Status of Vessel Biofouling Regulations and Compliance Technologies - 2014

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Abstract

A number of recent studies have determined that vessel biofouling is a comparable if not more significant vector than ballast water for introduction of aquatic invasive species. However, the control of vessel biofouling remains largely voluntary which is inhibiting the development of technologies to address the problem. We update previous reviews of the status of biofouling control technologies, describe the status of biofouling control regulations, and discuss the extent to which "technology-forcing regulations" might be successful at providing economic incentives for development of effective technologies.

Introduction

The introduction of aquatic invasive species (AIS) associated with global shipping has been identified as a significant threat to ocean and coastal ecosystems, and the cause of hundreds of millions of dollars in economic damage annually.[1] There are two main sources of shipping-related AIS introduction: ballast water and vessel biofouling. Several recent studies have determined that vessel biofouling is either comparable to or more significant as a vector for introduction of AIS than ballast water.[2] However, while the U.S. and other nations are beginning to regulate the discharge of ballast water in their territorial waters, and the International Maritime Organization (IMO) is poised to regulate ballast water globally, perhaps as soon as next year, the control of AIS via vessel biofouling remains mostly voluntary. This may change over the next few years as more nations, and the IMO, begin to recognize that relying on voluntary control of vessel biofouling will not significantly reduce AIS threats, and start to develop regulations that require more stringent hull cleaning schedules and more advanced hull cleaning technologies.

Shipping companies have at least some economic incentives to voluntarily address hull fouling because excess vessel biofouling reduces hull speed and fuel efficiency, increases engine wear, and can increase compliance costs associated with meeting recently enacted restrictions on greenhouse gas (GHG) emissions.[3] In most situations, however, methods used to reduce hull fouling in order to reduce ship operating costs (e.g., hull cleaning only during scheduled dry docks), may have minimal effect on AIS problems related to vessel biofouling because they do not address biofouling growth in niche areas (e.g., sea chests, thrusters, cooling water pipes, etc.) which contribute to AIS, but have little effect on hull performance or engine or fuel efficiency.

Routine in-water hull cleaning between dry docks could significantly reduce AIS problems. However, many currently available in-water hull cleaning methods neither contain the organisms that are removed from surfaces nor treat them before they are released into coastal water. As a result, current cleaning methods could contribute to rather than reduce AIS problems. Alternative or modified in-water hull treatment technologies that contain or treat waste rather than discharging it directly into coastal waters would be more costly than current methods and would provide no offsetting economic gains to ship owners. Consequently, “natural” markets for in-water hull treatment technologies that are aimed at both improving ship fuel efficiency and reducing AIS problems do not exist. With no “natural” market there has been very little effort put into developing and commercializing such technologies. As a result international, national, and state regulations that are being considered to manage AIS problems associated with hull fouling need to be designed to be “technology-forcing” and “market forcing.” They need to be designed and implemented in ways that encourage the development, commercialization, and widespread use of in-water hull cleaning technologies that are aimed at reducing AIS problems, as well as improving ship efficiency.

Focus of this paper

In this paper, we describe the current state of hull cleaning technologies and the international and national regulatory context that is affecting markets for these technologies and investments in these technologies. We then examine the outlook for the development of hull-cleaning technologies, drawing upon lessons still being learned from the unexpectedly slow development of regulation-driven global ballast water treatment markets, and examine similarities and differences between regulations to address vessel biofouling and regulations to address ballast water problems and promote alternative fuels.

One focus of this paper is the interplay between “technology-forcing” regulations, advances in technologies that allow shipping interests to comply, and the development of supply and market capacity for these technologies that will allow widespread shipping industry compliance. In the case of air pollution regulations, for example, an important policy question was whether the economic incentive of improved fuel efficiency and the possibility of generating GHG emission credits, in combination with a shift to mandatory reductions of certain emissions would be sufficient to promote the development and commercialization of related technologies. In the case of vessel biofouling, the important policy question is similar; will a combination of improved speed and fuel efficiency in combination with regulations that require the treatment of vessel biofouling in ways that reduce AIS threats be sufficient to promote the commercialization and use of in-water hull treatment technologies that will meet environmental as well as economic goals?

Hull Treatment Technologies

In this report, our focus is on in-water hull-cleaning methods rather than hull-coating applications or other proactive methods.[4] Hull-cleaning is typically conducted during drydock, but we are especially interested in technologies that that can perform interim underwater hull cleaning in port or at sea and that can reduce risks from hull-borne AIS threats. To date, underwater “hull husbandry” (a term used frequently to refer to systematic hull cleaning) has been conducted by divers or machines using brushes, scrapers, or pressure washers without any means of collecting the resulting debris. These approaches usually achieve hull cleaning goals related to improved vessel operations and fuel efficiency, but result in the release of AIS and perhaps residual tributyl tin (TBT) or copper coatings into the environment. All of these conventional in-water hull treatment technologies need to be significantly modified to reduce rather than contribute to global AIS threats.

