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Toxicity of treated bilge water: The need for revised regulatory control

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ABSTRACT

Water accumulating in the bottom of ships (bilge water), contains a mixture of oil, detergents and other compounds from on board activities. To evaluate ecological effects of released bilge water the chemical composition and toxicity of treated bilge water from seven passenger ships was analysed. The oil content was below 15 mg L^{-1}, the threshold for legal discharge, in all but one ship. Still, significant reductions in feeding and reproduction of *Acartia tonsa* were found after 48 h exposure in dilutions with 2.5–5% of bilge water. Mortality was significant at dilutions of 5–10% in 4 of the 5 bilge water samples. Surfactants were the most significant contributor to the toxicity on copepod vital rates and survival. Toxicity was also tested with Microtox where an EC_{50} was found at dilutions between 4.3% and 52%. The results show that ecological effects might occur also in diluted suspensions of bilge water.

1. Introduction

Release of oil from various shipping activities has over the past half century caused enormous problems to aquatic ecosystems. Most attention has been given to oil spills where marine biota initially are exposed to high oil concentrations which gradually are reduced through e.g. evaporation, photo-oxidation and bacterial break-down of the oil components. Less attention is given to the effects of the legally accepted release of smaller volumes of oil to the sea through activities like discharge of bilge water, ballast water and cleaning of tanks. Recent estimates indicate that the total chronic release of oil worldwide to the ocean averaged 270,000 tons per year over the period 1990–1999, equal to the largest single oil spills from an oil tanker accident, the Atlantic Empress in 1979, or about one third of the total release of oil from the Deepwater Horizon Macondo well in 2010 (Farrington, 2013). The input of oil from ship operations is continuous, so even though most oil fractions have a fairly rapid half-life they may cause permanently increased oil concentrations in areas with intense shipping. Marine biota in these areas hence run the risk of being chronically exposed to low but still elevated concentrations of oil.

Bilge water is the water that accumulates in the bottom of the ship and it is generated from machinery leakage and wash-down of fresh water. It may contain fuel, hydraulic oils, lubricant oils, volatile organic compounds, metals, detergents, degreasers and other chemicals derived from activities on board a ship (US EPA, 2008).

The International Maritime Organization (IMO) regulates handling of bilge water. The focus for regulation is set on the oil content of the discharged bilge water since this is generally considered to be the most important toxic component. According to the International Convention for the Prevention of Pollution from Ships, (MARPOL 73/78) no water may be discharged into the sea if it contains ≥15 mg L^{-1} of oil. To meet the IMO regulations the bilge water is either treated en route, in an oil separation system before being discharged to the sea or deposited at reception facilities on land. The treatment is complicated due to its mixed content of chemicals in the water. The most problematic is the mixture of oil and surfactants derived from cleaning, which prohibits the water from separating into two distinct phases. Despite this, a recent study indicates that oily water separators mounted on three container and bulk carriers significantly reduced most substances for which there are regulated concentration limits (McLaughlin et al., 2014).

The chemical composition of bilge water varies both between vessels and also from day to day within a vessel. Cruise ships and passenger ferries produce significantly more bilge water than ships of other categories due to their complicated constructions and support for many passengers (US EPA, 2008). In a survey by Det Norske Veritas (DNV) the median production of bilge water was estimated to be 7500 L day^{-1} from passenger ships, 360 L day^{-1} from offshore ships, and 50 L day^{-1} from tankers and cargo vessels (Sjøfartsdirektoratet, 2009). The corresponding amount of oil being released from a passenger ship, assuming a maximum allowed oil content of 15 mg L^{-1}, would be 112 g oil day^{-1}, from an offshore ship 6 g oil day^{-1} and from tankers and cargo vessels 1 g day^{-1} $ship^{-1}$. Large cruise ships with gross tonnage from 20,000 to 78,000 operating off Alaska produced

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5–20 m^3 of bilge water per day equal to 75–300 g oil day^{-1} in legal discharges (US EPA, 2008). There is to our knowledge no data on the volumes of other components discharged with the bilge water.

An important group of chemicals present in bilge water are the surfactants. Many surfactants are known to be toxic in themselves and mixtures of oil and surfactants may be more toxic than each of the individual components, either caused by synergistic effects of the actual toxicity the two components or as a result of an increased dissolution of the crude oil by the dispersant making it more bioavailable for the exposed organisms (Greer et al., 2012; Wu et al., 2012; Almeda et al., 2014b).

In general, toxicity tests of crude oil on planktonic species have been carried out with just the water-soluble fraction of the oil since this often has been considered to be the only bioavailable fraction (e.g. Berdugo et al., 1977; Berrojalbiz et al., 2009). However, oil discharged to sea water also occurs as droplets either formed by natural factors (wind, waves) or by dispersants applied after oil spills (Mukherjee and Wrenn, 2009). It has been shown that suspended oil droplets in the size range of food particles can be ingested by several species of zooplankton and hence add to the uptake of oil (Lee et al., 2012; Almeda et al., 2014a, 2014b, 2014c). Surfactants in bilge water are also likely to contribute to the formation of oil droplets, which might hence affect the toxicity of the oil fraction. Since the bilge water is released in the water column, planktonic species in areas with intense shipping are prime targets for environmental effects. Zooplankton, larvae and phytoplankton are particularly at risk since they have limited capabilities to avoid areas of oil-contaminated water.

