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IMO BALLAST WATER CONVENTION AND ENFORCEABILITY OF G2

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ABSTRACT

IMO's G2 guideline (Guidelines for ballast water sampling) clearly states that ballast water samples are required to be representative of the whole ballast water discharged. Enforcement and implementation of the ballast water convention largely depend on defendable case based on evidence that a ship entering territorial waters has not complied with regulations. Statistical representativeness of ballast water samples have been discussed in this study with additional emphasis on practicality of the sampling procedure. Universally accepted mathematical methodologies for determination of a representative number of "samples" from an unknown "population" have been used to identify minimum number of samples which could be considered statistically representative of the ship's ballast water. Results clearly indicate that a large amount of ballast water must be sampled to achieve certain level of confidence which could be translated as true representation of the ship's ballast water discharged and potentially used in any further legal actions by states or ship operators.

Key words: *underwater acoustic communication, direct-sequence spread spectrum, delay-locked loop, synchronization.*

1. INTRODUCTION

Ballast water convention foresees that ships calling at ports will be required to present "adequate" documentations with respect to their ballast water operations to prove that they are not suspected of any violations. If there are clear basis for port authorities to be suspicious of violation of the ballast water regulations or there are clear grounds for potential damage and pollution to the territorial waters or in some cases on a random basis, ships could be subjected to an onboard "inspection". According to the Convention, inspections will include sampling of the ship's ballast water. As a result and in particular cases, port authorities may ask a suspected ship to leave the territorial waters prior to completion of her cargo and ballast water operations (Blair 2008). All these cases could potentially lead to legal cases, costing port authorities, port state controls, ship operators, ship owners and cargo owners exceeding millions of dollars.

Sampling is an essential part in any environmental pollution control or prevention policy. According to guidelines G2 (Guidelines for ballast water sampling), ballast water samples should be "representative" of the "whole" ballast water discharged (IMO 2008b). Representativeness of ballast water samples has not yet been clearly discussed and currently there are no clear guidelines on how to achieve such true representativeness.

Factors that certainly add high level of uncertainties to any statistical analysis of ballast water samples could be categorised as:

- Sampling points and techniques (also referred to as sampling regimes)
  - Sampling from tanks (sampling location)
  - Sampling from discharge line and during ballast water operations
- Biological content and homogenous distribution of species inside a tank
  - Size and shape of the tank
  - Source of the sea water

Any sampling regime will have to consider a minimum number of ballast water "samples" from the total amount of ballast water to be discharged in order to achieve a "statistically" representative result and with high level of confidence. This will certainly lead to legally defendable cases when there is a potential for prosecution or arrest of the ship.

This research is funded and supported by UK's Maritime and Coastguard Agency (MCA). The statistical representativeness of ballast water sampling is analysed using the methodology for determining the sample size for a "population". This will provide the amount of ballast water that needs to be collected to ensure that the ballast water samples are true representative of the ballast water discharged. In order to define samples "proportion" the analysis has been focused on the non-compliance of D-2 standard of the Convention, which is to have more than 10 viable organisms that are ≥ 50 µm in minimum dimension.

Sampling for environmental protection

Compliance with standards is, indeed, an essential condition for effective implementation of any environmental regulation. To achieve this objective, "adequate inspection and monitoring" is usually required (RCEP 1998). There is abundant literature about the usage of sampling in environmental policies. Some of the Statutory Instruments of British law in relation to environmental regulations, for instance, imply sampling (SI 2000, SI 2007). There are also guidelines emphasizing the need of having sampling when pollution is introduced into the environment, such as oil pollution after an accident (Watterson *et al* 1999).

Moreover, there is a strong trend considering that sampling for compliance should incorporate a statistical analysis to ensure the results are statistically representative. The "Royal Commission on Environmental Pollution" has recognised the importance of statistical analysis presented a document to the British Parliament (RCEP, 1998) highlighting that any numerical environmental standard needs to be robust, must recognise scientific assessment and should try to be a statistically verifiable standard. It also pointed out that the standard should embed the substance's nature as well as the statistical variation in the parameter to which it relates to.