In-water treatments designed to capture or kill debris and thereby reduce AIS threats include, but are not limited to, methods such as enclosing the hull (while in water) in a close-fitting impermeable wrapping material, and/or applications of chemical, heat, or ultrasonic treatments, alone or in some combination.[5] These methods and some other options are described in a 2012 New Zealand report (Inglis, et al. 2012)[6] that relies on earlier work by Bohlander (2009)[7] and Floerl, et al. (2010)[8]. These sources list removal by hand, mechanical removal, encapsulation, heat treatment or hull-time in freshwater as potential in-water cleaning or treatment approaches that could address AIS problems. However, mitigating AIS threats is possible only if these methods employ technologies that effectively capture and/or kill all living organisms that are removed from the hull. Most of the options described in the New Zealand report involve mechanical removal with the ability to capture debris. The other options that can capture vessel biofouling organisms are largely dismissed because of: the amount of time required; difficulty containing debris; the need to apply and discharge biocides; or other factors. Other reviews of hull cleaning technologies (see U.S. EPA 2011[9], CSLC 2013[10]) have described recent developments that address environmental harm and decreased fuel efficiency associated with biofouling.

In this report, we have focused on technologies that are in use or under development that either kill hull-fouling organisms before they are released into the environment or capture debris from hull cleaning and treat it or dispose of it in containment facilities on land..

We also considered whether technologies addressed “niche areas,” including anodes, gratings, propellers, and sea chests, which have been found to be “hot spots” for biofouling that affects AIS but does not necessarily affect vessel efficiency. In terms of overall fouling and species richness, one study concluded that these niche areas, per unit area, pose up to five times greater AIS threats than hull areas..[11] With the exception of propellers, there is little incentive from a fuel savings perspective to keep niche areas free of biofouling.[12] Thus, there has not been a market driver for development of these technologies in the same way as for hull-cleaning technologies.

Technologies we have identified that capture or kill AIS, and their respective features[13], are listed below:

1. **CleanHull AS** cleans hulls with a brushless high-pressure seawater jet using a remotely-operated vehicle (ROV), and a single-brush technology for niche areas. Operating locations include Spain, Singapore, Sweden, and Denmark; and plans for locations in the United States and Brazil.
2. **In-water treatment of Ecospeed** coating by Hydrex has been studied in Rotterdam, which found that use of Ecospeed combined with regular cleaning by the diver-operated, three-brush Hydrex “Typhoon” prevented heavy fouling from occurring without release of biocides.[14] In-water cleaning is now allowed at the Port of Rotterdam only for vessels coated with Ecospeed.[15]
3. **Envirocart** is a company in Western Australia that uses a hydraulically powered unit with rotating discs to clean hulls, and hand tools for cleaning niche areas. The company’s

promotional materials claim that its technology is self-contained, suggesting a reduced risk of AIS release in-port.

4. **Hull Bug** is a U.S. Office of Naval Research pilot project involving use of ROVs.
5. **Seaward** uses a self-propelled, diver-driven "Scamp" machine as its hull-cleaning method, and also cleans/polishes niche areas such as the propeller, thruster, and sea chest using high-pressure jets. The Scamp was modified to capture debris for a U.S. Navy test, but this was dismantled after the test, and the Scamp technology in current use does not capture AIS.
6. **T&C Marine** in Australia features a thermal-shock technology.
7. **UMC International's Mini-Pamper** and Associated Network provides hull cleaning through a twin-brush diver-operated machine that UMC says can be modified to contain debris with enough commercial interest, and niche-area cleaning through a single-brush machine that can contain debris.[16] Based in the United Kingdom, its promotional materials indicate that it has more than 300 treatment locations.
8. **Whale Shark Environmental Technologies** in Vancouver, British Columbia received a $646,000 grant from Canada's Sustainable Development Technology Corporation to develop its Whale Shark hull-cleaning system designed to collect and clean debris that is removed from hulls before releasing it to the sea.

Regulatory Context

Regulations enacted by the government of New Zealand in May 2014 that are scheduled to come into effect in 2018 might provide the impetus needed to jump-start the development and commercialization of technologies that address the need for ships to have their hulls cleaned between dry docks in order to reduce the spread of AIS. Some technologies that are likely to be effective and could be employed by ship owners to comply with these new NZ regulations are described in the regulation and supporting documents. However, NZ has not yet approved any specific technologies or best management practices (BMPs) that can be applied to assure compliance. Similarly, California continues to develop vessel biofouling regulations, and is conducting tests of what would be considered best available technologies (BATs), but so far has only issued an interim BMP that "dischargers are encouraged to employ."[17] The following sections summarize the status and trends in these and other pending international and national vessel biofouling regulations.

International Context: IMO 2011 Biofouling Guidelines

The International Maritime Organization (IMO) issued guidelines in 2011 for the control and management of biofouling to minimize the transfer of AIS.[18] The guidelines, while voluntary in nature, provide a framework for shipowners to address the threat of AIS introduction through this vector. The guidelines recommend that shipowners develop a biofouling management plan for each vessel that takes account of vessel type, size, hull configuration and pattern of activity, and tracks biofouling in a record book. In the guidelines, the IMO expresses concern about the impact of in-water cleaning on anti-fouling coatings (and potential release of biocides into the environment); therefore, the guidelines state that in-water cleaning or scrubbing of hulls for the purpose of delaying drydocking beyond the specified service life of the coating is not recommended. Among the recommendations for future work is a call for research into in-water cleaning technologies that ensure effective management of the anti-fouling system as well as the removal and capture of biofouling material and other contaminants..

