility of using high-performance antifouling coatings. While these may be more expensive to purchase, they will keep vessels biofouling-free for longer and reduce the need for interim in-water maintenance. This does not address the biosecurity risk posed by certain niche areas. Commercial diving operators recommend that niche areas such as propellers, sea chest grates, transducers and sonar domes are cleaned every 6–12 months.

5. Review and comparison of the relative environmental and economic risks associated with in-water cleaning and other hull cleaning strategies

In this section we evaluate the relative environmental risks and economic costs associated with different forms of in-water and shore-based hull cleaning, and use this information to identify situations where in-water cleaning may be permissible. Environmental risk is defined here as the combined biosecurity risk (introduction or spread of NIS) and contaminant risk (release of toxins) associated with cleaning a vessel's hull. As part of this evaluation we also consider the biosecurity and contaminant risk posed by no hull maintenance (i.e. the unmanaged, or baseline risk; Hopkins and Forrest 2008). For example, the risks from biofouling are principally associated with the release of competent life-stages of a pest organism from the vessel into a marine environment in which it does not already occur.

Competent life stages are those that are capable of establishing self-sustaining populations and could be adult life-stages, gametes, larvae or vegetative fragments (Grahame and Branch 1985; Santelices 1990; Ceccherelli and Cinelli 1999). These can be released or can detach from the vessel even when no cleaning is taking place. The likelihood of this is influenced by factors such as local environmental conditions, the reproductive state of the organisms and the length of time the vessel spends in port (Apte et al. 2000; Minchin and Gollasch 2003). It has been suggested that in-water cleaning may enhance the release of competent life-stages through direct dislodgement from the vessel or by triggering reproductive activity that causes propagules to be released (Hopkins and Forrest 2008 and references therein). However, there is little empirical evidence that propagules released in this manner are competent to establish.

The biosecurity risk posed by different methods of defouling will depend on the rate at which competent stages are released from the vessel and are not effectively contained. Similarly, toxins are released from antifouling coatings continually, even when no cleaning is occurring. The environmental risk posed by in-water cleaning will depend on how much the rate of toxin release is enhanced by active abrasion or manual polishing of the coating relative to normal operation of the vessel.

5.1 Scenarios for hull cleaning

There are many situations in which hull cleaning may be required and where a decision must be made about whether this is to be done in shore-based facilities or while the vessel is still in the water. Such decisions must take into account (at least) the nature of cleaning and maintenance required (e.g. propeller polishing vs paint renewal), the risks to biosecurity and water quality associated with the method of cleaning and the economic costs to the vessel operator of the cleaning method and of any delays associated with it.

In this section we developed a range of scenarios for cleaning, based on information reviewed in earlier sections of the report. The scenarios were developed using five factors—biofouling origin, biofouling extent, vessel type, antifouling coating type, and proposed cleaning method—that were identified in our review as important exacerbators of risk (Figure 5.1). We created a list of all possible combinations of the five factor levels (with some exceptions, specified below) to represent situations in which vessel hull cleaning may be required. We also provided initial evaluations of the biosecurity and contaminant risks associated with different available cleaning methods and their costs for vessels of different sizes (Table 5.2).

Our evaluations of risk are intended as a starting point for discussion, and will benefit from feedback from and discussion with managers and stakeholders. We evaluated risk using a simple ordinal scale: negligible, low, moderate or high. The scenarios and their associated risks and costs are provided as a 'look-up' table (Table 5.2) to assist decision makers evaluate the consequences of different approaches to cleaning. In the section below, we describe how each of the five factors used in the evaluation can influence risk.

5.1.1 Definition and discussion of risk factors

5.1.1.1 Definition of risk

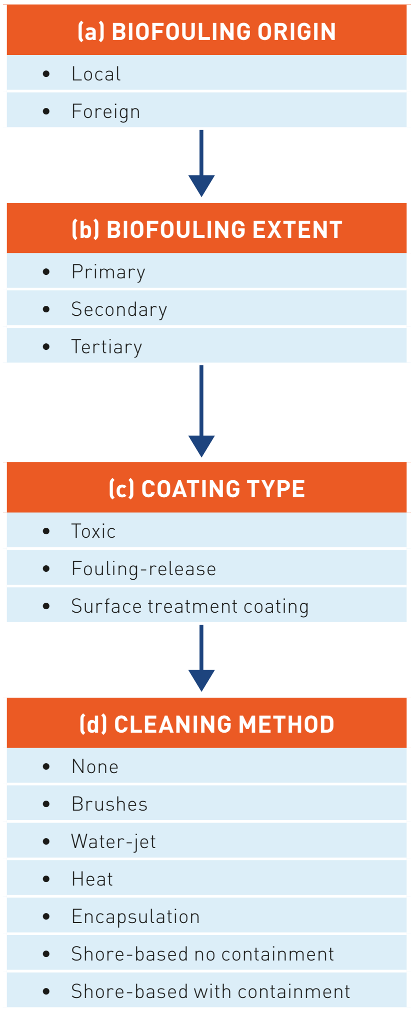
The term 'biosecurity risk' describes the *risk associated with the cleaning activity* of introducing or spreading NIS by releasing (but failing to capture) adult organisms or propagules into a local environment. It does not necessarily describe the biosecurity risk posed by the entire vessel *following* the treatment. This is because some cleaning methods are unable to remove all biofouling from treated areas, and are unable to treat niche areas. Vessels that have been cleaned using these methods may still contain biofouling assemblages and continue to pose a biosecurity risk. Similarly, the 'contaminant risk' describes the *risk associated with the cleaning activity* of introducing toxic substances (antifouling biocides) into the local marine environment.

Baseline risk is the rate at which propagules of non-indigenous species (biosecurity risk) or toxic contaminants (contaminant risk) are released from vessels containing different amounts of biofouling that are not cleaned.

5.1.1.2 Risk factor 1: Biofouling origin

Vessels that have not left, or which have remained within the vicinity of, their homeport since their last antifouling paint treatment, are likely to have developed biofouling assemblages that consist exclusively of species (both non-indigenous and native) that are already present within the local area (Floerl and Inglis 2005). Local release of these organisms is generally not considered a biosecurity risk unless the species has a very restricted distribution.

In contrast, vessels that have originated from overseas are likely to contain biofouling assemblages in which a large proportion of species are not present locally. Similarly, vessels arriving from domestic locations that are known to have populations of unwanted species (defined here as any species contained in the *Australian Consultative Committee on Introduced Marine Pest Emergencies (CCIMPE) trigger list*, or in New Zealand's Unwanted Organisms Register) could be considered high risk if they are entering a region in which the species does not presently occur. The introduction of propagules or individuals of these species via natural spawning, dislodgement or as a result of hull cleaning activities could lead to local establishment (Apte et al. 2000; Minchin and Gollasch 2003).



Biosecurity and contaminant risk associated with hull cleaning determined by combinations of a, b,c, d and e.

Figure 5.1 Factors used to evaluate biosecurity and contaminant risk of different hull cleaning strategies

We considered situations for vessel hull cleaning using all possible combinations of factor levels.

5.1.1.3 Risk factor 2: Biofouling extent

The nature and extent of biofouling on a vessel influence the biosecurity risk of a vessel. Biosecurity risk is likely to increase with an increase in biofouling extent as the diversity and abundance of biofouling assemblages are usually correlated with the percentage cover and biomass (Inglis et al. 2008). The extent of biofouling also determines which methods are available and/or appropriate to remove it from a vessel.

For example, heat treatment is able to remove biofouling assemblages at an early stage of development, but is unable to treat more mature assemblages that contain firmly attached, calcareous organisms such as adult barnacles, tubeworms and bivalves.

The extent of biofouling also indicates the rate at which biocides are released from antifouling coatings. For example, heavy biofouling on a vessel may indicate that the paint is old and, therefore, is leaching very little biocide. The build-up of biofouling through, for example, an excessive lay-up period, can also obstruct release of biocide from the paint matrix (Valkirs et al. 2003). In either case, the unmanaged (baseline) contamination risk of a heavily fouled vessel is likely negligible or low.

We used three categories of biofouling extent in our evaluation of risk: primary, secondary and tertiary biofouling (Figure 5.1). These reflect recognised stages in the development of a biofouling assemblage.

- **Primary** biofouling assemblages consist of a microbial layer comprised mainly of bacteria and diatoms ('biofilm') and the initial stages of macro-fouling, such as macroalgae (e.g. *Enteromorpha* spp.), recently settled barnacles and encrusting bryozoans (Woods Hole Oceanographic Institute 1952).
- **Secondary** biofouling assemblages are slightly more complex in structure and contain additional early colonists, such as hydroids and small tubeworms (e.g. serpulids) (Woods Hole Oceanographic Institute 1952).
- **Tertiary** biofouling is the final successional stage and comprises diverse and fully developed assemblages of solitary and colonial organisms (e.g. adult barnacles, tubeworms, ascidians, sponges, bryozoans, hydroids and bivalves), as well as nestling motile taxa such as amphipods, crabs, errant polychaetes and fishes (Woods Hole Oceanographic Institute 1952).

The baseline biosecurity risk is a function of biofouling origin and extent. We attributed the following baseline biosecurity risks (Table 5.1)

Primary biofouling from a foreign source	Low baseline biosecurity risk
Secondary biofouling from a foreign source	Moderate baseline biosecurity risk
Tertiary biofouling from a foreign source	High baseline biosecurity risk
Any biofouling (primary, secondary or tertiary) from a local source	Negligible baseline biosecurity risk

5.1.1.4 Risk factor 3: Antifouling coating type

Antifouling paints were divided into two main categories: biocidal and non-biocidal paints (Table 5.1). Biocidal paints encompassed all paints relying on active biocides for biofouling prevention. We attributed equal environmental risk to all biocidal paints. As shown in Section 2, most primary and booster biocides used in modern antifouling paints can have harmful impacts on non-target organisms or the physical environment (e.g. water quality). Some popular biocides (e.g. Irgarol 1051) are highly toxic to non-target organisms and are already banned from use in some countries. The Australian Pesticides and Veterinary Medicines Authority and New Zealand's Environmental Risk Management Authority clearly document the toxicity and long degradation times in the marine environment of many chemicals currently used as biocidal agents in antifouling paints.