In the field of maritime environmental protection, there are also few regulations including standards for the environmental protection. Discharging oily water with more than 15 ppm into the sea is prohibited by MARPOL 73/78, therefore oily water separators are continuously monitored (IMO 2006). Determination of sulphur content in the bunker oil is another example of "sampling" in the maritime regulations. During bunkering, the fuel supplier provides a certificate indicating that the content of the fuel are complying with Annex VI of MARPOL requirements (IMO 2008a). Ships are not generally equipped with the facilities onboard to test and analyse the fuel against the standards. Three samples are taken at the beginning, middle and end of the supply and kept onboard. In case of any dispute bunker suppliers will be held responsible and may be prosecuted since it was certified that the content of the fuel met the requirements of Annex VI of MARPOL 73/78. Nonetheless, unlike ballast water management, none of the marine environmental protection regulations requires a continuous sampling and representative analysis as part of their regulatory process to control pollution. This makes ballast water management the first case in the marine field to require representative samples.

2. QUANTITATIVE MEASURES IN BALLAST WATER REGULATIONS AND GUIDELINES

Regulatory and guiding documents referring to "quantitative measures" regarding ballast water management are three: the regulation D-2 (*Ballast Water performance standard*) of the Convention, and Guidelines G8 (*Guidelines for approval for Ballast Water Management Systems*) and G2 (*Guidelines for Ballast Water Sampling*).

Any ballast water management systems will have to be tested and type-approved by G8 which will be subsequently challenged by G2 and during its real operations. It is imperative to have relevance, consistency and agreement between various parts of the regulations and guidelines which refer to quantitative measures for sampling for "type approval" and sampling "for compliance".

D2 Ballast Water performance standard

D2 is one of the two standards developed by the Convention which numerically quantifies the quality of the ballast water that ships are allowed to discharge. This regulation also sets the performance standard for ballast water treatment systems.

To enter into force, the Convention needs to be ratified by at least 30 States which combined merchant fleet is at least 35% of the gross tonnage of the world's merchant shipping. At the moment only 14 States have ratified it. Nevertheless, the Convention is expected to be able to entry in force by 2010 (Matheickal 2008).

G8 Guidelines for approval for Ballast Water Management Systems

The G8 defines the recommended procedures for "type approval" of ballast water treatment systems and ensures that the system under consideration meets the standards set by regulation D2 of the Convention.

According to G8 and as one of the final stages of the approval when the ballast water treatment system is going to be tested onboard the ship and in real operations, three replicate samples of treated ballast water need to be collected during the beginning, middle and the end of discharge (IMO 2005).

G2 Guidelines for Ballast Water Sampling

Guideline G2 has been under discussion for a while and it was not until October 2008 that a resolution was achieved at MEPC 173(58). G2 describes the sampling protocol for determining whether a ship is in compliance with the Convention (IMO 2008). According to G2, any sampling protocol testing compliance with the Convention should observe ten principles to help ensure consistency of approval between Parties and to provide certainty to the shipping industry.

The most relevant principles to the current study are number 2, 5, 6 and 7, which are as follows:

- the sampling protocol should result in samples that are representative of the whole discharge of ballast water from any single tank or any combination of tanks being discharged
- the quantity and quality of samples taken should be sufficient to demonstrate whether the ballast water being discharged meets with relevant standards
- sampling should be undertaken in a safe and practical manner
- sampling should be concentrated to a manageable size

G2 does not provide any further guidelines or indication on what a representative sample is but it clearly mentions that representativeness will depend on the statistical significance and is required.

3. STATISTICAL EPRESENTATIVENESS OF BALLAST WATER SAMPLES

The concept of representative samples implies that the collected sample reproduces the same characteristics of the environment that was originally taken from; and that every individual has an equal chance of appearing in the sample, this is usually achieved by "simple random sampling" (Barnett 2004). Statistical representativeness in relation to ballast water management, however, is a concept that has not yet been discussed.

Before the methodology is presented some terminologies need to be clarified:

- A *sample* is a subset of the "population" sampled, in other words, it is a small proportion of the "population".
- A "*population*" in statistic terms could be defined as the group of items from which samples are taken. If the number of samples and the size of each sample are increased, this will lead to increase in accuracy and precision of the results, but at the expense of higher cost (Barnett 2004) and time.
- The "*sample size"* is the number of "population" members selected when a sample is taken from a "population".
- A "*proportion*" refers to the targeted variable from the "population" that is subjected to study; it usually refers to the relation of the targeted variable over the "sample size".