Australia and New Zealand

Australia and New Zealand have taken a keen interest in vessel biofouling and related AIS issues for many years, dating back to a Code of Practice for Antifouling and In-water Hull Cleaning and Maintenance, developed in 1997 by the Australian and New Zealand Environment and Conservation Council (ANZECC).[19] In recent years these two nations have been responsible for the production of several reports on the feasibility of hull-cleaning technologies that are being considered by many national and regional agencies.

In a report prepared in 2009 for the New Zealand Ministry of Agriculture and Forestry Biosecurity, the author, Jerry Bohlander, observed that "it is likely that future regulatory actions governing discharges from underwater hull cleaning, should they occur, would give the commercial marine technology sector the incentive to invest capital in the development of contained underwater hull cleaning and water treatment systems." Bohlander contacted underwater hull cleaning vendors in four countries about "capture" technologies for in-water cleaning and noted that they indicated that they were reluctant to invest in development of such technologies in the absence of regulatory drivers requiring shipping companies to use them.[20]

Bohlander identified four "capture" technologies; however, two (Seaward's modified SCAMP and the U.K. HISMAR system) were either not operational (SCAMP) or in a conceptual stage at the time the report was written (HISMAR).[21] Another technology, the CleanHull ROV water jet system, did not have a waste water treatment system; and the fourth technology, the U.S. Navy's Advanced Hull Cleaning System (AHCS), while considered to be more technically advanced than the rest, was still considered to be a prototype.

Bohlander suggests there would be a market in New Zealand for such a technology if required by regulation, noting that New Zealand's international ports are visited by 3,000 to 5,000 major vessels a year. He suggested that as many as 30 inspections per day would be needed to enforce vessel biofouling regulations in New Zealand, including multiple inspections of repeat visitors.

The Bohlander report was followed by a review of biosecurity and contaminant risks associated with in-water cleaning by Floerl, et al., prepared in 2010 for the Australian Department of Agriculture, Fisheries and Forestry.[22] Floerl, et al. found four different types of technologies available or in development in 2010:

- Brush systems (in use)
- Underwater jet (in use)
- Heat treatment (under development)
- Encapsulation (under development)

However, the authors noted that none of the brush systems or underwater jet systems had yet demonstrated the ability to remove 100% of biofouling and contain 100% of the removed material. Heat treatment was determined to be unable to treat advanced fouling and niche areas. And as of 2010, the effectiveness of encapsulation had yet to be demonstrated successfully. But the report notes that in-water hull cleaning can be significantly less costly than hull cleaning during dry docking because of both the relatively high cost of dry docking and because of relatively long down times associated with hull cleaning during dry docking.

In 2013, the Department of Fisheries of the Government of Western Australia commissioned Franmarine Underwater Services to prepare a report on in-water hull cleaning system cost and a related cost-benefit analysis.[23] (Franmarine is the developer of "Envirocart," an in-water treatment system designed to capture, contain, and treat biological waste generated by hull cleaning.) The analysis included an assessment of capital cost of equipment, in-water hull cleaning times, and dive team costs for both nearshore and offshore cleaning, and estimated that, for a given vessel type/size, dry-docking could cost up to five times the cost of in-water cleaning.

The New Zealand Craft Risk Management Standard

On May 15, 2014, after several years of analysis, the government of New Zealand issued a Craft Risk Management Standard (CRMS) to address biofouling on vessels arriving at New Zealand ports. The CRMS is scheduled to come into force in May 2018, with voluntary compliance encouraged during the four-year interim period which was included in the regulations to allow time for technologies and markets to develop and allow vessel operators time to decide the most cost-effective way to comply.

The CRMS applies to any vessel that will anchor, berth or be brought ashore in New Zealand whose voyage originated outside New Zealand's territorial waters. Vessels must arrive with a "clean hull"—one on which no biofouling of live organisms is present other than that within thresholds defined in the regulation. In general, allowable biofouling includes a slime layer and goose barnacles on hull surfaces. For vessels staying for 20 days or less and visiting only certain locations additional fouling is allowed in niche and other areas, but these vessels are to remain under "biosecurity surveillance" while in New Zealand.

Three categories of options are considered to be acceptable for meeting the CRMS clean hull standard. First, all biofouling must be removed from all parts of the hull by an approved facility 30 days or less before visiting New Zealand. If not cleaned before arrival, cleaning can take place within 24 hours of arrival in a facility or by a system approved by the New Zealand Ministry for Primary Industries (MPI). Second, the operator can perform continual maintenance using a best practice such as applying antifouling coatings; using a marine growth prevention system on sea-chests; and performing in-water inspections with biofouling removal as required. The New Zealand CRMS notes that following IMO biofouling guidelines is considered to be a best practice. Third, the CRMS allows application of approved treatments listed on its website. The CRMS also notes that as an alternative to these three approaches, a vessel operator may apply for MPI approval of a Craft Risk Management Plan that documents equivalent measures were taken to reduce risk of introduction of AIS to New Zealand waters.

A review of the MPI web site indicated that, as of November 18, 2014, MPI had not yet approved any hull cleaning facilities or systems in New Zealand, any in-water-inspection providers in New Zealand or overseas, or any biofouling treatments, as described in the options for compliance with the CRMS.

