BALLAST WATER EXCHANGE: TESTING THE DILUTION METHOD (PETROBRAS, BRAZIL)

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ABSTRACT

The ballast water exchange method devised by PETROBRAS (Brazilian State Oil Company), the dilution method, is based on ballasting through the top of the tank while unloading by gravity through the bottom. This method is safe, even at high seas, for the ship's structure and crew members. In June 1998, a full-scale experiment was performed to assess the efficiency of this method on a segregated ballast tank of the oil carrier *M/V Lavras* (2,286m^3). A simulation model of its theoretical performance established sampling points in the tank, representing areas of different exchange rates. Sampling was done with a pneumatic pump (10L/min, 20mm-diameter hoses) which was efficient for phytoplankton (concentrated in a 20µm mesh), but zooplankton sampling required tows (200µm mesh) through a manhole. Sediment from the empty tank was sampled before and after the experiment. The amount of the original water that remained after exchanging 3 tank volumes (21 hours) depended on the parameter analyzed: chlorophyll *a* (14%), methylene blue (10%), density of phytoplankton cells (4%); only oceanic zooplankton groups were found, with dominance of oceanic copepods; and microalgae cysts/resting spores were close to non detectable in the water column. Sediment was not quantified, but visual observation after deballast showed that the thick layers previously present were partly washed out. Cysts/resting spores that remained in the tank (1-2 x 10^5.L^{-1}) indicate that sediment in ballast tanks represents a problem for further investigation.

INTRODUCTION

Domestic and international shipping is the major cause of the introduction of exotic species in aquatic environments, because vessels provide habitats for organisms that live in their ballast water, in sediments in the ballast tanks, and as hull fouling [1]. Potentially harmful algae, especially those that survive the voyage as resting cysts, have been introduced as exotic species [2].

The International Maritime Organization (IMO) has developed voluntary guidelines as a first step to address control and management of ships' ballast water. A working group of the Maritime Environmental Protection Committee (MEPC) is working on regulations for acceptance and implementation by all IMO member nations. These guidelines seek to establish management and treatment options that are efficient, safe for the ship and the environment, and cost effective.

A review of management strategies [3] indicated mid-ocean ballast exchange on route as one of the most promising options at present. Ballast exchange while in oceanic water, with increased salinity and oligotrophy, decreases the likelihood of introducing exotic species viable in coastal waters. There exist two methods tested to date: (1) the complete deballast-reballast procedure, which is not always possible, especially at high seas; and (2) the continuous flow-through exchange method that overfills the tank and floods the deck, which can pose problems to routine deck operations unless extra pipework is installed to overcome the problem.

The dilution method, devised by PETROBRAS (Brazilian State Oil Company), is based on loading ballast through the top of the tank while unloading by gravity through the bottom, at the same flow rate. A full-scale experiment was performed on the oil carrier *M/V Lavras* (PETROBRAS) to assess the efficiency of this method. The results presented here were submitted to the 42nd MEPC session and are now part of the "tool box" of ballast water management options under consideration by the Ballast Water Working Group.

MATERIALS AND METHODS

The experiment took place from 26 to 28 June 1998. The ballast water was taken while the ship was anchored close to the mouth of the Amazon River (lat. 00° 28.7 S; long. 047° 25.8 W; local depth =15m). It took 7 hours to ballast the tank. The ballast exchange was carried out en route, after the ship reached 200 n m offshore (depth > 2000m). It took 21 hours to exchange 3 tank volumes (one tank = 2,286m^3).

Characterization of coastal and oceanic waters used as controls was done by casting sampling devices from mid ship during ballasting (coastal) and between the second and the third ballast exchange (oceanic). Parameters used to indicate the efficiency of the method were: methylene blue, salinity, chlorophyll *a*, phytoplankton and zooplankton populations, and microalgae cysts/resting spores (water and sediment).