The main mathematical formula used for determining a "sample size" for a proportion is the following which is universally accepted and used for calculating a "proportion" from a finite "population" (Desu & Raghavarao 1990, Thompson 2002; Stattucino Applet 2008). This equation will provide the number of samples that are required to be taken in order to ensure that the sampled "proportion" is representative of the "population". In other words, the following equation will estimate the amount of ballast water (in m^3) that needs to be sampled for ensuring that the sampled ballast water is representative of the ballast water discharged:

$$n = \frac{N\, z_{\alpha/2}^2\, P(1-P)}{(N-1)\, e^2 + z_{\alpha/2}^2\, P(1-P)}$$

where

n = "sample size" or the number of $1m^3$ ballast water samples that needs to be taken in order to have a true representation of the ballast water discharged.

N = "population" size or total amount of ballast water discharged, in m^3.

P = probability of success or the estimated proportion of an attribute that is present in the "population". In this context it refers to the probability of having ≥10 viable organisms/m^3 of ballast water sampled.

(1-P) = is the probability of failure (Q) that represents the probability of having < 10 viable organisms/m^3 of ballast water sampled.

$Z\alpha_{/2}$ = confidence coefficient for a given confidence interval (for a confidence level of 95%, $Z\alpha_{/2}$=1.96)

e = standard sampling error: error that is assumed while the sampling is carried out. A value of 1-5% is considered as normal.

In large statistical analysis, it is usually recommended to collect some samples before determining the "sample size". This pre-sample analysis should indicate the amount of viable organisms present in the water (i.e. the "proportion") and will help defining the *P* (probability of success). Since in D-2, G8 and G2 we will have to consider the whole discharged ballast water, pre-sample of ballast water in this case is not possible; hence, the proposed analysis has been carried out without priori knowledge of the content of ballast water onboard the ship. This will lead to assumption for the maximum variance (*P*=0.5; *Q*=0.5) meaning that 50% of the water that is sampled meets the criteria of *P* (ballast water contains ≥ 10 viable organisms per m^3), and another 50% meet the criteria of (*1-P*) (ballast water contains < 10 viable organisms per m^3).

To discuss the statistical representativeness of ballast water samples collected onboard a ship our analysis has considered the definition of "non-compliance" according to D2, which is to have more than 10 viable organisms that are ≥ 50 µm in minimum dimension in one m^3 sample of the ballast water.

Assumptions

Organisms are heterogeneously distributed inside ballast tanks (Murphy *et al* 2002). Additionally, source of ballast water in each tank could vary from tank to tank and is dependant of ship's mission profile and ballasting patterns. Sampling equipments and sampling points present extreme limitations and uncertainties during sampling and limit accessibility to all corners of the tank. In order to structure and simplify the real scenarios, the following assumptions have been made:

- "Population" is the whole volume of ballast water to be discharged. (to comply with G2)
- One m^3 of ballast water is a member of the "population". (to comply with D2)
- One sample contains $1m^3$ of ballast water.
- Each member of a "population" contains homogeneously distributed organisms.
- Ship has 8 ballast tanks
- A "Bio-Section" is a part of ballast water inside a ballast tank which could be sampled inside the tank or during discharge. (to consider G8)
- A "Bio-Section" has homogeneously distributed biological content.
- Any 1 m^3 sample of ballast water taken from a "Bio-Section" will be a true representative of that "Bio-Section".

Hypotheses

Various hypotheses were examined to make sure that all aspect of sampling procedure and in particular practicality of sampling was considered. Bearing this as an starting point and in order to see whether biological representativeness of a ballast tank or discharging period can be truly defined in a three layer approach, five hypotheses were set out.

Hypothesis 1: Full Ballast Capacity

The "population" (N) is equivalent to the total amount of ballast water that may be discharged. This hypothesis assumes that the origin of the ballast water onboard ship is the same, and there are neither "Bio-Sections" nor the ship has ballast tanks or subdivisions. Hence, the 8 ballast tanks were considered as one large tank. In this case, if the Master decides to discharge 1,000 m^3 of ballast water, then the "population" will be 1,000.

Hypothesis 2: Ship has 8 ballast tanks and each tank contains 27 "Bio-Sections"

This hypothesis follows the same idea as Hypothesis 2 but considers that each ballast tank can be divided into 27 "Bio-Sections" as shown in figure 1(b). Statistical "population" for this hypothesis is 216.

Hypothesis 23: Ship has 8 ballast tanks and each tank contains three "Bio-Sections"

In this hypothesis it is considered that a ship has 8 ballast tanks and each tank is divided into 3 "Bio-Sections" as shown in figure 1(a). The "population" of ballast water onboard would be 24.