U.S. Federal and State Regulatory Context

The 2011 EPA report on underwater ship husbandry discharges outlines the regulatory context at the international, Federal, and state levels.[24] EPA recognizes that methods and technologies to manage vessel biofouling are in early stages of development, and so relies largely on the 2011 IMO guidelines for vessel biofouling management. These include minimizing hull fouling on long-distance voyages; selecting and maintaining an appropriate antifouling management system; performing in-water inspection; cleaning and maintenance of hulls; thorough cleaning of hull and other niche area when a vessel is in drydock; and other specified management measures consistent with IMO guidelines. The U.S. Coast Guard (USCG) requires rinsing of anchors and anchor chains, and removal of fouling from the hull, piping and tanks on a regular basis.[25] The 2013 Vessel General Permit also requires inspection of hard-to-reach areas of vessels during drydock.[26]

A Sample of Current Hull Husbandry Practices in the U.S.

We conducted confidential interviews with senior executives at marine services companies in three U.S. states with operations throughout the East Coast to gain an understanding of how shipowners and operators are addressing vessel biofouling. One executive noted that there is little in-water hull husbandry activity taking place between dry docks, since there are no regulations that require it. Another estimated that his company—the main service provider in the port where the interview took place—undertakes about five or six underwater cleaning jobs per year in conjunction with hull inspections, although they may perform some propeller polishing and "minor" cleaning more often. He noted that his company receives more inquiries about hull cleaning when fuel price increases make reduced hull efficiency more costly. Another executive at one company with operations throughout the East Coast indicated that his company performs one to two dozen in-water hull cleanings per year, but they are "not a staple" of the company's business.

Two executives noted that the real risk from vessel biofouling is from ships that remain idle in port for long periods of time. In one case, at the port where his operation is located, the typical turn-around time for ships is relatively short because ship traffic is predominantly from container-ships. In this particular port, they use a limited arsenal of hull cleaning technologies—primarily pressure-washing for hulls and "grinder wheels" for propeller polishing. He noted that more extensive in-water cleanings tend to be done at ports with greater underwater visibility. He identified two diver-based technologies as being the most commonly used in some other ports: Brush Kart and SCAMP.[27] Another interviewee mentioned the Hydrex "Typhoon" in-water cleaning technology, but noted that it is only used in conjunction with the application of Hydrex "Ecospeed" paint. Another company noted that in-water cleaning is typically conducted three to five miles offshore for safety, visibility, and, in some states, regulatory reasons. However, a port service provider in another port noted that all in-water cleanings are conducted in the port. In summary, we detected significant variability in the frequency, type, and location of hull cleaning activities at different U.S. East Coast ports.

Cost and time estimates provided by the companies we interviewed indicate that a typical in-water cleaning for a 180 to 200 meter (590 to 656 foot) container vessel would cost on the order of $20,000 to $50,000 and take about two days for an entire hull; costs would be proportionately higher and as long as four days for larger vessels.[28] According to one executive with several decades of experience in the business, how frequently in water cleaning might be needed between dry docks depends on a number of factors, In his view, "post-TBT paints" are the primary cause of vessel biofouling problems, noting that until TBT was banned problems with vessel biofouling were "unheard of." In his view, trade routes are another crucial factor, with more fouling observed on ships coming from South America and Africa. He confirmed that idle time is another important factor and noted that container ships with quick turnaround times tend to have less fouling than tankers and bulkers that are more likely to sit idle for longer periods.

State Efforts toward Stricter Regulation

To fill gaps in Federal programs, the California State Legislature has instructed the Marine Invasive Species Program of the California State Lands Commission (CSLC) to develop hull-husbandry regulations to address the threat of introduction of AIS into California waters. A December 2013 report by CSLC to the Legislature describes these gaps and outlines the approach California is taking to fill them.[29]

The key problem with both Federal (EPA and USCG) and California programs identified in the CSLC report is that the report refers to requirements that biofouling be removed from vessel surfaces on a “regular” basis. However, since “regular” is not defined, this amounts to a recommendation, not a requirement. The CSLC notes that this ambiguous wording in the ruling leads to an “unenforceable” requirement.[30]

A second issue is the paucity of Federal data about biofouling management. Although EPA collects some data in the context of the Vessel General Permit, the California report notes that this is not frequent enough for a proper risk analysis for AIS introduction. To help fill that data gap, in 2008 California began requiring submission of annual hull husbandry reports from ships operating in its waters.[31] CSLC notes that these data have not only helped inform California’s analysis of AIS risk, but also have contributed to efforts in Alaska, Oregon, and Washington.

One similarity between the Federal and California programs is the extent to which they have relied on “reactive” approaches that remove biofouling after it is established on hull surfaces. This suggests that management should take place largely toward the end of the period in between dry docking when biofouling might already be significant and already be contributing to AIS problems. California proposes a comprehensive (both reactive and proactive) approach that includes both management plans (consistent with IMO’s 2011 guidelines) and other measures, such as a focus on cleaning niche areas like sea chests that are more likely to experience fouling. And, as mentioned previously, in the most recent Vessel General Permit, EPA is adding emphasis on inspecting hard-to-reach areas in dry dock.

