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Verifying Compliance with Ballast Water Discharge Regulations

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U.S. and international rules have been proposed to reduce the risks associated with invasive aquatic organisms by requiring that ships' ballast water be treated to kill or remove living organisms and achieve certain standards before being discharged. Enforcing these rules requires verifying when a discharge violates these standards. A preliminary comparison of verification systems indicates that mandatory reporting and inspecting treatment equipment do not provide an acceptable level of confidence and that sampling and analyzing enough ballast water to achieve acceptable confidence is prohibitively costly. The most cost-effective alternative that achieves an acceptable level of confidence involves indirect measures of ballast water using sensors that indicate whether discharge standards are met.

Keywords ballast water regulations, enforcement, invasive species

Introduction

The international maritime industry, with more than 70,000 merchant vessels, is responsible for transporting more than 80% of the goods traded in world markets, and is a foundation for the global economy.[1] However, commercial shipping is also responsible for transporting ballast water and introducing aquatic invasive species to coastal waters where they can cause enormous ecological and economic damage.[2]

The 1990 U.S. Non-indigenous Aquatic Nuisance Prevention and Control Act (NANPCA) was the first federal law to address the problem of aquatic invasive species.[3] It focused mainly on ballast water introductions. The NANPCA contained provisions that required ships headed for the Great Lakes to exchange their ballast water at sea. The law was reauthorized in 1996, renamed the National Invasive Species Act (NISA) and expanded to encourage, but not require, ballast water exchange for all ships arriving from outside the 200-mile U.S. exclusive economic zone (EEZ).[4] NISA also made reporting of ballast water management to a national registry mandatory for all ships entering U.S. ports. In 2004, the U.S. Coast Guard (USCG) published regulations requiring vessels to maintain a ballast water management plan that involves mid-ocean exchange of ballast water, retention of

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ballast water, or approved, environmentally sound alternatives and established a national mandatory ballast water management program.[5]

Although offshore ballast water exchange has functioned as an interim management approach for reducing the risks posed by aquatic invasive species, it is now broadly accepted that ballast water exchange does not provide an adequate level of environmental protection, and that it can be dangerous for vessels and crew.[6] Therefore, both the International Maritime Organization (IMO), through the adoption of the 2004 International Convention for the Control and Management of Ships' Ballast Water and Sediment (hereafter IMO Ballast Water Convention),[7] and, more recently, the USCG[8] have proposed ballast water discharge standards that limit concentrations of living organisms that can be released with ballast water and new regulations that require ship operators to meet those limits.

To address the IMO and U.S. discharge standards, technology developers and manufacturers around the world have designed and built a variety of onboard ballast water treatment systems (BWTSs) to achieve the prescribed discharge limits.[9] There are now several BWTSs that have been rigorously tested (land based and shipboard) by independent laboratories and received IMO-type approval certifications from various administrations. These include: deoxygenation; filtration plus ultraviolet (UV) radiation; and various chemical treatments such as chlorine, ozone, and peracetic acid.

While scientific research was under way to establish allowable ballast water discharge standards and technical research was under way to find treatment systems capable of meeting them, policy-related research was undertaken to assess and compare alternative national or international regulatory and legal frameworks that have been proposed to control ballast water discharge.[10] Limited economic research has also been undertaken to identify the most cost-effective ballast water treatment strategies from the perspective of regulated shipping interests and "optimal" methods for governments to enforce ballast water regulations.[11]

In general, the economic models that have focused on cost-effective ballast water enforcement have used data about vessel type, ballast capacity, voyage route, the ballast water source port, season, and exposure and vulnerability of at-risk ecosystems at the discharge port to identify which vessels pose high ballast water discharge threats.[12] They have not focused on cost-effective ways to actually carry out the enforcement of ballast water regulations by detecting, verifying, and prosecuting violations. These are essential tasks that are particularly difficult because, for practical reasons, ballast water regulations cannot place limits on concentrations of living organisms that exist in ballast water on board ships, only on ballast water that is discharged from ships. This means that a violation does not occur until it is probably too late to be prevented. It also means that the characteristics of ballast water taken aboard a vessel or the vessel type or route may be leading indicators of potential violations before mandatory ballast water treatment. But they may be less important in identifying potential and actual violations than information about the effectiveness of the onboard BWTS and whether it is in proper operating condition and performing to specifications.

Because the international maritime industry is diffuse and obscure, it is difficult to regulate effectively. As described above, however, three key factors will determine whether the IMO Ballast Water Convention and U.S. ballast water regulations will be successful at reducing environmental and economic risks from harmful aquatic invasive species:

1. the limits the regulations place on allowable concentrations of living organisms in ballast water discharge;
2. the availability of technologies to meet those limits; and
3. the willingness of ship operators to comply with ballast water regulations by installing, maintaining, and effectively using those technologies.

Research related to the first two factors—biology and technology—have already yielded results that have been used as the basis for the IMO Ballast Water Convention,[13] and the recent USCG proposed ballast water rule making,[14] and will provide the basis for planned USCG "practicability" reviews where assessments of costs, risks, and engineering and market constraints will be used to determine feasible standards for ballast water discharge.[15] However, the third factor–achieving acceptable compliance rates–will be at least as important to the success of ballast water regulations as the other two factors, but it has been the focus of little research.