We attributed a low baseline contaminant risk to all vessels coated in biocidal antifouling paints, irrespective of biofouling extent. The rate at which biocides are emitted from antifouling paints is affected by the presence of biofouling and surfaces covered in extensive biofouling are unlikely to emit any biocides (Valkirs et al. 2003; Ron Brown, Altex Coatings, personal communication 2009). However, because biofouling does not occur uniformly over an entire vessel hull, we expect some biocide to be released even from heavily fouled vessels (Table 5.1).

Non-biocidal paints were further divided into two sub categories (fouling release, and surface treatment coating) that differ in two important aspects.

1. Fouling-release coatings are intended for vessels that travel frequently and at speeds > 15 knots (Section 2). Yachts and other slow vessels that use this type of paint require regular hull cleaning.. Fouling-release coatings are also very soft and fragile and, therefore, in our risk evaluation, we have not considered brush cleaning technology for recreational vessels coated in fouling-release paints.
2. Surface-treated coatings (STCs) are a novel type of non-biocidal coating. STCs are hard paints without antifouling properties and suitable for all in-water cleaning technologies, including abrasive brush systems (Candries 2009).

We attributed a negligible baseline contaminant risk to any non-biocidal coating type (Table 5.1).

5.1.1.5 Risk factor 4: Cleaning method

Based on the review in Section 3, we distinguished seven types of cleaning method (Figure 5.1):

- no cleaning
- in-water cleaning using brush systems
- in-water cleaning using water-jet systems
- in-water cleaning using heat treatment
- in-water cleaning using enveloping technology such as wrapping
- out-of-water cleaning in facilities that are not able to capture and contain all cleaning waste (e.g. tidal grids and some slipways)
- out-of-water cleaning in facilities that are able to capture and contain all cleaning waste (e.g. drydocks).

No cleaning

No cleaning represents the baseline risk scenario.

In-water cleaning using brush systems

Our review of currently available brush-based cleaning technologies (Section 3) indicated that none of the currently available technologies are able to remove all biofouling from a surface or capture all of the removed material. Therefore we have assumed that in-water cleaning using brush systems will result in the loss of some, potentially viable, organisms to the environment (Woods et al. 2007; Hopkins et al. 2008). The quantity of material that is: (i) not removed from a hull, and/or (ii) lost during the cleaning process is proportional to the extent of biofouling before cleaning (Hopkins et al. 2008). The biosecurity risk associated with brush cleaning was therefore considered to be low for primary or secondary biofouling of foreign origin, and moderate for tertiary (Table 5.1). The use of brushes is a very abrasive hull cleaning method and can cause damage to the underlying antifouling paint. Brush cleaning is also unable to capture all cleaning waste, which can contain paint residue. The result may be that biocidal material is released into the environment as a consequence of temporarily increased biocide leaching rates and paint chips removed from the hull by the cleaning process (Valkirs et al. 2003; Schiff et al. 2004; Hopkins report to MAFBNZ). We attributed a high contaminant risk to in-water cleaning using brush technology (Table 5.1).

In-water cleaning using water-jet systems

Current water-jet technology is unable to contain all of the biofouling material removed, with the result that viable organisms may be lost to the environment. We thus attributed a low biosecurity risk to in-water jet cleaning of foreign primary or secondary biofouling assemblages and a moderate biosecurity risk for cleaning of tertiary biofouling. The effect of water jet cleaning on biocidal paint surfaces has not been formally examined. However, at least one manufacturer claimed that powerful water jet systems can strip a hull back to bare metal. We therefore attributed a high contaminant risk to water jet cleaning of biocidal paint surfaces.

In-water cleaning using heat treatment

Heat treatment was not considered for vessels with tertiary biofouling assemblages, as the heat treatment systems reviewed in Section 3 are intended to treat only light to moderately fouled surfaces (primary and secondary biofouling). Based on the absence of independent testing of the effectiveness of heat treatment and its impact on coatings, we attributed unknown biosecurity and contaminant risks to this method (Table 5.1).

In-water cleaning using enveloping technology such as wrapping

Our review suggests that enveloping techniques can be an effective method for killing all biofouling on a vessel, irrespective of biofouling extent. However, some inadequacies and losses to the environment have been noticed in most trials documented to date, and no independent evaluations of the effect of enveloping on different antifouling coating types have been carried out. We therefore attributed unknown biosecurity and contaminant risks to this treatment technology (Table 5.1).

Out-of-water cleaning in facilities that are not able to capture and contain all cleaning waste

Some slipways and tidal grids do not capture and contain biofouling waste and liquid effluent generated during the cleaning process. Cleaning in shore-based facilities is generally done with high-pressure water-blast, resulting in complete biofouling removal and the generation of liquid effluent containing high levels of biocide. Woods et al. (2007) examined the viability of organisms removed from vessel hulls in shore-based facilities and found that some organisms survive the water-blasting treatment. If these organisms are not contained in the facility, but are allowed to re-enter the sea via cleaning effluent or the rising tide, they represent a biosecurity risk. We attributed a low biosecurity

risk to situations where vessels with primary or secondary foreign biofouling are cleaned in facilities that fail to collect and contain all waste material, and a moderate risk when tertiary biofouling is cleaned in such facilities. Because of the use of high-pressure water-blast in land-based operations, we attributed a high contaminant risk to the cleaning of hulls coated in biocidal antifouling paints where some of the liquid effluent is lost to the marine environment (Table 5.1).

Out-of-water cleaning in facilities that are able to capture and contain all cleaning waste

Woods et al. (2007) tracked the fate and viability of defouled material in drydocks and slipways where all solid waste and effluent are captured and treated using a combination of settlement tanks and filters. They found that it was unlikely for viable biological material to be returned to the sea. Many of these facilities also dispose of paint waste on land, and the cleaning effluent is stripped of biocidal paint particles using a series of settlement tanks and filters, and recirculated to the water-blast. We attributed negligible biosecurity and contaminant risks to hull cleaning operations in shore-based facilities such as drydocks, where biofouling and paint waste are collected and retained (Table 5.1).

Table 5.1 Estimated biosecurity and contamination risk associated with hull cleaning of vessels with different biofouling extent, biofouling origin and antifouling

BIOFOULING ORIGIN	BIOFOULING EXTENT	BASELINE BIOSECURITY RISK
Local	Any	Negligible
Foreign	Primary	Low
	Secondary	Moderate
	Tertiary	High
COATING TYPE		**BASELINE CONTAMINANT RISK**
Biocidal		Low
Non-biocidal		Negligible

CLEANING METHOD	BIOFOULING EXTENT & ORIGIN	BIOSECURITY RISK	CONTAMINANT RISK (BIOCIDAL COATING)	CONTAMINANT RISK (NON-BIOCIDAL COATING)
None	Any	Baseline	Baseline	Baseline
Brushes	Primary/secondary biofouling, foreign origin	Low	High	Negligible (STC)
	Tertiary biofouling, foreign origin	Moderate	High	Negligible (STC)
	Any local biofouling	Negligible	High	Negligible (STC)
Water-jet	Primary/secondary biofouling, foreign origin	Low	High	Negligible
	Tertiary biofouling, foreign origin	Moderate	High	Negligible
	Any local biofouling	Negligible	High	Negligible
Heat treatment	Primary/secondary biofouling, foreign origin	Unknown	Unknown	Unknown
	Tertiary biofouling, foreign origin	Unable to clean tertiary biofouling	N/A	N/A
	Any local biofouling	Negligible	Unknown	Unknown
Encapsulation	Any foreign biofouling	Unknown	Unknown	Negligible
	Any local biofouling	Negligible	Unknown	Negligible
Shore-based (no retention)	Primary/secondary biofouling, foreign origin	Low	High	Negligible
	Tertiary biofouling, foreign origin	Moderate	High	Negligible
	Any local biofouling	Negligible	High	Negligible
Shore-based (with retention)	Any foreign biofouling	Negligible	Negligible	Negligible
	Any local biofouling	Negligible	Negligible	Negligible

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels

Scenarios where cleaning is associated with negligible biosecurity and contaminant risks are highlighted in orange

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Foreign	Primary	Non-biocidal (FR)	None	Nil	Low	Negligible
Foreign	Primary	Non-biocidal (FR)	Brushes (IW)	N/A	N/A	N/A
Foreign	Primary	Non-biocidal (FR)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Low	Negligible
Foreign	Primary	Non-biocidal (FR)	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Unknown	Unknown
Foreign	Primary	Non-biocidal (FR)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	Negligible
Foreign	Primary	Non-biocidal (FR)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Low	Negligible
Foreign	Primary	Non-biocidal (FR)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Foreign	Primary	Non-biocidal (STC)	None	Nil	Low	Negligible
Foreign	Primary	Non-biocidal (STC)	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Low	Negligible
Foreign	Primary	Non-biocidal (STC)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Low	Negligible
Foreign	Primary	Non-biocidal (STC)	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Unknown	Unknown
Foreign	Primary	Non-biocidal (STC)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	Negligible

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Foreign	Primary	Non-biocidal (STC)	Shore-based – no retention	RV: ~A\$575 50 m: ~ A\$12 000 100 m and longer: N/A	Low	Low
Foreign	Primary	Non-biocidal (STC)	Shore-based + retention	RV: ~A\$575 50 m: A\$9000–26 000 100 m: A\$30 000–85 000 200 m: ~A\$195 000	Negligible	Negligible
Foreign	Primary	Biocidal	None	Nil	Low	Low
Foreign	Primary	Biocidal	Brushes (IW)	RV: A\$240 50 m: A\$4000–13 000 (niches) A\$10 000–20 000 (all) 100 m:A\$5000–16 000 (niches) A\$21 000–31 000 (all) 200 m:A\$9000–22 000 (niches) A\$65 000–78 000 (all)	Low	High
Foreign	Primary	Biocidal	Water-jet (IW)	RV: A\$240 50 m: A\$8000–14 000 100 m: A\$21 000–26 000 200 m: A\$72 000–76 000	Low	Low
Foreign	Primary	Biocidal	Heat (IW)	RV: N/A 50 m: A\$35 000? 100 m: A\$50 000? 200 m: A\$71 000	Negligible	Negligible
Foreign	Primary	Biocidal	Encapsulation (IW)	50 m: A\$2000–7500 100 m: A\$7000–14 000 200 m: A\$14 000–24 000	Negligible	Negligible
Foreign	Primary	Biocidal	Shore-based – no retention	RV: ~A\$575 50 m: ~ A\$12 000 100 m and longer: N/A	Low	High
Foreign	Primary	Biocidal	Shore-based + retention	RV: ~A\$575 50 m: A\$9000–26 000 100 m: A\$30 000–85 000 200 m: ~A\$195 000	Negligible	Negligible
Foreign	Secondary	Non-biocidal (FR)	None	Nil	Moderate	Negligible
Foreign	Secondary	Non-biocidal (FR)	Brushes (IW)	N/A	N/A	N/A
Foreign	Secondary	Non-biocidal (FR)	Water jet (IW)	RV: A\$240 50 m: A\$8000–14 000 100 m: A\$21 000–26 000 200 m: A\$72 000–76 000	Low	Negligible

