In-water vessel cleaning: current and emerging technologies, associated risks, and management options for Hawaii

FINAL REPORT
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Chela Zabin, Ian Davidson and Greg Ruiz
Smithsonian Environmental Research Center

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Executive Summary

Some 417 non-native or cryptogenic species are reported as having become established in Hawaiian waters (Carlton & Eldredge 2009). Although the impacts of most of these species are unknown, some have been demonstrated to negatively impact native species and habitats (reviewed in Carlton & Eldredge 2009). A recent analysis indicates that Hawaii's marine non-native and cryptogenic species are being detected at an exponentially increasing rate (Davidson et al. 2014a). Most of these species were accidentally introduced by ships, with vessel hull fouling playing a larger role than ballast water release in Hawaii (Eldredge & Carlton 2002, Godwin 2003). Up to 78% of Hawaii's non-native species likely arrived in the islands as a result of biofouling, making this the single-most important vector both historically and currently (Davidson et al. 2014a).

In response to a growing awareness of ship fouling as a potent vector for marine bioinvasions, regulations and guidelines at international, federal, and local levels are increasingly focused on reducing biofouling. Cleaning ships in water between drydock intervals is a major tool for reducing fouling. However, in-water cleaning (hereafter IWC) as it is currently practiced typically involves scraping, brushing, or blasting off fouling, releasing potentially viable organisms and/or their propagules as well as paint components into the water. Thus, IWC is also increasingly becoming restricted or banned. In Hawaii, IWC is allowed as long as certain state and federal discharge standards for water quality are met (Tanimoto, pers. comm 2015). No current regulation for IWC addresses biosecurity. As a result, there is a risk that IWC requests in Hawaii will increase in the near future because of biofouling and in-water cleaning policy developments elsewhere in the Pacific.

As jurisdictions around the world address the issue of biofouling and in-water cleaning, new technologies for IWC are being developed in response to the need for ships to reduce hull fouling while simultaneously preventing the release of chemical contaminants and non-native species. As part of an overall approach to managing biofouling, these technologies will have to be evaluated for their efficacy in providing the needed hull husbandry for proper vessel operation while reducing the risk of species transfers during the cleaning process. Costs to industry, logistical, and permitting issues also need to be considered.

To assist Hawaii's Department of Land and Natural Resources (DLNR) in the development of its vessel biofouling policy, this report provides a review of available and emerging IWC technology, a literature review of the risks associated with IWC, and initial data on IWC in Hawaii. We also outline potential options for the management of IWC. Here are our key findings:

- Approximately 100 vessels were cleaned by the major IWC companies in Hawaii in 2015. Detailed information is not available, but the companies reported cleaning a wide variety of vessel types, including some foreign ships and other craft that travel outside of the state.
- The methods currently in use in Hawaii (and in widespread use around the world) do not capture the biological and chemical debris generated by IWC, posing a potential biosecurity risk in cases where biofouling is not of local origin, and raising water quality concerns.

- While not widely available, there are several companies developing technologies that integrate biofouling removal and containment into their cleaning systems. Increased operating cost and regulatory issues associated with these units provide a challenging environment for market penetration and more widespread use. However, around the world, these technologies are advancing and some are close to being market-ready and others are in operation in ports in Europe, Canada, Australia, and New Zealand. Several companies are also beginning in-water tests in California, where most IWC within ports is currently banned due to water-quality concerns.
- Other methods which focus on killing but not removing biofouling, such as heat treatment and encapsulation, are potentially promising for reducing both biosecurity and chemical pollution risk. They may also be the least damaging to hull coatings, helping to prolong the effective duration of antifouling and foul release coatings. Their efficacy may be limited to light fouling only (slime layers), however, and such a pro-active hull cleaning strategy has little precedent in maritime shipping.
- There are no universally accepted performance standards for IWC technology which poses a challenge to government entities concerned with biosecurity and water quality as well as for the developers and industry investing in new technology. Last year, New Zealand released a standardized framework for evaluating IWC technology (Morrisey et al. 2015), which may be useful to other jurisdictions that are considering IWC policy changes. Among the key recommendations are 1) third-party, independent testing of any proposed new technology 2) that tests be carried out on the vessel types and in the conditions for which the technology is intended to be used. The document also sets standards for biofouling removal, efficacy of particle capture and filtration of effluent.
- Based on our literature review, it appears that all IWC systems examined by researchers to date pose some potential biosecurity risk during deployment and preparation, the cleaning process itself, debris removal, and effluent filtration. However, these risks may be minimized as technology develops and as performance standards are put into place. Even with some risk, capture technology (for organisms and paint) provides greater biosecurity than the status quo of no attempted capture.
- A risk-based decision tool may be the best approach to deciding whether and how a fouled vessel should be cleaned in water. Such a tool weighs the potential risks a given vessel presents based on factors such as origin of fouling, extent of fouling, and paint type and condition. An IWC decision framework and a series of management options are included in this report.
- Most of the Hawaii-based IWC companies interviewed indicated a willingness to use debris-capture technology if it were available. Other ideas for the development of IWC policies that would protect the environment and be feasible for industry included promoting more frequent (pro-active) hull cleanings, greater use of non-toxic coatings, and the adaptation of the US Navy's best management practices (BMPs).
- There are a number of options for addressing the biosecurity risks associated with IWC. These include a range of actions ranging from least restrictive (no action) to most restrictive (ban all IWC). The latter would be too restrictive for industry and IWC is an important tool for reducing invasion risk in Hawaii and promoting efficient shipping. Further efforts should be made to better understand IWC in

Hawaiian waters and promote a sustainable approach to the practice, including developing and encouraging the use of BMPs, education/outreach campaigns, incentivizing debris-containment technology for IWC in Hawaii, further data gathering, and the development of a risk-assessment decision tree for IWC.

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1.0 Background

1.1 Non-native species and ship biofouling in Hawaii

As one of the most remote land masses in the world, the Hawaiian archipelago was colonized by only a few hundred terrestrial species, which underwent rapid speciation, resulting in a unique biota featuring many rare and endemic species (Carlquist 1982). Colonization by coastal marine species was also limited by the vast ocean; many major groups found elsewhere in the Pacific are absent here and levels of endemism are high (Kay 1987). This isolation ceased almost as soon as humans landed in the islands, bringing with them, both intentionally and accidentally, many species not native to the islands.

Today, approximately 22% of Hawaii's terrestrial species are non-native, and at lower elevations on many of the islands native species are virtually absent (Sohmer & Gustafson 1987). Extinctions of native species have been linked both directly and indirectly to many of these non-natives (Stone 1999). In the marine environment, some 417 non-native or cryptogenic species are reported as having become established (Carlton & Eldredge 2009). Although the impacts of most of these species are unknown, at least five non-native algal species, a mangrove, an octocoral, two crustaceans, and two fishes have been demonstrated to negatively impact native species and habitats (reviewed in Carlton & Eldredge 2009). A recent analysis indicates that Hawaii's marine non-native and cryptogenic species are being detected at an exponentially increasing rate (Davidson et al. 2014a).

Most of these species were accidentally introduced by ships, with vessel hull fouling playing a larger role than ballast water release in Hawaii (Eldredge & Carlton 2002, Godwin 2003). Up to 78% of Hawaii's non-native and cryptic species may have arrived in the islands as a result of biofouling, making this the single-most important vector both historically and currently (Davidson et al. 2014a).

Hawaii's economy is heavily reliant on shipping. Honolulu Harbor ranks in the top 40 North American ports by volume, and the islands represent a critical link between Pacific Rim countries and the mainland United States for commercial trade. A recent analysis of commercial shipping traffic found that 1302 to 1431 ships had arrived from over 352 locations around the world between 2010-2013 (Davidson et al. 2014a). These ships represent potential opportunities for the transfer of non-native species to Hawaiian waters.

The extent of fouling on vessels arriving to Hawaii has not been well quantified, but the research that has been done to date indicates that at least some vessel types are transporting non-native species. In a pilot study (Godwin & Eldredge 2001), divers examined eight vessels (seven towed cargo barges and one towed floating drydock), surveying for species richness and composition. They found a diverse group of biofouling organisms, including at least 37 species non-native to Hawaii. In a larger, follow-up study in Oahu's major commercial harbors, Godwin et al. (2004) surveyed 35 vessels, ranging from large commercial ships to fishing boats and yachts. Fouling cover was low on several vessel types, notably the overseas fishing vessels and barges, but heavy on others, including interisland tugs and barges as well as some yachts and miscellaneous vessels. As a group, yachts arriving from overseas carried 21 non-native species; miscellaneous vessels, which included a floating dry dock, carried 19, as did the interisland barges; 26 non-native species were found on interisland tugs. This study indicated that non-native species routinely arrive to Hawaii in vessel biofouling from overseas, and that interisland ship traffic may be an important vector for spread between neighbor islands.

While some of the yachts surveyed by Godwin et al. (2004) were heavily fouled, a study of resident private boats (Leonard 2009) indicated that most (66%) boats were clean or only lightly fouled, and only 11% of boats were heavily fouled. However, even heavily fouled resident boats as a group may pose relatively little risk to biosecurity; none of the 64 boat owners interviewed had left the state in the past year, and only 21% had visited a neighbor island.

1.2. Hull husbandry practices on ships arriving to Hawaii

Biofouling creates drag, making ship operations less fuel-efficient. Ship operators typically use marine coatings as a primary tool to prevent the accumulation of fouling. Anti-fouling paints work primarily through the use of biocides, which are toxic to many marine organisms and discourage settlement on ships' surfaces. Copper is the major toxic component in modern antifouling paints. Foul-release coatings (silicon or fluoropolymer-based) are biocide-free and have a smooth surface that does not allow organisms to adhere firmly; those that do settle on these vessels are sloughed off when ships get underway. These coatings rely on movement to remove fouling; they tend to be easily damaged by scrubbing. Mechanically resistant paints (epoxy, ceramic and/or glass mixes) are also biocide-free, but unlike foul-release coatings, they are hard and durable, and designed for regular in-water cleanings.

The effectiveness of any coating decreases over time and ships must be periodically removed from the water and repainted. Between these drydock intervals, most ship operators also conduct in-water inspections, repairs, and cleaning to remove accumulated biofouling. At any given point in time, the degree to which a ship is fouled is the result of a complex number of factors including: time since last dry dock, paint type, frequency of use, typical speed while underway, length of time in port, and geographic location of operations.

Davidson et al. (2014a) polled commercial vessels arriving to Hawaii on their anti-fouling practices. The 125 ship operators who responded reported some practices that might decrease the risk of biofouling-mediated invasions and other practices that might increase risk. For example, risk might be reduced due to the high level of awareness among vessel operators of biofouling practices and regulations: 65% were familiar with the International Maritime Organization's biofouling guidelines and log book, over one-third reported having these items aboard, and 29% reported using the plan and record book. Additionally, three-quarters of respondents reported that their sea chests, a location that is often heavily fouled, were inspected and cleaned during dry dock and 55% had marine growth management systems installed in sea chests or sea strainers. Finally, operators reported relatively short dry dock intervals: 85% of vessels reported having dry docked in the past 3 years and 5% within the past 4 years. A five-year interval is more common and is generally what is required by ships' classification societies. However, fouling typically accumulates more quickly in tropical waters; given this, the shorter drydock interval may be a response to a greater need.

On the other hand, Davidson et al. (2014a) found that a significant percentage (21%) reported lay-up periods of more than 10 days, which increases the risk of biofouling accumulation, and 42% reported having visited another tropical port since last dry dock, which increases the likelihood of the transfer and survival of foreign tropical biofouling species in Hawaiian waters. In addition, relatively few vessels – just 28% – had cleaned in-water since last dry dock.

The cleaning regimes for Hawaii-based pleasure craft, both sail and motorboats, were recently assessed (Leonard 2009). A survey of 64 boat owners indicated that all had some type of antifouling paint applied within the last five years. In-water hull cleaning was being done on a regular basis: ~27% of boat owners cleaned one to two times a year, and 22% between three and six times a year.

1.3. Regulatory Background

As a response to a growing awareness of ship fouling as a potent vector for marine bioinvasions, the reduction of biofouling has become a focus of regulations and guidelines at international, federal, and local levels. Most of the rules and guidelines require that ships have a documented antifouling program (e.g. International Maritime Organization, US Coast Guard, Australia New Zealand Environmental Conservation Council, reviewed in McClay et al. 2015), which includes regular inspections and maintenance, and some specify an acceptable fouling extent and composition for arriving vessels (e.g., no visible macro-organisms, Papahanaumokuakea Marine National Monument; slime layer or gooseneck barnacles only, New Zealand). New Zealand is the first country to issue a standard for biofouling that will be mandatory in 2018.

In-water cleaning as it is currently practiced typically involves scraping, brushing, or blasting off fouling, releasing potentially viable organisms and/or their propagules, as well as paint components into the water. Thus, while cleaning in-water between drydock intervals is a major tool for the reduction of biofouling, which helps ships to meet clean hull requirements, in-water cleaning is also increasingly becoming restricted or banned. In some locations, such as the state of Washington and certain water bodies in California, concerns about the release of toxic chemicals, such as copper, from antifouling paints, are the main reason for bans on in-water cleaning (state regulations reviewed in McClay et al. 2015). In New Zealand, new guidelines for in-water cleaning currently under review were created to deal with both chemical contaminants and biosecurity, allowing cleaning only in circumstances when both issues can be sufficiently addressed (Craft Risk Management Standard 2014). In Hawaii, in-water cleaning is allowed as long as certain state and federal discharge standards for water quality are met (Tanimoto, pers. comm 2015). No current regulation for in-water cleaning addresses biosecurity. Thus, there is a risk that in-water cleaning requests in Hawaii will increase in the near future because of biofouling and in-water cleaning policy developments elsewhere in the Pacific.

1.4. Purpose of the current project

Around the world, new technologies for in-water cleaning are being developed in response to the need for ships to reduce hull fouling while simultaneously preventing the release of chemical contaminants and non-native species. While some of these are still largely experimental, others are now available for limited commercial use. The purpose of this project is to develop an understanding of current and emerging technologies for in-water cleaning in the United States, and Hawaii in particular, and to understand the relative risk for biosecurity associated with each method. This will help guide decision makers in creating in-water cleaning policies and procedures that are clear and risk-based.

This project builds on an earlier report for CGAPS and DLNR (Davidson et al. 2014a), which described the biofouling vector in Hawaii and outlined possible management options. For the current project, SERC helped DLNR to organize a one-day stakeholders workshop on the risks associated with in-water cleaning in June 2015 (http://dlnr.hawaii.gov/ais/2017/01/03/in-water-cleaning-operationstechnology-and-biosecurity-risks/) . SERC and DLNR then developed a questionnaire which DLNR staff used in 2016 to conduct interviews with vessel-cleaning companies to assess the nature and scope of IWC activities in Hawaii. SERC also submitted a draft report on current and emerging IWC technologies in September 2015 and a literature review on risks associated with IWC to DLNR in November 2015. Those draft reports, combined with DLNR's new interview data, were used to generate management recommendations, and are included in this final report.

