Diagnostics in ballast water management

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Abstract. Diagnostics in ballast water management is the main remedy to protect against the threat of spreading invasive species that can be carried in ships’ ballast tanks. This phenomenon is getting better known and understood. New and more effective methods of preventing threats related to this are being developed. Procedures are created to ensure environmental safety in the face of ever-increasing transport by sea. The article characterizes both the background of the problem, basic diagnostic medics used in ballast water management, as well as procedures and basic techniques used to ensure the safety of the natural environment.

1 BACKGROUND

Nowadays most of cargo is being transported by sea. It may be not the fastest but for sure the cheapest solution. Vessels transport three to five billion tonnes of ballast water in one year period. Maritime scientist assumed that every given day, up to 10000 different marine species are released outside their natural habitats. We often consider which is the most economical way, but should that be the only one factor? We should not forget about the slogan “SAFETY FIRST”. Hearing that we consider human and other living species safety, cargo and equipment safety. Awareness of growing risk that some species may be transported in ballast water to a brand new area, where due to lack of natural predators treating them they may dominate or even eliminate others. This threat, not only potential, has huge influence on marine environment.

Fig. 1. Legislation evolution.

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One of the legislation points is Ballast Water Management Awareness. This subject is related to water transport from one to another region. It came together with steel-hulled vessels more than 100 years ago. Ballast operation is needed (due to its impact on vessel stabilisation) for safe travelling around seas and oceans. The first recognition of the problem of transportation of alien species is dated for 1903, when scientist discovered mass occurrence of the Asian phytoplankton algae Odontella in the North Sea.

MPEC – IMO Marine Environment Protection Committee is the Organization that put effort to establish rules that may prevent such cases of spreading unwanted organisms. The negotiation period can be counted in years. Global maritime community analyzed all pros and cons and decided that ballast water management is entering into force.

Diagram of legislation evolution is presented on Fig. 1.

Now we can find more than 25 regional authorities that announced their own requirements. As the main are treated: IMO and United States Coast Guard. However case study based on new technology implementation, should be divided into two groups: new buildings and retrofits. The thesis that it should be split into two case studies is related to practice installation conditioning. At the first quarter of the 2017 USCG revealed their final rule implementation schedule. The table 1 presents main dates and requirements.

| Table 1. USCG implementation schedule. [4] |
|--------------------------------------------|
| **Total ballast capacity** | **Date of vessel launching** | **Compliance date** |
| New buildings | All | On or after 1 Dec 2013 | On delivery |
| Retrofits | < 1500 m³ | Before 1 Dec 2013 | First scheduled dry-docking after 1 Jan 2016 |
| | 1500m³ – 5000m³ | | First scheduled dry-docking 1 Jan 2014 |
| | > 5000m³ | | First scheduled dry-docking after 1 Jan 2016 |

Ship-owners must consider their operation area, because if they have clients in United States of America they have to install proper system for ballast water treatment. Having in mind strict restrictions USCG provides two additional compliance alternatives:

- Exclusive use of ballast water from a public water system in United States.
- Discharge of all ballast water into an onshore facility or another vessel, barge for treatment purposes.

2 BALLAST WATER DIAGNOSTICS AND ITS ENFORCEMENT

Ballast water management is governed by regulations which stipulate limits for: quantity of organisms as well as concentration of indicator microbes that are allowed to be discharged in ballast water. Units dedicated to ballast water treatment must show that they meet these limits not only during type approval, but also during whole product life cycle.

The maritime industry require standardization. BWM convention define international standards for ballast water treatment in Regulation D-2. According to diagnostics, which show measured levels different actions may be required. This may be divided into three consecutive levels, where different actions should be undertaken. This may be presented as on Fig. 2.
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|------------------------|--------------------------|-----------------|
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| Retrofits < 1500 m     | Before 1 Dec 2013         | First scheduled dry-docking after 1 Jan 2014 |
| Retrofits 1500–5000 m  | First scheduled dry- docking 1 Jan 2014 |
| Retrofits > 5000 m     | First scheduled dry- docking after 1 Jan 2016 |

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2 DETECTION

First step, in all cases requires measurement. This is very difficult issue in case of ballast water in ships, as they may only be probed – and outcomes may vary significantly due to ambient conditions, as presented on Fig. 6. Different probing techniques may also be sensitive to various factors. Basic, simplest method is microscopic evaluation, which diagram is presented on Fig. 3. More advanced technique is HR-LOPC, which diagram is presented on Fig. 4. The FlowCAM technique is the first one that may execute tests in different classes of samples. Its diagram is presented on Fig. 5. A broad overview of existing specific methods can be found in [3].

![Fig. 1. Main components of an Early Warning System for Non-indigenous Species and Ballast Water Management. BW = Ballast Water. [6]](image)

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**Microscope**

| Replicate Sample x 5 | * presented in 70% ETOH* |
|----------------------|---------------------------|
| Initial sample vol = 40 ml |

**Phytoplankton**

- 160-400 x magnification
- Vol removed for Sedgewick Rafter = 1 ml
- Vol processed = 0.05 ml

(0.125% of initial sample vol)

**Zooplankton**

- 40-80 x magnification
- Vol removed for counting chamber = 5 ml
- Vol processed - Bosminids = 10 ml
- Other zooplankton = 15 ml
- Rotifers = 20 ml

(25-50% of initial sample vol)