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Foreign	Secondary	Non-biocidal (FR)	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Unknown	Unknown
Foreign	Secondary	Non-biocidal (FR)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	Negligible
Foreign	Secondary	Non-biocidal (FR)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Low	Negligible
Foreign	Secondary	Non-biocidal (FR)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Foreign	Secondary	Non-biocidal (STC)	None	Nil	Moderate	Negligible
Foreign	Secondary	Non-biocidal (STC)	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Low	Negligible
Foreign	Secondary	Non-biocidal (STC)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Low	Negligible
Foreign	**Secondary**	Non-biocidal (STC)	**Heat (IW)**	50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Unknown	**Unknown**
Foreign	**Secondary**	Non-biocidal (STC)	**Encapsulation (IW)**	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	**Negligible**
Foreign	Secondary	Non-biocidal (STC)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Low	Negligible

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Foreign	Secondary	Non-biocidal (FR)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Foreign	Secondary	Biocidal	None	Nil	Moderate	Low
Foreign	Secondary	Biocidal	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Low	High
Foreign	Secondary	Biocidal	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Low	High
Foreign	Secondary	Biocidal	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Unknown	Unknown
Foreign	Secondary	Biocidal	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	Unknown
Foreign	Secondary	Biocidal	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Low	High
Foreign	Secondary	Biocidal	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Foreign	Tertiary	Non-biocidal (FR)	None	Nil	High	Negligible
Foreign	Tertiary	Non-biocidal (FR)	Brushes (IW)	N/A	N/A	N/A
Foreign	Tertiary	Non-biocidal (FR)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Moderate	Negligible
Foreign	Tertiary	Non-biocidal (FR)	Heat (IW)	N/A	N/A	N/A

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Foreign	Tertiary	Non-biocidal (FR)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	Negligible
Foreign	Tertiary	Non-biocidal (FR)	Shore-based – no retention	RV: A$240 50 m: ~ A$12 000 100 m and longer: N/A	Moderate	Negligible
Foreign	Tertiary	Non-biocidal (FR}	Shore-based + retention	RV: A$240 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Foreign	Tertiary	Non-biocidal (STC)	None	Nil	High	Negligible
Foreign	Tertiary	Non-biocidal (STC)	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Moderate	Negligible
Foreign	Tertiary	Non-biocidal (STC)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Moderate	Negligible
Foreign	Tertiary	Non-biocidal (STC)	Heat (IW)	N/A	N/A	N/A
Foreign	Tertiary	Non-biocidal (STC)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	Negligible
Foreign	Tertiary	Non-biocidal (STC)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Moderate	Negligible
Foreign	Tertiary	Non-biocidal (STC)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Foreign	Tertiary	Biocidal	None	Nil	High	Low

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Foreign	Tertiary	Biocidal	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Moderate	High
Foreign	Tertiary	Biocidal	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Moderate	High
Foreign	Tertiary	Biocidal	Heat (IW)	N/A	N/A	N/A
Foreign	Tertiary	Biocidal	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Unknown	Unknown
Foreign	Tertiary	Biocidal	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Moderate	High
Foreign	Tertiary	Biocidal	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Primary	Non-biocidal (FR)	None	Nil	Negligible	Negligible
Local	Primary	Non-biocidal (FR)	Brushes (IW)	N/A	N/A	N/A
Local	Primary	Non-biocidal (FR)	Water-jet (IW)	RV: A$240 50 m: A$ 8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	Negligible
Local	Primary	Non-biocidal (FR)	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Negligible	Unknown
Local	Primary	Non-biocidal (FR)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Negligible	Negligible

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Local	Primary	Non-biocidal (FR)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	Negligible
Local	Primary	Non-biocidal (FR)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Primary	Non-biocidal (STC)	None	Nil	Negligible	Negligible
Local	Primary	Non-biocidal (STC)	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Negligible	Negligible
Local	Primary	Non-biocidal (STC)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	Negligible
Local	Primary	Non-biocidal (STC)	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Negligible	Unknown
Local	Primary	Non-biocidal (STC)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Negligible	Negligible
Local	Primary	Non-biocidal (STC)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	Negligible
Local	Primary	Non-biocidal (STC)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Primary	Biocidal	None	Nil	Negligible	Low

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Local	Primary	Biocidal	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Negligible	High
Local	Primary	Biocidal	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	High
Local	Primary	Biocidal	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Negligible	Unknown
Local	Primary	Biocidal	Encapsulation (IW)	RV: ~A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Negligible	Unknown
Local	Primary	Biocidal	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	High
Local	Primary	Biocidal	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Secondary	Non-biocidal (FR)	None	Nil	Negligible	Negligible
Local	Secondary	Non-biocidal (FR)	Brushes (IW)	N/A	N/A	N/A
Local	Secondary	Non-biocidal (FR)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	Negligible
Local	Secondary	Non-biocidal (FR)	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Negligible	Unknown
Local	Secondary	Non-biocidal (FR)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Negligible	Negligible

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Local	Secondary	Non-biocidal (FR)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	Negligible
Local	Secondary	Non-biocidal (FR)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Secondary	Non-biocidal (STC)	None	Nil	Negligible	Negligible
Local	Secondary	Non-biocidal (STC)	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) AU$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Negligible	Negligible
Local	Secondary	Non-biocidal (STC)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	Negligible
Local	Secondary	Non-biocidal (STC)	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	Negligible	Unknown
Local	Secondary	Non-biocidal (STC)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Negligible	Negligible
Local	Secondary	Non-biocidal (STC)	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	Negligible
Local	Secondary	Non-biocidal (STC)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Secondary	Biocidal	None	Nil	Negligible	Low

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Local	Secondary	Biocidal	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Negligible	High
Local	Secondary	Biocidal	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	High
Local	Secondary	Biocidal	Heat (IW)	RV: N/A 50 m: A$35 000? 100 m: A$50 000? 200 m: A$71 000	**Negligible**	Unknown
Local	Secondary	Biocidal	Encapsulation (IW)	RV: ~A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	**Negligible**	Unknown
Local	Secondary	Biocidal	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	**Negligible**	High
Local	Secondary	Biocidal	Shore-based + retention	RV: ~A$575 **50 m: A$9000–26 000** **100 m: A$30 000–85 000** **200 m: ~A$195 000**	Negligible	Negligible
Local	Tertiary	Non-biocidal (FR)	None	Nil	Negligible	Negligible
Local	Tertiary	Non-biocidal (FR)	Brushes (IW)	N/A	N/A	N/A
Local	Tertiary	Non-biocidal (FR)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	Negligible
Local	Tertiary	Non-biocidal (FR)	Heat (IW)	N/A	N/A	N/A
Local	Tertiary	Non-biocidal (FR)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Negligible	Negligible

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Local	Tertiary	Non-biocidal (FR)	Shore-based - no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	Negligible
Local	Tertiary	Non-biocidal (FR)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Tertiary	Non-biocidal (STC)	None	Nil	Negligible	Negligible
Local	Tertiary	Non-biocidal (STC)	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Negligible	Negligible
Local	Tertiary	Non-biocidal (STC)	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	Negligible
Local	Tertiary	Non-biocidal (STC)	Heat (IW)	N/A	N/A	N/A
Local	Tertiary	Non-biocidal (STC)	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: $14 000–24 000	Negligible	Negligible
Local	Tertiary	Non-biocidal (STC)	Shore-based - no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	Negligible
Local	Tertiary	Non-biocidal (STC)	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible
Local	Tertiary	Biocidal	None	Nil	Negligible	Low
Local	Tertiary	Biocidal	Brushes (IW)	RV: A$240 50 m: A$4000–13 000 (niches) A$10 000–20 000 (all) 100 m:A$5000–16 000 (niches) A$21 000–31 000 (all) 200 m:A$9000–22 000 (niches) A$65 000–78 000 (all)	Negligible	High

Table 5.2 Evaluation of environmental and economic risks associated with available cleaning strategies for commercial and recreational vessels. Continued

BIOFOULING ORIGIN	BIOFOULING EXTENT	COATING TYPE[a]	CLEANING TYPE (IW = IN-WATER)[b]	COST BY VESSEL SIZE[c]	BIOSECURITY RISK	CONTAMINANT RISK
Local	Tertiary	Biocidal	Water-jet (IW)	RV: A$240 50 m: A$8000–14 000 100 m: A$21 000–26 000 200 m: A$72 000–76 000	Negligible	High
Local	Tertiary	Biocidal	Heat (IW)	N/A	N/A	N/A
Local	Tertiary	Biocidal	Encapsulation (IW)	RV: A$300-500 50 m: A$2000–7500 100 m: A$7000–14 000 200 m: A$14 000–24 000	Negligible	Unknown
Local	Tertiary	Biocidal	Shore-based – no retention	RV: ~A$575 50 m: ~ A$12 000 100 m and longer: N/A	Negligible	High
Local	Tertiary	Biocidal	Shore-based + retention	RV: ~A$575 50 m: A$9000–26 000 100 m: A$30 000–85 000 200 m: ~A$195 000	Negligible	Negligible

[a] FR = fouling release coating; STC = surface-treated coating..

[b] Water-jet and heat cleaning treatment will not remove biofouling from niche areas.

[c] RV = recreational vessels. Cost indicative of a yacht of approx. 12.5m in length.

5.2 Deciding on in-water vs shore-based hull maintenance

In-water cleaning of vessel hulls is most defensible in situations where the cleaning technique reduces or does not affect the biosecurity risk posed by the vessel and does not increase the release of contaminants above the baseline rate. It is least defensible when it causes a significant increase in the rate at which organisms, propagules or biocidal contaminants are released into the sea, relative to baseline, or when the cleaning method is likely to cause damage to the antifouling coating (potentially increasing future biofouling risk).