2.0 In-water Cleaning Technologies and Practices

Major reviews of the risks and effectiveness of various in-water cleaning (hereafter IWC) technologies include Bohlander (2009), who reviewed antifouling coatings as well as current and developing technologies around the world for in-water hull husbandry and cleaning, and Floerl et al. (2010), who summarized the state of technology for both coatings and IWC in light of their biosecurity and contaminant risks, effectiveness, cost, and appropriateness for various vessel types. In 2014, SERC provided the state of Washington with a synopsis and update to the Floerl et al. 2010 report as part of an assessment of biofouling risk for Puget Sound (Davidson et al. 2014b) and collaborated with the consulting firm SAIC in a review of IWC technology and policy for the US Coast Guard (McClay et al. 2015). A more recent review (Morrisey and Woods 2015) was released after our draft report was submitted. It does not differ from our report in general conclusions, but does provide some additional information on specific technologies.

The current report builds upon and provides updates to these previous reports, covering technologies widely in use today and emerging new technologies, some of which are in limited commercial use.

2.1 Major technologies widely in use

2.1.1Commercial vessels

Method: Mechanized brushes diver driven/ROVs

Five companies do in-water large-vessel cleaning in Hawaii. Two of these are major companies, with offices in multiple locations worldwide, and three are locally based, although one also has an office in California. Two companies also have major contracts with the US military as well as cleaning commercial vessels.

For large commercial vessels, in-water cleaning is usually done with rotating brush systems, operated by divers or remotely operated vehicles (ROVs), often supplemented by pressure washing and/or hand cleaning by divers for niche areas not easily reached by mechanical methods. Currently, most in-water cleaning systems in place for larger vessels do not have the built-in capacity to contain and/or process biofouling and paint debris. None of the Hawaii companies employ such capture technology.

2.1.2 Recreational boats and other small craft

Method: Hand scrubbing/hand tools

Several companies in Hawaii, about six of which are located on Oahu, are involved exclusively or nearly exclusively in cleaning of yachts and other small craft. None of these currently employ capture technology. Individuals may also work more informally cleaning private boats.

Scrubbing by divers using hand tools is the most widely used in-water method for removing biofouling on small vessels such as yachts. This method can be relatively inexpensive, particularly when done on a regular basis by the boat owners or crew while the boat is at berth, or by a single commercial diver using minimal gear. Boat owners can easily remove light fouling with a sponge or other soft implements. Heavier fouling, which usually includes harder organisms such as barnacles and calcareous tubeworms, requires more aggressive scrubbing or scraping, including by mechanized methods, and is usually done by commercial divers.

2.2 Emerging technologies

2.2.1 Biofouling capture

While not widely available, there are several technologies that integrate biofouling removal and containment into their cleaning systems. Several of these are in operation and/or close to market-ready, although in some cases challenges remain, including increased operating cost and regulatory issues. Below we review some examples of these technologies.

Method: Vacuum and filtration systems, coupled with brushes, blades or water jets

<u>US Navy's Automated Hull Maintenance Vehicle (AHMV) and Advanced Hull Cleaning System (AHCS).</u> This system includes a submersible cleaning and maintenance platform (SCAMP, such as those developed by Seaward Marine Services), or brush cart, that also vacuums debris as it cleans. This effluent is transferred to a pier-side waste management unit. The system filters out solid debris greater than 20 microns. Discharged water from the unit has concentrations of <5mg/L of biota and <1 mg/L of copper (Floerl et al. 2010). A prototype of this system is owned by the Naval Sea Systems Command (NAVSEA) and is located in Pearl Harbor, but is currently not in use due to the high operating costs –

currently five times higher than methods that do not capture debris – associated with this system (McClay et al. 2015).

<u>MARAD/Terraphase Engineering System</u>

The US DOT Maritime Administration (MARAD), in collaboration with a private engineering firm, Terraphase Engineering Inc. and commercial divers from Jacksonville, Florida-based Underwater Services International, recently developed and tested a new in-water cleaning system in San Francisco Bay (Terraphase Engineering 2012). The system uses a diver-guided brush system, outfitted with a rubber "skirt" to capture debris and a suction hose to vacuum debris and deliver it to a pier-side filtration system (Fig. 1). Solids are filtered out using a series of progressively smaller filters (down to 5 microns for capturing solids) and an organo-clay filter system to capture dissolved metals.

The initial goal of this project was to evaluate the effectiveness of capturing and removing metals, specifically copper and nickel, from wastewater produced by in-water vessel cleaning and to develop an economically feasible best available technology (BAT) standard for such operations in California waters. The first test was carried out on a MARAD vessel at berth, with all wastewater captured and contained into a land-based treatment and storage system. The effluent from this system did not meet the discharge standards of the SF Bay Regional Water Quality Control Board, but the Board indicated it would allow the use of this technology if discharge water could be diluted sufficiently to reduce the concentration of heavy metals.

This system allowed the San Francisco Bay water quality board to recommend a set of BAT standards for minimizing copper and zinc run off as a result of IWC (San Francisco Bay Regional Water Quality Control Board 2015, included here as Appendix 1). The board did not address invasive species issues specifically, but presumably biofouling would also be efficiently captured by this system. The board did state that in order to minimize paint damage, the cleaning system should be limited to the use of non-metal brushes suitable for cleaning soft fouling only. A second test of the system was run in San Francisco Bay in late July 2015, and successfully met discharge standards under the BAT, according to a report written by Underwater Services International.

Figure 1. Above, the MARAD/Terraphase scrubber with skirt and propeller-generated suction (center of device), fitted with a hose to capture wastewater, bottom and top views, and below, the pierside debris containment and filter system. Photos from Terraphase Engineering.

Whale Shark Environmental Technologies

All-Sea Enterprises, based in Vancouver, B.C., is developing an ROV cleaning system, called the Whale Shark ROV, which contains and treats the debris removed during in-water cleaning. The system includes rotating brushes enclosed in a hood, with all debris pumped to the surface through flexible hoses (Fig 2). The company has also developed a propeller cleaning ROV, the Beluga Environmental Propeller cleaning system, which also captures and pumps debris to the surface. The system removes organic debris and treats the effluent through a filter system, returning the treated water to the ocean.

The effectiveness of the Whale Shark in treating the effluent generated in cleaning a container vessel in Algeciras Bay, Spain was evaluated by the University of Cadiz in 2010. The vessel's antifouling coating was silicon-based and it had no macrofouling, only a biofilm layer. Additionally, this test was conducted on a foul-release paint, rather than an antifouling coating. Researchers found no statistically significant differences in a variety of water quality parameters, including pH, temperature, conductivity, salinity, dissolved oxygen, turbidity, zinc, copper, chlorophyll a, phytoplankton mass, and zooplankton mass and diversity. The researchers recommended the use of 50 micron filters "for complete effectiveness"; the test employed 100 micron filters. They also reported that the technology performed well in terms of capturing and filtering larger particles of fouling in previous tests of more heavily fouled vessels. After further modifications, in 2011 the company gained permission to use the Whale Shark in the Port of Vancouver. The company's goal was to complete testing by summer 2015 and to have a commercially available unit soon after. The company estimated that the use of the WhaleShark would add ~$7,000 CAD to the cost of cleaning a 300-m ship (McClay et al. 2015).

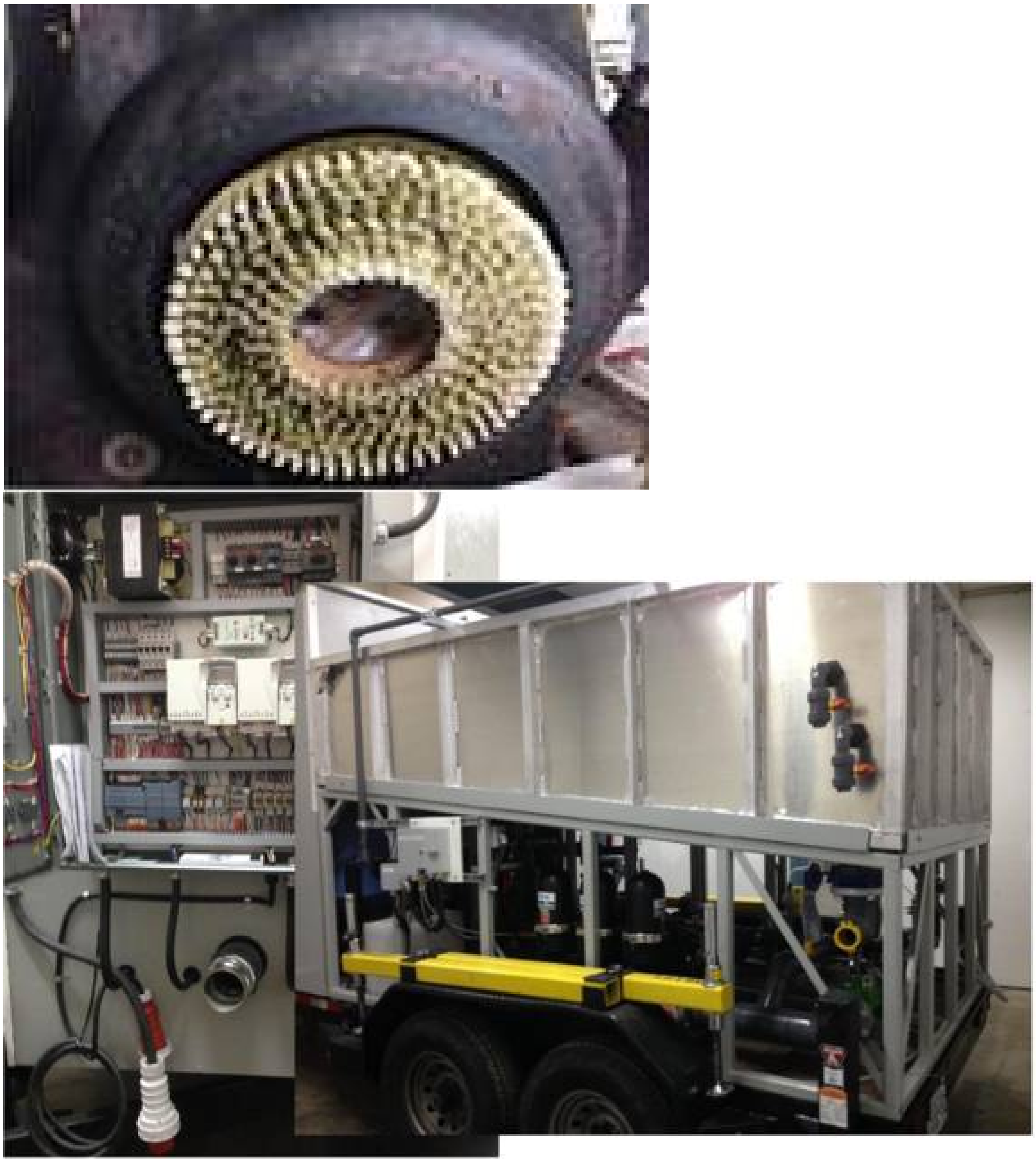


Figure 2. Whale Shark Environmental Technologies rotating brush and filtration system. Photos: All-Sea Enterprises.

ECOStation

A Norwegian-based company, ECOSubsea, has created a system called ECOStation that combines ROV-driven water pressure cleaning with suction technology to capture debris. The ECOStation system is designed to minimize paint wear by using relatively low water pressure (100 up to 250 bars). The system has been in operation for one year in Southampton, UK, where it has exclusive access as the only hull-cleaning system that meets environmental standards, as well as in major ports in Sweden, Norway, and Denmark.

The company claims a 97.5% debris collection rate and a reduction in chemical contamination due to its gentler cleaning methods. In Southampton, water pressures of 100 to 120 bars are used, with 150 in one case of a heavily fouled roll-on, roll-off vessel (Ostervold, pers. comm. 2015). The company says its has been successful with all types of fouling encountered to date. Early tests of the system on a wide range of antifouling paint types indicated that it did not damage the paint (Litlved 2012). Capture efficiency, which was greater than 97% during these tests, has been improved with modifications to filters, and the remaining effluent is now also sterilized with a UV treatment (Ostervold, pers. comm. 2015). The company estimates the cost of cleaning to commercial vessels to be \$3 to \$10 USD per m^2.

Envirocart

In 2014, Gage Roads Diving Franmarine, a company based in Henderson, Australia, won an award for Excellence in Marine Biosecurity from the Western Australia Department of Fisheries for its Envirocart in-water cleaning technology. The Envirocart uses rotating brushes or blades for cleaning and captures and filters removed debris, but the company offers a suite of different technologies for various paint types and needs. The basic cleaning technology is a diver-driven hydraulically powered unit which can be fitted with various brush types or blades for contactless cleaning (Fig. 3), and can be used in a fully contained mode, which claims 100% capture of debris. The captured material is pumped through several filtration stages, which have the ability to remove particles up to 5 microns. The remaining filtrate is sterilized using UV light. Smaller niche areas are then treated with a variety of hand tools, which come with shrouds for suctioning debris, and a “magic box” which provides high-pressure water cleaning in an enclosed box.

The Envirocart was tested for the Department of Fisheries (DoF) on several paint types including epoxy, silicone foul-release, and copper-based antifouling and on various levels of biofouling (Lewis 2012). Following some recommended modifications, the company passed DoF’s requirements in terms of both biofouling and contaminant containment without damaging painted surfaces. In May 2015, the DoF approved Envirocart for in-water hull cleaning on vessels that use non-biocidal paint and travel regionally. Its use on biocidal coatings was under review and testing in the last 12-18 months.

Franmarine estimates the costs of using the Envirocart at \$144-152 USD per m^2, plus mobilization and consumables at (\$10,000 to \$13,000). Within a year, the company expects to be able to operate the system remotely, which will bring costs down.

Figure 3. Envirocart being operated by a diver (above). (Below) Half-cleaned tug photographed during testing for the Western Australia Department of Fisheries. Photos from Franmarine, http://www.gageroadsdiving.com.au/projects/envirocart/.

HISMAR

New cleaning technology called Hull Identification System for Marine Autonomous Robotics or HISMAR is under development in Europe. Several academic and commercial institutions were involved in this product's development, which was initiated with funding from the European Union. The project was coordinated by the University of Newcastle, with Stankin Moscow State Technical University as a second partner. HISMAR is a wheeled ROV that can be programmed with a detailed map of the ship's design in order to make modifications for challenging portions of the vessel's surface (Fig. 4). It uses water jets as its main cleaning method, containing debris in a hood for removal and filtration (Narewski 2009, Balashov et al. 2011). We were unable to ascertain the current status of this system.