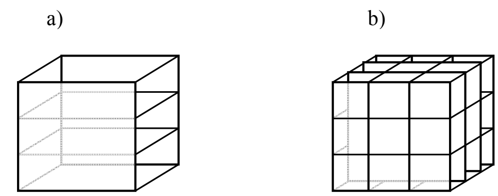

Figure 1 Ballast tank containing "Bio-Sections" of ballast water: a) tanks with 3 Bio-Sections, b) tanks with 27 Bio-Sections

Hypothesis 4: Ship has 8 ballast tanks and each tank is a Bio-Section, each m^3 of a tank is a true representative of the tank

Each tank is a "Bio-Section" and the volume of water in each tank is homogeneously distributed. Each tank may contain ballast water of different source; hence, one m^3 of ballast water taken from a tank is biologically a true representative of the particular tank only. Statistical "population" in this case will be 8.

Hypothesis 5: Ship has 8 ballast tanks and same "Bio-Sections" for all ballast tanks

Similar to hypothesis 3, there are 3 "Bio-Sections" in each ballast tank. But in this hypothesis we consider that all ballast tanks contain the same ballast water (same source) and the characteristics of the three "Bio-Sections" are also the same in the 8 ballast tanks. Total "population" in this case will be 3.

Determination of number samples to collect

In these hypotheses, the "populations" of ballast water to discharge are considered to be 3, 8, 24, 216 and 1,000. Table 1 shows the amount of ballast water that requires to collect as sample if small volumes of ballast water are to be discharged and for a confidence level of 95%, maximum variance and sampling error of 1%.

Table 1 Sample sizes for the "populations" considered in the hypotheses and for a sampling error of 1%, Confidence level of 95% and maximum variance (*P*=50%, *Q*=50%)

"Population" of ballast water (m^3)**,** *N*	3	8	24	216	1,000
% of "Population" of ballast water required for sampling	**100%**	**100%**	**100%**	**97.7%**	**90.6%**
Number of 1 m^3 samples (m^3), *n*	**3.00**	**7.9**	**23.9**	**211.2**	**905.7**

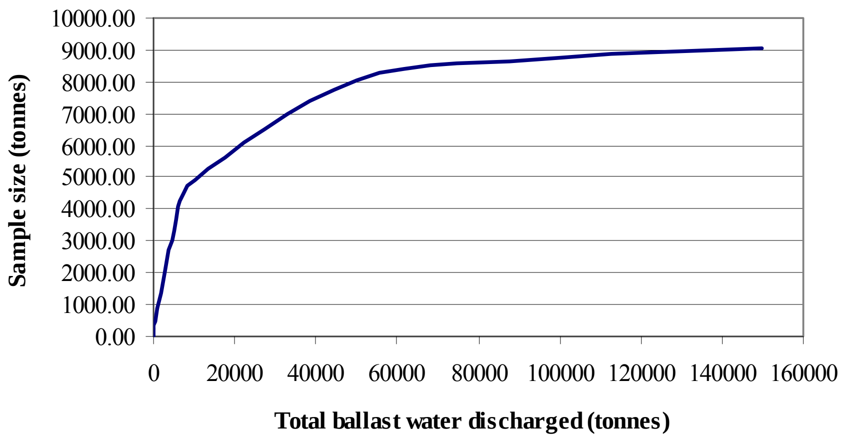

Figure 2 Sample size (n) for a confidence level of 95% and sampling error of 1%

With a maximum variance, when the discharged volume is small, usually the total amount of water discharged will need to be sampled (e.g. for "population" size of 24, all the 24 m^3 need to be sampled).

These "populations" are unrealistic as ships carry and discharge larger volumes of ballast water; but it provides a preliminary result that when discharging small volumes of ballast water, almost all of the discharged amount need to be sampled. In addition, in the case that the ballast tanks were divided into "Bio-Sections" or what G8 suggests as "top/middle/bottom" sections it requires homogeneous distribution of organisms in that section, which in reality is not true. Hypothesis 1 is the one which is closest to a real discharge scenario. In addition, it is worthwhile to mention that following the findings the number of samples to collect for "type approval" purposes (G8) significantly differs from the statistical representativeness analysis and sampling for "compliance" purposes.