**Fig. 3. Diagram of microscopic evaluation. [5]**
Differences in method sensitivity resulted in splitting sampling methods into targeted ones (which are highly sensitive to specific species, but omit possible other ones, even if they had been very dangerous) and into community profiling (which are less accurate, but give responses to a far higher spectrum of potential threats). Their processes may be compared and presented as on Fig 7.
Fig. 7. Workflow for targeted probe-based detection (left) and HTS-based community profiling (right), including potential sources of error introduced at each process step. False positive and false negative errors can derive from multiple steps in each process. *Encompasses a broad range of error sources including, but not limited to, poor filtering of reads, failure to remove chimeras, and inaccuracies in taxonomic assignment. [3]

Relatively new class of methods used in ballast water diagnostics are genetic methods. They offer brand new approach and possibilities, due to their extremely distinctive properties, as in comparison to traditional, morphological methods. The may be compared as on Fig. 8.

| Criterion                                | Genetic methods | Traditional morphological methods |
|------------------------------------------|-----------------|----------------------------------|
| Sensitivity                              | HIGH            | low                              |
| Specificity                              | HIGH            | low                              |
| Ability to identify sub-adult or partial specimens | HIGH            | low                              |
| Ability to identify cryptic taxa         | HIGH            | low                              |
| Quantification                           | low             | HIGH                             |
| Opportunity for passive surveillance     | HIGH            | low                              |
| Affordability of up-front costs          | low             | HIGH                             |
| Affordability per sample                 | HIGH*           | low                              |
| Speed of analytical turnaround           | HIGH            | low                              |
| False negative avoidance                 | HIGH            | low                              |
| False positive avoidance                 | low             | HIGH                             |

Fig. 8. Genetic vs. morphological methods. [3]
3 WARNING SERVICE AND RESPONSE CAPABILITY

Results of ballast water testing may force necessity of further actions. They may have different directions – towards vessel, other vessels, or authorities. Simple graph of possible warning actions is presented on Fig. 9.

![Fig. 9. Risk assessment approach. Four-step risk assessment approach. [1]](image)

| Group of organisms | Counts per volume |
|--------------------|-------------------|
| ≥50 μm             | <10 per m³        |
| ≥10 μm < 50 μm     | <10 per mL        |
| *Vibrio cholerae*  | <1 cfu per 100 mL or |
| (O1 and O139)      | <1 cfu per 1 g (wet weight) |
| *Escherichia coli* | <250 cfu per 100 mL |
| *Intestinal Enterococci* | <100 cfu per 100 mL |

*Fig. 10. The BWM Convention ballast water performance standard (Regulation D-2) for maximum limits of viable organisms per defined volume of discharged ballast water. [7]*

Finding an excessive amount of chemicals or phyto- or zooplankton may require undertaking standard preventive actions to protect the local environment against the intrusion of alien species. The most widespread among them are presented in Fig. 10. Decision graph for additional actions may consist of many basic steps. It may be presented as on Fig. 11.
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Risk assessment approach. Four-step risk assessment approach. [1]

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Fig. 11.

Institutions, authorities and stakeholders involved in an Early Warning System for Non-indigenous Species and Ballast Water Management. [6]

Depending on hazard different actions may be required. They are illustrated on following Figures.

Fig. 12.

Overview of ballast water treatment measures on board a ship. [7]

Most frequently used techniques reducing biohazards are shown on Fig. 13.
Fig. 13. Techniques of reducing biohazards. [2]

There is always a risk of injuries to human crew; some standard security procedures are shown on Fig. 14.

| Activity                  | Exposure                        | Quantification (IMO, 2012) |
|---------------------------|---------------------------------|-----------------------------|
| Handling of chemicals     | Dermal/inhalation (leaks, spills) | 100 mg (0.1 ml)/container   |
| Startling of BWMS         | Type-specific                   | Case by case                |
| BW treatment              | Type-specific                   | Case by case                |
| Ballasting/ routine deck work | Dermal (BW tank exhaust)      | Case by case                |
| De-ballasting             | Dermal/inhalation (spray drift) | Not considered              |
| Tank cleaning             | Dermal (whole body)/inhalation | 8 h d. 1, on 5 d/ wk, 1 wk y. 3 |
| Other maintenance work    | Type-specific                   | Case by case                |
| Multifunctions, accidents | Inhalation/death (hands)       | Not considered              |
| Port state control        | Inhalation/death (hands)       | 2 h d. 1, on 5 d/ wk, 45 wk y. 3 |
| Sampling (compliance control) | Inhalation                       | 3 h d. on 1 d/ mth. 1            |
| Tank inspection           | General public                  | 5 h d. 1, on 14 d y. 3       |
| Swimming/recreational activities | Inhalation/death (oral)     | ~200 g d. 1                  |
| Seabed consumption        |                                 |                             |

Fig. 14. Scenarios and pathways for human exposure to chemicals from BWMS. [7]

In serious cases it may be necessary to inform other vessels. Such decision diagram is shown on Fig. 15.

Fig. 15. Decision Support System model for an Early Warning System: warnings to vessels. EWS
3 CONCLUSIONS

Diagnostics in ballast water management is the main remedy to protect against the threat of spreading invasive species that can be carried in ships' ballast tanks. This phenomenon is getting better known and understood. However, it is still a problem widely known only to a small group of specialists. This article presents a comprehensive picture of the problem, characterizing the basic methods and procedures. It has a cognitive character, as well as allowing for a deeper look at the problems occurring as a result of the unintentional transport of living organisms in ballast water tanks.

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