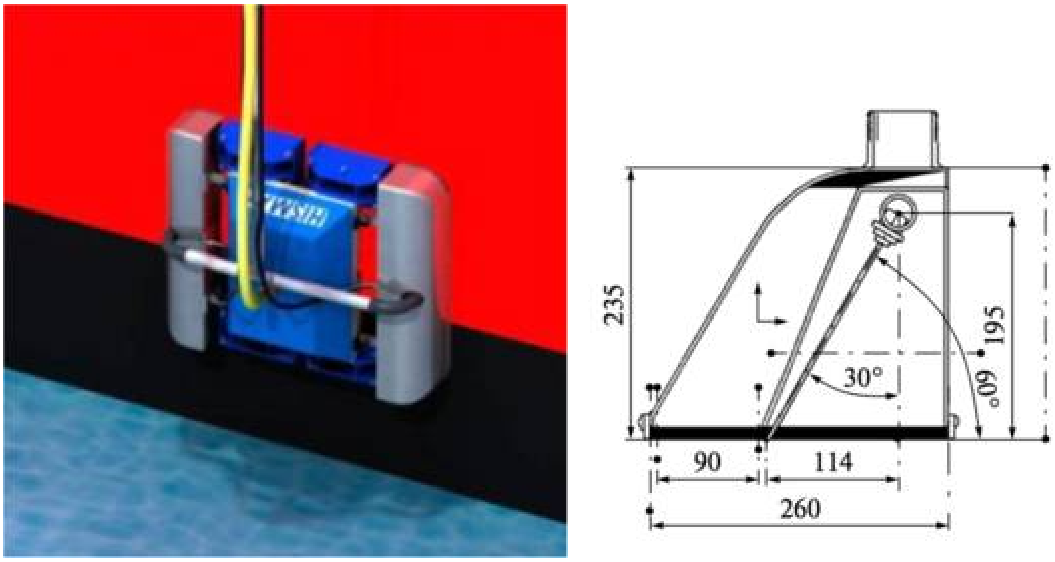


Figure 4. Schematic of the HISMAR transport platform (L) and a cross section of the cleaning head (R), which are shown as silver bars on each side of the platform in the picture on the right. Figures from Narewski 2009 and Balashov et al. 2011.

Trident 5 TecHullClean

Underwater Contractors Spain (UCS), in collaboration with shipbuilder Trident BV and Maersk Line, has engineered a diver-driven rotating brush system with debris capture and filtration called TecHullClean. The technology features a hydraulic suspension system which controls the pressure of the brushes against the vessel, debris capture, and debris delivery to a mobile filtration system at the surface (Fig. 5). The system has been approved by paint companies Jotun and International Paint as appropriate technology for their products. The system includes an air venturi to increase the flow of debris through the hose, speeding the capture process. The shore-side filtration system puts debris through a series of increasingly smaller filters, starting with larger mesh filter insert boxes (Fig. 6), and decreasing down to as fine as 5 microns, although 25-100 micron is the size the company is using in Spain.

The UCS group has permits to work in the south of Spain and in Vancouver, Canada, and is in the final stages of permitting for work in the ports of Southampton, UK and Rotterdam, Netherlands as well as Valencia and Barcelona, Spain. Their partners in the United States, SubSea Global Solutions, are working with a similar system, and are hoping to test it soon in the port of Long Beach, CA.

Figure 5. Above, the complete Trident V system. Figure 6. Below, details of the filter system, which makes use of the large surface area of the filter box to remove larger particles. Photos: UCS.

Innermost Containment Systems LLC

A simple containment device that appears most appropriate for smaller vessels has been developed by Innermost Containment Systems and is in use at Moss Landing and Santa Cruz harbors, in California, where the company owner is continuing to work on further refinements. This system surrounds the boat with a rubberized envelope, while divers clean (Fig. 7). All debris and water inside the envelope can then be pumped out and filtered pierside (Fig. 8).

The system has been used for boats up to 50 ft, but Innermost is planning to begin work on 80' vessels later this year (M. Zlotkin, pers. comm. 2015), and to eventually scale up to service container ships. Tests of filtration effectiveness have been carried out by McCampbell Analytical in Pittsburg, CA; levels of copper after final filtration appear to meet the BAT approved by the San Francisco Bay Regional Water Quality Control Board (see MARAD section above).

While cost varies depending on the amount of waste generated, on average the system adds $100 USD to the regular cost of in-water cleaning, starting at approximately $200 for a 3 m boat, and ~$100 more for each additional 3 m.

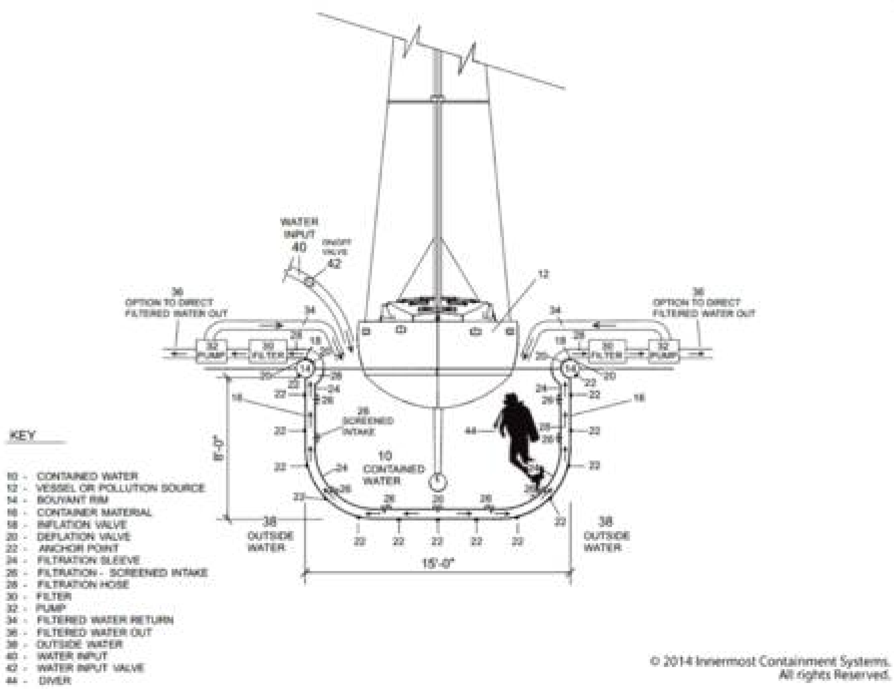


Figure 7. Schematic of Innermost Containment System showing boat and diver inside container.

Figure 8. Debris and wastewater being suctioned out of the container following work on a boat. Photos from Innermost Containment Systems.

<u>Hulltimo Smart</u>

A small version of the debris capture system is being sold for recreational craft (and swimming pools) by Hulltimo-Mauritius. The device is a small robotic hull cleaner, driven by the user dockside by means of a monitor and keyboard (Fig. 9). The company claims the device captures all debris in bag with filtration to 100 microns and complies with European and IMO standards. The cleaning device uses soft, rotary brushes, which tilt to get to waterline and curved areas, and can clean a 11 m boat in one hour. The device is intended to be used for regular, frequent cleanings of lightly fouled (=slime layer) boats. The company did not respond to requests for more details on their system.

Figure 9. The Hulltimo device being driven remotely. Photo: Hulltimo Mauritius
https://services.crmservice.eu/raiminisite?a=FEY9pLHXWFV1XHUy5r0nDqOUKD6w3VRLkQkSahxnWjg=

Cavidyne and Cavi-Jet: Water jets and cavitation cleaning

Other available cleaning methods include water blasting or using cavitating bubbles to remove biofouling rather than brushes or blades. Companies that produce these devices, such as Cavidyne and the Italian company Cavi-Jet say that their products can be used at very low pressure, which increases diver safety and avoids paint damage that can lead to chemical contamination. Cavi-Jet did not respond to requests for more information on their products.

Cavidyne's technology works by generating bubbles that collapse, creating a vacuum that removes fouling. Their products are being marketed as appropriate for multiple surfaces and paint types, and can be used at higher pressure for stronger cleaning (although presumably this would also damage paint). Cavidyne's systems range in size and thus might be appropriate for small as well as large craft.

In their review of IWC technology, Floerl et al. (2010) reported that these companies indicated that debris-capture technology could be coupled with their cleaning devices, but the companies do not appear to be actively working on this. Cavidyne carried out tests of its CaviBlaster Model 1222 (Fig. 10) in San Francisco Bay in October 2015 to determine effectiveness in killing the biofouling it removes as well as evaluate impacts on water quality (I. MacDowell, pers. comm. 2015).

Figure 10. Cavidyne's CaviBlaster cleaning tool. Photo: Cavidyne.

2.2.2 Technologies to kill biofouling organisms

A second major group of developing technologies uses various methods to kill but not necessarily remove biofouling organisms. In some cases, dead organisms may simply detach and fall off over time; in cases where this does not occur, or does not occur quickly, these methods may achieve biosecurity goals, but not meet the needs of vessel owners in terms of reducing drag and fuel consumption.

Method: Hot water/steam

There are several examples of hot water or steam being used to kill biofouling in small-scale applications, as well as efforts to utilize such technology on a larger scale. For example, heat was been used to kill the invasive kelp *Undaria pinnatifida* on a sunken trawler off the coast of New Zealand's Chatham Islands and on the seafloor (Fig. 11). In the case of the trawler, plywood "hot boxes" with heating elements built by New Zealand Diving and Salvage LTD were used to heat the surface of the vessel to 70° C. The boxes were moved methodically along the hull to cover the entire vessel; blowtorches were used in niche areas where boxes could not make an effective seal (Wotton et al. 2004). Resurveys of the vessel 18 months later determined that the treatment had been successful.

Figure 11. The plywood box, equipped with heating elements, which was used to kill the invasive seaweed *Undaria pinnatifida* on a sunken trawler. Photo: New Zealand Diving and Salvage LTD, in Wotton et al. 2004.

<u>Hull Surface Treatment</u>

A method using heated seawater, Hull Surface Treatment (HST) has been developed by Commercial Diving Services Pty Ltd Australia for commercial use to keep vessels free of light to moderate fouling. HST heats water inside a remotely operated rolling thermal applicator similar in concept to the "hot box" used for the *Undaria* removal above, equipped with rubber skirts and held against the ship's hull using magnets. The applicator moves along the vessel surface in a grid pattern, using hot water provided by a tender-mounted boiler unit to heat the ship's surface to 40° C (Fig. 12). The fouling is killed and left to slough off when the vessel gets underway. This technology is limited to ferrous hulls and to vertical or near vertical surfaces; divers are still needed to clean niche areas.

Because the system does not damage paint, it does not release chemical pollutants to the environment. The system is approved for use in all commercial ports in New Zealand and in Sydney, Kembla, Brisbane, Melbourne, Great Barrier Reef Marine Park, and Freemantle in Australia. T&C Marine holds the international license and is the exclusive provider in Australia. It is marketing the technology as a “pre-emptive” way to maintain a clean hull by removing slime layers and early settler stages of invertebrate species such as tubeworms and barnacles. The technology has won numerous awards for innovation.

To complement this technology, the company also employs heated seawater to sterilize ship’s sea chests. The surface and sea chest treatments were demonstrated to achieve 100% mortality of fouling organisms by Leach (2011).

Fig 12. HST’s thermal applicator (shown above) moves along a ship’s hull in a grid pattern, sterilizing the surface. Photos: Leach 2011 and T&C Marine.

Method: Encapsulation

Pilot-scale projects in various locations and on submerged structures around the world, including pier pilings on Maui, have indicated that wrappings can be used to kill biofouling on small vessels, maritime structures, and on the seafloor (reviewed in Floerl et al. 2010; T. Montgomery, pers. comm. 2015), provided that the wrapped area can be properly sealed for a sufficient period of time.

Small-boat owners have employed a similar concept, wrapping “boat skirts” (or plastic tarps) around their vessels, or moving boats into floating boat lifts which can then be filled with freshwater to kill biofouling. While not legal to do so, some boat owners add bleach to the water held around their boats. Boat skirts are not allowed by some marinas as they tend to get fouled over time and sink.

Biofouling Solutions Pty Ltd
An Australian company, Biofouling Solutions Pty Ltd, has developed technology to use encapsulation as a way to kill biofouling on a variety of vessel types. The company’s IMProtector mobile encapsulation unit can be used with or without chemicals added to enclosed space. Prototypes for use on recreational and fishing vessels have been built and tested. The company had also planned to develop units for larger vessels and for oil rigs, but further development of this technology has stalled pending financial support.

2.3 Discussion

The ideal IWC technology would meet multiple goals:

1. Effectively remove biofouling from vessels or other submerged structures, including niche areas. This reduces the biosecurity risk posed by fouled vessels and improves a ship’s fuel efficiency, safety, and maneuverability
2. Kill all biofouling or contain all released viable biofouling, in cases where fouling communities might include non-native species, and follow best management practices for disposal at an on-shore solid waste treatment facility
3. Extend the performance period of ship coatings (IWC technology utilized must not damage or impair coating)
4. Prevent the release of chemical contaminants into the environment during cleaning by containment and proper disposal
5. Be widely available
6. Not be cost prohibitive
7. Be safe for equipment operators
8. Perform cleaning over a reasonable (hours/days) time frame

At this writing, none of the technologies described in this document meet all of these goals. Most notably for the purposes of this project, the methods *currently* in use in Hawaii do not contain the biological and chemical debris generated by in-water cleaning, posing a potential biosecurity risk in cases where biofouling is not of local origin, and raising water quality concerns. New technologies that capture debris or render it nonviable are advancing, but are available in only a few locations worldwide, and are currently more costly than traditional methods. Nonetheless, these capture technologies would improve the IWC situation in Hawaii if they were adopted.

However, there has been a proliferation of new IWC technology in the past decade, as governments and industry attempt to address both the biosecurity and chemical contamination issues, while meeting ships' husbandry needs. These new technologies differ from current practices in some critical ways.

- Reductions to paint wear by using wipers, blades, heat, cavitating bubbles, vacuum or suction tools or lighter weight brushes with adjustable pressure (i.e., USN recommendations, http://www.supsalv.org/webApp/AppBrush/AppBrushes.asp). These methods have developed at least in part in response to new some of the new coating types, which cannot stand up to vigorous scrubbing. It seems likely that methods that reduce wear on traditional antifouling paint would also reduce the release of copper and other toxins to the environment. However, many of these gentler methods may not be effective on heavy or hard fouling.
- Reductions to the release of debris and process water. Many of the companies reviewed in this report are working on ways to reduce the biosecurity and water quality risks by containing removed debris for shore-side disposal and filtration. Containment methods typically include a hood or shroud that covers the cleaning tools or cart and a suction device that transfers the debris through flexible hoses to a containment and filtration unit.
- Other methods aim to kill biofouling without harming paint using heat treatment or encapsulation. Heat treatments, which include steam, hot water blasts, or heating units to heat water held against a ship's surface, have been demonstrated to be effective on both small and large scales. Encapsulation alone or with the use of chemicals inside the wrapping has been tried and found to be successful in killing a variety of biota. These methods may also be less harsh on anti-fouling coatings, however neither of these methods actively remove fouling and thus may not meet hull husbandry requirements.
- Some methods, such as the large-scale heat treatment used by Hull Surface Treatment, are meant to be used on light fouling only and claim to prevent the buildup of heavier fouling by interrupting the successional buildup of biofouling. The use of these gentler methods requires a shift to more frequent pro-active rather than reactive, maintenance.
- The status of these new technologies ranges widely, from small-scale field or laboratory trials to actual port operations, but the number of companies that are already in operation or ready to begin in-port tests is increasing.