This proposed mix of proactive (i.e., application of preventive paints and coatings) and reactive approaches suggests the need for cleaning in between dry docking periods, using in-water hull husbandry techniques utilizing divers and/or remotely operated vehicles. However, hull cleaning can involve removal of some anti-fouling coating or paint, presenting another environmental risk—discharge of heavy metals such as copper into inshore waters.[32] This has led to prohibitions or restrictions on in-water hull cleaning in California and some other states. These include Washington, which does not allow in-water cleaning of boat hulls painted with soft, toxic paint[33]; Maine, which prohibits underwater cleaning except as part of emergency repairs, and Massachusetts, which allows hull husbandry discharges only three or miles offshore.[34]

In 2012, California tested an in-water system for possible approval as a Best Available Technology (BAT) suitable for in-water cleaning. The results of this test are included in a 2012 report prepared for the U.S. Department of Transportation Maritime Administration (MARAD). The technology tested was an in-water scrubber unit with rotating plastic brushes to remove fouling, with the unit designed to then capture and contain the biological material before it could be released into the environment. The project report indicates that the technology was capable of containing and capturing the biological material, and that a treatment system can remove copper and other particulates.[35] While this technology has not yet received approval as a BAT, it has been designated as an “interim best management practice (BMP)” by the San Francisco Bay Regional Water Quality Board.[36] Use of this BMP is not mandatory, however, and as of June 2014, the BMP had not been used in San Francisco Bay, according to two individuals knowledgeable about the technology.

The 2012 MARAD report indicates that the cost of in-water cleaning without capture of biological materials averages around $50,000 for a large commercial vessel. This corresponds roughly with estimates provided to us in confidential interviews with marine services companies in three East Coast states. It also compares favorably with estimates of dry dock costs of hundreds of thousands of dollars, according to the MARAD report.[37]

The CSLC report notes that, due to lack of plans at the Federal level to develop more comprehensive biofouling policies, California is working collaboratively with the governments of Australia and New Zealand to craft policies affecting vessels involved in global trade.[38]

Technology-forcing Regulations and the Status of Hull-cleaning Technologies and Markets

General Stages of Technology-forcing/Market-forcing regulations

Technology-forcing regulations (TFRs) are regulations that require industry to meet safety, health, or environmental standards that are not possible with technologies that are available at the time the regulations are written. They usually have implementation and enforcement delays that are thought to be long enough to allow technologies that can meet regulatory standards to be developed and adopted by industry. TFRs have been used successfully in the past in many areas, most notably in the auto industry where they were used to phase out lead additives from gasoline (resulting in cleaner emissions), limit NO_x emissions from car tailpipes, and more recently to force improved fuel efficiency standards and reduced greenhouse gas emissions for passenger cars.

In the shipping industry, IMO ballast water treatment regulations that most observers expect to be ratified in 2015 and implemented a year later are also potentially technology-forcing. They provide a useful context for assessing what might be expected as vessel biofouling regulations begin to be developed and implemented around the world. The environmental risks and public costs of AIS introductions via ballast water have been recognized and understood for many years. However, there has been little incentive for the shipping industry or outside entrepreneurs to identify and develop a technological solution to ballast water problems because minimizing ballast water risks, while good for coastal ecosystems and the general public, is a potentially costly endeavor with no economic payoff for shipowners. Recent U.S. and pending IMO regulations that require vessels to install and operate ballast water treatment systems are intended to have the effect of creating a previously nonexistent market for these systems which, in turn, is expected to allow industry to meet the regulatory standard. Although vessel biofouling regulations are lagging far behind ballast water regulations in terms of being “technology-forcing”, the same pattern and stages of development can be expected.

In general, technology-forcing regulations aimed at achieving environmental goals tend to follow five stages of development:

1. Identify an environmental problem and establish an acceptable but currently unachievable or uneconomic standard to mitigate the problem (e.g., an emission standard to reduce air pollution, an allowable number of living organisms in ballast water discharges, a clean hull standard to minimize risk of AIS, etc.)
2. Impose regulations that require manufacturers, owners, operators, etc. to employ technologies that can meet these environmental standards by a certain point in time (e.g. a date 3, 4, or 5 years in the future)..
3. Rely on potential profits in these new markets to attract investments in research and development that will find technological solutions that can meet these new environmental standards by the regulatory deadline.
4. Rely on implementation of the regulation and the availability of technologies to comply to attract enough technology supply and installation or service capacity for markets to develop that will allow widespread compliance.
5. Implement compliance monitoring and enforcement strategies that will result in most or all businesses that are subject to the regulation using technologies that meet the new standard.

In general, New Zealand's adoption of the Craft Risk Management Standard in 2014 is an example of a TFR that is in Stage 3; the problem has been identified and the standard has been established (Stage 1); and the regulation has been passed and the compliance deadline has been set (Stage 2). Now, ideally, the potential profits in the new regulation-driven market for in-water hull cleaning technologies will provide incentive for investments in finding ones that are acceptable to New Zealand regulators (Stage 3), and those technologies being commercialized (Stage 4) before the standards are implemented and enforced in May 2018 (Stage 5).

Stages of Development for New Technologies

The pattern of development of TFRs, that is how long they spend in each of the five stages listed above, depends critically on the evolution of compliance technologies and related markets. The pattern of development of these new technologies and markets, in most cases, is determined by many factors besides the implementation of regulations. There may be real technological or economic constraints to the development of technologies that can meet regulatory standards. And, there are clear economic incentives for industry not to invest in or encourage the development of compliance technologies that may be costly to them and provide regulators with justification and political support for enforcing TFRs. Industry tends to characterize TFRs that are ambitious in terms of expecting technological advances to allow widespread compliance as being "aspirational" and "not practicable." Regulators often view such industry claims as being based less on pragmatism and a determination of what is "practicable" and more on self-interest and "gaming" the regulatory process in order to reduce or delay compliance costs and/or justify flexible enforcement and low penalties for violations.