Even small rates of noncompliance can prevent some environmental regulations from ever achieving their goals.[16] This is an important consideration in the case of ballast water regulations where risk factors are difficult to measure accurately and risk reductions from widespread compliance may not be adequate to offset the high risks posed by just a few ships that discharge ballast water that does not meet standards.

Overview of Ballast Water Discharge Standards

The USCG has proposed to implement regulation of ballast water discharges in two phases, with the Phase One a set of standards similar to standards in the IMO Ballast Water Convention[17] and Phase Two standards potentially 1,000 times stricter than the Phase One standards.[18] The USCG Phase One standards require ballast water discharged by ships to contain:

1. less than 10 viable organisms per 1 m^3 greater than or equal to 50 μm in minimum dimension;
2. less than 10 viable organisms that are less than 50 μm in minimum dimension and greater than or equal to 10 μm in minimum dimension; and
3. less than the following concentrations of indicator microbes, as a human health standard: (a) toxicogenic *Vibrio cholerae* (serotypes O1 and O139) with less than 1 colony-forming unit per 100 ml, (b) *Escherichia coli* less than 250 cfu per 100 ml, and (c) intestinal *Enterococci* less than 100 cfu per 100 ml.

Factors Influencing Compliance

Compliance rates related to environmental regulations are influenced by normative factors such as moral convictions and peer and community pressure, and economic factors related to the costs of complying and the expected cost of not complying.[19] However, economic theories of deterrence and practical experience have indicated that, in situations where environmental regulations are imposed on large industries, compliance rates depend primarily on economic factors, in particular, how regulated businesses (potential violators) compare the economic benefit of not complying (e.g., cost savings) with the potential costs of not complying and getting caught (e.g., expected penalties or sanctions).[20]

Benefits of Noncompliance

In the case of ballast water regulations, the potential benefits of not complying are associated with cost savings from not installing, operating, or properly maintaining a certified BWTS.[21] Because it will be relatively easy to identify vessels that do not have a certified BWTS, it is reasonable to assume that most, if not all, shipowners and ship operators planning to visit U.S. ports will install one. The benefits of noncompliance, therefore, are likely associated primarily with the cost savings of not using or maintaining a BWTS that has already been installed. However, there may also be other significant economic benefits associated with not using a BWTS, even if it has been installed. For example, if verification of compliance involves only onboard inspections of the BWTS, there may be benefits in having a pristine or slightly used BWTS that will easily pass inspection rather than a heavily used BWTS that may be fouled or degraded and more likely to fail inspection and result in penalties or delays.[22]

Cost of Noncompliance

The expected costs of not complying with ballast water regulations will depend on the level and effectiveness of enforcement. Based on conventional deterrence models, these costs can be measured by examining an enforcement chain that includes: (1) the probability of a ballast water discharge violation being detected, (2) the probability of a detected violation resulting in a citation, (3) the probability of a citation being successfully prosecuted, and (4) the size of the expected penalty.[23]

Equation 1 presents an overview of a "deterrence model" that can be used to assess and compare alternatives for enforcing ballast water regulations based on these four factors.[24] Information is currently lacking to completely characterize and compare potential enforcement systems for ballast water regulations on the basis of all of the parameters included in Equation 1. However, it is not too early to begin comparing the measurement, reporting, and verification (MRV) systems that are under consideration that will determine the value of one critical parameter in Equation 1: (a), the probability that ballast water that does not meet standards will be detected. This single parameter is important for two reasons. First, it has an enormous influence on the expected cost of noncompliance and, therefore, has a significant effect on compliance rates. Second, it is, by itself, a useful measure of the overall confidence that can be placed in the verification program in particular and in the effectiveness of ballast water regulations in general.

Equation 1: Economic deterrence model applied to ballast water regulations[0]

Noncompliance with U.S. ballast water regulations involves discharging ballast water into U.S. waters that does not meet U.S. discharge standards. Assessing enforcement deterrence in this case involves comparing the expected benefits and expected costs of noncompliance under various enforcement regimes, where

$$\text{Expected Cost} = C = a \times b \times c \times d \times e$$

where

a = probability that a discharge violation will be detected
b = probability of a detection resulting in a citation
c = probability of a cited violation being prosecuted and resulting in a penalty
d = average assessed or schedule - based penalty for a violation
e = average "final settlement" amount expressed as the % of the average "assessed or schedule-based penalty" the shipowner or ship operator expects to pay.

Expected Benefits = B = cost savings of not properly installing, operating, and maintaining a certified BWTS.