The biosecurity and contamination risks associated with heat treatment and encapsulation of vessels are currently not well understood. It is also not known how these methods affect the performance of different antifouling coatings in the longer term. Due to the absence of independent testing and documentation, we do not currently regard heat treatment and encapsulation as suitable in-water cleaning methods. Once such information is available, the suitability of these methods should be revised.

Most requests to undertake in-water hull cleaning come from vessel operators for reasons of performance. Occasionally, directives to clean hulls will come from environmental managers when there is a perceived large baseline biosecurity risk. Here, we provide five examples of realistic scenarios that environmental managers may be presented with to illustrate how a decision for or against in-water hull cleaning may be made. The full range of scenarios are listed in Table 5.2.

> 1. *The operator of a commercial vessel (200 m) requests permission for in-water cleaning to remove algal and slime biofouling from hull areas for vessel performance. The vessel services ports in Australia, Korea and Japan and is coated in biocidal antifouling paint .*

The baseline biosecurity risk of this vessel is low (primary biofouling from a foreign location) and the contaminant risk is low (standard toxin leaching rate). Given the vessel's size, the only available shore-based facility is a drydock. Treatment of the vessel in a drydock poses negligible biosecurity and contaminant risks (Table 5.2). We evaluated the environmental (biosecurity and contamination) and economic risks associated with different methods for in-water and shore-based hull maintenance based on four risk factors: biofouling origin (local or foreign), biofouling extent, antifouling coating type and cleaning method. Based on the results of our evaluation, we make the following suggestions. The cost for cleaning at a drydock is approximately A$195 000, plus losses in revenue for the time it takes to travel to the drydock (one to eight days) and undergo treatment. The alternative use of brush-based or water jet in-water cleaning would cost approximately two to three times less (A$65 000–78 000). However, in this instance in-water cleaning is associated with a low biosecurity risk and a high contaminant risk (Table 5.2).

> *2. A local port tug vessel (20 m) requires removal of extensive tertiary biofouling from hull areas, rudders and thrusters. The vessel is painted with biocidal antifouling coating.*

The baseline biosecurity risk of this vessel is negligible: it has never left the local area and its biofouling can be assumed to be from local sources. The baseline contaminant risk is also low (standard biocide release rate; Table 5.2). Cleaning of the vessel in a slipway facility would cost approximately A$3000 with a negligible associated biosecurity risk and a negligible or high contaminant risk, depending on whether the facility is able to fully contain water-blast runoff (negligible risk of contamination) or not (high risk). Cleaning at a dry-dock (negligible biosecurity and contaminant risks) would cost approximately A$9000–26 000 (Table 5.2). The vessel could be cleaned in-water using brush or water jet technology for approximately A$10 000, with no associated biosecurity risk (local biofouling) but a high risk for contamination.

The presence of tertiary biofouling on hull areas is an indication that the antifouling coating has exceeded its service life. In-water biofouling removal would represent a short-term solution and the most feasible option would be to remove this vessel from the water for cleaning and renewal of the antifouling coating (total cost approximately A$10 000 plus lost service time; Table 5.2).

> *3. A dredge spoil barge (100 m) is towed from overseas and arrives heavily fouled. The hull is coated in old antifouling paint that contains a biocide. Removal of biofouling from its hull is envisaged (a) because it may represent a biosecurity risk and (b) to improve towing efficiency.*

The barge has a high baseline biosecurity risk as it carries extensive (tertiary) biofouling from a foreign source. In-water removal of the biofouling (A$21 000–31 000) can be achieved using brush or water jet technology, which has a moderate associated risk of releasing viable, potentially non-indigenous, organisms into the surrounding water and a high associated contamination risk (biocidal paint waste). Again, the extensive nature of the biofouling indicates a failed antifouling paint coating and simple in-water biofouling removal would be a short-term solution. To avoid the high contamination risk of in-water brush cleaning, it is

preferable to remove the barge from the water for cleaning and renewal of the antifouling coating in a drydock (A$30 000–85 000) (Table 5.2).

> *4. A visibly fouled yacht arrives from an overseas location within the distributional range of a high-profile NIS list and biofouling removal is requested by the relevant authority. The yacht's hull is painted with a non-biocidal fouling-release coating.*

This yacht has a moderate to high baseline biosecurity risk as it carries secondary or even tertiary biofouling from a foreign source where a high-risk NIS is known to occur. The contaminant risk of the yacht—and of any in-water or shore-based cleaning method—is negligible because of the non-biocidal antifouling coating. The vessel could be removed from the water for cleaning for approximately A$575, with negligible associated biosecurity risk (Table 5.2). The yacht could be cleaned in-water using water jet technology (if available) for approximately A$240. However, this would have a moderate associated risk of releasing viable non-indigenous propagules or organisms into the surrounding water. In-water cleaning using brushes and scrapers is not advisable for fouling-release coatings. The most feasible option for this vessel would be removal from the water for cleaning.

> *5. A container vessel (200 m) servicing ports along the East coast of Australia and the West coast of North America requests permission for propeller polishing and removal of tertiary biofouling assemblages from sea chest grates, sonar domes and transducers.*

This vessel has a high baseline biosecurity risk because it potentially carries tertiary biofouling from foreign locations. The baseline contaminant risk is low if the vessel uses a biocidal antifouling coating, or negligible in the case of a non-biocidal paint type. The sonar dome and transducers are generally not coated in antifouling paint and their cleaning poses a negligible contaminant risk. In this scenario, the propeller is painted with a fouling-release coating (non-biocidal) and the sea chest grates are painted with a biocidal antifouling coating.. Cleaning the ship's niche areas using brushes, scrapers or water jet would cost approximately A$9000–22 000 and would be associated with a moderate risk of releasing viable, potentially non-indigenous material into the surrounding water and, in the case of the sea chest grates, a high contamination risk (Table 5.2).

Because of its large size, the only alternative for this vessel would be shore-based treatment in a drydock, at approximately A$195 000. In this scenario, managers have an important choice to make. They may decline the operator's application for in-water cleaning, with the likely result that the vessel will remain uncleaned to avoid the costs of drydocking and continue to pose a moderate biosecurity risk to its destination ports. Alternatively, permission for in-water cleaning could be granted at a relatively low economic cost and with a moderate associated risk of releasing viable biofouling material and contaminants into the surrounding water.

5.3 Recommendation for situations where in-water cleaning may be permissible

The *ANZECC Code* currently prohibits in-water hull cleaning as a method of vessel maintenance unless permission is granted by the local administering authority. This is done out of dual concerns about contamination by antifouling toxins and the introduction and spread of NIS. We suggest a revision of the ANZECC Code to reflect achievements in antifouling coating and in-water cleaning technology made over the past 12 years.

The suggestions and recommendations based on our literature review are:

- In-water removal of biofouling organisms acquired from the local environment poses a negligible biosecurity risk even in the absence of containment measures. In-water cleaning of hull surfaces painted with non-biocidal antifouling coatings poses a negligible contaminant risk. In-water cleaning should therefore be permissible on vessels using non-biocidal antifouling coatings and where the biofouling is of local origin. However, the cleaning method must not damage the antifouling coating (e.g., brush cleaning is not suitable for fouling release coatings due to a high risk of coating damage).
- In-water removal of secondary or tertiary biofouling from hull or niche area surfaces coated in non-biocidal antifouling coatings should not be permissible if the biofouling is likely to have originated from foreign locations. Exceptions should be considered only if clear independent scientific evidence provided by a qualified agency is presented that the proposed cleaning methodology is able to capture and contain all waste material generated during the cleaning process.
- In-water cleaning of hull or niche area surfaces coated in biocidal antifouling coatings should not be permissible because commercially available in-water cleaning technologies are currently not able to capture and contain all biological and paint waste released during the cleaning process. This is a particularly high risk in instances where abrasive or high-pressure cleaning exposes

older antifouling coatings that contain TBT. Permission for in-water cleaning of biocidal coating surfaces should be considered only if the cleaning operation does not result in a pollution or biosecurity risk. Clear independent scientific evidence provided by a qualified agency must be presented that the proposed cleaning method is able to capture and contain all waste material generated during the cleaning process

- Heat treatment and enveloping technologies should not be regarded as appropriate in-water cleaning methods because their effectiveness and associated environmental risks are not fully understood. They should not be permissible methodologies for in-water hull cleaning until clear evidence is presented by a qualified agency that they are able to effectively kill all biofouling and that they have no adverse effects on coating surfaces or the environment
- Biofouling often occurs principally in niche areas that are (frequently) not coated in antifouling paints. The only cleaning methods available for these areas at present are handheld brushing, scraping or water jet devices. All systems reviewed in this report are at moderate risk of releasing viable organisms into the surrounding water. Maintenance of operationally important niche areas (e.g. sea chest gratings, sonar domes, thrusters, etc.) is acknowledged to be important and may have to be done in-water. However, vessel owners and operators should be encouraged or required to take *proactive* measures that *prevent* the development of biofouling beyond a slime or algal layer. This can be achieved by frequent in-water cleaning (before calcareous growths occur) and/or the use and performance monitoring of marine growth prevention systems (MGPSs).
- The development of in-water cleaning technologies that more effectively capture biofouling and coating waste should be encouraged, as it would result in a higher level of acceptability

for in-water cleaning of surfaces coated in biocidal paints and/or containing biofouling from foreign sources.

In our evaluation, we have only considered two types of environmental risk: biosecurity and contamination. Even if both of these risks are mitigated by some cleaning methods, in-water cleaning may not be acceptable in some jurisdictions because of other effects on water quality, such as visible discolouration from paint dyes or release of large quantities of de-oxygenated or chemically enriched water following encapsulation.

In this section we have provided a suggested evaluation of environmental and economic risks associated with shore-based and in-water hull cleaning. A full expert risk assessment is beyond the scope of this review, and development of a decision tool will benefit greatly from input from and discussions with stakeholders and managers..

6. Processes and regulations for management of in-water cleaning

Information on current regulatory processes for in-water hull cleaning in Australia and New Zealand was obtained by consulting publications and websites of relevant national, state and regional government authorities and through interviews with key personnel.