Earlier reviews of in-water cleaning technology by Bohlander (2009) and Floerl et al. (2010) compared the range of methods available in terms of their cleaning effectiveness, risk of chemical contaminant release, as well as appropriateness for different paint types and vessel types. In summary, they found that the various methods ranged in their effectiveness in removing biofouling, being most effective on soft fouling and on flat surfaces, and least effective in heterogeneous "niche" areas. They also found that most of the cleaning methods tended to damage paint surfaces, particularly soft paint (ablative or sloughing) types, thus releasing toxins to the environment. Additionally, they found that where tests had been carried out, the methods ranged in their ability to capture biofouling and paint residue. While technologies have been steadily improving since these reports were written, there remains a need for independent, third-party testing, to ensure that new IWC methods meet environmental standards and hull-husbandry needs. (Where possible, we reviewed and included the results of these tests in this document, but some companies did not want to release or did not have independent tests available.)

There are currently no universally accepted performance standards for IWC technology. Such standards would be useful to governments and permitting agencies, which will need to approve the use of new technologies, and to the developers and potential users investing in new technologies. To our knowledge, the government of New Zealand is the only entity that has developed a framework for testing IWC technologies (Morrisey et al. 2015). The goal of this document was to develop science-based appropriate, standardized tests to evaluate systems in terms of biosecurity risk before they are permitted to operate in New Zealand waters. Performance standards were developed for both technologies that remove biofouling and for those that kill biofouling (e.g., through encapsulation or heat treatment) as well as for the containment and treatment of removed debris and effluent. Among the recommendations for the framework is the use of an approved independent contractor for evaluating new technologies and that tests be carried out on the vessel types and in the conditions for which the technology is intended to be used. These standards may be useful to other jurisdictions, such as Hawaii, considering policy on IWC.

Performance standards aside, permit issues may be another hurdle to the advancement of some of the new in-water cleaning systems. In the US, the debris that is removed from a vessel's surfaces during cleaning is considered discharge that is covered under the EPA's Vessel General Permit (VGP), with state EPAs or other agencies typically signing off on such permits. However, release of filtered water from dockside after treatment may be considered commercial discharge not covered under the VGP, requiring a National Pollutant Discharge Elimination System (NPDES) permit instead. In the state of California, where several IWC companies are attempting to move forward with in-port tests, regional water quality control boards must issue such permits. California disallows IWC in copper-impaired waterways, which include most of the state's busiest commercial ports. Currently, the San Francisco Bay Regional Water Quality Control Board is allowing testing to of new IWC technologies as long as they are in compliance with a Best Available Technology document issued earlier this year (Appendix 1). The MARAD/Terraphase Engineering system and Innermost Containment Systems are moving forward with tests of their in-water cleaning, containment, and filtering systems with this BAT as a guideline. In addition, several large commercial companies that want to test new IWC technologies, are, at the time of this writing, working with the California State Lands Commission, the EPA, regional water quality boards, and the ports of Los Angeles and Long Beach to resolve permit issues. In the state of Washington, which normally disallows all IWC due to chemical contamination, cleaning has also been permitted in at least one case of which we are aware – on the non-biocidal Hydrex EcoSpeed paint, provided that the ship operator clean four weeks prior to entry into state waters to reduce biosecurity risk (Davidson et al. 2014b). The decisions reached by these state and local authorities and any subsequent tests of the new IWC systems may also provide information useful in decision-making in Hawaii.

In-water cleaning is an important tool for the reduction of biofouling-mediated species introductions and is a key component of ship husbandry, but it can also pose a biosecurity risk if viable non-native species are released during cleaning. A comprehensive biofouling management plan needs to assess the relative risks of allowing, disallowing or restricting in-water cleaning. For Hawaii, developing technologies that reduce or eliminate the risk of chemical or biological contamination provide a potential solution, as long as they can be cost-effective.

3.0 Literature review of biosecurity risks associated with in-water cleaning

3.1 Background

It is in the interest of vessel operators and resource managers alike to reduce biofouling on the submerged surfaces of vessels. A ship with clean surfaces is more fuel-efficient, and operational components such as water intakes, propellers, and thrusters perform better when unobstructed by biofouling. Keeping vessels clean helps to reduce unintentional introductions of non-native species, and helps ships meet the maintenance requirements and clean-hull standards that are increasingly being adopted around the world.

Biofouling reduction is primarily achieved through the use of marine coatings, applied in dry dock at regular intervals, which work either through chemical or mechanical means to discourage attachment or accumulation of fouling. Additional anti-fouling systems, which may include the use of chemicals, heat, UV light, or fresh water, may be used inside sea chests, internal sea-water systems, and in other areas of ships that are subject to higher rates of fouling accumulation.

Despite these practices, fouling builds up over time in unpainted areas, such as rudders and dry dock strips (the areas of the ship that are in contact with blocks that support the ship while in dry dock). Heterogeneous surfaces and areas of a vessel that are not routinely subjected to laminar water forces while underway (e.g., niche areas) also tend to accumulate biofouling more rapidly than smooth, exposed hull surfaces. Additionally, not all organisms are deterred by marine coatings: the bryozoan *Watersipora subtorquata* for example, settles readily on the copper paint that is toxic to most marine life, facilitating settlement by other organisms that can attach to the bryozoan (Floerl et al 2004). Finally, all coatings have a limited performance life, and their efficacy diminishes over time. Periodic removal of biofouling to enhance vessel operation and prolong coating performance is a routine part of ship husbandry. Typically, this is done in-water between dry dockings; in-water cleaning is faster and far less expensive than cleaning in dry dock.

While IWC is an effective way to reduce biofouling extent, and thus reduce the likelihood that a ship will transport species, it also presents a risk of contaminant release if paint particles are removed during cleaning. In addition, if the fouling on the ship is not of local origin, in-water cleaning presents a potential biosecurity risk through the release of viable organisms as adults, juveniles, viable fragments, resting stages, and gametes into the water where cleaning is done (e.g., Hopkins and Forrest 2008, Bohlander 2009, Floerl et al. 2010, Woods et al. 2012). Many species, including sponges, tunicates and algae can survive cleaning and regrow from small fragments (Hopkins et al. 2011).

Given these environmental concerns, the state of Hawaii is interested in determining whether it needs to make changes to current IWC policy. Currently, IWC is allowed in the state under the federal EPA Vessel General Permit, which Hawaii's Department of Health (DOH), Clean Water Branch, typically signs off on. Operators also need to meet the terms of Hawaii's Clean Water Act Section 401 Water Quality Certification, which requires providing the DOH with information on coating types and cleaning practices and abiding by key water quality standards. The state does not take biosecurity risks into account in allowing IWC. Given that IWC can be an excellent tool to reduce the transfer of non-native species, it is important to weigh the relative risks of IWC against other biofouling management alternatives (e.g., Hopkins and Forrest 2008). This section reviews the literature on the biosecurity risks associated with cleaning both in and out of water, and compares these to the risk posed by not allowing cleaning.

3.2 Approach

Our earlier report (Davidson et al. 2014) and previous research (e.g. Eldredge & Carlton 2002, Godwin 2003) indicated that biofouling is a major vector of non-native marine species introductions to the state. The goal of this report is to use existing literature to review the factors that contribute to introduction risk via biofouling and biofouling removal methods. The focus of this report is on biosecurity risks; risks of chemical contaminant release are mentioned only very broadly. (For a detailed review of chemical contaminant risks as a result of in-water cleaning, see Floerl et al. 2010.)

Several earlier reports, notably major reviews of marine coatings and cleaning technologies (Bohlander 2009, Floerl et al. 2010), and the references contained therein, were used as starting points for this report. Systematic literature searches were conducted using the Web of Science database. Additionally, we reviewed reports and regulations from Australia and New Zealand that include risk-assessments and management recommendations based on vessel details and include summaries of these in our Discussion section.

3.3 Baseline risk posed by biofouling

Species transfers occur when biofouling organisms leave the vessel as mobile adults or juveniles, vegetative fragments, resting phases (such as cysts), swimming larvae or propagules. These 'founding' organisms can then establish populations, usually within ports initially, and may spread later into more natural settings such as coral reefs or estuaries. This can happen as ships enter or sit in port, or during IWC, which by definition removes organisms from fouled vessels.

A fairly substantial literature exists that examines the factors that contribute to the risk posed by fouled vessels. While details vary, this body of research finds that, in general, the risk of non-native species transfers by fouled vessels or maritime structures varies with these major factors:

<u>Species composition.</u> The identity of the species in a ship's biofouling community is important and is determined by a vessels' voyage routes and source regions (e.g. other ports) visited. Species originating from locations that are similar environmentally generally pose a higher risk than those originating from very different environments (e.g., Gollasch 2002). For example, species from the Caribbean are likely well matched to conditions in Hawaii and therefore have a higher likelihood of surviving and becoming established, while most species from temperate locations such as the Pacific Northwest are not. Some species however, have very broad environmental tolerances, and can thrive in both tropical and temperate systems.

In cases where all attached biota are of local origin (such as on resident boats that do not leave Hawaii) fouled vessels pose little risk. However, non-native species that are already established in Hawaii may be spread further by intra-regional traffic (i.e., between islands).

This appears to be at least a contributing factor to the spread of the Caribbean barnacle *Chthamalus proteus* within the state (Godwin 2003).

<u>Degree of fouling.</u> Vessels with more fouling, in general, pose a greater risk than vessels with less fouling. This is because they tend to have more biota that can enter a port (termed propagule pressure) and usually more species that increase the risk of suitable establishment conditions for at least some of those species. More highly fouled vessels tend to have a more diverse assemblage of species, increasing the likelihood that some species are present that will be able to survive in the new location. In addition, the number of individuals (and/or colony size for vegetatively reproducing species) on a vessel is positively correlated with risk of establishment. More individuals represent more opportunities for successful invasion (i.e. high propagule pressure, Grevstad 1999, Ruiz et al. 2000, Lockwood et al. 2005, Drake and Lodge 2006).

<u>Species condition.</u> Many species that attach to ships in port may not make a journey in good condition and/or may not arrive in a reproductive state. Dead or dying organisms are less likely to become established than healthy ones. However, propagules or gametes may be released as a stress response, so even moribund individuals can pose an invasions risk. As an example, the Mediterranean mussel, *Mytilus galloprovincialis,* arrived in Hawaii in 1998 on the decommissioned USS Missouri, which was moved to the state from Puget Sound. Scientists observed the mussel spawning as the ship approached. The adult mussels attached to the Missouri subsequently died, but juvenile mussels were found two months later inside the ballast tank of a resident submarine in Pearl Harbor (Apte et al. 2000).

The risk posed by an individual vessel varies with the above factors (Hopkins and Forrest 2008). In practice, it is possible to identify riskier vessels based on travel and degree of fouling, factors that can be assessed from vessel records and a visual inspection. Many decision-support trees for biofouling management, such as those contained in Australia and New Zealand's Anti-fouling and In-water Cleaning Guidelines, include these factors (http://www.agriculture.gov.au/biosecurity/avm/vessels/anti-fouling-and-inwater-cleaning-guidelines). It is much more difficult to assess condition of the species in the fouling assemblage.

Managers may decide to exercise different options with regards to biofouling reduction, depending on the degree of risk presented by an individual vessel. In this report we discuss the main options, summarized in Fig. 12:

- no management
- out-of-water cleaning
- in-water cleaning

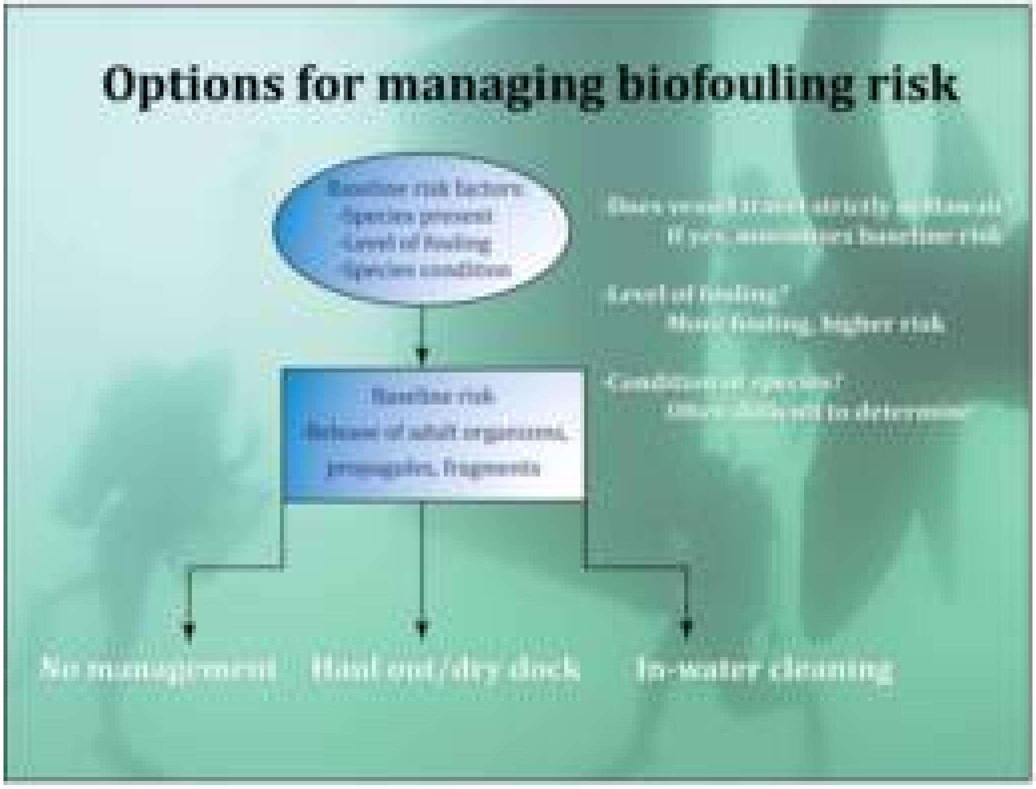


Figure 12: Baseline risk factors for NIS transfers via biofouling and three potential management options for biofouling reduction. Figure adapted from Hopkins and Forrest 2008.

3.4 Review of options for biofouling reduction

3.4.1. Option 1: No management of biofouling

As mentioned above, for resident vessels and those traveling exclusively within Hawaii, biofouling transfer presents no biosecurity risk of new NIS incursions, but secondary spread of established NIS may be a concern. For vessels entering Hawaii from elsewhere, the risk posed by a fouled ship is a combination of the baseline risk factors described above and the likelihood of species being released from the ship. All other things being equal, the risk of species release increases with two major factors: 1) the time spent in port, which increases the opportunity for organisms to leave the vessel (Floerl and Inglis 2005), and 2) the number of stops within a region, such as Hawaii, which increases the opportunities of infection somewhere in the state (Fig. 13).