The *M/V Lavras* is a double hull vessel of 66,500t dw. The experiment was done in one of its 7 segregated ballast tanks (starboard, number 4). The tank cleaning system of this ship has an independent pump, online with the sea chest that connects to one deck line with valves

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Hallegraeff, G.M., Blackburn, S.I., Bolch, C.J. and Lewis, R.J. (eds)
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that can feed water to the ballast tank through 3 manholes that are 65cm in diameter. Three steel pipes (2m long, 15cm in diameter) were designed and manufactured for water injection. An orifice plate was manufactured and fitted online with the tank cleaning system so as to add a known concentration of methylene blue (dye used as tracer) to the water as it was being pumped to ballast the tank. Methylene blue was measured with a HACH's spectrophotometer (DR 2010).

A computer-simulated model of the performance of the method guided the placement of sampling points in the tank (Fig.1): 1, 2, 3, represented areas of higher exchange, while points A, B, C were "shadow" areas.

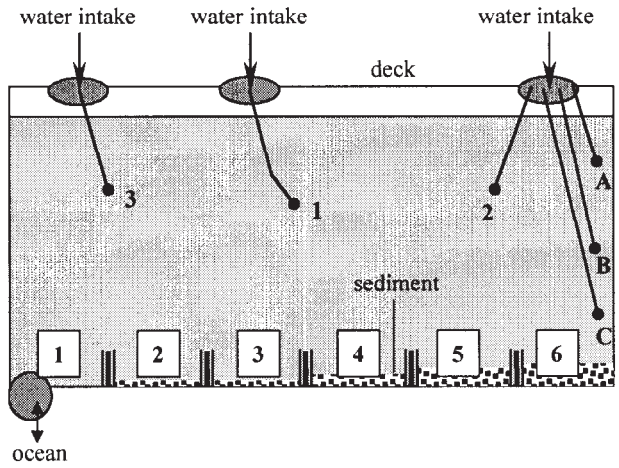

Fig. 1. Experimental tank (length=22m; hight=15m; width=6m): water column sampling points (1, 2, 3, A, B, C), sediment sampling points (boxes 1-6), water intake through manholes, and tank-ocean connection are shown.

Water from the tank was sampled by a pneumatic pump that delivered water through a 20mm-diameter hose (10L/min). The hoses were placed in the empty tank, before ballasting. Sampling was done before the beginning of the exchange (T_0), and at 3 other sampling times (T_1, T_2, T_3), that is, after each exchange of one complete tank volume. Each sampling lasted ca. 2 hours. This flow rate and diameter of the hose were efficient for phytoplankton, but not for zooplankton (see below).

Salinity was determined by Mohr-chloride titration and chlorophyll *a* was determined by a Turner® TD-700 fluorometer, after filtration through cellulose membrane (0,45µm) and extraction with 90% acetone [4].

Phytoplankton samples from the tank were collected by the pump (at least 100L) and concentrated by a 20µm-mesh net, while 1-L water samples were collected from the environment. Organisms larger than 20µm, with or without chloroplasts, were counted and identified by the settling technique. Average values of counts done in triplicate are reported (coefficient of variation <18%).

Zooplankton samples were taken from the tank by the pump and concentrated by a 200µm-mesh net. On-board observations showed that this sampling was not effective (discussed below). Samples were then collected directly in the tank with a 200µm-mesh net from 12m to the surface, while tows from the environment were taken from ca. 10m to the surface, all in triplicate. The organisms were sorted, identified and counted using a stereomicroscope through standard procedure [5].

Splits from the pump+net samples collected in the tank for phytoplankton were used for cysts/resting spores. Samples from the coastal environment were concentrated by a 20µm net from a known volume. Sediment samples in the empty tank were taken before and after the experiment by scraping only the surface layer to avoid material from the anoxic layer below (one sample for each of the 6 sections) (Fig.1). Mud deposition was limited to the sides of the bottom of the tank, where samples were collected, and on the longitudinals of the forward section. All sediment samples were processed for quantitative analysis [6] and counts were done by the settling technique.