Whatever political, regulatory, or economic factors may influence the availability of technologies to comply with TFRs, it is useful to understand how these technologies can be expected to develop. Regardless of whether there is a regulatory incentive, the development of new technologies tends to follow the same general stages as they evolve from a concept to commercially available, cost-effective product or service. Risk of technological, infrastructural, or institutional failure is greatest at the earliest stages in the process. As a technology clears each successive hurdle and moves on to the next stage, the likelihood of widespread commercial applications grows. In the case of regulation-driven technologies to achieve environmental goals, the more widespread the commercial applications, the more likely it is that the targeted environmental goals will be achieved.

The ten stages of new technology development are as follows:

1. Proof of concept
2. Basic science and engineering
3. Early experimentation
4. Initial, small-scale implementation
5. Comparison of methods
6. Standardization of methods
7. Specialized techniques and materials
8. Limited application by early adopters
9. Industrial development, lowering costs
10. Routine/widespread adoption

Hull-fouling has economic consequences for ship owners and operators due to its negative effects on fuel efficiency, engine wear, etc. For this reason, in-water hull cleaning products have been available for some time. In-water hull cleaning technologies that minimize the risk of AIS by capturing or treating wastewater and address niche areas, however, are potentially more costly and provide no offsetting economic benefit to ship owners and operators. As a result, markets for in-water hull treatment technologies that improve ship fuel efficiency and reduce AIS problems do not currently exist and, therefore, there has been little effort put into developing and commercializing such technologies. For these reasons, hull cleaning technologies that remove fouling organisms but do not capture the resulting debris can be viewed as being in Stage 9 or Stage 10 of the development curve. In contrast, technologies that clean hulls and capture wastewater can be viewed as having only reached Stage 3 or Stage 4. Ones also addressing niche areas would likely be at an even earlier stage of development. As in-water hull-cleaning combined with wastewater capture moves from being voluntary to being mandatory, the rate at which technologies that meet these needs develop can be expected to increase.

Will Technology-forcing Regulations be Effective in this Context?

As noted in his 2009 report for the New Zealand Ministry of Agriculture and Forestry Biosecurity, when Bohlander contacted underwater hull cleaning vendors in four countries about technologies for in-water cleaning that also capture waste, they indicated that they were reluctant to invest in development of such technologies in the absence of regulatory drivers that will create customers for these technologies. In the case of capture technologies that deal with niche areas, there is even less incentive, since, except for propeller polishing, there is little fuel efficiency benefit and no regulatory requirements. Whether technology-forcing regulations will successfully drive a new market for in-water hull cleaning and capture technology will depend on the answers to the following questions which are associated with both the implementation and enforcement of vessel biofouling regulations and the development and commercialization of vessel biofouling technologies.

First, will the market that is created by the implementation of the current regulations be large and certain enough to attract adequate investment in developing the necessary technology? That is, will implementing this regulation in New Zealand, and possibly California, be sufficient to drive the development and commercialization of this technology? Will innovators see enough potential profit in a market that is comprised of vessels affected by these regulations being implemented in limited geographical areas to make the necessary investments, or will the regulations need to be implemented across a wider region such as the U.S., the E.U., or the IMO to have that type of impact? If so, how likely is it that this will take place and how long will it take?

Will the regulations be effectively enforced, and will noncompliance result in penalties that are certain, meaningful, and sufficient to encourage widespread compliance? If the potential market remains relatively small, but the clean hull regulations are strictly enforced and the penalties for noncompliance sufficiently strict, the demand may be adequate to drive the necessary advances in technology. On the other hand, if there is not a clear enforcement plan or strict penalty schedule, ship owners and operators may find noncompliance less costly than compliance.

Other questions that will determine whether TFRs will successfully create new markets in hull cleaning and wastewater capture technology include how regulators will respond in different situations. How will they respond, for example, if sufficiently funded research and development has not resulted in technologies that will allow widespread compliance? What would regulators do if bottlenecks along the supply, installation and service chain prevent widespread compliance by the time compliance is required? And, how will regulators respond if they suspect that the industry has decided to "game" the regulatory process through insufficient funding of research and development to find technological solutions to vessel biofouling problems, characterizing regulatory requirements as being not practicable or enforceable, and using its political influence to delay implementation or make paying penalties for violations a reasonable cost of doing business?