The risk posed by a fouled vessel can be avoided by not allowing the vessel to enter port, a measure that is not likely to be frequently exercised except under extreme circumstances, although there is precedent for this in Hawaii. In 1999, a large (~900 foot) floating dock towed by a salvage tug from Chile to China started having engine trouble and wanted to pull into Honolulu Harbor for repairs. The floating dock was covered in fouling an estimated 3 inches deep, and the repair work was likely to take 2 to 3 weeks. The Captain of the Port, after consulting with local scientists, determined that the vessel posed a high biosecurity risk. After discussions with the owner, it was determined that the best approach was to hire a local tug to take over control of the dry dock, keeping it 15 miles offshore while the salvage tug came in for repairs.

These types of “stochastic” vessels, with long port times and slow movements, represent a very small portion of the ship traffic to Hawaii, and are often particularly risky due to high levels of fouling. A more moderate option, in cases of intermediate fouling levels, would be to reduce risk by limiting the time in port (Hopkins and Forrest 2008).

Figure 13: The no-management option. Risk of NIS transfers is a combination of the baseline risk factors and the vessel residence time.

3.4.2 Option 2: Cleaning out of water (dry dock or haul out)

For large vessels, cleaning out of water is part of routine maintenance and coincides most often with regularly scheduled re-application of antifouling coatings. For large vessels, this is typically done in a dry dock, which is a narrow on-shore basin or floating structure that can be flooded to allow a ship to be positioned and then drained to allow access to submerged surfaces (Fig. 14). Small boats are also removed from the water for application of anti-fouling paint and for repairs. Very small boats can be removed from the water on trailers, while larger yachts are hauled out on slings (Fig. 15). Boats are placed on blocks or otherwise kept upright while undergoing repairs or painting.

There are two commercial dry dock facilities on Oahu, Marisco Shipyard and Pacific Shipyards, which can service vessels up to 400 feet long, and Honolulu Marine LLC which operates the Kewalo Shipyard, which uses a marine railway to haul out vessels up to 100 foot in length. The vessel types cleaned by these facilities include interisland cargo barges and tugs, local tourist industry and public sector vessels, and local and foreign commercial fishing vessels (Godwin et al. 2004). These facilities are highly regulated by state and federal rules to prevent the discharge of contaminants into the environment. Measures to prevent discharge include tarpaulins to catch spray from hydroblasts, a catchment and retention system for all solid and liquid debris generated by cleaning, and the removal and disposal of the material by companies licensed to deal with hazardous waste.

Smaller boat yards, in which boats might be cleaned out of water, are prohibited from allowing wastewater to run into storm drains or return to the environment. Such facilities must obtain permits and dispose of wastewater properly, but it is unclear how well these facilities are monitored.

Figure 14. Dry docks. (Top) Navy submarine maneuvering into a flooded dry dock. US Navy photo by Brian Nokell. (Bottom) Ship on dock blocks out of water on a floating dry dock by George Chernilevsky. Both photos licensed under Public Domain via Commons.

Figure 15. Small boat hauled out for repairs. Photo by Ken Heaton, licensed under Public Domain via Commons.

The biosecurity risk associated with cleaning vessels out of water is a combination of the baseline risk factors described above, the increased risk of releasing organisms to the environment as a result of the cleaning procedure, and the risk due to incompletely cleaned patches. There is also a risk of releasing contaminants from the antifouling coatings to the environment if proper controls are not employed.

Release of biofouling organisms can occur at several stages in the process (Fig. 16), beginning with preparing and removing a vessel from the water. Mobile individuals such as fish and crabs have been observed leaving vessels as they were being removed for cleaning onshore (Coutts and Dodgshun 2007). In a study in Australia that simulated the removal of fouled vessels from the water, researchers tested the effects of fouling extent and emersion duration on the loss of mobile species (Coutts et al. 2010). Individuals of 24 out of 31 mobile species detached from fouled settlement plates that were removed from the water, including a number of common non-native species established in Australia. More individuals (up to 19.8%) were lost from plates with a moderate level of fouling than from more heavily or lightly fouled surfaces, presumably because lightly fouled surfaces had smaller mobile species such as amphipods better adapted to clinging to lightly textured surfaces and the heavily fouled surfaces offered more shelter where the organisms could hide. The authors also noted that viable individuals of sessile organisms also occasionally fell from the plates upon removal from the water.

Once a vessel is out of the water, high-pressure water blasts and/or scraping and brushing is used to remove fouling. If cleaning takes place near the water and the solid debris is not contained, viable organisms may be returned to the water (Woods et al. 2012, McClary & Nelligan 2001, Hopkins et al. 2011). Similarly, if cleaning effluent or process-water is not fully captured, and/or not appropriately filtered or treated, small organisms, larvae, and gametes can be released into the water as well as paint and other contaminants (Woods et al. 2012, McClary and Nelligan 2001).

Researchers in New Zealand have measured the amount and viability of fouling organisms at each stage in the process of out-of-water vessel cleaning at five facilities, including large vessels in drydock and small yachts hauled out and placed in boatyards (Woods et al. 2012). In samples of biofouling removed from the vessels via hydro-blasting, Woods and colleagues found that as many as 39.9% of hard-bodied organisms and 38.9% of soft-bodied organisms were still viable after rehydration. Researchers also sampled effluent at several stages of various dry-dock treatment facilities. The samples included 1) hydro-blast run-off before it entered settlement tanks, 2) first chamber of settlement tanks, 3) final chamber of settlement tanks, and 4) final discharge of effluent. The facilities varied in the number of settlement tanks, whether effluent was filtered before disposal, and disposal methods for solids (to landfill or sea) and effluent (to sewage or sea). Facilities that filtered effluent used either sand filters or 20-mm screens.

The study found numerous taxa, including intact animals, propagules, and unicellular organisms in the effluent water. The hydro-blast run-off water, prior to entering settlement tanks, had concentrations up to 187,400 individuals per 10L. In the first chamber of settlement tanks, the concentration of animals, propagules and unicellular organisms was reduced by 20.5-100%. In the final chamber of settlement tanks, the concentration was reduced by 75.6-100% compared to the original concentration. Finally, in the discharge effluent, there was an overall organism concentration reduction of 98.5% at facilities with three stages of filtering and screening (Woods et al. 2012). These results and the findings of another study (McClary and Nelligan 2001), indicate that filtration and organism capture methods can be effectively used to reduce biological viability in discharge effluent. However, it has been suggested that the final filtration size of 60 microns is the appropriate size for excluding most of the invasive species of concern in New Zealand.

Finally, while access to a vessel may be easier in dry dock, resulting in a more thorough cleaning, a risk remains from residual biofouling of incompletely cleaned patches, particularly for hard-bodied animals that can withstand exposure (authors' pers. obs). We have documented live barnacles on ships arriving to California that had survived drydock cleaning and an application of anti-fouling paint (Fig. 17).

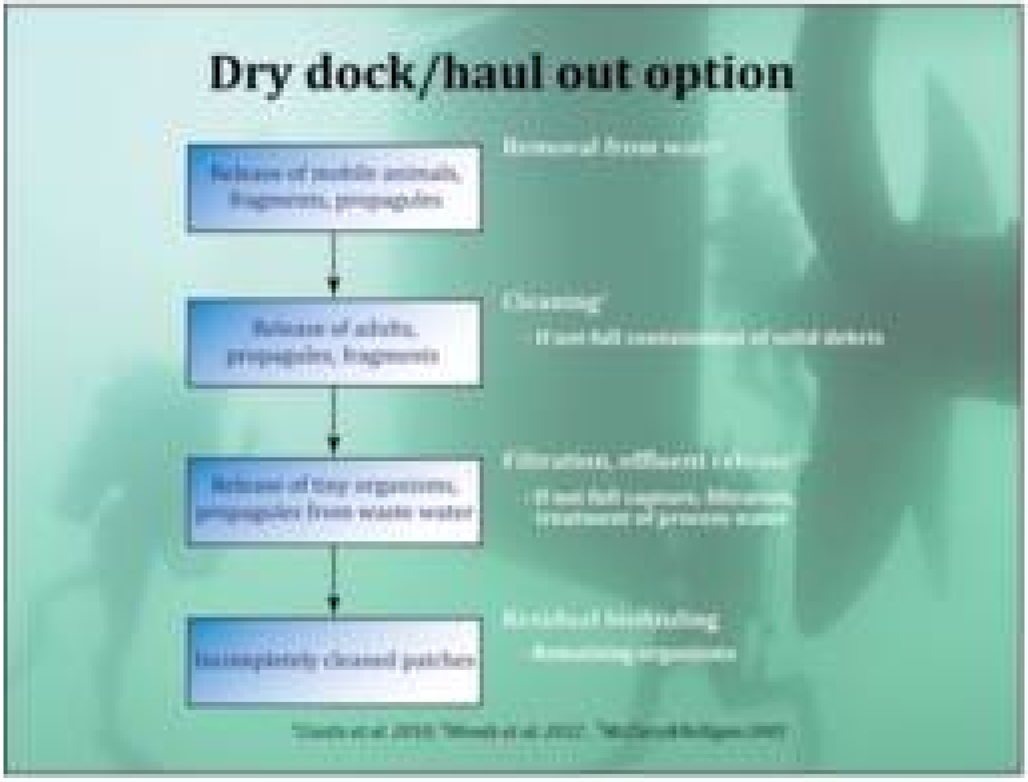


Fig 16. Biosecurity risks poses by the process of cleaning vessels out of water.

Fig 17. Barnacles coated in red anti-fouling paint collected by SERC from a ship in the port of Los Angeles, CA. (Top) The large barnacle is dead, but the cluster of small barnacles on its side were alive, as were the two uppermost barnacles in the bottom photo, which have white shells.

3.4.3 Option 3: Cleaning in-water

Cleaning in-water is significantly less costly than cleaning on land. Small-boat owners frequently clean their own boats or may pay commercial divers to do so. Costs range widely depending on location, extent of fouling, and boat size, but are typically in the hundreds of dollars. In-water cleaning for large commercial vessels can take 1-3 days, and may involve substantial set-up expenses. Again, costs vary greatly, but are in the tens of thousands of dollars, still easily half the cost of cleaning in dry dock.

The frequency of in-water cleaning of ships and boats varies greatly based on vessel type, operational characteristics, voyage routes and other factors. Some large commercial vessels are cleaned once or twice between dry dock intervals, while others may not do in-water cleaning. The cleaning regimes for Hawaii-based pleasure craft, both sail and motorboats, were assessed and reported in 2009 (Leonard 2009). A survey of 64 boat owners indicated that all had some type of antifouling paint applied within the last five years. In-water hull cleaning was carried out on a regular basis: ~27% of boat owners cleaned one to two times a year, and 22% between three and six times a year.

The biosecurity risk posed by in-water cleaning is a combination of the baseline risk factors (species composition, degree of fouling, and species condition), the risk of releasing organisms to the environment, and the risk posed by residual fouling remaining on the vessel after cleaning. Other debris and chemical contaminants can also be released as a result of in-water cleaning (Hopkins et al. 2010). As with out-of-water cleaning, release can occur at several stages in the process (Fig. 18), but because the vessel's submerged surfaces are in direct contact with the water, the risks are usually higher for in-water cleaning.

Organisms can be inadvertently dislodged during vessel set up and dive operations before cleaning commences (Hopkins & Forrest 2008), as well as during cleaning if there is not full capture and containment of solid debris (Hopkins & Forrest 2008, Hopkins et al. 2010, Hopkins et al. 2011, Woods et al 2012). Traditional cleaning methods, which are used in Hawaii, allow all debris to fall to the ocean floor.

In a study in New Zealand (Woods et al. 2012), researchers found that organisms dislodged from vessels had a high rate of survival. Woods et al. examined biofouling removed from boats in water using paint scrapers and soft cloths, mimicking a cleaning method typically used on smaller vessels with lighter fouling. They determined that 62% of biofouling organisms removed were viable, including many ascidians, sponges, and mobile polychaetes, molluscs, nemerteans, and flatworms. Removal of fouling with handheld scrapers resulted in larger fragments than did the use of mechanized rotating brushes in a comparative study (Hopkins et al. 2011). In general, larger fragments of colonial organisms, mostly tunicates and bryozoans, (dimensions of up to 600 mm^2) had a greater reattachment and survival rate than smaller ones (dimensions up to 18 mm^2) in laboratory and field trials, although results varied by species and harbor conditions (Hopkins et al. 2011).

Several new in-water cleaning technologies that capture solid debris and effluent are in development and/or in use in few locations around the world. Tests of two types of rotating brush and debris-capture systems in New Zealand found that these technologies captured >95% of the removed debris on average, with better capture rates on flat vs. heterogeneous surfaces and on low to moderately fouled vs. heavily fouled surfaces (Hopkins & Forrest 2008, Hopkins et al. 2010). Most of the debris lost to the environment had been crushed by the cleaning brushes; the authors estimated that <20% of total biomass removed from a vessel using these methods would remain viable (Hopkins et al. 2010). A more recent test of Franmarine's Envirocart indicated that all biofouling was captured by the shroud and suction technology in three trials (Lewis 2012), although it is unclear how this was evaluated. Several other technologies still in development, such as the use of heat treatment or encapsulation, focus on killing biofouling and/or sterilizing vessel surfaces. While these methods may hold a greater promise for reducing the loss of viable fouling organisms (and are perhaps gentler on anti-fouling coatings), they require further development and independent testing and evaluation (Floerl et al. 2010).

Debris-capture systems such as those mentioned above typically deliver solid debris and liquid process water to shore-based containment and filtration systems (see review in Zabin et al. 2015). While the details of these systems vary, they generally include running the debris and effluent through increasingly smaller sizes of screens and/or filters to separate solids before water is discharged to the environment. Solids are removed for land-based disposal. Some systems also include a final step of sterilization of the effluent with ultraviolet radiation before release. As with on-land cleaning, there is the potential to return viable organisms to the environment as well as to discharge copper and other toxic paint residues removed by abrasive cleaning if the level of filtration is not appropriate (Bohlander 2009, Floerl et al. 2010, McClary&Nelligan 2001).

Finally, a risk remains from residual biofouling/incompletely cleaned patches, particularly on vessels with more developed fouling communities (Davidson et al. 2008, Hopkins et al. 2010). Both of the systems tested by Hopkins et al. (2010) were fairly effective at removing low to moderate levels of fouling, typical of the levels found on active commercial ships, removing on average >80% of fouled surfaces. The authors noted that they would expect the brushes to be more effective on foul-release coatings, but that more loss of removed material could also be expected. Both systems had poorer performance as fouling cover increased, reaching levels that would be expected on a vessel with a long lay-up period. Performance was particularly poor in removing calcareous organisms, with about 50% cover of these organisms remaining. While some of the residual calcareous cover included damaged organisms, which might not be expected to survive, Hopkins and colleagues (2010) noted that for some common fouling species, notably the tubeworm *Hydroides elegans,* damage results in release of gametes. In our own experience collecting organisms from ships hulls, removal of adult barnacles frequently results in release of larvae (authors' pers. obs).

Davidson et al. (2008) tested the efficacy of in-water cleaning of a heavily fouled obsolete vessel, photographing and collecting samples from the ship before and after cleaning. Cleaning was carried out by a commercial dive operation using a submersible cleaning and maintenance platform (SCAMP) on the ship's hull and hand-held brushes on appendages. Fouling cover was reduced from an average of 90% prior to cleaning to 37% post cleaning (Fig. 19). Species richness and abundance was reduced on a per-sample basis, however, across the whole ship only three species out of 26 taxa recorded alive in pre-scrub sampling were not found afterwards (Davidson et al. 2008). Scrubbing appeared to be most effective in removing algae and less so for animals attached with byssus or cemented to the surface.