Table 1

Alternatives for verifying that ballast water discharges meet regulatory standards

1. Reporting—Mandatory *reporting* by shipowner, master, or chief engineer with occasional equipment *inspections* (e.g., by USCG).
    a. Certified system aboard and was in operating condition.
    b. Certified system in operating condition was used properly.
    c. Certified system in operating condition was used and was effective.
2. Monitoring–*Indirect* measures of compliance using reports from shipboard sensors to validate treatment operations and BW conditions that establish whether BW meets standards.
    a. Certified system was in operating condition and was used.
    b. Certified system in operating condition was used effectively.
    c. BW was exposed to conditions that are known to kill or remove organisms to levels of discharge standards.*
3. Measurement–Biological sampling for the *direct* quantification of live organism abundances in BW at discharge.
    a. Small (low sample frequency, small sample sizes and volume, and low precision).
    b. Medium (more frequent and more precise).
    c. Large (high sample frequency, large sample sizes and volume, and high precision).

Note: Options shown within each alternative are increasingly demanding. Abbreviations = USCG, U.S. Coast Guard; BW, ballast water; BWTS, ballast water treatment system.

*Because of large variability in physical and biological characteristics of BW and the mechanical limitations of various treatment systems, a BWTS may be installed and operated properly, but still not meet equipment performance specifications. Therefore, inspecting or monitoring BWTSs may not provide a high level of confidence that BW discharge will or will not meet standards.

Alternative Verification Approaches

Ship and route profiling tools noted earlier can be used to identify ship visits that pose the most and least threatening ballast water discharge risks, and similar tools can be used to identify shipowners or ship operators that are suspected of being likely violators of ballast water regulations. However, the three basic alternatives for validating that ballast water aboard a ship entering a U.S. port meets discharge standards are: reporting, monitoring, and measurement.

Table 1 describes and lists increasingly demanding versions of each of these three basic alternatives. The alternatives have different costs and are expected to result in different levels of confidence that ballast water discharge violations will be detected, as reflected in different expected values of the parameter (a) in Equation 1. It is not possible at this time to estimate an absolute measure of (a) or a precise dollar cost associated with each of these alternatives. However, based on recent experience with various types of direct and indirect measurement systems; general information regarding the time, manpower, materials, and equipment required to use each alternative; and how likely it is that each will detect illegal ballast water discharge, it is possible to make some preliminary cost-effectiveness comparisons.[25] Table 2 provides a preliminary assessment and comparison of the cost and effectiveness of the ballast water discharge verification alternatives listed in Table 1.

Table 2

Preliminary comparison of the cost and cffectiveness of ballast water compliance verification alternatives

Method	Cost	Effectiveness
Reporting: Mandatory reporting by shipowner, master, operator, or person in charge that BWTS has been installed, maintained, and used properly and that it is performing adequately to achieve BW discharge standards.	Nearly zero[a]	Very low[b]
Inspections: Random or targeted onboard inspections of BWTS.	Relatively low[c]	Relatively low[d]
Monitoring (indirect measurement): Use of sensors and data reported out by sensors to determine if BWTS is operating properly to infer compliance or to determine if BW meets discharge standards.	Moderate Installation: \$5000–\$10,000/vessel Operation: \$3,000/year/vessel[e]	Relatively high[f]
Sampling (direct measurement): Direct sampling and analysis of BW discharge to determine if it meets BW discharge standards.	Very high \$75,000–\$125,000/vessel/ sampling event[g]	Low–very high[h]

Note: Abbreviations = BWTS, ballast water treatment system; BW, ballast water, USCG, U.S. Coast Guard; IMO, International Maritime Organization.

[a] Verification merely involves reviewing paperwork.

[b] There is a high likelihood of misreporting and difficulty detecting misreporting.

[c] USCG inspections of BWTS can be incorporated into the current USCG vessel inspection program.

[d] Inspections of BWTS equipment cannot assure that equipment has been installed, maintained, and operated properly to achieve BW discharge standards.

[e] Based on integrated water quality sensor packages placed on commercial vessels of opportunity for oceanographic research. Validation of sensor performance and sensor output correlation with treatment system performance is critical prior to adoption of indirect measurements.

[f] BWTS that are operated properly, especially if they are not installed or maintained properly, may not successfully treat BW at all times. On the other hand, sensors designed to verify that BW discharge meets standards (e.g., conditions exist or have existed that are "proven" to adequately eliminate or kill organisms to meet BW standards) can be very effective.

[g] Because of the large volumes (and high flow rates) of ballast water being discharged and the relatively small concentrations of living organisms allowable, a great deal of ballast water must be sampled and analyzed to make a statistically reliable determination that discharge does or does not meet standards. Draft US EPA Environmental Technology Verification Program "Generic Protocol for the Verification of Ballast Water Treatment Technologies" suggest that 60 m^3 of water may need to be sampled and analyzed to determine if a treatment system meets IMO and Phase One U.S. discharge regulations with 95% confidence. Actual costs, of course, depend on the intensity of sampling (% of ballast water analyzed per vessel) and the extent of sampling (% of vessels sampled). Cost estimate based on current costs of shipboard testing of BWTS for certification.

[h] Confidence in verification of BW discharge based on direct sampling depends on the intensity of sampling (% of BW analyzed per vessel) and the extent of sampling (% of vessels sampled). In general, low and even moderate sampling results in relatively low confidence that BW discharge violations are detected. Only intensive and extensive sampling (at very high cost) results in high levels of confidence that BW discharge violations will be detected.