RESULTS

The water used to ballast the tank (coastal) was considered markedly different from the water used for the exchange (oceanic) (Fig.2). The influence of the nutrient-rich discharge from the Amazon River was detected closer to shore through lower salinity, higher chlorophyll *a* and greater phytoplankton densities (with some freshwater species). The coastal phytoplankton revealed the dominance of chain-forming diatoms, while the oceanic was composed of naked and large-size armored dinoflagellates, coccolithophores and small pennate diatoms. Zooplankton groups present only on the coast were Gastropoda Larvae, Bivalve Larvae, Mysidacea, Hydromedusae, Echinodermatha Larvae, and Stomatopoda Larvae, while Foraminifera, Polychaeta, Fish Eggs, Fish Larvae, Salpidae, Amphipoda, Cladocera, and Pteropoda were restricted to oceanic waters. Cysts/resting spores in the water of the coastal site increased from surface ($34.L^{-1}$) to a depth of 7m ($108.L^{-1}$). Diatom resting spores comprised the bulk of the cells found.

In the tank, the average salinity increased from 31.61 (T_0) to 35.95 (T_3) (Fig.2). A trend of lower salinity at sites A, B and C suggest the presence of the "shadow" area indicated by the simulation model.

The amount of the original water that remained after exchanging 3 tank volumes varied according to the parameter analyzed (Fig.2): chlorophyll (14%), methylene blue (10%) or phytoplankton > 20µm (4%). These differences are expected and can be attributed to distinct behavior of each parameter in the tank and their methods of analysis. In the best case scenario (4%), only cells larger than 20µm were considered. In the worst case scenario (14%), all photosynthesizing organisms larger than 0.45µm were included, but most of the chlorophyll *a* (in average 80%) was present as phaeophytin throughout the experiment, indicating that organisms were photosynthetically inactive.

Ninety-one phytoplankton species were identified, but only 6 were common to both coastal and oceanic environments (their occurrences were not considered in the analysis). Two freshwater diatom species that were not in the coastal sample (*Aulacoseira granulata* and *Polymixus coronalis*) were detected in the tank water from T_0 to T_3. These species, commonly associated to sediments, were probably revolved from the bottom of the tank during ballasting. This ballast tank had not been cleaned for ca. 5 years, so that its sediment and associated biota represented a composite from different ports of the eastern coast of South America, from Brazil to Argentina, some of them located in rivers.

