Marine Pollution Bulletin xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Risk assessment of bilge water discharges in two Baltic shipping lanes

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ARTICLE INFO

Keywords:
Bilge water
Oil
Metals
Environmental concentrations
Toxicity
Baltic Sea

ABSTRACT

Environmental concentrations and effects of bilge water contaminants in two Baltic Sea areas were estimated from modelling of discharge rates and analytical data on bilge water from seven ships. Biodegradation of bilge water oil was accounted for and annual water concentrations were estimated to peak in late spring, which coincides with the beginning of a period with extensive biological activities in the sea. Concentrations on bilge water metals were calculated both as water concentrations and as the annual contribution of metals to sediments. The predicted bilge water concentrations of oil and metal in the marine environment were estimated to be 4 to 8 orders of magnitude lower than reported toxic concentrations. However, available toxicity data are based on short term exposure and there is to date limited information on toxic effects of the small but chronically elevated contaminant concentrations derived from bilge water discharge and other operational shipping activities.

1. Introduction

Petroleum oil is detrimental to a range of marine organisms and input to the sea from increasing ship traffic calls for holistic studies of environmental effects. When oil is released by accident the environmental concentration will be highest during and right after the spillage and then gradually decrease. Continuous inputs of small volumes of oil may be quickly diluted but if input rates exceed degradation rates environmental concentrations will be chronically elevated. In heavily trafficked shipping lanes there is hence a risk that continuous operational discharges of oily water result in harmful concentrations. Whereas there is a substantial documentation in the scientific literature on the impacts of large oil spills (Depellegrin and Pereira, 2016; González et al., 2006; White et al., 2012), little data is available on the effects of the small but continuous release of petroleum oil from operational activities such as discharge of treated bilge water, and leakage of lubrication oil from propeller shaft bearings (Baussant et al., 2011). The actual levels of bilge water derived contaminants in seawater, sediment, and biota will depend on the volumes and chemical content of discharged bilge water, but also on factors like dilution and spreading of the discharged water, degradation rates of organic contaminants, adsorption of contaminants to particulate matter, sedimentation to the sea floor etc. (Gong et al., 2014; Hazen et al., 2016; Sørensen et al., 2014). Up to date very few studies have been conducted on the effects of chronic release of bilge water although short-term incubations (48 h) revealed significant effects at dilutions of 5–10% on vital rates of the copepod *Acartia tonsa* (Tiselius and Magnusson, 2017).

Bilge water is formed on board all ships and contains a mixture of potentially harmful components such as residuals from lubricants, fuel oil and cleaning fluids. A ship's production of bilge water varies from one instance to another, and variations are large also between ship types and between individual ships of the same type. Larger volumes of bilge water are produced on passenger ships than on cargo ships and there seems to be a correlation between the produced bilge water volume and the main engine power (Det Norske Veritas, 2009). This makes it possible to use information on ship traffic along with ship specific data on ship type and engine size to predict the total volumes of produced bilge water.

From a regulatory perspective, the effects are moderated by an international convention. The Annex 1 of the convention MARPOL 73/78 allows bilge water discharges containing < 15 ppm oil from ships 'en route' (International Maritime Organization, 2011). The convention also requires that ships have equipment on board that treats the water and prohibits the release of water with higher oil content. These treatment units, often referred to as oily water separators (OWS), come

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http://dx.doi.org/10.1016/j.marpolbul.2017.09.035
Received 3 May 2017; Received in revised form 14 September 2017; Accepted 16 September 2017

in various designs and employ different principles. Commonly, treatment starts by gravimetric separation in a settling tank for a removal of heavy fractions and lighter oil fractions in the bilge water. Further removal of remaining pollutants is achieved by using principles of centrifugal separation, filtration, or absorption or adsorption combined with flotation or flocculation, to give a few examples. Several technologies of different design comply with regulations. In order to ascertain that the separators perform according to standards they need to pass type approval tests before being introduced on the market. The bilge water can be treated on board and discharged to sea, or pumped ashore in port. Approximately 75% of all produced bilge water is pumped over board after treatment and the remaining 25% is left to reception facilities in ports (Det Norske Veritas, 2009). Although there is a continuous production of bilge water on board a ship, it is a conscious decision by the crew of the ship when and where the treated water should be discharged to the recipient.

Bilge water is discharged through an opening in the ship hull placed above the water line, and the relatively small volumes that are released will quickly be diluted in the sea water. The initial and dramatic physical effects of an oil spill, such as smearing of birds and marine mammals are therefore not expected to occur from the oil in the discharged bilge water. Instead, if there are effects on the environment these are more likely to be the result of a chronic exposure of marine biota around shipping lanes to slightly elevated concentrations of oil, metals and other components of the bilge water. Toxic effects may be caused by a) the specific mixture of compounds found in the bilge water, b) biodegradable compounds, e.g. oil and detergents, reaching chronically elevated concentrations in the sea, and c) the continuously increasing concentrations of non-degradable compounds like metals. Due to rapid dilution of the discharged bilge water the toxicity caused by the unique mixture of compounds could be expected to only be of concern immediately around the discharge point.