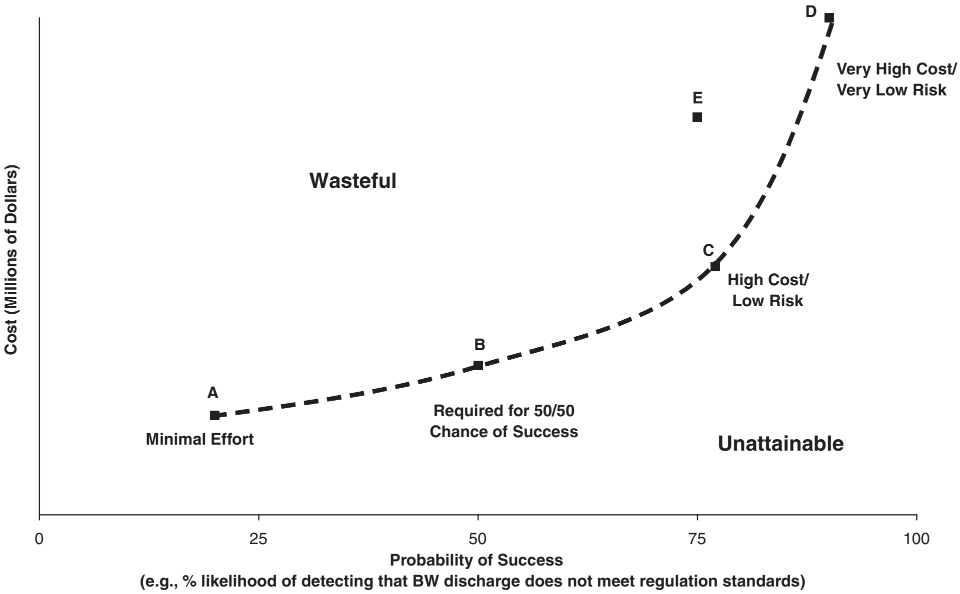


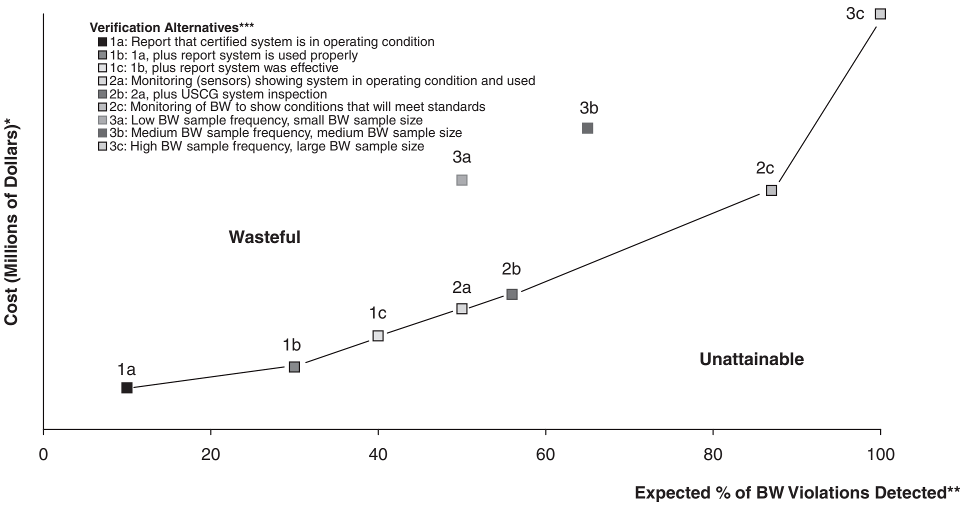
Figure 1. A general cost-effectiveness curve showing wasteful, unattainable, and cost-effective alternatives for achieving varying levels of success.

Cost-Effectiveness Comparisons

Figure 1 presents a generalized cost-effectiveness curve that depicts the typical situation where costs increase as an attempt is made to increase some measure of effectiveness. In the case here, increased effectiveness means more ballast water discharge violations detected by a verification system as reflected in higher values of (a) in Equation 1. In this figure, alternatives with combinations of cost and effectiveness that are on or above the "cost-effectiveness curve" (e.g., B, C, or E) are feasible. However, those that are above the curve (e.g., E) are "wasteful" because there are alternatives that fall on the cost-effectiveness curve that achieve the same or a higher level of effectiveness at a lower cost. There are no alternatives that fall below the curve in the area marked "unachievable" because alternatives do not exist to achieve any given level of effectiveness at a lower cost than alternatives that are on the cost-effectiveness curve. Because there are no alternatives that fall below the curve, and the alternatives that fall above the curve are rejected as being wasteful, the rules for choosing the best alternative are: (1) choose the alternative that is on the curve and provides as much effectiveness as can be afforded, or (2) decide what minimum level of effectiveness is acceptable and choose the alternative that is on the curve at that level of effectiveness.