The aim of the present study was to investigate the toxicity on the marine environment of treated bilge water from large passenger ferries sailing in Swedish waters. No effort has been made to rank different treatment technologies. The toxicity of the bilge water from seven ferries collected before and after treatment was tested with Microtox, a screening test with marine bacteria. Since zooplankton is the prime group affected by a continuous release of contaminated water to the sea, further experiments were conducted using treated bilge water from four of the ferries recording the survival and sub-lethal effects on the marine copepod *Acartia tonsa*.

2. Material and methods

2.1. Bilge water sampling

Treated bilge water, after passage through an oily water separator, was collected between May 2015 and February 2016 from seven passenger ships (ships A–G) ranging in size from 19,700–52,000 gross ton. Sampling was done between one and three times from each ship (Table 1). The oil separating equipment differed between the ships. Water from ships A and B was pumped from a storage tank to the treatment system without any mixing. The chemical composition of the bilge water may therefore depend on the level of the storage tank and on what time in the treatment process the sampling was carried out. Samples were therefore taken both at early operation (EO, Table 1) and late operation (LO). The bilge water in ships C to G was mixed during treatment and samples were taken only once at each sampling occasion. All sampling was done when the ships were in the port and not during operation at sea. The ship-mounted measuring instruments always reported the oil content to be <15 mg L^{-1}, which is the upper limit for bilge water to be released into the sea. The collected bilge water was stored in dark 1 L glass bottles at 4 °C in the dark until chemical analysis and toxicity tests.

Table 1
Treated bilge water samples collected from ships A–G. Samples from ships A1, A2, B1 and B2 were taken both at beginning of the bilge water treatment, EO (=Early Operation) and at the end of the treatment, LO (=Late Operation).

Sampling date	Ship ID	Chemical analyses	Test with Microtox	Test with *Acartia tonsa*
7 May 2015	$A1_{EO}$	X	X	X
8 May 2015	$A1_{LO}$	X	X	
2 June 2015	$A2_{EO}$	X	X	X
3 June 2015	$A2_{LO}$	X	X	
26 May 2015	$B1_{EO}$	X	X	X
27 May 2015	$B1_{LO}$	X	X	
15 June 2015	$B2_{EO}$	X	X	
15 June 2015	$B2_{LO}$	X	X	
17 Nov 2015	B3	X	X	
1 June 2015	C1	X	X	X
11 Nov 2015	C2	X	X	
11 June 2015	D1	X	X	X
15 June 2015	D2	X	X	
2 Dec 2015	D3	X	X	
26 Nov 2015	E	X	X	
27 Nov 2015	F	X	X	
10 July 2015	G	X	X	

2.2. Chemical analyses

All sampled bilge water was analysed for the total oil index and carbon fractions (>C10–C12, >C12–C16, >C16–C35 and >C35 –<C40), $\sum$PAH16, anionic surfactants and metals including a metalloid (V, Cr, Mn, Co, Ni, Cu, Zn, Fe, As, S, Cd, Pb and in some samples also Hg). Five ships were also analysed for cationic and non-ionic surfactants. The total oil index includes all hydrocarbons, alkanes and aromatic compounds. Accredited laboratories performed all analyses. Total oil index and oil fractions were analysed using GC-FID (methods EN ISO 9377-2, Z1 and TNRCC method 1006), PAH using GC–MS (method US EPA 8270 and EN ISO 6468), BTX using GC–MS Headspace and GC-FID (methods US EPA 624, US EPA 8260, EN ISO 10301, MADEP 2004, rev. 1.1), surfactants using UV–VIS spectrophotometry (methods EN903 and ISO7875-2), BOD7 according to EN1899-1 and CODCr according to TNV 757520.

2.3. Toxicity tests

2.3.1. Sub-lethal effects on the marine bacteria - Microtox

A standard Microtox screening (SS-EN-ISO 11348-3:2008) was conducted to test the toxicity of the treated bilge water. In this assay, toxicity is measured as the inhibition of bioluminescence of the marine bacteria *Vibrio fischeri*. The bacteria are exposed to the bilge water in a range of dilutions for 5 or 15 min. The dilution at which 20% and 50% inhibition of the luminescence occurs is recorded and termed EC_{20} 5 min/15 min and EC_{50} 5 min/15 min, respectively. In this study only EC_{20} and EC_{50} after 15 min exposure are reported.

2.3.2. Lethal and sub-lethal effects on the marine copepod Acartia tonsa

Detailed methods and statistical procedures of the copepod experiments are given in the SI. Briefly, bilge water from ship A (two sampling occasions A1 and A2), and ships B, C and D (one sampling occasion from each ship) were tested in three experiments where a dilution series was created ranging from 0.01 to 10% of bilge water. The animals were fed microalgae ad libitum during the experiments (*Rhodomonas baltica*, 30,000 cells mL^{-1}), which lasted for 48 h. We used egg production as a measure of reproduction, pellet production as a measure of feeding and dead females as measure of mortality.

2.4. Statistical treatment

For the copepods we used ANOVA to determine significant differences between controls and treatments and the dilutions of the bilge water were used as fixed factors. Vital rates of *A. tonsa* in the controls varied between experiments and all rates were therefore normalised to the controls before analysis. In case of significant treatment effects, Dunnett's post-hoc test was used to compare the controls with each treatment. A significance level of 0.05 was used. Since the mixture of

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