The aim of the present study is to assess the risk for harmful effects of bilge water pollutants, in particular oil related compounds and metals, to ecosystems in regions with intense shipping activities in the Baltic Sea. Two regions were selected, the Hanö Bight north of Bornholm in the southern Baltic Sea and the western part of the Gulf of Finland. These are regions with heavy traffic dominated by cargo ships, followed by tankers and passenger ships in descending order (Swedish Maritime Administration, 2016).

Release rates of bilge water may be estimated for various ship types and total releases to an area can be calculated if information on the traffic intensity of the different ship types is known. Functions correlating bilge water production to installed main engine power on passenger ships and cargo ships along with AIS data on traffic activity were used in this study Bilge water emission factors and data on traffic activity, were treated in a model for calculating emissions from ship traffic, the Ship Traffic Emission Assessment Model (STEAM). However, the important measure for the marine organisms is the actual concentration of toxic substances at any given point in time and space. Thus, degradation and dilution effects should be taken into account when doing a risk assessment. In the present study degradation rates for bilge water oil were obtained from the scientific literature whereas metals were presumed to remain in the water column for a fixed time of 30 days and thereafter sink to the bottom for final deposition. A risk assessment was thereafter made by comparing estimated environmental concentrations of bilge water derived oil and metals to literature data on toxicity of these groups of contaminants to marine biota.

The Baltic Sea is considered to be one of most disturbed seas in the world and therefore particularly sensitive to additional anthropogenic stressors (Magnusson and Norén, 2012). It is classified by the International Maritime Organisation (IMO) as a Particularly Sensitive Sea Area (PSSA) and therefore international regulations on ships concerning emissions of oil are more demanding here than in most other sea areas. The biodiversity in the Baltic Sea is naturally low due to the brackish conditions and a limited input of biota from other sea areas, so negative effects on a single or a few key species can disturb the entire ecosystem (Tedengren and Kautsky, 1987; Ytreberg et al., 2011). The catchment area of the Baltic Sea is densely populated and highly industrialized which in combination with the enclosed location lead to poor circulation and low water exchange with the North Sea. The combination of vulnerability of the area and the intense and increasing shipping traffic calls for strong action and mitigation schemes which make our study timely and urgent.

2. Method

In the study a specifically designed model for ship traffic combined with bilge water emission factors was used in order to establish the amounts of contaminants discharged during a year in the investigated areas. Based on these modelled environmental concentrations a risk assessment was made using toxicity data for marine organisms from the scientific literature.

2.1. STEAM model

STEAM combines vessel specific activity from Automatic Identification System (AIS) with ship technical data and produces predictions for instantaneous engine power usage, fuel consumption and emissions. Recently, a new functionality was added which enables STEAM to produce estimates of bilge water production and release from vessels to sea.

According to IMO SOLAS convention Chapter V (IMO, 1974), all vessels over 300 gross ton have to carry and use AIS which uses Very High Frequency (VHF) radio messages to transmit and receive automatic updates of vessel location and identity without human intervention. The AIS was designed as navigational aid to prevent collisions and facilitate vessel traffic monitoring, but it also enables detailed tracking of vessel behaviour and emission modelling. Maximum rate of AIS transmission is every 2 s, but update rate depends on vessel speed in such a manner that fast moving targets transmit more often than stationary ones. This amounts to large volumes of data, which may consist of billions of position reports each year in regional studies.

The activity of individual vessels is tracked by AIS data, which provides, at minimum, vessel identity, location and instantaneous speed over ground. Based on this information, STEAM estimates the thrust needed to obtain the speed indicated by AIS. This is done with the resistance calculation method of Hollenbach (1998) which estimates the frictional component of vessel resistance as a function of hull wet surface area and the residual component based on hundreds of scale model tests. This step requires significant detailed information on the physical properties of the vessel, which is mostly obtained from IHS Fairplay data, but some, like hull form description, need to be evaluated using principles of ship design. The functionality of STEAM is described in more detail in earlier work (Jalkanen et al., 2009; Jalkanen et al., 2012; Johansson et al., 2013).

The process of vessel specific prediction of discharges is repeated for all vessels found in the AIS data which enables STEAM to produce numerical summaries of these quantities. Further, locations of emissions are tracked and summed in order to generate gridded emission maps, which describe the spatiotemporal variations of emissions as a function of realistic traffic situation. In case of emissions to water, the consecutive step involves the dispersion of water pollutants as a function of water movement. STEAM is an emission model, which cannot be used for studies of dispersion of pollutants in water or in the atmosphere.

The data used for modelling of bilge water discharges in the present study represent ship traffic in 2012. The use of data from one year as representative values was the preferred option over using average values for multiple years, as this significantly reduces the amount of model data. Comparisons with 2013, 2014, and 2015 reveal no great changes in ship activities in the studied areas over the latest years. The shipping lanes in the Hanö Bight and the Gulf of Finland in general experienced somewhat increased traffic of tankers, but decreased traffic of other cargo ships and passenger ships between 2012 and 2015.