In three trials evaluating the effectiveness of Franmarine's Envirocart, which also uses rotating brushes, primary and secondary fouling were completely removed or nearly so (Lewis 2012), and thus met standards set by Western Australia's Department of Fisheries. The report did not provide details on the level of remaining cover or species composition post cleaning.

Manual cleaning of small vessels also likely leaves some residual fouling. Floerl et al. (2008) found 1-15 fouling species on 80% of yachts surveyed in New Zealand, all of which had been cleaned within three weeks prior to surveys.

Remaining fouling, when it contains non-native species, continues to present a biosecurity threat, and may also provide refugia or facilitate settlement by other species (Hopkins et al. 2010). Mechanical cleaning may also increase the susceptibility of surfaces to settlement (Floerl et al. 2005) if surfaces are not sterilized or repainted after cleaning.

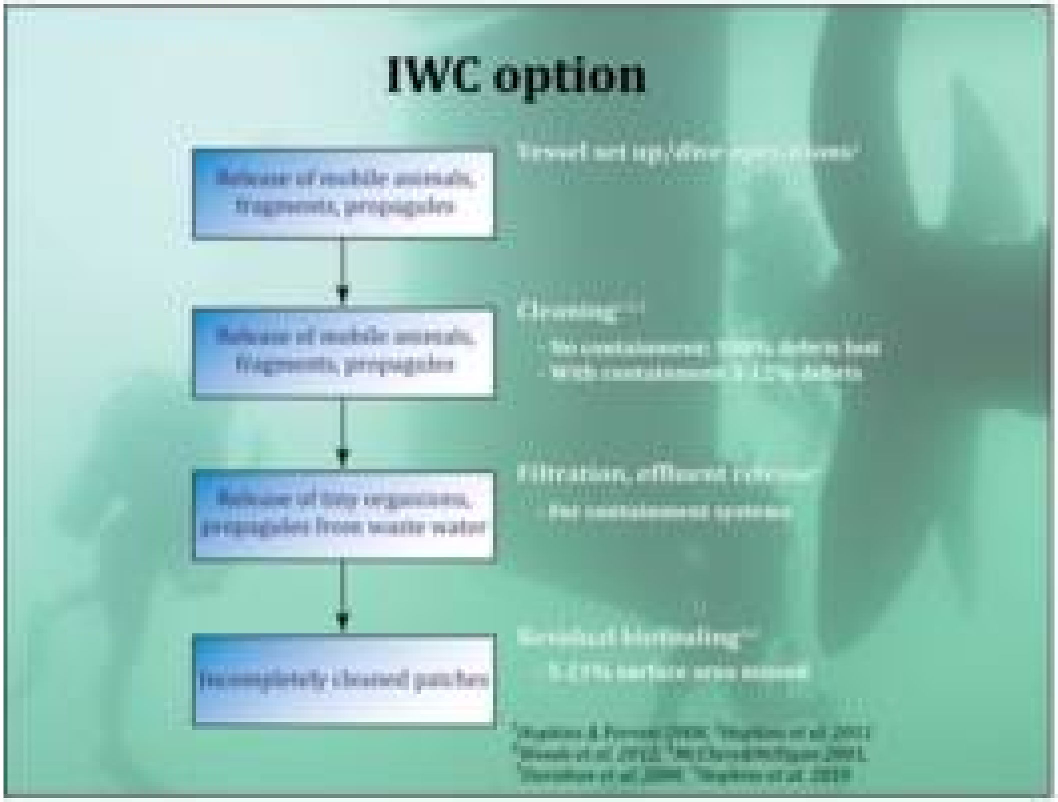
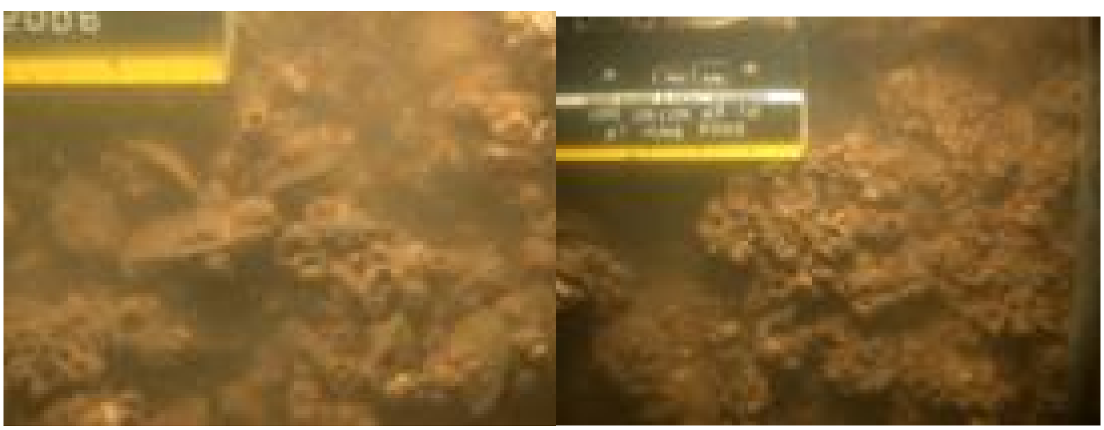


Figure 18. Biosecurity risks associated with in-water cleaning.



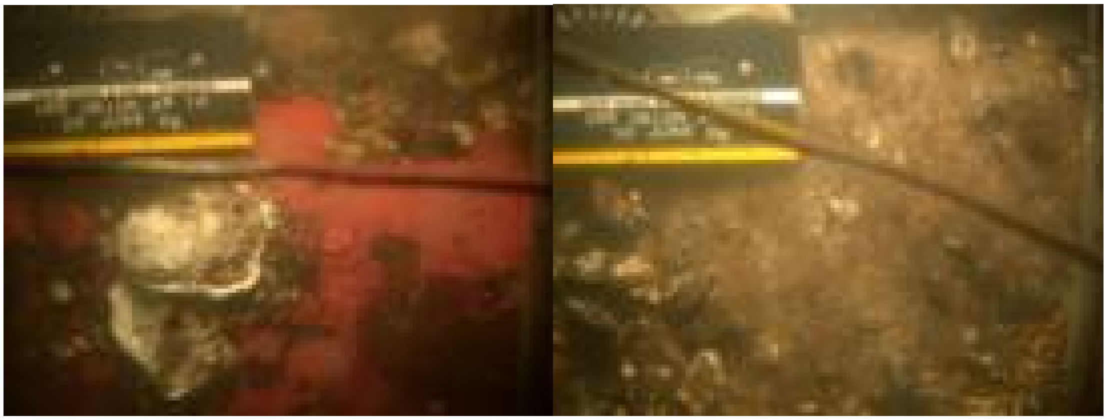


Figure 19. Photos from a heavily fouled ship before (above) and after (below) in-water cleaning with a SCAMP unit. Rotating brushes were used for the hull and handheld tools for ship appendages. Photos: SERC.

3.5 Discussion

3.5.1 Risk comparison

All other things equal, vessel cleaning out of water poses less of a biosecurity risk than IWC, particularly if measures to contain and properly dispose of debris are taken. In situations where all solid material is contained and disposed on land, and effluent is treated and directed to municipal facilities, the risk is nearly zero. In their study comparing IWC and out-of-water cleaning, Woods and colleagues (2012) found that a higher percentage of organisms were viable following cleaning in water (62%) compared with those removed in commercial drydock (38%) or small-vessel haul out facilities (20%). Floerl et al. (2003) also noted high viability of biofouling removed during IWC. These differences are likely attributable to a combination of the removal method used (scrapers and soft cloths for IWC vs hydroblasting in drydock/haulout) and the desiccation experienced during out-of-water cleaning. More aggressive cleaning methods, such as rotating brushes or water blasting used in water likely generate fewer viable organisms (e.g. Hopkins et al. 2011). All traditional IWC methods result in viable material being released to the environment, however, whereas a large percentage, if not all such material, is contained in dry dock or haul out. In addition, IWC poses a greater risk of releasing toxic chemicals from antifouling coatings to the environment compared with land-based facilities with the ability to capture and process waste water from cleaning operations.

While a superior approach from a biosecurity perspective, vessel cleaning in land-based facilities is significantly more costly than cleaning in water. For small boats, cleaning out of water is easily twice as expensive as paying for commercial diver services in water. For large commercial vessels, costs of drydock can be an order of magnitude higher than IWC (Floerl et al. 2010). As a result, bans on IWC likely lead to vessels accumulating more fouling between drydock intervals and/or going elsewhere for IWC. Neither of these outcomes is ideal for industry or biosecurity. While some states have gone the route of complete bans on IWC, other regions are taking a biosecurity risk based approach to biofouling management, in which IWC might be allowed under certain circumstances, but not in others (e.g., Hopkins and Forrest 2008, Inglis et al 2012).

There are biosecurity risks inherent in each of the strategies – no management, out- -of-water cleaning, and in-water cleaning – as discussed above. In each case, the risk is a combination of the baseline risk posed by biofouling and risks inherent in each management strategy (Fig. 20). The extent of the baseline risk is dependent on factors such as extent of fouling, fouling composition, and fouling condition, which vary with the particulars of each vessel. The no-management option does not reduce baseline risk, although some strategies can be employed, such as limiting the length of port stays, to manage risk. Both cleaning options, dry dock and IWC, reduce biofouling extent, and thus reduce baseline risk from intact vessel biofouling communities to the lesser residual risk posed by incompletely clean patches (Fig. 20). Both, however, have the potential to release viable organisms during cleaning, and thus need to be carefully considered within the larger context of biofouling management. These risks can be reduced by requiring containment and proper disposal of biofouling and paint debris. This is currently more tractable for land-based cleaning operations; technology to do so for in-water cleaning is not as well-developed or widely available, and typically costs more than non-containment methods. For IWC, another option is to allow it in situations where the baseline risk is low.

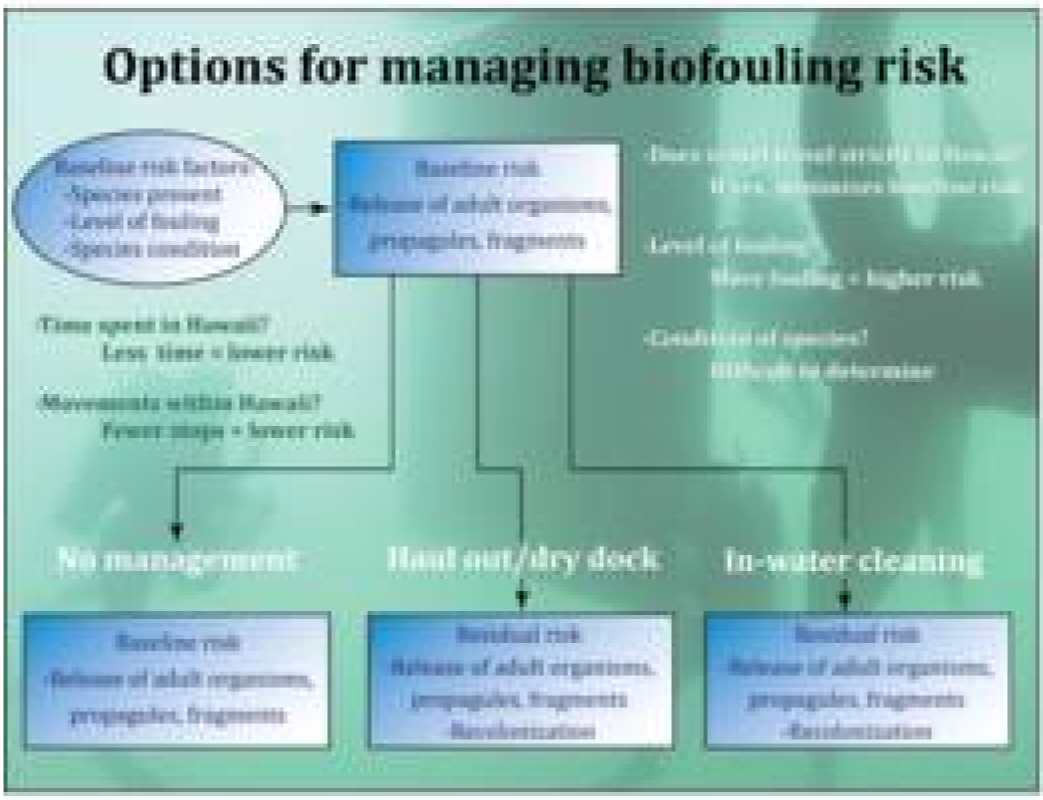


Figure 20. Biosecurity risks associated with the various options for management of biofouling.

3.5.2 Risk-based approach to biofouling management

In their review of in-water cleaning technologies and risks associated with IWC, Floerl et al. (2010) discussed levels of biosecurity and contaminant risk in terms of four major risk factors:

1) biofouling origin: local or foreign
2) biofouling extent: primary, secondary, tertiary. Primary fouling was defined as consisting of a biofilm and initial stages of fouling by macroorganisms, such as green

algae and newly settled barnacles and encrusting bryozoans. Secondary fouling contains more species, such as tubeworms and hydroids. Tertiary fouling contains a diverse assemblage of early and late successional species, including adult barnacles, bivalves, sponges and tunicates.

3) coating type: biocidal vs. non-biocidal (e.g., fouling-release, surface treatment coating)
4) cleaning method: none, brushes, water-jet, heat, encapsulation, shore-based with incomplete containment, shore-based with complete containment. Because there was some reported loss from all reviewed IWC systems with containment, the authors conservatively assumed these to have the same risk level as IWC without containment.

Different combinations of these factors allowed them to review risk associated with more than 100 possible scenarios and to make the following suggestions for limiting the risk associated with IWC:

- Allow IWC on vessels with non-biocidal coatings and slime layer only
- IWC OK on heavier fouling if of local origin
- Cleaning method must not damage paint
- Encourage proactive maintenance, particularly of niche areas
- Encourage the development of capture technologies

The findings of Floerl et al. (2010) were influential in the development of a set of guidelines adopted by Australia and New Zealand (Anti-fouling and In-water Cleaning Guidelines June 2013), which allow IWC in low-risk situations. Specifically, the guidelines take into account antifouling coating type and condition, the origin and extent of the fouling, and the cleaning method. IWC is allowed if: 1) the antifouling coatings are deemed suitable for cleaning, 2) cleaning methods do not damage coatings, 3) discharges meet local standards and 4) biofouling is minimal (slime layer only). Cleaning of surfaces with macrofouling is also allowed if the first three conditions apply and fouling is of “regional” origin. If fouling is domestic (from outside of the region, but within the country) or international, cleaning may proceed if more restrictive conditions aimed at minimizing risk of release can be met, such as containment of all debris. A decision-support tool for evaluating risk was released with the guidelines document in 2013, as Appendix 1 (included here as Fig 21). The decision-support tool requires adequate documentation for various risk factors, with a default of assuming high risk if documentation is missing.