If a large volume of ballast water is to be discharged, and assuming that no "Bio-Sections" are considered (Hypothesis 1), then the amount of ballast water to collect as sample is not as high as the volume discharged (e.g. for a ballast water discharged volume of 50,000 m^3, 8056 m^3 of water needs to be sampled). Despite the reduction, the volume to collect as sample still remains comparatively very high.

If the sampling error is increased the amount of ballast water discharged that needs to be sampled decreases. On the other hand, the amount of ballast water that needs to be sampled increases when the confidence level is increased. Moreover and as mentioned previously, the percentage of ballast water discharged that needs to be collected as sample decreases when the total ballast water discharge is a large amount. The most conservative scenario for having a representative condition and meeting the specifications of the Convention and guidelines is given by the case of Figure 2 (for a sampling error of 1%). In this specific case, the minimum amount of ballast water required for sampling would be around 9% of total ballast water discharged. This value corresponds to discharging 100,000 m^3; still the amount to sample remains very high (9000 m^3).

The graphs of figure 3 illustrate the trend of the percentages of the ballast water discharged that needs to be collected as sample ("% BW to sample") to ensure that the samples collected are statistically representative of the total ballast water discharged. The graphs show the results for a maximum variance, confidence levels from 90 to 95% and sampling errors of 1% and 5%.

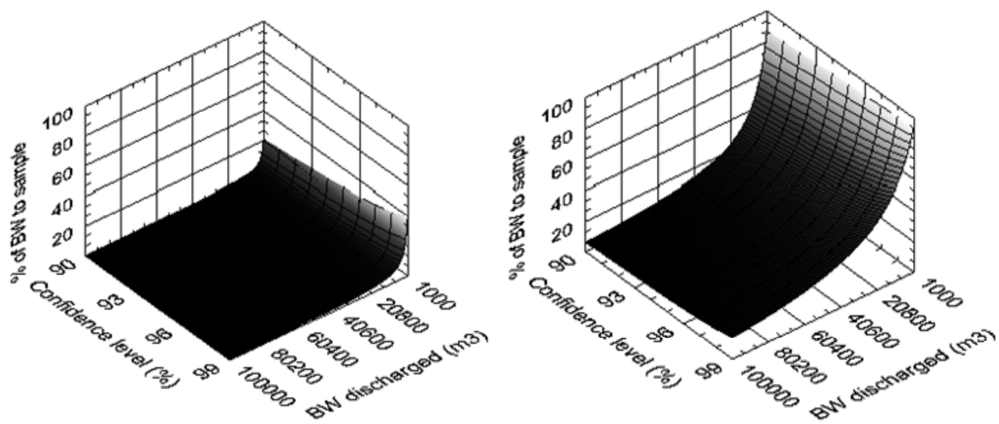

Figure 3 Representation of the amount of ballast water required to sample to ensure statistical representativeness for the case of maximum variance sampling error of 1% (right) and 5% (left)

4. CONCLUSIONS

Statistics play an important role in the development of any environmental policy. Statistical analysis which will lead to definition of representativeness of ballast water sampling has not been clearly defined or discussed within IMO guidelines and ballast water Convention.

IMO's G2 requires that sampling regimes or protocols should result in samples that are representative of the whole discharge of ballast water. Neither biological contents of ballast tanks are homogenous, nor are sources of the ballast water in the tanks the same. This will lead to the observation that statistics can provide the definition of what a representative sample is.

In order to asses the representativeness of the sampling results a thorough statistical analysis has been carried out. Various hypotheses and assumptions were examined to make sure that all aspect of sampling procedure and in particular practicality of sampling has been considered.

Results of the statistical analysis clearly indicate that to achieve 95% confidence that samples provide a representative of the whole discharge of ballast water a large volume of ballast water need to be sampled and analysed. As an example, for a ship to discharge 216, 5,000, 10,000 and 50,000 m^3 of ballast water, it is required to sample 211, 3,288, 4,899 and 8000 m^3 of her ballast water respectively. This is certainly not practical and manageable due to high cost, time and undue delay to ship's operation.

In addition to biological representativeness of samples, implementation and enforcement of the Convention should also ensure that the samples taken and the ballast water standards are statistically representative of the ballast water discharged. D-2, G2, G8 all include quantitative based standards and guidelines for compliance and type approval purposes. Currently, the G8 does not agree with statistical representativeness and compliance requirements for G2. In addition, verifiable statistical procedures to provide adequate confidence in representativeness of ballast water samples have not been discussed although 16 States have currently agreed to ratify the Convention and its associated regulations as it is.

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