Preliminary Comparison of Alternatives

The basic empirical information required to construct a precise cost-effectiveness curve for comparing ballast water verification alternatives has not yet been developed. However, it is possible to construct a planning-level cost-effectiveness curve to help assess and compare these alternatives. Performing such a preliminary exercise is useful because it helps draw attention to research questions that need to be addressed before designing a verification program. In some cases, it can also be used to identify and screen out alternatives that



*Includes public cost of detecting and verifying violations (does not include cost to shippers for penalties or sanctions resulting from detected violations).
**Percent of illegal ballast water discharge detected is a measure of confidence in the verification system.
***Refer to Table 1 for more detail on these alternatives.

Figure 2. A cost-effectiveness curve comparing alternatives for verifying compliance with ballast water regulations.

appear to be clearly inferior, for example, because they seem likely to fall far above the cost-effectiveness curve (wasteful) or are not located far enough out on the cost-effectiveness curve (are not effective enough) to be acceptable. Based on planning-level estimates of cost and effectiveness, for example, the rebuttable presumption might be established that, until more data become available, certain alternatives for verifying that ballast water discharge standards are met appear more promising and deserving of attention than others.

Figure 2 provides a preliminary cost-effectiveness comparison of the verification alternatives listed in Table 1. In general, verification methods based only on *reporting* are shown to be the least costly, but to generate the least confidence because of a high likelihood of undetected misreporting. Methods based on *inspecting* BWTS are more costly and generate more confidence than reporting systems alone, but are not highly reliable because a BWTS may not achieve certified performance standards without fail (particularly if not properly installed, operated, and maintained). The most interesting comparison, however, is between *monitoring* systems based on sensors that involve indirect indicators of whether ballast water meets discharge standards and *direct measurement* systems that involve actual sampling and analyzing ballast water as it is discharged.

Interpretation of Figure 2

At one extreme on the cost-effectiveness curve is a low cost and low confidence verification system that involves merely accepting a report from the “master, owner, operator, agent or person-in-charge” of a ship arriving at a U.S. port that it has a certified BWTS on board (Option 1a in Table 1 and Figure 2).[26] This could easily be incorporated into current USCG ship reporting and inspection practices at a relatively low cost.

At the other extreme is a verification system that involves extensive and intensive sampling and biological analyses to determine concentrations of live organisms in ballast water upon discharge (Option 3c in Table 1 and Figure 2). This could be highly effective at detecting ballast water discharge violations, but would be extremely costly in terms of time and money. For example, current shipboard evaluations of biological efficacy during BWTS testing often involve teams of four to six specially trained technicians, several hours of sample collection time during ballast water discharge, dozens of hours of sample analyses, and often costs over $100,000 per sampling event. Sampling from a single vessel to achieve even 50% or 75% confidence that ballast water being discharged meets or does not meet standards (Options 3a and 3b, respectively, in Figure 2) could cost several hundred thousand dollars. Using available sampling and analytical methods, the cost per vessel to achieve closer to 90% or 100% confidence would be significantly higher. Of course, confidence in the overall verification system depends on the number of vessels sampled in addition to the intensity of sampling from individual vessels. This means that achieving high confidence by intensively sampling individual vessels is likely to make an extensive sampling program prohibitively costly and could result in relatively low overall confidence levels.

Between these two extremes on the preliminary cost-effectiveness curve are a range of alternatives that involve applications of indirect measures, such as sensors that monitor conditions within ballast tanks or in ballast piping during uptake and discharge of ballast water to validate that they are (and have been) consistent with proven operational parameters known to remove or kill planktonic organisms. For example, commercially available industrial or environmental sensors that quantify dissolved oxygen (for BWTS based on deoxygenation) or total chlorine (for BWTS based on electrochlorination) generate data that can serve as reliable proxies to establish with high confidence that a particular treatment system maintained conditions that have been proven to effectively and consistently meet discharge standards. The same level of rigorous and independent performance evaluation and validation required for BWTS certification needs to be applied to sensors that are used in compliance monitoring. However, there are already established programs, such as the Alliance for Coastal Technologies in the United States,[27] that currently conduct such independent sensor testing.

At this preliminary stage of analysis, Figure 2 provides only a basis for posing an operational hypothesis that indirect sensor-based measurements are more cost effective than any direct ballast water sampling alternative that is not prohibitively costly. Critically important questions still need to be addressed regarding how emerging technologies involving sensors and sampling might change the relative position of alternatives in Figure 2. From a cost-effectiveness and regulatory impact perspective, there are equally important questions that need to be addressed soon regarding whether spending to increase the volume and statistical accuracy of direct ballast water sampling will result in more or less favorable shifts in the cost-effectiveness curve than similar amounts of spending to improve the precision and reliability of indirect measures of ballast water discharge using sensors.

Results

Benefits of Noncompliance

Since most vessels planning to visit U.S. ports will install a certified BWTS, the main compliance issue will involve whether ship operators are using them and, if so, properly operating and maintaining them.[28] Preliminary economic research has indicated that the cost of purchasing and installing a typical BWTS is in the range of $600,000 to $1.2 million, and the annual cost of maintaining and operating it ranges from $15,000 to $125,000.[29] A rough approximation of the annual benefit to a shipowner or ship operator of noncompliance by not using and maintaining the BWTS is therefore the midpoint of estimated annual operating and maintenance costs, about $70,000 per year. As mentioned previously, however, there may be additional benefits associated with not using BWTS; for instance, when verification systems rely on inspecting equipment. An unused or slightly used BWTS is more likely to pass inspections and result in fewer penalties and sanctions than a well-used BWTS.