6.1 Developments for managing in-water cleaning

6.1.1 International developments

In July 2007, the 56th meeting of the IMO Marine Environment Protection Committee (MEPC) recognised that biofouling was a significant issue and agreed that an item be added to the Work Program to address this issue. A Biofouling Correspondence Group was established to develop international biofouling management measures. Currently the group is developing guidelines for the control and management of ships' biofouling to minimise the transfer of invasive aquatic species for voluntary implementation.

The guidelines recognise the necessity for vessels to undergo in-water cleaning to maintain their performance. Based on this necessity, guidance is provided on conducting in-water cleaning activities that, where possible, minimise environmental impacts. Conducting in-water cleaning activities in accordance with any relevant regulations on in-water cleaning or pollution is also advised. It is expected that the guidelines will be completed in 2010 for finalisation by IMO in 2011.

Australia and New Zealand are active in the Biofouling Correspondence Group and IMO meetings, taking into consideration implications or clarifications in respect to other international conventions that may apply.

6.1.2 National System for the Prevention and Management of Marine Pest Inclusions

Australian guidance with regard to biofouling management for all major vessel classes is promulgated through the National System for the

Prevention and Management of Marine Pest Incursions (the National System). Guidance documents are available through the National System website <http://www.marinepests.gov.au>.

The national biofouling management guidelines for a range of vessels refers to the ANZECC Code, encourages vessel operators to plan in-water inspections and notes that permission to undertake in-water cleaning must be granted by the relevant state/territory authority.

6.2 Current Australian and New Zealand regulations

To address the preventative aspect of exotic species transfer and release of toxic substances, various states and the Northern Territory in Australia have addressed the ANZECC Code in different ways. Some have used it to form regulations, while others have enacted it specifically into legislation, with various levels of enforcement and resulting penalties for breaching the regulations (Table 6.1). Details on the situations in the various Australian jurisdictions and New Zealand are provided below.

Table 6.1 Aspects of the ANZECC Code that have been applied in Australian jurisdictions and in New Zealand

	REGULATIONS OR LEGISLATION?	ENFORCED?	GOVERNMENT DEPARTMENT RESPONSIBLE FOR ENFORCEMENT?	APPLICABLE TO RECREATIONAL VESSELS, COMMERCIAL OR BOTH?
New South Wales	Other Acts	Yes	DECCW and NSW Maritime	Both
Northern Territory	Other Acts	No	Darwin Port Corporation; DNRETAS; DRDPIFR	Both
Western Australia	Other Acts	No	DoF, DEC, DoT	Neither
South Australia	Specific legislation	Yes	EPA(SA) & local government departments	Both
Victoria	Specific legislation	Yes	VRCA and EPA	Both
Tasmania	Other Acts	No	DPIPWE	Both
Queensland	Other Acts	No	EPA	Commercial
Australian Government	Other Acts	No	DEWHA, DAFF	Both
New Zealand	Other Acts	No	MAFBNZ and local government councils	Both

DECCW: Department of Environment, Climate Change and Water; DRDPIFR: Department of Regional Development, Primary Industry, Fisheries and Resources; DNRETAS: Department of Natural Resources, Environment, the Arts and Sport; DEC: Department of Environment and Conservation; DoF: Department of Fisheries; DoT: Department of Transport; EPA: Environmental Protection Agency; VRCA: Victorian Regional Channels Authority; DPIPWE: Department of Primary Industries, Parks, Water and Environment; MAFBNZ: Ministry of Agriculture and Forestry–Biosecurity New Zealand; DEWHA: Department of Environment, Water, Heritage and the Arts; DAFF: Department of Agriculture, Fisheries and Forestry.

6.2.1 New South Wales

New South Wales has not enacted the ANZECC Code into legislation in the state (Table 6.1). However, Section 120 (Prohibition of pollution of waters) of the *Protection of the Environment Operations Act* (POEO Act) (1997) provides protection against pollution of waters. Under the POEO Act, it is an offence to pollute waters or permit waters to be polluted, except where that pollution occurs in compliance with a regulation or environment protection licence. The definition of 'water pollution' includes introducing any matter into waters such that it changes the physical, chemical or biological condition of the waters.

The Department of Environment, Climate Change and Water regulates activities listed in Schedule 1 of the POEO Act (including large marinas and boat repair facilities) through environment protection licences. NSW Maritime is the regulatory authority for non-pilotage vessels undertaking activities away from licensed premises.

The Department of Environment, Climate Change and Water has developed guidelines to help marinas, boatsheds and slipways improve their environmental performance. These guidelines do not support in-water hull cleaning, scraping or any underwater process that could pollute waters. Further, the NSW Ports Corporations do not generally permit in-water hull cleaning in their designated ports.

6.2.2 Northern Territory

The Northern Territory also has guidelines in place to limit in-water hull cleaning and maintenance (Table 6.1). However, the ANZECC Code is not enacted in Northern Territory legislation.

In Darwin, applications for in-water hull cleaning are made to the Darwin Port Corporation's (DPC) harbour master who seeks advice from other government departments (the Department of Natural Resources, Environment, the Arts and Sport and the Department of Resources). In-water hull cleaning and maintenance is not allowed without written permission from the DPC. These applications are generally denied in accordance with the ANZECC Code; however, the harbour master will occasionally allow in-water propeller polishing of commercial ships residing in the Port of Darwin. The Darwin Port Corporation's authority only extends to the limits of the Port of Darwin. No close management of in-water hull cleaning occurs outside the Port of Darwin and yacht cleaning operations are generally unregulated.

There is currently no legislation in the Northern Territory that specifically pertains to in-water hull cleaning, although sections of various Acts are relevant to the issue. For example, the DPC has provisions for the regulatory control of in-water hull cleaning under bylaws in *the Darwin Port Corporation Act of 2005*. In relation to material dislodged during hull cleaning, Section 36 of the Act states:

> *'Where an undesirable substance is put, falls or flows into or on the Port, the Port Corporation may take such action as it thinks fit to remove, disperse, destroy or mitigate the damage caused by, the undesirable substance'.*

Section 15 of the *Fisheries Act 2005* (administered by the Department of Resources) states that a person shall not:

> *'bring into, or release in, the Territory any live aquatic life, live fish, or any live eggs, fry, spat, or larva of fish'*

or

> *'directly or indirectly introduce, cast, place, discharge, or allow to fall, flow, or percolate or be carried by wind, tide, or current a poisonous, toxic, narcotic, noxious, or other substance (including heavy metal or solid debris) into waters of the Territory where an effect of the substance is, or may be, that fish or aquatic life are stunned, injured, killed, or detrimentally affected, or the habitats, food, or spawning grounds of fish or aquatic life are detrimentally affected'.*

The Department of Natural Resources, Environment, the Arts and Sport has orders indirectly applying to the in-water hull cleaning of vessels under the *Waste Management and Pollution Control Act 2007,* where directives refer to the generation of waste and pollution from such activities.

Strict guidelines for vessels entering Darwin marinas are issued on the Northern Territory Government website <www.nt.gov.au/d/Fisheries/index.cfm?newscat1=&newscat2=&header=Vessel Inspections>

A vessel inspection protocol was introduced in 1999 for all international arrivals to the marinas, following the discovery of the black striped mussel, *Mytilopsis sallei*, in the Northern Territory. Depending on the voyage and maintenance history of the vessel, a hull inspection and treatment of internal seawater systems may be required and clearance certification is needed to access Darwin marinas. Vessels are thus required to have clean hulls. Operators are discouraged from in-water cleaning en-route to Darwin and are advised that 'all boat cleaning should be performed at an approved location and in a manner that ensures no material returns to the marine environment'. Adherence to vessel inspection and clearance certification prior to marina entry is strictly monitored and enforced. However, hull cleaning and maintenance practices are not strictly monitored.

6.2.3 Western Australia

The Department of Environment and Conservation (DEC), the Department of Fisheries (DoF) and the Department of Transport all administer legislation that controls certain aspects of marine pollution. However, there is no specific reference to the ANZECC Code, or in-water hull cleaning and maintenance, in any Western Australian legislation (Table 6.1). In Western Australia, overlapping jurisdiction and gaps in legislation make it unclear who is the administering authority for upholding the ANZECC Code. Recent communications between DoF and DEC regarding in-water cleaning of several barges in Dampier emphasises the lack of certainty as to the legislative basis for the imposition of the code. In-water hull cleaning is partially regulated by port authorities, to the extent that they do not allow cleaning within port boundaries. This has been seen to have the effect of shifting cleaning operations outside port boundaries. In many areas of the state there is a lack of facilities for drydocking of vessels other than small fishing or recreational vessels. In-water hull cleaning services for recreational vessels are openly advertised.

The former Department of Environmental Protection (DEP), now the DEC, introduced legislation in 1991 regarding the impact and use of antifouling coatings to ensure that toxic residues or discharges are not released into marine waters. Ship maintenance facilities can be licenced under Part V of the *Environmental Protection Act 1986* and management action prescribed so that all toxic residues are disposed of at approved landfill sites.

DoF is the lead agency for the management of aquatic biosecurity in Western Australia. DoF does not use the ANZECC Code as a tool to manage the translocation of non-indigenous fish. Detection, or suspected presence, of non-indigenous fish trigger a response from DoF under Regulation 176 of the Fish Resources Management Regulations 1995, which stipulates that 'a person must not bring into the State, or a particular area of the State, a live fish of a species not endemic to the State, or that area of the State'.

In Western Australia, there is a reliance on appealing to 'good environmental stewardship' with regard to in-water cleaning rather than a reliance on legislation for enforcement.

6.2.4 South Australia

South Australia is one of two states that have enacted the ANZECC Code into legislation (Table 6.1). It is managed by the South Australian Environment Protection Authority (EPA) under the Environment Protection (Water Quality) Policy (2003).