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[1] See Carlton, J.T. 2001. Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities. Pew Oceans Commission. Available at http://www.iatp.org/files/Introduced_Species_in_US_Coastal_Waters_Enviro.htm

[2] For an analysis of the vectors of AIS in California, see Williams, Susan L., et al. 2013. Managing Multiple Vectors for Marine Invasions in an Increasingly Connected World. *BioScience (2013) 63 (12): 952-966.*
Available at http://www.des.ucdavis.edu/faculty/grosholz/people/files/grosholz/WilliamsetalBioscience.pdf
See also Bax, N., A. Williamson, M. Aguero, E. Gonzalez, and W. Geeves. 2003. Marine invasive alien species: a threat to global biodiversity. Marine Policy 27: 313-323. And Carlton, J.T. 2001. Introduced Species in U.S. Coastal Waters: Environmental Impacts and Management Priorities. Pew Oceans Commission. Available at http://www.iatp.org/files/Introduced_Species_in_US_Coastal_Waters_Enviro.htm

[3] See http://www.imo.org/MediaCentre/HotTopics/GHG/Documents/REPORT%20ASSESSMENT%20OF%20IMO%20MANDATED%20ENERGY%20EFFICIENCY%20MEASURES%20FOR%20INTERNATIONAL%20SHIPPING.pdf

[4] Hull fouling has been addressed to date through anti-fouling paints and coatings. These present their own risks: for example, tributyl tin (TBT) paints have effectively been banned globally and copper-based coatings can leach heavy metals into the marine environment. Alternative paints and coatings have been developed, but the need for cleaning still remains.

[5] http://www.biosecurity.govt.nz/files/regs/ships/crms-biofouling-guidance-document.pdf

The proactive "ultrasonic" treatment option involves creating acoustic cavitation so organisms can no longer attach. However, we have not seen any documentation that it is effective.

[6] Inglis, Graeme, Oliver Floerl and Chris Woods (National Institute of Water and Atmospheric Research). 2012. Scenarios of Vessel Biofouling Risk and Their Management: An Evaluation of Options. New Zealand Ministry of Agriculture and Forestry Technical Paper No. 2012/07. Available at http://www.biosecurity.govt.nz/files/publications/technical-papers/2012-07-vessel-biofouling-scenarios-final-report.pdf

[7] Bohlander, Jerry. 2009. Review of options for in-water cleaning of ships. Ministry of Agriculture and Fisheries Biosecurity New Zealand Technical Paper No. 2009/42. Available at http://www.biosecurity.govt.nz/files/pests/salt-freshwater/options-for-in-water-cleaning-of-ships.pdf

[8] Floerl, Oliver, Lisa Peacock, Kimberley Seaward and Graeme Inglis. 2010. Review of biosecurity and contaminant risks associated with in-water cleaning: Keeping marine pests out of Australian waters. Commissioned by the Department of Agriculture, Fisheries and Forestry. Available at http://www.marinepests.gov.au/marine_pests/publications/Pages/review_of_biosecurity_and_contaminant_risks_associated_with_in-water_cleaning.aspx

[9] U.S. Environmental Protection Agency. 2011. Underwater Ship Husbandry Discharges. EPA 800-R-11-004. Available at http://nepis.epa.gov/Exe/ZyNET.exe/P100DCL4.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2011+Thru+2015&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A\zyfiles\Index%20Data\11thru15\Txt\00000003\P100DCL4.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h|-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p|f&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

[10] California State Lands Commission. 2013. California's Marine Invasive Species Program and the United States Federal Programs that Manage Vessels as Vectors of Nonindigenous Species: A Comparison of the Relative Effectiveness at Reducing the Risk of Nonindigenous Species Introduction from Maritime Shipping Activities. Available at http://www.slc.ca.gov/Reports/MISP/Other/MISP_ComparisonReport_2Dec13.pdf

[11] Piola, Richard and Claire Conwell, Cawthron Institute. 2010. Vessel biofouling as a vector for the introduction of non-indigenous marine species to New Zealand: Fishing vessels. New Zealand Ministry of Agriculture and Forestry Biosecurity Technical Paper No. 2010/11. Available at http://www.biosecurity.govt.nz/files/pests/salt-freshwater/vessel-biofouling-as-vector-for-introduction-of-non-indigenous-marine-species-to-nz-fishing-vessels.pdf. For an analysis of biofouling of sea chests, see Frey, Melissa A., et al. 2014. Fouling around: vessel sea chests as a vector for the introduction and spread of aquatic invasive species. Management of Biological Invasions (2014) Volume 5, Issue 1: 21-30.

[12] For a discussion of the fuel-savings benefits of propeller maintenance, see Hydrex. 1012. Ship Propeller Maintenance: Polish or Clean? Hydrex White Paper No. 10. Available at http://shiphullperformance.org/publications

[13] Note that this list only includes products or services that minimize the risk of AIS introduction. We have attempted to identify all in-water cleaning methods addressing AIS introduction, by conducting internet searches and by contacting knowledgeable individuals from government agencies, academia, and vendor companies. There may be other products/services in use or under development that were not identified by these sources. Additional in-water hull cleaning technologies that do not capture or kill potential AIS have been developed and are in use. Some of these are mentioned elsewhere in this paper, but are not listed here.