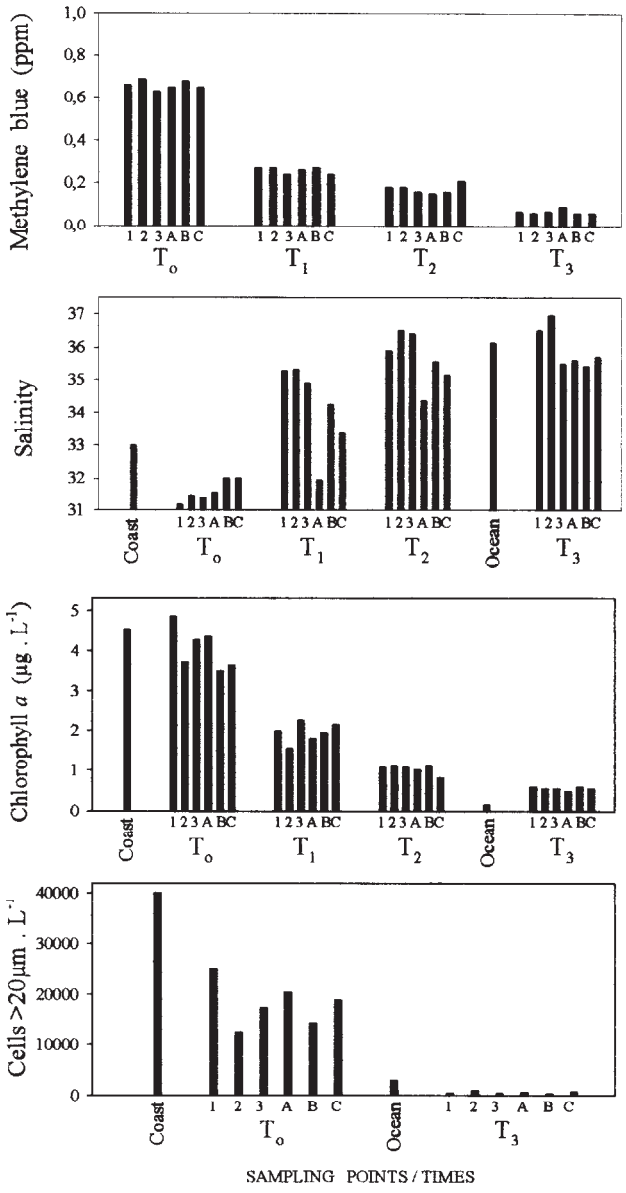

Fig. 2. Parameters analyzed during the ballast exchange: (a) methylene blue, (b) salinity, (c) chlorophyll *a*, (d) phytoplankton. For X-axes: coast and ocean are the controls from the environment; sampling in the tank was done before the exchange started (To), and after each exchange of one tank volume (T1-T3).

The pump greatly underestimated the concentration and composition of the zooplankton so that direct net hauls in the tank were also used (Tab.1). A stronger hose with greater diameter and higher flow rate could have counteracted the capability of larger and stronger swimmer species to escape from the pump sampling. Because of these methodological difficulties, only qualitative data is presented for the zooplankton.

Table 1. Zooplankton: comparison of sampling methods.

DATA PER SAMPLING TYPE	PUMP	NET TOWS
Time required	≅ 2 hours	≅ 10 min
Volume filtered	3.6 m^3	9.9 m^3
Mean density	33.8 $org.m^{-3}$	53.4 $org.m^{-3}$
Mean n° of groups	6	12
Size of organisms	200 - 2400 µm	200 - 7000 µm

Twenty-three zooplankton groups were found. Twelve groups were exclusively in the coastal or in the oceanic environment. Eleven groups were found in the tank: Copepoda, Decapoda, Cirripedia, Chaetognatha, Isopoda, Polychaeta, Siphonophorae, Foraminifera, Gastropoda, Echinodermata and Engraulidae. Of the groups found in the tank, three are considered predominantly coastal (Cirripedia Nauplius, Gastropoda Larvae and Echinodermatha Larvae) and two are preferentially oceanic (Foraminifera and Siphonophorae) [7]. All coastal groups were found at T_0, coastal and oceanic ones were present at T_2, but only Foraminifera and Siphonophorae were found at T_3. Copepods, found in all samples, confirmed this trend: the coastal species *Acartia lilljeborg* and *Pseudodiaptomus acutus* dominated at T_0, while the oceanic species *Farranula gracilis* and *Clausocalanus furcatus* dominated at T_3.

The microalgae cysts/resting spores found in the sediment and in the water column were mostly composed of diatom resting spores, with a minor contribution of dinoflagellate cysts (Fig.3). The concentrations in the water were three orders of magnitude lower than in the mud (10^2 and 10^5 $cells.L^{-1}$, respectively). Concentrations in the water decreased during the experiment. Sampling sites A, B and C, located in the section which originally had more accumulated sediment, showed the highest cyst/resting spore concentrations found in the water, probably due to ressuspension. The sediment was not quantified, but visual observation after deballast showed that the thick layers previously present, especially in section 6, had been partly washed out. The concentration of cysts/resting spores in the mud, however, increased in all sections investigated. Since the oceanic water can be considered a diluting agent rather than a source of cysts/resting spores, we speculate that their increase in the sediment may be attributed to their mobilization and redistribution from the sediment of the tank itself, due to turbulence caused during water exchange.