The ANZECC Code has been enacted directly and the following framework specifically applies to in-water hull cleaning in South Australia:

> *22—Antifoulants*
>
> 1. *In this clause, antifoulant means any chemical substance designed for application to water submerged surfaces to inhibit the growth of plants, animals or other organisms on those surfaces.*
> 2. *If a person uses an antifoulant, the code titled Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance 1997 prepared by ANZECC applies.*
> 3. *The Authority or another administering agency may issue an environment protection order to a person who uses an antifoulant to give effect to the code referred to in subclause (2).*
> 4. *A person must, in using an antifoulant, or removing an antifoulant from any surface, comply with the following provisions:*
>   a. *the only antifoulant containing tributyltin that may be used is one where the release rate of tributyltin from the antifoulant is less than 5 micrograms per square centimetre per day (as determined in accordance with a method approved by the Authority);*
>   b. *an antifoulant containing tributyltin must not be used on a vessel that is less than 25 metres in length unless the hull of the vessel is made of aluminium;*
>   c. *the cleaning of the hull of a vessel or the surface of any structure that has been coated with an antifoulant, or of any equipment contaminated with antifoulant, may only be carried out:*
>   i. *in drydock; or*
>   ii. *above the high water mark of any waters; or*
>   iii. *below the high water mark of any waters while the tide is out to such an extent that there is no tidal water coming into contact with the vessel, structure or equipment;*
>   d. *antifoulant residues*
>   i. *must not enter any waters; and*
>   ii. *must not come into contact with any land that is below the high-water mark of any waters; and*
>   iii. *must be collected and disposed of at a waste depot that is authorised under the Act to receive such waste.*
>
> *Mandatory provision: Category B offence*

The legislation applies to both recreational and commercial vessels of all sizes and to licenced activities such as approved dockyards

and slipways. In the past, applications for in-water cleaning have been lodged by vessels, as provided for by the ANZECC Code, but exemptions were rarely given and only in accordance with the code recommendations. Although the current legislation covers both recreational and commercial vessels, provisions for recreational vessels and their slipways are currently under review. South Australia's Code of Practice for Vessel and Facility Management (Marine and Inland Waters) is available at <www.epa.sa.gov.au/pdfs/vessels.pdf>.

6.2.5 Victoria

Victoria has enacted the ANZECC Code through the Victorian Regional Channels Authority *Port Operating Handbook* (Table 6.1). The Victorian Regional Channels Authority was established under the *Port Services Act (1995)* to manage Victoria's regional shipping channels. It is a legal requirement for ships to have their hull cleaned and repaired every five years and operators of the drydock and commercial slipways in Melbourne are required by the Victorian Environmental Protection Agency to dispose of hull cleaning waste to appropriate onshore sites. Hull cleaning regulations are enforced through the ports harbour masters but do not preclude the relevant Environmental Protection Agency and AQIS requirements. Any rules apply only to all commercial vessels greater than 200 gross tons in port waters. Section 4.4.2 of the Victorian Regional Channels Authority *Port Operating Handbook* states:

1. *No part of a vessel's hull is to be cleaned in port waters without a prior written permit issued by the Harbour Master.*
2. *In-water hull cleaning is prohibited, except under extraordinary circumstances. A permit for in-water hull cleaning will not normally be granted.*
3. *The cleaning of sea chests, sea suction grids and other hull apertures may be permitted by the Harbour Master, provided that any debris removed (including encrustation, barnacles, weeds) is not allowed to pass into the water column or fall to the sea bed and subject to any other conditions attached to the permit. An application seeking permission to carry out this work must be lodged with the Harbour Master at least five (5) working days before the anticipated start date. Such applications will detail how encrustations, barnacles and other debris will be contained and or collected for disposal as well as the method of disposal and, such cleaning must not proceed unless and until a permit has been issued by the Harbour Master.*
4. *The polishing of ship's propellers may be permitted subject to any conditions attached to the permit issued by the Harbour Master. An application seeking permission to carry out propellor polishing must be lodged with the Habour Master at least five (5) working date nd sSuch works must not proceed unless and until a permit has been issued by the Habour Master.*

EPA's State environment protection policy—Waters of Victoria regulates any discharge from vessels of any sizes in its Clause 47, even though in-water cleaning is not specifically mentioned:

> *'Port, marina and vessel operation and maintenance activities need to be managed to minimise environmental risks to beneficial uses. To enable this:*
>
> 1. *operators of vessels must not discharge to surface waters sewage, oil, garbage, sediment, litter or other wastes that pose an environmental risk to beneficial uses. To help achieve this, operators of vessels need to install effective waste containment facilities on board, to enable the transfer of wastes to approved treatment or disposal facilities. In particular, a priority needs to be placed on containing sewage waste from vessels with toilet or overnight accommodation facilis.;*
> 2. *the Environment Protection Authority, the Department of Infrastructure and Marine Safety Victoria will work with other relevant protection agencies, port and marina managers, and shipping and boating industries to develop and implement programs to manage sewage, oil, garbage, sediment, litter or other wastes, on vess.;*
> 3. *port owners or managers need to develop and implement environment improvement or management plans, in conjunction with operators of businesses in ports and port waters and local communities. These plans need to include effective management practices for port and port related activities, including, where relevant, the provision of vessel waste reception facilities, ballast water management, stormwater management, vessel loading and unloading, and containment of wastes from vessel maintenance. The provisions of these plans need to be incorporated into the operations of businesses in ports or port waters.*
> 4. *marina owners or managers need to develop and implement environment improvement or management plans that are consistent with guidance from protection agencies, including that provided or adopted by the Environment Protection Authority in the Cleaner marinas: EPA guidelines for protecting Victoria's marinas (1998), as amended and the Best Practice Guidelines for Waste Reception Facilities At Ports, Marinas And Boat Harbours In Australia and New Zealand (1997), as amended.'*

6.2.6 Tasmania

In Tasmania the ANZECC Code has not been incorporated into state legislation (Table 6.1). However, the *Environmental Management and Pollution Control Act (1994)* contains sections that would allow prosecution for in-water cleaning if it could be demonstrated that 'environmental harm' had been caused by the liberation of either marine pests and diseases or heavy metals (both defined as pollutants under the Act). In reality, this is difficult to achieve unless actively policed and monitored. Overall, in-water hull cleaning activities in Tasmania are currently unregulated for all vessel types. However, the state port authority (Tasports) advises that although they do not have a formal policy prohibiting in-water cleaning, they do not allow it and have the ability to rescind berthing rights if required.

The Environmental Protection Authority also has the power to issue the vessel with an Environmental Protection Notice in the event that the Authority became concerned that a vessel may undertake in-water cleaning. Councils and Crown Land Services also have a role in planning issues associated with new developments. However, a regulatory framework has not yet been developed and regulation of slipways will be continued on a case-by-case basis using the existing provisions of the *Environmental Management and Pollution Control Act (1994)*.

A number of best practice guidelines have been, or are being, developed by the Department of Primary Industries, Parks, Water and Environment. These include the '*Environmental Guidelines for Boat Repair and Maintenance, March 2009*'. They follow the recommendations set forth in the ANZECC Code. While they remain a non-regulatory set of guidelines, attaching them to new developments as part of the permit conditions does allow some level of regulatory capacity.

6.2.7 Queensland

In Queensland there are guidelines relating to in-water hull cleaning and maintenance, and these are consistent with the recommendations of the ANZECC Code regarding antifouling toxins. However, there is no specific legislation restricting in-water hull cleaning and these guidelines only apply to commercial vessels (Table 6.1). In-water cleaning of recreational vessels is currently unregulated. Generally, applications for in-water hull cleaning of commercial vessels are turned down by the Environmental Protection Agency and any breaches of the recommendations made by the ANZECC Code are prosecuted using legislation covered under the *Environmental Protection Act (1994)* for release of contaminants, Chapter 8, Part 3C:

> *'[s440ZG] Depositing prescribed water contaminants in waters and related matters*
>
> *A person must not—*
>
> a. *unlawfully deposit a prescribed water contaminant—*
>   i. *in waters; or*
>   ii. *in a roadside gutter or stormwater drainage; or*
>   iii. *at another place, and in a way, so that the contaminant could reasonably be expected to wash, blow, fall or otherwise move into waters, a roadside gutter or stormwater drainage;*
>
> b. *unlawfully release stormwater run-off into waters, a roadside gutter or stormwater drainage that results in the build-up of earth in waters, a roadside gutter or stormwater drainage.*
>
> *Maximum penalty—*
>
> a. *if the deposit or release is done wilfully—835 penalty units; or*
>
> b. *otherwise—300 penalty units'.*

As such, in-water cleaning is prohibited solely on the grounds of environmental contamination risk and not due to a risk of introducing or spreading non-indigenous species.

6.2.8 Australian Government legislation

Under international law, Australia has jurisdictional rights over waters within its Exclusive Economic Zone (EEZ), extending to 200 nautical miles from the territorial sea baseline (normally measured from the low water mark on the coast), as well as over the continental shelf extending beyond this point. The waters extending to 12 nautical miles are referred to as the 'territorial sea'. The Australian states and the Northern Territory (NT), in agreement with the Australian Government, have jurisdictional rights over the water column and subjacent seabed to three nautical miles from the baseline. All waters outside this three nautical mile barrier are subject to Australian Government jurisdiction however some Australian Government legislation applies in the State/NT jurisdiction where there is no complementary State/NT legislation.

The *Protection of the Sea (Harmful Antifouling Systems) Act 2006* implements the International Convention on the Control of Harmful Antifouling Systems on Ships (AFS Convention), which entered into force internationally and for Australia on 17 September 2008. The requirements relate to the type of anti-fouling systems that can be applied to ships over 400 gross tons and above, engaged in international voyages, and to facilities used by the oil production industry. Surveys and certification is required. For ships 24 metres or more in length but less than 400 gross tons engaged in international voyages there is a requirement for a declaration and appropriate documentation to be carried. For ships and small vessels that fall outside this legislation and the AFS Convention, the ANZECC Code would apply. It should be noted that the AFS Convention does not address the efficacy of the application of the antifouling system.

While no Australian Government law imposes any specific restrictions on in-water hull cleaning or maintenance in Australian Government waters, Chapter 4 of the *Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act)* is concerned, in part, with the protection of defined matters of national environmental significance

(including the Commonwealth Marine Area, Ramsar wetlands and listed threatened and migratory species). Actions that are likely to significantly affect protected matters can be referred to the Australian Government Environment Minister for a decision on whether assessment and approval is required under the EPBC Act.

The dumping of wastes and other matter at sea is subject to the *Environment Protection (Sea Dumping) Act 1981* implementing the *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972* (the London Protocol). A permit allowing disposal at sea is required under this Act; however, it does not apply to the disposal of wastes or other matter incidental to, or derived from, the normal operations of vessels or man-made structures at sea, unless the wastes or other matter have been transported to a vessel or structure for their disposal. Currently, biofouling organisms are considered to be incidental to or derived from normal operations of a vessel and therefore this Act is unlikely to apply to in-water cleaning.