New Zealand’s Craft Risk Management Standard 2014, which is currently voluntary but on track to become mandatory by 2018, requires vessels arriving to New Zealand to have a clean hull. One of the ways vessels can meet this requirement is by cleaning within 24 hours of arrival. These vessels must submit an application to do so, use only approved treatment methods, and provide evidence that treatment has reduced risk to a level equivalent to arriving with a clean hull.

The Anti-fouling and In-water Cleaning Guidelines document is currently under review in Australia and New Zealand. Some of the challenges for implementation of the rules include how best to define regional (vs. domestic) in considering the origins of fouling, the lack of a framework for checking if cleaning methods damage paint or release contaminants, and the need to further develop and do independent third-party testing of IWC technologies (S. Gorgula, pers. comm). In the meantime, South Australia and Western Australia are moving forward with regulations and guidelines (S. Gorgula presentation June 2015, https://dlnr.hawaii.gov/ais/files/2013/12/Vessel-In-Water-Cleaning-in-Australia-Gorgula.pdf). In New Zealand, IWC is regulated by regional councils, some of which are considering incorporating the guidelines into their Regional Coastal Plans. Although this is harder to implement, all jurisdictions of which we are aware have articulated the need to promote a “clean before you go” mentality, and a shift toward more proactive cleaning before accumulation of heavy fouling, with South Australia setting an ambitious goal of no secondary fouling accumulation on vessels by 2020.

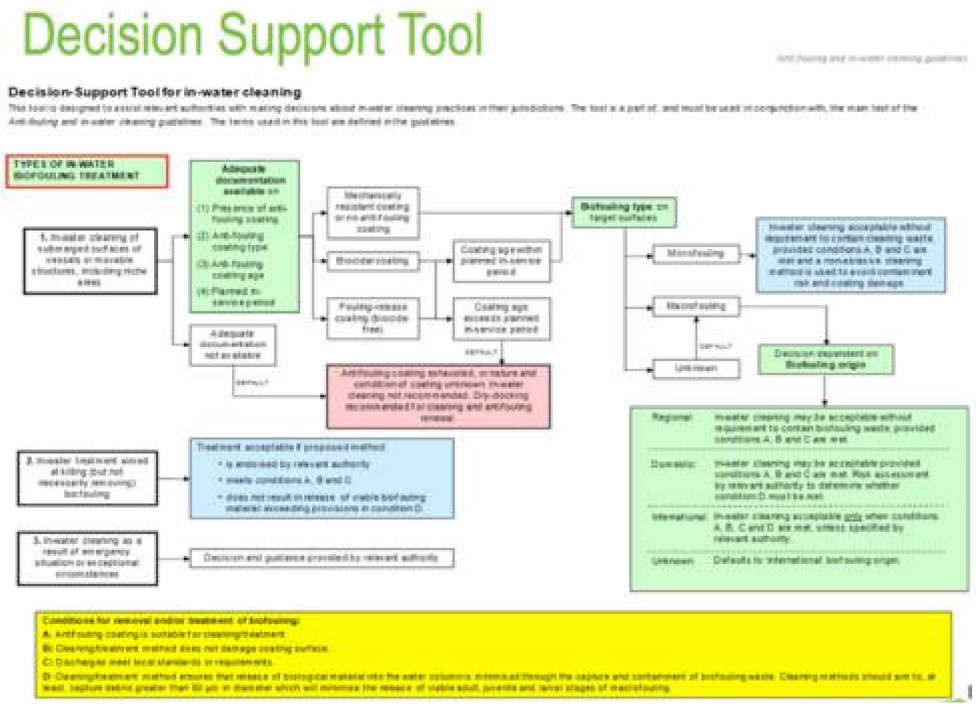


Fig. 21. The decision-support tool developed by Australia and New Zealand in regards to IWC.

4.0 An assessment of in-water cleaning in Hawaii

4.1 Approach

The extent and nature of IWC in Hawaii has not been quantified, but this is key to determining the potential risks as well as to the development of sound policy. To gain an understanding of current IWC practices, volume, and associated risks, and to gain input from stakeholders on best approaches to managing risks, DLNR and SERC staff, in consultation with an industry representative, developed a questionnaire for use in in-person interviews with IWC companies (Appendix 2). The questionnaire asked about numbers and types of vessels cleaned, cleaning methods, paint types, degree of fouling, and the use of new technology such as debris-capture methods. Additional questions addressed awareness and interest in new IWC technologies and solicited ideas and advice on potential IWC policy for Hawaii that would be feasible for their companies and protect the environment.

Through discussions with stakeholders and additional research by DLNR and SERC staff, we identified eight companies on Oahu that perform in-water cleaning of vessels, and these were the focus of DLNR's interview attempts. There are smaller companies as well as individuals who clean recreational and other small vessels on Oahu and the neighbor islands, these operators are challenging to identify and contact, and, given limited resources, we elected to focus on the larger operators. Most of the vessels cleaned by small operators are also likely to travel solely within the state. Thus they pose less of a potential risk for the introduction of new NIS but may play a role in spread of established NIS within the state. The eight large Oahu companies were contacted by phone and email.

Six of the eight companies agreed to respond to questionnaires. Interviews were conducted in person in two cases, over the phone in another, and three companies responded via email. One company did not respond to multiple attempts to answer the questionnaire, and one company could not be reached because contact information was unavailable.

4.2 IWC Cleaning in Hawaii

Altogether, the four companies that responded to the questions reported cleaning ~100 vessels (cumulative total) in water in 2015. Respondents said they serviced a wide variety of vessels, including military, seafaring commercial, non-seafaring commercial, cruise ships, research and fishing vessels, barges, yachts and small recreational boats. A fifth company that did not respond to the questionnaire advertises boat-hull cleaning, and is likely focused strictly on small recreational boats. One company reported that none of the vessels they cleaned in 2015 traveled outside of Oahu. Another company reported cleaning mostly local boats with occasional work on visiting boats. Companies did not provide travel information on the vessels they cleaned, saying that the information was classified, inconvenient to access, or not available.

All respondents reported that all of their customers employ some sort of anti-fouling system. Anti-fouling paint was the most common coating type used, although some vessels use fouling release paints, or some combination of these. Three companies indicated that certain vessel types tended to be more heavily fouled than others: one did not elaborate, one noted that military vessels tended to be the cleanest, and a third mentioned certain foreign commercial vessels tended to be the dirtiest. Respondents reported that visiting yachts tend to arrive clean and request cleaning of locally derived fouling before departure.

Companies reported using manual, mechanical and water blasting methods for cleaning. <u>None use debris-capture technology, which is not surprising given its limited market penetration to date</u>. All indicated that paint type and age affected the IWC method used, with brush and other tool selection based on fouling and paint type.

4.3 Solutions for the industry and environment

Four of the six companies said they are aware of emerging and new technologies that capture debris, and one was able to provide the name of a company that produces these systems. One respondent said they would use a debris-capture system if it were available, and two said they would, provided that there was customer demand for it or that customers approved of it. Two companies said they would not use such systems, one because of the increased cost and space requirements, and the other because they don't believe debris-capture is necessary.

There were a number of suggestions on IWC policy development. One respondent suggested that Hawaii utilize the Navy's best management practices, which, among other things, dictate inspections at regular intervals that trigger cleanings based on extent of fouling. Two suggested vessels undergo more frequent cleanings on a prescribed schedule (i.e. monthly or quarterly); another respondent suggested that the cost of more frequent cleanings could be offset in the long run because cleaner ships are more fuel efficient and easier to keep clean. Clear guidelines for how and where cleaning should occur were another suggestion, as was having a capture system available, and the greater availability and use of non-toxic hull paints that prevent fouling and/or more ecofriendly bottom coatings. These responses demonstrated an industry willingness (for the most part) to reduce the difficulties associated with biofouling that impinge on the environment and on the shipping industry itself.

4.4 Discussion

Most of the major commercial operators responded to the survey, so it is likely that the information gained pertains to most of the in-water cleaning of seafaring vessels in the state. The surveys support anecdotal information that IWC cleaning of large seafaring commercial and military vessels is taking place in Hawaii and that debris-capture systems are not in use here. Unfortunately, there is still very little quantitative information on which to conduct a risk assessment of IWC in Hawaii. The basic elements of a risk assessment would include 1) numbers of vessels that travel outside of Hawaii and interisland and 2) how heavily fouled these are. Without this information, or reasonable proxies thereof (i.e., age and type of antifouling paint, time since last IWC, etc.), it is impossible to determine the extent of biosecurity risk posed to the state.

Nearly all respondents were in agreement that one approach to IWC that would benefit the environment and the industry would be more regular and frequent vessel cleanings. Many pointed out that this would decrease biosecurity risk as well as save on fuel use, reduce emissions, lead to lower amounts of toxic paint released into the environment, and improve safety while reducing fuel costs to ship operators. It should be noted that more frequent cleanings with the goal of keeping fouling at the level of slime layer only has been articulated in IWC/biofouling management for South Australia.

IWC risks can be reduced (but not completely eliminated) by debris containment systems. Cost and space considerations are the main concerns with the use of this new technology. IWC companies in busy international ports may have an economy of scale that makes purchasing and using these systems feasible; companies in Hawaii may not have sufficient volume to individually purchase such a system. However the majority of companies interviewed indicated they would be willing to use this technology if it were available to them and economical.

5.0 Management recommendations

Biofouling has been the single-most important vector in marine invasions in Hawaii to date, likely responsible for more invasions than the better-known vector of ballast water release. One way to reduce biofouling biosecurity risks is through periodic in-water cleanings. Such cleanings are relatively inexpensive compared to dry docking, are critical to safe and efficient ship operations, and reduce the risk of species transfers as ships move between ports. However, cleaning operations can themselves present a biosecurity risk if fouling is not of local origin. Water quality can also be compromised by the release of toxic chemicals in anti-fouling paint if paint is old or damaged by cleaning methods.

Research on the risks associated with cleaning vessels, reviewed in Section 3 of this report, indicates that viable organisms can be released to the environment during set-up for cleaning and during the cleaning process itself if solid debris and wastewater are not captured and/or if effluent is not sufficiently filtered before being discharged to the ocean. Incomplete cleaning may also result in stressed or damaged organisms remaining on the ship that release propagules or viable fragments. Drydocking, with proper containment of cleaning waste, and debris-capture methods for in-water cleaning can reduce biosecurity risks, but are expensive. Other technologies that kill, rather than remove fouling organisms are relatively new and not widely available. They also may not meet industry needs for ship husbandry.

Ideally, policy on IWC would be developed based on clear information about the risks associated with current and potential future practices. To date, the volume and nature of in-water cleaning in Hawaii is still not well characterized. Based on DLNR interviews with most of the commercial operators on Oahu, it appears that ~100 vessels were cleaned in water over the past year. The biosecurity risk from IWC in Hawaii could be low if these vessels were not heavily fouled and/or all fouling was of local origin, but based on information provided by interviewees this does not appear to be the case. Some unknown percentage of vessels cleaned in the state had traveled outside of Hawaii and thus pose a potential biosecurity risk, although the extent and species composition of fouling on these vessels is not known. It is also possible that the number of vessels cleaned in the state could increase in the future as more jurisdictions ban IWC. The potential contaminant risk from IWC is also not known and is beyond the scope of this report.

Given this lack of information, state policy makers may want to consider a suite of potential management options. Additional data gathering, education/outreach, and creative, cooperative solutions may also be considered as appropriate approaches. Some of these potential options are outlined below.

<u>Option 1. Do nothing (status quo).</u> This approach might be considered if the state is willing to make the assumption that there is little to no risk posed by current IWC activities and that any potential risk is outweighed by the economic costs and legal and technical difficulties involved in regulation. DLNR could also decide to not take immediate action until more data are available (Option 3) and/or choose this option, but rethink other actions if IWC increases in the future.

<u>Option 2. Institute voluntary measures</u>, such as the development of best management practices (BMPs), voluntary reporting of relevant data, and education/outreach to vessel owners, operators, and IWC companies. This approach could be considered if the assumption is made that current risk is relatively minimal and/or could be reduced to an acceptable level by voluntary measures. This approach can be broadly inclusive, lending itself to collaboration between various state agencies, industry and other stakeholders, and is not as onerous as mandatory regulations.

This option could include the creation of BMPs for IWC, involving industry expertise in the development of appropriate, logistically feasible cleaning approaches for different vessel types, paint type and condition, level of fouling and origin of fouling, taking both biosecurity and contaminant risks into account. Models for BMPs may already be available (i.e., from USN and from California Professional Divers Association) that could be reviewed and adapted for use in Hawaii. Stakeholder meetings organized to review and work on BMPs could also provide opportunities for continued education on risks associated with IWC and to build trust and collaborations between management agencies, industry and other stakeholders. Ideally the USN would also be involved.

For BMPs to be widely adopted, the state will need to invest significantly in education/outreach programs to reach boaters and small-time commercial divers on Oahu and neighbor islands as well as larger operators. This could include stakeholder workshops, presentations at harbor and boaters organizations, trainings for commercial divers, the distribution of written materials, and the development of online materials. A voluntary online risk assessment tool (similar to the one in use in Western Australia, https://vesselcheck.fish.wa.gov.au/), which would allow vessel operators to assess risk, could be created for both local and visiting vessels. The tool could potentially make recommendations for appropriate cleaning practices based on risk factors.

This option could address the issue of biofouling more generally, creating a greater awareness of the risks of NIS and biofouling. Vessel operators could be encouraged to clean proactively before leaving for overnight stays away from their homeports and to clean more frequently, with the goal of keeping biofouling at slime layer level. Such cleanings require less vigorous scrubbing, which may reduce contaminant release, as well as the risk of releasing fouling organisms acquired in another location. The state may also want to consider a sticker/certification type program to encourage adoption of new BMPs for hull maintenance and cleaning, although the state would need to determine how to assess compliance.

A rigorous scientific assessment of practices before and after development and promotion of BPMs is needed to determine whether these voluntary efforts are effective. This element is commonly absent from boater-education efforts. Anonymity and incentives for participation may be needed to encourage individuals to respond to surveys.

Option 3. Gather additional data. This option could be exercised alone, or in combination with other options listed here. DLNR could decide that insufficient evidence exists to take any action immediately, and use this option as a stand-alone approach until such data are available. Alternately, the state could move forward with other options, but include data collection to a) assess the effectiveness of programs such as those suggested in Option 2; b) guide additional, future IWC management based on better quantification of risk.

Potential ways to gather data for risk assessment include the following:

-Incoming vessels could submit information to the state on their biofouling program, which could include providing copies of a vessel biofouling management plan and log book with records of service. This requirement would be similar to the one proposed for California. For commercial vessels, if IMO number is gathered, travel history can be reconstructed and matched with biofouling plan.

-Incoming vessels could use an online risk assessment tool. Data would be aggregated for analysis, rather than used to regulate specific vessels.

-IWC companies could use the online tool on behalf of their customers or otherwise submit the following information on vessels they clean: IMO or other identifier, vessel type, travel history (which could, at its most simplistic, separate in-state vs. out of state), sit time and location prior to cleaning, fouling extent and composition, paint type and condition, and cleaning method used.