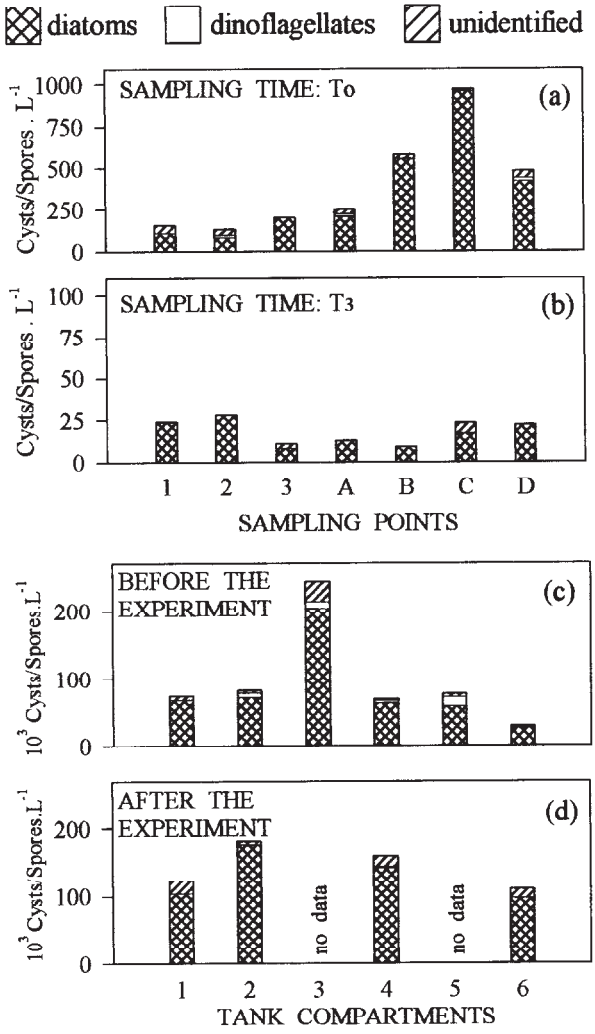

Figure 3. Cyst/resting spore in the tank: (a-b) in the water column and (c-d) in the sediment.

DISCUSSION

The dilution method is safe, even at high seas, for the ship's structure and crew members. The worst case scenario when assessing the effectiveness of the water exchange (14% of the chlorophyll *a*) showed that phytoplankton was photosynthetically inactive (present as phaeophytin). This was probably due to mechanical stress and darkness in the tank, as has been shown in studies of survival of phytoplankton in ballast tanks [8,9].

Species composition in the tank can be important for the degree of efficiency of the mid-ocean exchange, since diatoms are expected to sink while flagellates can remain in the water column [10]. In this trial of the dilution method, there was no stratification of the diatom-dominated community in the tank (no difference between sites A,B,C), probably due to the turbulence caused by the injection of the water through the manhole.

The turbulence in the tank was also important for the re-suspension of sediments (and its associated biota) that could, therefore, be discharged offshore. Nevertheless, high numbers of cyst/resting spores in the remaining sediment may still be delivered to the environment during further deballasting procedures, acting as a inoculum for species proliferation. Even complete deballast/reballast does not eliminate, for any type of vessel, all water and sediment from the tank. This residual water often contains more planktonic organisms which can be concentrated through sinking during the voyage, before the deballast/reballast procedure [11]. The amount of water exchange varies with tank design and older vessels do not seem to be as efficient as newer ones [12,13]. Once again, the turbulence induced by the dilution method could counteract, in part, this problem.

Salinity, the parameter representing the dissolved fraction in the tank, confirmed the simulation model (that is, section 6 of the tank represented a "shadow" area where dilution was more deficient). Future modeling can take into account the behavior of particles in the tank and further improve the degree of efficiency of the dilution method. Both the flow rate and the water intake system can be adjusted to adapt the method to other tank designs. The dilution method can be used in conjunction with other ballast management options (e.g., filtration, heat).

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