Cost of Noncompliance

As Equation 1 illustrates, the expected cost of noncompliance is associated with the likelihood of a detected violation being cited and prosecuted and the expected penalty. However, it is reasonable to assume that all of the parameters in Equation 1 are the same for all verification systems except the parameter (a). Therefore, the expected value of (a) can be used under each verification alternative as a relative indicator of the cost of noncompliance under each alternative.[30]

There are also factors other than the relative value of (a) that may give an advantage to indirect sensor-based measures over direct ballast water sampling. Through the use of onboard sensors, it is possible to determine if ballast water meets standards prior to or immediately at the time of ballast water discharge that can result in some violations being prevented. Direct sampling of ballast water discharge, on the other hand, can require several hours of sample collection and more hours of ballast water testing and analysis to detect a violation as it is occurring. It is not clear if ballast water regulations will allow enforcement staff to prevent ballast water that does not meet standards from being discharged. However, in the extreme case where the use of reliable and precise sensors result in (a) $= 1.0$ (100% detection), and where ballast water that is determined not to meet standards is not allowed to be discharged, there can be 100% confidence that the ballast water regulations are meeting their goals. If a 100% detection rate cannot be used to prevent 100% of illegal ballast water discharges, it will at least provide enforcement staff the opportunity to prosecute and penalize up to 100% of violators.

From a strictly economic perspective, a high level of confidence in the deterrence effect of the verification program could be achieved using a validation system with relatively low detection rates as long as penalties imposed on violations that are detected are relatively high. Based on Equation 1, for example, the deterrence effect of achieving 90% detection rate ($a = 0.9$) with an expected penalty ($b \times c \times d \times e$) of $100,000 would achieve an expected cost of noncompliance of $90,000, which is the same as the expected cost of noncompliance if the detection rate is 100% ($a = 1.0$) with an expected penalty ($b \times c \times d \times e$) of $90,000. A more thorough version of this deterrence model, however, would need to account for how repeat offenders are treated, whether penalties include loss of port visiting privileges or other nonpecuniary sanctions, how responsible parties (perhaps including BWTS vendors or insurers) share liability, and other matters that have yet to be determined.[31]

Conclusions

The international maritime industry is inherently difficult to regulate because of the nature of ocean shipping; complex state, federal, and international jurisdictions; often unclear vessel ownership and liability issues; impacts of traditional risk-sharing institutions (e.g., Protection and Indemnification Clubs [P&I Clubs]); and other factors. However, the success of any maritime regulation depends to a significant extent on the first link in the enforcement and deterrence chain—the ability to identify noncompliance. This article presented a preliminary analysis of alternative compliance verification and violation detection approaches for the new U.S. and international ballast water discharge regulations that results in the following preliminary conclusions:

1. Verification systems based on mandatory reporting and inspections of BWTS alone will not achieve acceptable levels of confidence that ballast water regulations are meeting their goals
2. Verification systems based on direct measurement (ballast water biological sampling) that are not comprehensive in terms of being both intensive (high volumes of ballast water sampled per vessel) and extensive (many vessels sampled) will not provide acceptable levels of confidence. Those that are comprehensive enough to provide acceptable levels of confidence will be prohibitively costly.
3. Verification systems based on indirect monitoring of ballast water using sensors appear to be the best alternative because they have the potential to provide a high level of confidence at a cost that is far lower than even the lowest cost and least reliable biological sampling strategies.
4. The success of a verification system based on sensors will depend on the development of accurate, reliable sensors that generate data that are at least as capable of withstanding technical, statistical, and legal challenges as the results of any direct ballast water discharge measurement system that can meet the practicability test.
5. Whether any verification system for detecting violations will effectively deter violations will depend in crucial ways on whether detected violations result in certain and meaningful penalties and sanctions; how they are shared by ship operators, shipowners, equipment vendors, insurance groups and clubs; how repeat offenders are treated; and other factors unrelated to expected detection rates.
6. The fact that onboard ballast water sensors can predict likely violations prior to ballast water discharge means that they can be used to prevent as well as detect violations. This is another advantage of using sensors to detect imminent violations rather than relying on direct testing of ballast water at the time of discharge to validate violations.

Recommendations

Based on this preliminary assessment of the alternatives that are available to meet the verification requirements of an enforcement system for implementing national and international ballast water regulations, the most promising path forward seems to involve indirect measures of ballast water characteristics using sensors rather than mandatory reporting, inspecting BWTS equipment, or direct ballast water sampling and analysis. Similar comparisons of other aspects of the enforcement chain need to be undertaken soon to identify features of an overall compliance program that will allow ballast water regulations to meet their goals at the lowest possible cost to ship operators and the general public.