-IWC companies could document results of cleaning (written descriptions, photos/videos) and/or allow DLNR researchers to document fouling before and after.

-IWC companies could allow DLNR to document the extent to which fouling is lost during cleaning and to collect debris to assess viability of fragments.

The state could choose to collect data by requiring the submission of the above information, or by requesting it. Requests for voluntary data submission and cooperation with professional researchers may be more readily accepted by industry. On the other hand, such requests may be ignored. Requiring the submittal of data is likely to result in a higher volume and potentially more representative data.

Option 4. Investigate the possibility of making debris-capture technology available to Hawaii IWC companies. This option could be selected if DLNR determines that the current or future risk of IWC is unacceptable, given the technologies now in use, and could be exercised in combination with any of the other options listed here. It seems likely that none of the current large IWC companies have a large enough customer base to make purchasing this technology economically feasible at this time. The state may determine that only high-risk vessels (identified through a standardized risk assessment, such as the decision tree in Fig. 11) need to be cleaned in a debris-capture system. This would reduce demand for use of the system and lessen scheduling conflicts.

Additional challenges, including finding space for the filtering units and potential permit conflicts for the discharge of effluent, also need to be resolved before use of debris-capture technology can move forward. The state could opt to take the lead in identifying performance standards for the new technology and working to resolve permitting and other issues. Performance standards have recently been set for IWC technology in New Zealand (Morrisey et al. 2015) and permitting challenges are being discussed in other jurisdictions (e.g., California, where concerns over copper-impaired waters and sediments prevent IWC in some locations, creating conflict between agencies that wish to promote IWC and those that regulate copper inputs); these may provide models for Hawaii. If initial research identifies systems that are feasible and legal/logistical issues can be worked out, the state could then research the possibility of funding a system that could be used collaboratively by local businesses. In the ideal, the USN would also coordinate efforts with the state and local companies. Smaller systems, such as that developed by Innermost Containment Systems, could be considered by the state and local harbors for use by companies that clean smaller vessels, and may present fewer logistical and financial challenges.

<u>Option 5. Institute mandatory regulations.</u> Given the current lack of data for a risk-based management, one approach would be to invoke the precautionary principle and assume that current IWC activities pose some degree of risk of NIS introductions to the state. The state could determine that this risk is unacceptable and prohibit all IWC. This would also address water-quality concerns, provided that on-shore cleaning facilities handle waste appropriately. However, this would pose a serious economic hardship on local businesses and would likely result in less frequent cleaning of vessels, given the expense of hauling out/dry docking. The net effect on biosecurity may create a worse situation if vessels become increasingly fouled during inter dry-docking periods.

A less restrictive approach to reducing risk would be to allow some IWC, using a risk-based formula for making these determinations, such as the decision tree (Fig. 11) developed by Australia and New Zealand. Regulations would need to include a requirement that vessels provide paperwork to document their antifouling regime and recent travel, as well as a framework for visual inspections, which would be used to assess fouling extent under certain circumstances. Vessels that are determined to be high-risk would be permitted to be cleaned only with appropriate debris-capture technology in water or in drydock. Data from interviews carried out by DLNR were insufficient to determine how many of the vessels being cleaned in-water in Hawaii now would be considered high-risk, so the economic impact of these types of regulations cannot be determined.

A number of the other actions mentioned as part of Option 2, such as the use of approved BMPs or more frequent cleaning of vessels to minimize fouling build up, could be made mandatory rather than voluntary, particularly if the state determines that there is little voluntary adoption of these activities.

Whatever approach is taken, DLNR will need to coordinate with other state agencies such as the Department of Health and the Department of Transportation to ensure that any new policy aligns with the goals of these other departments. A legal review may be needed to ensure that various departmental policies and regulations are not in conflict and/or to determine whether revisions to regulations are needed to achieve common objectives.

Cooperation and coordination with the USN and Coast Guard would also be ideal, as some portion of the seafaring vessels cleaned in the state are likely Navy vessels, and the Navy is also investigating IWC methods. It will also be critical to the successful development of IWC policy to engage with industry, including commercial, research and recreational vessel owners and operators, in-water cleaning companies, boatyards, commercial divers, marina staff and port operators. These stakeholders can provide critical expertise and insights and their cooperation is critical to improving biosecurity in the islands.

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Appendix 1

IN-WATER VESSEL HULL CLEANING

Best Management Practice

Fact Sheet – May 2015

Vessel hull cleaning in dry dock is the preferred hull cleaning method to minimize the impact of biocides and fouling organisms to surface waters, when technically and economically feasible, regardless of the vessel hull's coating system.

The U.S. Environmental Protection Agency's 2008 and 2013 Vessel General Permits prohibit in-water vessel hull cleaning in California unless conducted using Best Available Technology (BAT) as determined by California State Water Resources Control Board staff. Since the State Water Board has not yet determined BAT for in-water hull cleaning, San Francisco Bay Regional Water Quality Control Board staff have prepared the following interim best management practice (BMP) for in-water hull cleaning. Until the State Water Board determines BAT for in-water hull cleaning, dischargers are encouraged to employ the following interim BMP, or a more environmentally protective practice. Failure to do so may result in unauthorized discharges of pollutants into waters of the United States and Regional Water Board enforcement.

This BMP should be employed when completing in-water hull cleaning on vessels with biocide-based coatings (to reduce the release of fouling organisms and biocides) and on vessels with biocide-free coatings (to reduce the release of fouling organisms). However, following this BMP is not required when cleaning vessels that utilize a biocide-free coating system and have not operated outside of the Golden Gate since their most recent dry docking.

INTERIM BMP

The interim BMP for in-water hull cleaning consists of a containment and collection system capable of collecting all process water generated during in-water hull cleaning and directing it to a treatment system (Figure 1). This interim BMP is not a mandatory treatment system. A different collection and treatment system capable of achieving the same or greater pollutant capture and removal is acceptable.

The interim BMP employs a scrubber unit with rotating plastic brushes to remove attached biological material from a vessel's hull. The scrubber unit is held against the hull with approximately 1,000-pounds of pressure per square foot by a self-contained propeller and an approximately 400-gallon-per-minute (gpm) pump on a pier or barge.

A suction line attached to the discharge outlet from the scrubber unit collects and directs the process water to the pier or barge, where it is filtered by a 100-micron stainless steel mesh screen, followed by two 10-micron filter cartridges in parallel, followed by four 5-micron filter cartridges in parallel, and lastly conveyed through four pressure vessels arranged in parallel, each containing 3,000 pounds of organo-clay. If necessary, additional pressure vessels can be used in series or in parallel to fully accommodate the flow rate and maximize pollutant removal. The discharge point into the receiving water should be a minimum of 10-feet below the water surface. If large liquid storage containers are available, process water can be treated and discharged in batches.

SYSTEM AND DISCHARGE MONITORING

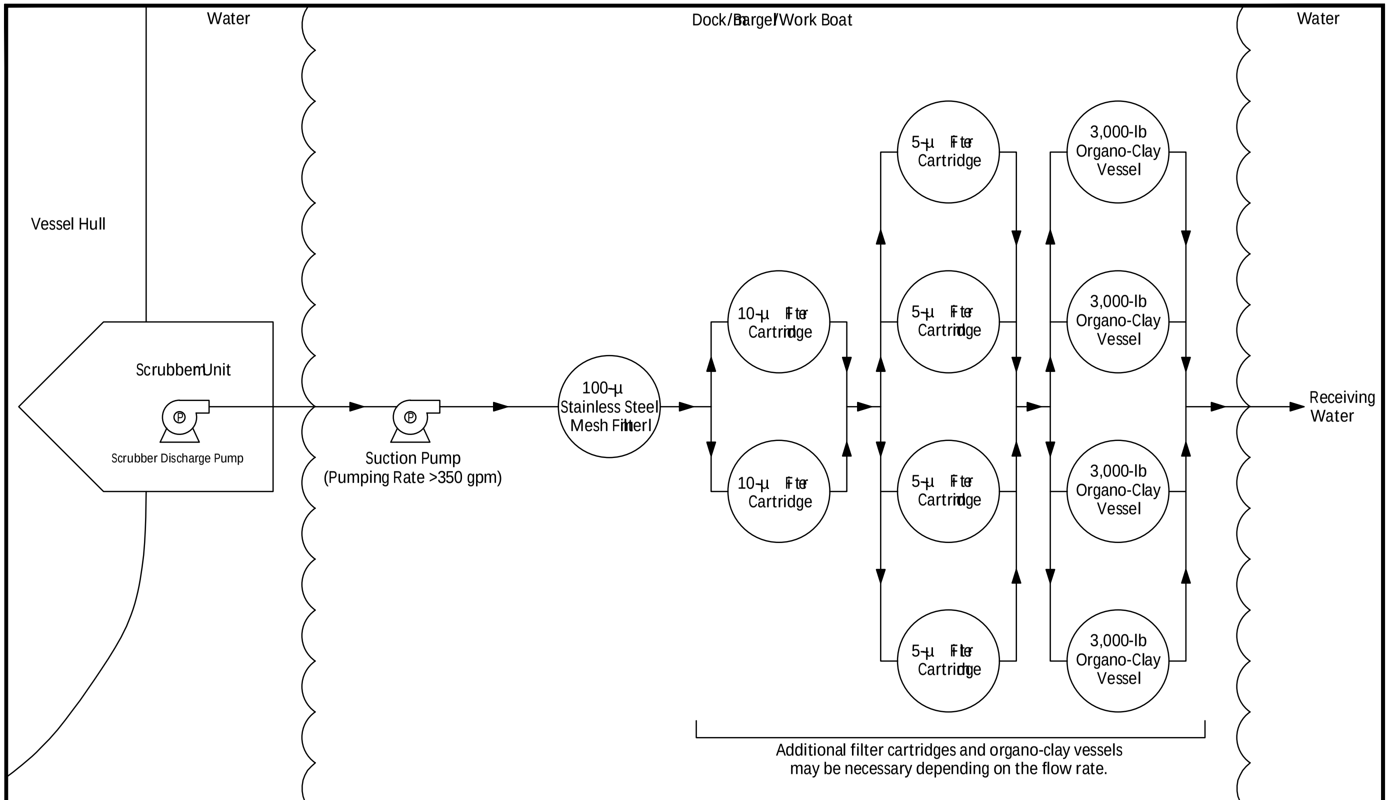
The suction pump flow should be monitored continuously and recorded hourly to ensure that a minimum of 350 gpm (400 gpm is optimal) of process water is recovered from the scrubber unit. Treatment system influent and effluent samples should be collected daily and analyzed for total and dissolved copper and zinc. Sampling should begin three detention times (the treatment system volume divided by the flow rate) after commencing operations and continue daily until operations cease. After sampling the influent, effluent samples should be collected following one additional detention time.

The analytic results should be submitted within 30 days of project completion to the San Francisco Bay Regional Water Board, Attn. David Elias, 1515 Clay St., Ste. 1400, Oakland, CA 94612. The analytic results should be accompanied by a detailed schematic of the treatment system employed. The results may be used in the future to determine BAT for in-water hull cleaning.

OPERATIONAL TRIGGERS

To ensure proper implementation of this interim BMP, or to confirm that another practice removes pollutants as well or better, treated process water discharged into the receiving water should not exceed a total copper concentration of 100-micrograms per liter (µg/L) nor a total zinc concentration of 700-µg/L. These triggers appear to be achievable and practicable. If monitoring results exceed these triggers, the treatment system should be modified or augmented to the extent possible to improve its performance until the triggers are achieved.

For questions, contact David Elias of the Regional Water Board at 510-622-2509 or delias@waterboards.ca.gov.



Notes:
1. Not drawn to scale.
2. Schematic for concept only, not valid as a treatment design.

R. Janoch 03-28-2013

SAFETY FIRST	CLIENT:	**In-Water Vessel Hull Cleaning BMP Fact Sheet**
terraphase engineering	PROJECT: In-Water Hull Cleaning	
	PROJECT NUMBER:	**Figure 1**

Appendix 2

Questions for companies engaged in in-water cleaning of vessels

Note: *the information we collect from you will be used in the formation of potential policy with regards to hull fouling and in-water cleaning practices. We will keep your name and company name confidential and any published data will be aggregated so that no individual can be identified.*

1. How many vessels did you perform in-water cleaning services for in 2015?

2. What types of vessels do you clean? Check all that apply and identify most common.
   - Military vessels
   - Seafaring commercial
     i. Bulker, Combo, Container, General Cargo, Reefer, RoRo, Tanker, Offshore supply vessel,
   - Non-seafaring commercial
     i. Tugs, Passenger, Recreational chartered fishing vessels, tug, barge
   - Cruise ships
   - Research vessels
   - Fishing fleet
   - Motor/sailing yachts
   - Inter-island cargo ships
   - Other

3. How do you perform **in-water cleaning** on boats/ships to remove **soft-fouling**? (ie: grass, scuz, slime layer)? Check all that apply and elaborate if necessary.
   - Manual scrubbing with cloth, blade, and/or brush
   - Mechanical scrubbing with cloth, blade, and/or brush
   - Water blasting
   - Drive boat/ship at high speeds (Specify speed)
   - Other

4. How do you perform **in-water cleaning** on boats/ships to remove **hard-fouling** (ie: barnacles, mussels, tubeworms, bryozoans)? Check all that apply and elaborate if necessary.
   - Manual scrubbing with cloth, blade, and/or brush
   - Mechanical scrubbing with cloth, blade, and/or brush
   - Water blasting
   - Drive boat/ship at high speeds (Specify speed)
   - Other

5. How do you perform **in-water cleaning** on niche areas (ie: sea chest grates, bow thrusters, propellers, rudders)?
   a. Manual scrubbing with cloth, blade, and/or brush
   b. Mechanical scrubbing with cloth, blade, and/or brush
   c. Water blasting
   d. Drive boat/ship at high speeds (Specify speed)
   e. Other
   f. All of the above
   g. Not sure

6. Do you capture and kill/sterilize <u>fouling organisms and toxic paint during **in-water-cleaning** events</u>? If yes, explain how.

7. Anti-fouling (AF) and foul-release (FR) paint questions:
    a. Does coating type or age effect the IWC method/tools you use?
    b. Do most customers use AF, FR, both, or none?

8. Are some vessels better at maintaining a clean hull and niche areas? What are the cleanest vs the dirtiest types of vessels?

9. What percentage of your customers have vessels that are:
    a. lightly fouled (such as scattered barnacle or tube worm patches, light algae at waterline, etc.)
    b. moderately fouled (multiple types of soft and hard fouling and/or but less than about 40% cover)
    c. heavily fouled (multiple types of soft and hard fouling and/or but more than about 40% cover)

10. What percent of your customers
    a. Travel only within Oahu?
    b. Travel to neighbor islands?
    c. Travel outside of HI and where do they go?

11. Are you aware of some of the new cleaning technologies in development? If so, elaborate.

12. Do any of these seem feasible for your company to use?

13. What are your suggestions and ideas for an in-water cleaning policy that would work for your company and help protect the environment?