[14] http://www.hydrex.be/upload/papers/pdfs/Ecospeed_February_2010.pdf See also http://subseaworldnews.com/2011/12/23/belgium-hydrexs-ecospeed-provides-cost-effective-non-toxic-fouling-

control-on-underwater-ship-hulls/ and http://www.maritime-executive.com/pressrelease/underwater-hull-cleaning-dutch-ports-allowed-ecospeed-vessels

[15] http://www.portofrotterdam.com/en/shipping/sea-shipping/port-information/documents/port_information_guide.pdf

[16] Bohlander, Jerry. 2009. Review of options for in-water cleaning of ships. Ministry of Agriculture and Fisheries Biosecurity New Zealand Technical Paper No. 2009/42. Available at http://www.biosecurity.govt.nz/files/pests/salt-freshwater/options-for-in-water-cleaning-of-ships.pdf

[17] http://www.waterboards.ca.gov/sanfranciscobay/publications_forms/documents/In-water_vessel_hull_cleaning_fact_sheet.pdf

[18] http://www.imo.org/blast/blastDataHelper.asp?data_id=30766

[19] Bohlander, Jerry. 2009. Review of options for in-water cleaning of ships. Ministry of Agriculture and Fisheries Biosecurity New Zealand Technical Paper No. 2009/42. Available at http://www.biosecurity.govt.nz/files/pests/salt-freshwater/options-for-in-water-cleaning-of-ships.pdf

[20] Bohlander, Jerry. 2009. Review of options for in-water cleaning of ships. Ministry of Agriculture and Fisheries Biosecurity New Zealand Technical Paper No. 2009/42. Available at http://www.biosecurity.govt.nz/files/pests/salt-freshwater/options-for-in-water-cleaning-of-ships.pdf

[21] Development of the HISMAR system, developed by researchers at University of Newcastle Upon Tyne and funded by the EU, appears to be dormant. An email was sent to the PI in the UK to see if there is any new activity to commercialize it, but as of September 2014, no response has been received.

[22] Floerl, Oliver, Lisa Peacock, Kimberley Seaward and Graeme Inglis. 2010. Review of biosecurity and contaminant risks associated with in-water cleaning: Keeping marine pests out of Australian waters. Commissioned by the Department of Agriculture, Fisheries and Forestry. Available at http://www.marinepests.gov.au/marine_pests/publications/Pages/review_of_biosecurity_and_contaminant_risks_associated_with_in-water_cleaning.aspx

[23] Franmarine Underwater Services Pty Ltd. 2013. In-Water Hull Cleaning System Cost and Cost-Benefit Analysis. Prepared for the Government of Western Australia, Department of Fisheries. Available at: http://www.fish.wa.gov.au/Documents/occasional_publications/fop115.pdf

[24] U.S. Environmental Protection Agency. 2011. Underwater Ship Husbandry Discharges. EPA 800-R-11-004. Available at http://nepis.epa.gov/Exe/ZyNET.exe/P100DCL4.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2011+Thru+2015&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A\zyfiles\Index%20Data\11thru15\Txt\00000003\P100DCL4.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h|-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p|f&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

[25] http://www.psmfc.org/ballast/wordpress/wp-content/uploads/2013/06/Invasive-Species-Related-Requirements-in-EPAs-Final-2013-VGP-R.-Albert-USEPA.pdf

[26] See http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/References/Booklets/2013/ABS_Trends_October2013

[27] Attempts have been made to modify SCAMP to contain debris, but we are not aware that similar attempts have been made for Brush Kart.

[28] Bohlander (2009) notes that, at that time, U.S. Navy non-contained cleaning costs ranged from $15,000 for a small frigate to $75,000 and up for an aircraft carrier.

[29] California State Lands Commission. 2013. California's Marine Invasive Species Program and the United States Federal Programs that Manage Vessels as Vectors of Nonindigenous Species: A Comparison of the Relative Effectiveness at Reducing the Risk of Nonindigenous Species Introduction from Maritime Shipping Activities. Available at http://www.slc.ca.gov/Reports/MISP/Other/MISP_ComparisonReport_2Dec13.pdf

[30] California State Lands Commission. 2013. California's Marine Invasive Species Program and the United States Federal Programs that Manage Vessels as Vectors of Nonindigenous Species: A Comparison of the Relative Effectiveness at Reducing the Risk of Nonindigenous Species Introduction from Maritime Shipping Activities. Available at http://www.slc.ca.gov/Reports/MISP/Other/MISP_ComparisonReport_2Dec13.pdf p. 44.

[31] http://www.slc.ca.gov/spec_pub/mfd/ballast_water/compliance_rptng_docs.html

[32] Terraphase JV, LLC. 2012. In-Water Hull Cleaning Summary Report Prepared for U.S. D.O.T.-Maritime Administration, Alameda, California.

[33] Pers. Communication with Ian Davidson, Smithsonian Environmental Research Center, June 13, 2014.

[34] U.S. Environmental Protection Agency. 2011. Underwater Ship Husbandry Discharges. EPA 800-R-11-004. Available at http://nepis.epa.gov/Exe/ZyNET.exe/P100DCL4.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2011+Thru+2015&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A\zyfiles\Index%20Data\11thru15\Txt\00000003\P100DCL4.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h|-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p|f&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL

[35]Terraphase JV, LLC. 2012. In-Water Hull Cleaning Summary Report Prepared for U.S. D.O.T.-Maritime Administration, Alameda, California.

[36] http://www.waterboards.ca.gov/sanfranciscobay/publications_forms/documents/In-water_vessel_hull_cleaning_fact_sheet.pdf

[37] Terraphase JV, LLC. 2012. In-Water Hull Cleaning Summary Report Prepared for U.S. D.O.T.-Maritime Administration, Alameda, California.

[38] Terraphase JV, LLC. 2012. In-Water Hull Cleaning Summary Report Prepared for U.S. D.O.T.-Maritime Administration, Alameda, California p.46.