It should be further noted that there are provisions under the *Quarantine Act 1908* that may be applied to internationally arriving vessels that are found to be harbouring biofouling pests that pose an unacceptable quarantine risk to Australian waters.

6.2.9 New Zealand

In New Zealand, regulation of vessel cleaning activities and pollution in the coastal zone is the responsibility of regional government authorities, with national oversight and guidance being provided by the Department of Conservation and the provisions of the *Resource Management Act 1991 (RMA)* and the New Zealand *Coastal Policy Statement*.

The RMA covers restrictions on use of the coastal marine area and discharges of contaminants into water, while the Resource Management (Marine Pollution) Regulations 1998 (the Marine Pollution Regulations) cover the disposal of waste.

In summary, the Marine Pollution Regulations deem the dumping of organic materials of natural origin (i.e. biofouling) to be a discretionary activity in any regional coastal plan or proposed regional coastal plan, thereby requiring resource consent for such dumping.

Further, the cleaning of the exterior of the hull of a ship or offshore installation below the load line falls outside the definition of the normal operations of a ship or offshore installation, which are excluded from the requirements of the Marine Pollution Regulations relating to dumping. Thus, the cleaning of biofouling from the exterior of the hull of a ship or offshore installation requires a resource consent for dumping.

(Refer to Appendix 5 for a detailed discussion of the relevant provisions of the RMA and Marine Pollution Regulations).

Sections 70 and 107 of the RMA remove the ability of regional councils to issue permits or plans allowing discharges that are likely to result in a visual, odorous or chemical change that would have adverse affects on aquatic life and that would therefore contravene Section 15 of the RMA. However, section 107(2) states that a consent authority may grant a discharge permit (or coastal permit) if exceptional circumstances justify the granting of the permit; or that the discharge is of a temporary nature; or that the discharge is associated with necessary maintenance work. However, in-water hull cleaning or discharges associated with hull scrapings are not restricted coastal activities as outlined in the New Zealand *Coastal Policy Statement* (Pattle Delamore Partners Ltd 2003).

New Zealand *Coastal Policy Statement* states that provisions should be made in coastal plans to require facilities for collection and disposal of residues from vessel maintenance. However, regional plan management of in-water hull cleaning in New Zealand is sparse. Of the 17 regional councils in New Zealand, five make specific mention in their coastal or regional management plans of release of discharges from vessel maintenance into coastal waters. However, Taranaki and Environment Southland are the only regional councils that prohibit any form of discharge. Environment Southland's policy is generally the most comprehensive and works in conjunction with the preservation of the Fiordland region through the *Fiordland (Te Moana o Atawhenua) Marine Management Act 2005*. The policy in this legislation requires that any ships to be used in Fiordland waters be thoroughly cleaned and disinfected before entering or being placed in those waters (Policy 7.3.8.2.4). Hull cleaning facilities for vessels already in the Fiordland coastal marine area are to be provided and adequate discharge disposal is also covered in the preceding policy (Policy 7.3.8.2.3). Other regional councils in New Zealand have not specifically addressed in-water vessel hull cleaning and maintenance in their coastal and regional plans (Pattle Delamore Partners Ltd 2003).

In New Zealand, the biosecurity risks associated with vessels entering New Zealand waters are managed under the *Biosecurity Act 1993*. MAFBNZ has responsibility for providing national leadership for the biosecurity system (Table 6.1).

MAFBNZ provides guidance on best practice vessel cleaning; vessel operators are asked to adhere to a hull maintenance regime, such as the recommended five-year and one-year drydocking intervals for commercial and recreational craft, respectively, with in-water inspection

and cleaning taking place between dockings. Regular in-water cleaning of light (slime and microbial film) biofouling is encouraged. However, in-water removal of mature biofouling assemblages in New Zealand waters is discouraged and discharges from any cleaning that is done should be disposed of in approved shore-based facilities.

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8. Appendices

Appendix 1 Antifouling coatings and biocide concentrations approved for use in Australia and New Zealand

Table 8.1 Antifouling coating types (including biocides) approved for use and sale in Australia.

Source: Australian Pesticides and Veterinary Medicines Authority <www.apvma.gov.au>.

APPROVAL NO.	PRODUCT NAME	ACTIVE(S)
40163	Antifouling Seaguardian	copper present as cuprous oxide/ hydrocarbon liquid/zinc as zinc oxide
40164	Antifouling Super Tropic	copper present as cuprous oxide/ hydrocarbon liquid/zinc as zinc oxide
42439	40 South Marine Paint Coppertox Longlife Antifouling	copper present as cuprous oxide/ hydrocarbon liquid/zinc as zinc oxide
42603	Antifouling Olympic 7154	copper present as cuprous oxide
45412	Interspeed Super Bwa900 Bright Red	cuprous oxide/diuron
46487	Antifouling Seasafe	copper present as cuprous thiocyanate/ shellsol t hydrocarbon solvent/ zinc as zinc oxide/zineb
46488	Antifouling Seavictor 50	4,5-dichloro-2-n-octyl-4-isothiazolin-3-one /copper present as cuprous oxide/ xylene/zinc as zinc oxide
46489	Antifouling Seavictor 40	copper present as cuprous oxide/ xylene/zinc as zinc oxide
46918	Hempels Antifouling Mille Dynamic Alu	copper present as cuprous thiocyanate/ diuron
46919	Hempels Antifouling Mille Dynamic	copper present as cuprous oxide/diuron
46920	Hempels Antifouling Nautic	copper present as cuprous oxide/diuron
47587	International Intervíron Super Antifouling Topcoat	cuprous oxide/diuron
47588	International Interviron Super Antifouling Basecoat	cuprous oxide/diuron
48843	40 South Marine Paint Atlantic Controlled Solubility Copolymer Antifouling	copper present as cuprous thiocyanate/ diuron/hydrocarbon solvent/methylated spirits/zinc as zinc oxide
48965	Marine Systems Traditional Copper Based Antifouling	cuprous oxide/hydrocarbon solvent
49606	International Longlife High Strength Hard Antifouling	cuprous oxide/diuron
49607	International Interspeed 2000 Hard Antifouling For Aluminium	cuprous thiocyanate/diuron
49608	International Epiglass Cruiser Superior Ablative Antifouling For Aluminium	cuprous thiocyanate/diuron
49609	International Vc Offshore With Teflon Racing Antifouling	diuron/xylene
49610	International Bottomkote Eroding Antifouling	cuprous oxide
49611	International Epiglass Micron Csc High Strength Self Polishing Antifouling	cuprous oxide/diuron

APPROVAL NO.	PRODUCT NAME	ACTIVE(S)
49612	International Coppercoat Ablative Antifouling	cuprous oxide/diuron
49871	International Biolux New Technology Micron Optima Water Based Antifouling	cuprous oxide/zinc pyrithione
49992	International Coppercoat Extra Trade Antifouling	cuprous oxide/diuron
51971	Intersmooth 360 Spc Antifouling	cuprous oxide/zinc pyrithione
52242	Wattyl Protective And Marine Coatings Seapro Cu120 Antifouling	copper present as cuprous oxide/diuron
53398	International Biolux New Technology Micron Extra High Strength Self Polishing Antifouling	cuprous oxide/diuron
54009	Wattyl Marine Coatings Trawler Antifouling	copper present as cuprous oxide/diuron
54048	Norglass Topflight Antifouling	cuprous oxide
54049	Norglass Soft Copper Anti-Fouling	cuprous oxide
54128	International Trilux Hard Antifouling For Aluminium	copper present as cuprous thiocyanate/ dichlofluanid
54514	Hempel's Antifouling Globic	4,5-dichloro-2-n-octyl-4-isothiazolin-3-one /cuprous oxide/ketones/xylene
55875	Abc 3 Antifouling	cuprous oxide/thiram/xylene/zinc oxide
56524	Wattyl Marine Coatings Seapro Plus Antifouling	copper present as cuprous thiocyanate/ diuron
56562	Intersmooth 460 Spc Antifouling	cuprous oxide/hydrocarbon liquid/ zinc pyrithione
56582	International Biolux Self Polishing Copolymer Micron 66 Antifouling	cuprous oxide/hydrocarbon liquid/ zinc pyrithione
56644	Altex Coatings Industrial & Marine Af3000 Anti-Fouling	copper present as cuprous oxide/thiram/ xylene/zinc as zinc oxide
58058	Altex Yacht & Boat Paint No 5 Antifouling	copper present as cuprous oxide/thiram/ xylene/zinc as zinc oxide
58059	Altex Yacht & Boat Paint N05 Antifouling Oyster White	copper present as cuprous oxide/thiram/ xylene/zinc as zinc oxide
58268	Awlcraft Marine Paint Awlcraft Antifouling	cuprous oxide/diuron/hydrocarbon liquid
58567	International Biolux New Technology Trilux 33 Hard Antifouling For Aluminium	copper present as cuprous thiocyanate/ zinc pyrithione
59136	Boero Supernavi Transoceanic Yacht Coatings Sa633 Self Polishing Ablative Antifouling	copper present as cuprous oxide/thiram/ xylene/zinc as zinc oxide
61966	Hempel's Antifouling Olympic 86951	copper present as cuprous oxide
61970	Hempel's Antifouling Olympic 86901	copper present as cuprous oxide
62940	Wattyl Protective And Marine Coatings Seapro Plus 100 Antifouling	copper present as cuprous thiocyanate/ diuron

a. Biocides approved for use in New Zealand.

b. Summary of approvals of substances transferred under the Hazardous Substances (Timber Preservatives, Antisapstains, and Antifouling Paints) Transfer Notice 2004 (as amended).