Notes

1. See United Nations Conference on Trade and Development, *Review of Maritime Transport 2008*, available at www.unctad.org/Templates/Page.asp?intItemID=4658&lang=1; and Equasis, “The World Merchant Fleet in 2007,” available at extranet.emsa.europa.eu/index.php?option=com.

2. National Research Council, *Stemming the Tide: Controlling Introductions of Nonindigenous Species by Ship’s Ballast Water* (Washington, DC: National Academy Press, 1996).

3. Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, 16 U.S.C. 4701.

4. National Invasive Species Act of 1996, Public Law 104–332.

5. U.S. Coast Guard Regulation, Ballast Water Management, 33 CFR Part 151.

6. See U.S. Department of Homeland Security, Coast Guard, Proposed Rule and Notice, 28 August 2009, Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters, 33 CFR Part 151, 46 CFR Part 162, *Federal Register* 74: 44632–44672.

7. International Convention for the Control and Management of Ships' Ballast Water and Sediments, Doc. IMO/BWM/CONF36, 16 February 2004.

8. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters, Proposed Rule and Notice, supra note 6.

9. N. Dobroski, C. Scianni, L. Takata, and M. Falkner, "Update: Ballast Water Treatment Technologies for Use in California Waters," California State Lands Commission, Marine Invasive Species Program, October 2009.

10. For a review of proposed national and international regulatory and legal frameworks, see J. Firestone and J. J. Corbett, "Coastal and Port Environments: International Legal and Policy Responses to Reduce Ballast Water Introductions of Potentially Invasive Species," *Ocean Development and International Law* 36 (2005): 291–316; and C. L. Hewitt, R. A. Everett, and N. Parker, "Examples of Current International, Regional, and National Regulatory Frameworks for Preventing and Managing Marine Bioinvasions," in G. Rilov and J. A. Crooks *Biological Invasions in Marine Ecosystems* (Berlin: Springer, 2009), 335–352.

11. The development of risk-based models to effectively target ballast water enforcement is described in S. C. Barry, K. R. Hayes, C. L. Hewitt, H. L. Behrens, E. Dragsund, and S. M. Bakke, "Ballast Water Risk Assessment: Principles, Processes, and Methods," *ICES Journal of Marine Science* 65 (2008): 121–131. A review of models that have been proposed or used is contained in Firestone and Corbett, supra note 10. This article also describes what the authors called a Ballast Water Discharge Compliance and Policy Support Model (BWDCPSM), which builds on previous models and focuses on five objectives: (1) minimize the number of viable organisms, (2) reduce the time to achieve reductions, (3) minimize the costs, (4) protect particularly sensitive ecosystems, and (5) maximize technology adoptions by vessels according to their risks.

12. Decision support systems that improve cost-effectiveness of enforcement by targeting enforcement effort on vessel arrivals that pose the highest risk, including the GEF/UNDP/IMO-funded Global Ballast Water Management Program, available at www.globallast.imo.org; a decision support system (DSS) developed and used by the Australian Quarantine and Inspections Service, available at www.aph.gov.au/house/committee/jpaa/aqis/em394.pdf; and the EMBLA program under development in Norway, available at research.dnv.com/marmil/ballast/info1.3.htm.

13. IMO Ballast Water Convention, supra note 7.

14. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters, Proposed Rule and Notice, supra note 6.

15. According to the U.S. Coast Guard proposed rule making, *ibid.*, at 44635:

> the practicability review could entail more than determining whether there exists one system that is capable of meeting phase-two standard . . . and could also include . . . parameters such as the capability of the vendor(s) to make the system(s) available, and the ship building and repair industry to install, systems in a timely and practicable manner given the large number of vessels . . . and the cost impacts of the system(s) on the regulated industry.

16. A few drivers significantly exceeding the speed limit pose much greater highway accident risks than many drivers slightly exceeding the speed limit. Similarly, a few people violating environmental regulations can pose environmental risks that cannot be offset by widespread compliance. For example, a recent survey indicated that, although fishermen believe the percentage of their peers who violate fishing regulations is small, they also believe that their illegal harvests are adversely affecting fish stocks and will cause fish stocks to continue to decline. D. M. King and J .G. Sutinen,

"Rational Noncompliance and the Liquidation of New England Groundfish Resources," *Marine Policy* 34 (2010): 7–21.

17. Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters, Proposed Rule and Notice, supra note 6.

18. Phase Two of the U.S. standards involves discharge standards 1,000 times stricter than Phase One, and also includes other restrictions such as limits on the ballast water discharge of virus and virus-like particles. However, Phase Two will come into force only after a "practicability review" of the availability of both methods to measure the stricter standards and ballast water treatments to meet the stricter standards. Based on this phased approach, ship operators will not be expected to comply with standards that cannot be measured or achieved using available technology. However, unresolved questions remain regarding how regulators will provide the necessary incentives for ship operators to comply with standards that are achievable and how regulators will verify when ships are meeting those standards.

19. Economic factors affecting compliance are associated with the potential illegal gain and the cost of getting caught. See G. Becker, "Crime and Punishment: An Economic Approach," *Journal of Political Economy* 76 (1968): 169–217. Normative factors affecting compliance are associated with an individual's moral obligation to comply, which stem from an individual's standard of personal morality and perceptions about whether rules and regulations are just and moral and are being applied fairly and equitably. See T. Tyler, *Why People Obey the Law* (New Haven: Yale University Press, 1990). Models of enforcement or compliance that incorporate both economic and normative factors are based on what has become known as the "enriched theory of compliance." See the following for a detailed discussion of this theory and related models: K. Kuperan and J. G. Sutinen, "Blue Water Crime: Legitimacy, Deterrence and Compliance in Fisheries," *Law and Society Review* 32 (1998): 309–338; and J. G. Sutinen and K. Kuperan, "A Socioeconomic Theory of Regulatory Compliance in Fisheries," *International Journal of Social Economics* 26 (1999): 174–193.

20. The original economic model of enforcement and compliance by Becker, supra note 19, became the basis for a series of subsequent studies on the economics of crime. See J. M. Heineke (ed.), *Economic Models of Criminal Behavior* (New York: North-Holland, 1978); and D. J. Pyle, *The Economics of Crime and Law Enforcement* (New York: St. Martin's Press, 1983). It is generally understood that economic factors, not normative factors, determine rates of corporate crime.

21. The results of a recent study of the costs of installing and operating certified ballast water treatment systems (BWTSs) indicated that the cost of purchasing and installing a certified BWTS is in the range of \$600,000 to \$1.2 million, and annual operating and maintenance costs are in the range of \$15,000 to \$125,000. Cost ranges reflect differences in ship type and size as well as differences in BWT systems. D. King, P. Hagan, and M. Riggio, "The Emerging Market for Ballast Water Treatment Technologies," 2009 unpublished draft.

22. This implies that enforcement strategies that rely on inspections of BWTS rather than direct or indirect measures of the effectiveness of BWTS may provide "perverse incentives" for limiting the use of BWTS that may result in more violations of ballast water discharge standards at the same time that fewer violations are detected.

23. This approach to estimating the deterrence effect of enforcement was introduced by Becker, supra note 19. A recent application of the approach that involved developing estimates of all parameters is described in King and Sutinen, supra note 15.

24. The parameter (e) in Equation 1 is included because experience with other at-sea enforcement systems (e.g., in commercial fisheries) indicates that violators who are prosecuted often negotiate a "settlement penalty amount" that involves them paying less than the official "scheduled penalty amount."

25. Cost-effectiveness analysis, which is sometimes referred to as incremental cost analysis, is normally used to compare alternatives when the difficulty of measuring benefits prevents the use of conventional cost-benefit analysis. See United States Army Corps of Engineers, "Evaluation of Environmental Investments Procedures Manual—Interim: Cost Effectiveness and Incremental Cost

Analysis," IWR Report 95-R-1 (1995); and H. M. Levin, and P. J. McEwan, *Cost-Effectiveness Analysis: Methods and Applications* (Thousand Oaks, CA: Sage, 2000).

> Cost-effectiveness curves are usually used to distinguish alternatives that are possible and cost-effective from those that are impossible or have higher costs than alternatives that achieve the same results. See M. Lothgren and N. Zethraeus, "On the Interpretation of Cost-Effectiveness Acceptability Curves," *Working Paper Series in Economics and Finance 323* (Stockholm: Stockholm School of Economics, 1999). Using basic information about the resources required to implement each alternative (cost) and the likelihood that it will detect an illegal ballast water discharge (performance), it is possible to make some preliminary cost-effectiveness comparisons using a planning level version of a standard cost-effectiveness curve.

26. This description of potentially responsible parties is taken from Standards for Living Organisms in Ships' Ballast Water Discharged in U.S. Waters, Proposed Rule and Notice, supra note 6, for example, § 151.1512.

27. Alliance for Coastal Technologies (ACT) is a U.S. National Oceanic and Atmospheric Administration (NOAA) funded program fostering the development and adoption of effective and reliable sensors and platforms for studying and monitoring aquatic environments. Since 2003, ACT has conducted a series of independent, third-party sensor performance demonstrations and verifications. See "Technology Evaluation Reports," available at www.act-us.info.

28. A related problem is whether a carefully maintained and properly operated BWTS is meeting performance standards. Issues related to how a ship operator who may have acted responsibly but failed to meet ballast water discharge standards will be treated, and how liability for BWTS not meeting performance standards will be shared between vendors, shipowners, insurance companies, and clubs is beyond the scope of this article.

29. See: King, Hagan, and Riggio, supra note 21; and Lloyd's Register, "Ballast Water Treatment Technology: Current Status" (2009).

30. Using ship or route profiling to target inspections and testing increases the value of (a) regardless of which validation method is used, but does not affect the relative size of (a) for various validation methods. This is determined by differences in the likelihood of a suspected violation being detected.

31. A recent survey of enforcement and compliance in U.S. fisheries, for example, indicated that permit sanctions (e.g., loss of fishing privileges) deterred violations far more effectively than financial penalties. King and Sutinen, supra note 15.