Source for all information: New Zealand Environmental Risk Management Authority website <www.erma.govt.nz> and Dr S. Collier, Senior Advisor, Hazardous Substances, ERMA.

a. ANTIFOULING BIOCIDES APPROVED FOR USE IN NEW ZEALAND

- copper oxide
- zinc oxide
- ziram
- thiram
- copper pyrithione
- zinc pyrithione
- tolyfluanid
- octthilinone
- irgarol 1051
- diuron
- copper thiocyanate
- chlorothalonil
- mancozeb
- dichlofluanid
- zineb

b. TRANSFER NOTICE 2004 (AMENDED IN 2008)

- Antifouling paint containing 84–138 g/litre **chlorothalonil** and 517–690 g/litre cuprous oxide. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.7B, 6.8B, 6.9B, 9.1A, 9.2C, 9.3B
- Antifouling paint containing 138 g/litre **chlorothalonil** and 722 g/litre cuprous oxide. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.7B, 6.9B, 9.1A, 9.2C, 9.3B
- Antifouling paint containing 62 g/litre **chlorothalonil**, 518 g/litre cuprous oxide and 82 g/litre mancozeb. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.7B, 6.8A, 6.9B, 9.1A, 9.2C, 9.3B
- Antifouling paint containing 215 g/litre **copper thiocyanate** and 36 g/litre dichlofluanid. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.3C
- Antifouling paint containing 230 g/litre **copper thiocyanate** and 40 g/litre diuron. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.2A, 9.3C
- Antifouling paint containing 220 g/litre **copper thiocyanate** and 20 g/litre irgarol 1051. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.9B, 9.1A, 9.3C
- Antifouling paint containing 290 g/litre **copper thiocyanate**, 220 g/litre zinc oxide and 55 g/litre zineb. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.7B, 6.8B, 6.8C, 6.9B, 9.1A, 9.3C
- Antifouling paint containing 195 g/litre **cuprous oxide**. [6.1E], 6.4A, 6.9B, 9.1A, 9.3C.
- Antifouling paint containing 245 g/litre **cuprous oxide** 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.3C 11
- Antifouling paint containing 521 g/litre **cuprous oxide**. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.7B, 6.8B, 6.8C, 6.9B, 9.1A, 9.3B
- Antifouling paint containing 408–494 g/litre **cuprous oxide** and 34–42 g/litre dichlofluanid. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.3B
- Antifouling paint containing 450–849 g/litre **cuprous oxide** and 40–70 g/litre diuron. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.2A, 9.3B
- Antifouling paint containing 580 g/litre **cuprous oxide**, 65 g/litre diuron and 320 g/litre zinc oxide. 3.1C, 6.1D, 6.4A, 6.8B, 6.9B, 9.1A, 9.2A, 9.3B
- Antifouling paint containing 760 g/litre **cuprous oxide**, 62 g/litre diuron and 165 g/litre zinc oxide. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.2A, 9.3B
- Antifouling paint containing 570 g/litre **cuprous oxide** and 20 g/litre irgarol 1051. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.9B, 9.1A, 9.3B
- Antifouling paint containing 750 g/litre **cuprous oxide**, 50 g/litre thiram and 260 g/litre zinc oxide. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.3B
- Antifouling paint containing 754 g/litre **cuprous oxide** and 550 g/litre zinc oxide. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.9B, 9.1A, 9.3B
- Antifouling Paint containing 780 g/litre **cuprous oxide** and 220 g/litre zinc oxide. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.3B
- Antifouling Paint containing 840 g/litre **cuprous oxide** and 350 g/litre zinc oxide. 3.1C, 6.1D, [6.3B], 6.4A, 6.5B, 6.7B, 6.8B, 6.8C, 6.9B, 9.1A, 9.3B
- Antifouling paint containing 640 g/litre **cuprous oxide** and 60 g/litre zinc pyrithione 3.1C, 6.1D, 6.3B, 6.4A, 6.7B, 6.8B, 6.8C, 6.9B, 9.1A, 9.3B
- Antifouling paint containing 648 g/litre **cuprous oxide** and 70 g/litre zineb. 3.1C, 6.1D, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.2D, 9.3B
- Antifouling paint prepared from: (1) 20 g/litre **diuron** (Part A), and (2) 1000 g/kg **cuprous oxide** (Part B). 3.1C, 6.1E, 6.3B, 6.4A, 6.5B, 6.8B, 6.9B, 9.1A, 9.2B, 9.3C 6.1D, 6.4A, 6.9B, 9.1A, 9.3B

Appendix 2 Costs associated with vessel maintenance

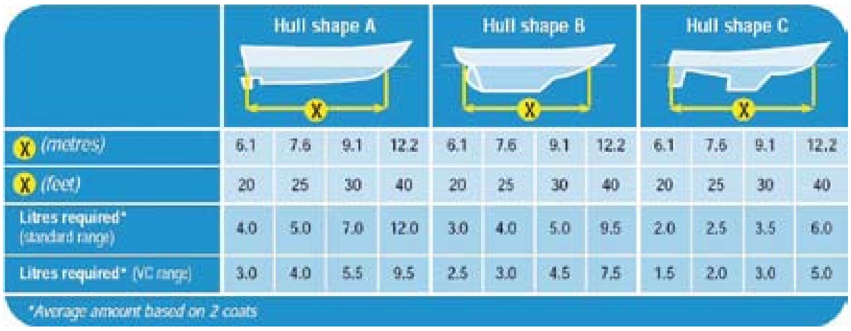
Table 8.2 Charges for hull maintenance related services in three Australian facilities

	FACILITY 1	FACILITY 2	FACILITY 3
Travel lift charge (out and back in)	Non-resident vessels A$14.34 /ft	A$12.50/ft including transport to hard-stand area	A$352
Water-blast	A$2.25 /ft (no time limit)	A$40 /h (Approx. 2hours required)	A$120
Hard-stand space hire	A$1.47 /ft/day	A$1.50 /ft/day	A$38.72 /day

Table 8.3 Indicative costs of antifouling coating for commercial yachts

	PRICE
Antifouling coating (4L)	A$179–399
Primer (4L)	A$80–150
Other painting supplies	Approx. A$250

Table 8.4 Antifouling coating quantities requires for yachts of different sizes



	Hull shape A				Hull shape B				Hull shape C			
X (metres)	6.1	7.6	9.1	12.2	6.1	7.6	9.1	12.2	6.1	7.6	9.1	12.2
X (feet)	20	25	30	40	20	25	30	40	20	25	30	40
Litres required* (standard range)	4.0	5.0	7.0	12.0	3.0	4.0	5.0	9.5	2.0	2.5	3.5	6.0
Litres required* (VC range)	3.0	4.0	5.5	9.5	2.5	3.0	4.5	7.5	1.5	2.0	3.0	5.0

*Average amount based on 2 coats

Table 8.5 Charges associated with hull cleaning and antifouling coating application from a New Zealand facility. Average values were used to estimate volume of fouling and paint waste.

	VESSEL SIZE: 500 GROSS TONNES	1000 GROSS TONNES	5000 GROSS TONNES
Drydock hire			
Clean only	A$2950 (2 days)	A$4350 (2.5 days)	A$7000 (3.5 days)
Clean and antifoul	A$7400 (5 days)	A$14 000 (8 days)	AU$22 500 (11 days)
Access equipment	A$2150	A$3 900	A$13 350
Cleaning[a]			
High-pressure	A$1450	A$2260	A$3900
Ultra high-pressure	A$29 800	A$46 400	A$72 900
Water charge			
High-pressure	A$1450	A$1450	A$2600
Ultra high-pressure	A$2900	A$2900	A$5200
Waste removal			
High-pressure	A$485 (1 tonnes)	A$970 (2 tonnes)	A$1455 (3 tonnes)
Ultra high-pressure	A$1450 (3 tonnes)	A$2910 (6 tonnes)	A$4365 (6 tonnes)
(Antifouling coating)	A$26 300	A$38 800	A$61 000
(Paint application)	A$5250	A$8100	A$13 000
Total (cleaning)	**A$8485**	**A$12 930**	**A$28 305**
Total (cleaning & painting)			
High-pressure	A$44 485	A$69 480	A$117 805
Ultra high-pressure	A$75 250	A$117 100	A$192 315

[a] High-pressure water-blast (8000 psi) is used to removed biofouling organisms and the outer, hydrolised layer of the antifouling coating. The vessel can then either go back into the water or receive a topcoat of antifouling coating. Ultra high-pressure (40 000 psi) is used to strip all paint back to the actual hull material. This is followed by application of complete anticorrosive and antifouling systems and done following major hull repairs or when existing paint coats are significantly damaged.

Table 8.6 Costs for hull cleaning and antifouling coating application for Australian vessels. Estimates obtained from Shipping Australia Limited, the Australian Shipowners Association and International Coatings Australia.

	VESSEL OF APPROX. 50 M IN LENGTH	VESSEL OF APPROX. 100 M IN LENGTH	VESSEL OF APPROX. 200 M IN LENGTH OR LONGER
1. Drydock hire			
charge per day	A$200–4500	A$4500–15 000	A$10 000–30 000
usual days in drydock	10–20	10–15	8–14
dock setup & docking	A$4500–10 500	A$25 000–35 000	A$35 000–55 000
2. Cleaning costs			
high-pressure water wash (Underwater)	A$6.80–8.50 /$\text{m}^2$	A$6.80–8.50 /$\text{m}^2$	A$6.80–8.50 /$\text{m}^2$
fouling removal (sea chests, propellers etc.)	A$50–80 /hr	A$57–85 /hr	A$65–88 /hr
3. Surface preparation and antifouling costs			
Preparation			
full dry blast	A$60–80 /$\text{m}^2$	A$60–80 /$\text{m}^2$	A$60–80 /$\text{m}^2$
spot dry blast	A$50–70 /$\text{m}^2$	A$50–70 /$\text{m}^2$	A$50–70 /$\text{m}^2$
spot power tool	A$50–80 /$\text{m}^2$	A$50–80 /$\text{m}^2$	A$50–80 /$\text{m}^2$
combined paint and application (spot repair 15%, refresh coat) 3 spot and 2 full coats	A$25–30 /$\text{m}^2$	A$25–35 /$\text{m}^2$	A$30–40 /$\text{m}^2$
Combined paint and application (full reblast and paint system) 6 full coats	A$30–35 /$\text{m}^2$	A$35–40 /$\text{m}^2$	A$38–45 /$\text{m}^2$
4. Additional charges			
Waste collection and removal	A$60–90 /t	A$60–90 /t	A$60–90 /t
dry solids	A$60–90 /t	A$60–90 /t	A$60–90 /t
shot from blasting	A$120–150 /t	A$120–150 /t	A$120–150 /t
paint waste	A$120–450 /l	A$120–450 /l	A$120–450 /l
environmental	A$5000–10 000	A$5000–20 000	A$10 000–30 000
5. General frequency of drydocking?	24–36 months	36–60 months	60 months