CHANGING CONCENTRATIONS OF BACTERIA IN SHIPS' BALLAST WATER DURING TRANSIT: ARE BALLAST TANKS INCUBATORS?

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Abstract

Ships' ballast water is a major source of biological invasions in coastal systems and contains a diversity of microorganisms, yet their population dynamics remain largely unexplored. We measured temporal changes in total bacteria concentration in 75 ballast tanks (34 with mid-ocean exchange and 41 unexchanged controls) across 21 ocean voyages, from multiple departure ports (5% of Mediterranean source, including Fos-sur-Mer and Tel Aviv) and representing all seasons. Bacteria concentration differences were tested as a function of depth, time, ballast management and season. Total bacteria decreased significantly over time, and the decrease was significantly greater in exchanged tanks. Increases over time occurred occasionally but infrequently in a few tanks (4% for both control and exchanged), suggesting growth (incubation). Across tanks, there was not a significant difference due to depth, as most tanks (85% controls and 89% exchanged) showed no vertical stratification. Overall, there were no significant seasonal effects in total bacteria dynamics across ballast tanks.

Keywords : Bacteria, Species Introduction, Migrant Species.

Introduction

The movement of ballast water by commercial ships is a major transfer mechanism for organisms throughout the world, resulting in established non-native populations (biological invasions) that are dramatically changing the structure and function of coastal ecosystems. Several recent studies underscore the large concentrations of protists, bacteria, and viruses in ballast water [1 - 4]. The dynamics of microorganisms, however, during transit remains largely unexplored [1, 2]. There has been some suggestion that conditions in ballast tanks may operate to increase microorganism concentrations, serving as incubators. Here, we test whether bacteria increase over time in ballast tanks, comparing the response in tanks that underwent ballast water exchange (BWE or ocean flushing to reduce the risk of invasion) to untreated control tanks.

Methods

From 1999-2005, we sampled 75 different ballast tanks to measure changes in total bacteria concentration. One to several ballast tanks were sampled across 21 different ocean voyages, from multiple routes and source ports (including the Mediterranean ports of Fos-sur-Mer (France) and Tel Aviv (Israel)), seasons, and ship types. A subset of the tanks (n=34) underwent BWE and parallel measures were taken for unexchanged control tanks (n=41) on the same voyage. For each tank, replicate samples were collected from at least two discreet depths, preserved for analysis, and quantified using direct counts and flow cytometry. We compared the effect of depth, season, time, and BWE on changes in total bacteria concentration.

Results

For both control and exchange tanks, bacteria concentrations differed significantly between the initial samples (T0) and samples after the first exchange was conducted (T1). On average, a lower concentration was found at T1, although some individual tanks (3 out of 23 control tanks and 3 out of 28 exchange tanks) had significantly higher concentrations at T1. In the latter exchange tanks, all observed increases occurred during the summer season. Across all voyages, there was a clear and significant difference between exchanged and control tanks, with exchange exhibiting lower average concentrations independent of depth The sharpest decrease occurred after the first exchange and stabilized afterwards. Even though time had an effect in reducing bacteria concentration, mid-ocean exchange had a greater effect than time alone. An incubation effect was found in 4% of the each control and exchange tanks. Overall, there was not a significant effect of depth on total bacteria concentrations for either exchanged or control tanks. Stratification was observed, however, in some individual tanks. For initial (T0) samples, stratification was found in 11 of 75 tanks, being significantly higher at the surface for all but 1 of these. For a later sampling time (T1), a stratified distribution was found in 6 control and in 2 exchange tanks; of these eight cases, higher numbers of bacteria occurred in deeper water for 2 control and 1 exchange tank. Therefore, a homogeneous distribution was typically found. Stratification only occurred in around 15% and 11% of the cases, for initial and later samples, respectively. Season had an effect on initial (T0) bacteria concentrations, being significantly greater in spring. For control tanks, the bacteria decreased with time for spring, summer and fall voyages, while increasing in the only winter tank. For exchanged tanks, concentration decreased after ballast exchange, except in summer when bacteria appeared to increase but not significantly, indicating a possible input of bacteria from mid-ocean. Thus, there was not a concrete difference in dynamics among seasons.

Discussion

Our results showed that concentration of bacteria decreased over time in both control tanks and exchanged tanks, although the decline in exchanged tanks was significantly greater. Ballast water exchange significantly decreased the bacteria abundance after the first exchange, becoming constant thereafter. This difference between exchange and control tanks was not observed for the single voyage by Drake *et al*. [2], and also included as 4 tanks in our dataset, where no differences were observed between these treatments. One possible explanation for this disparity may lie in the source water, originating from the eastern Mediterranean (Tel Aviv) in the latter study. In a second voyage from the Mediterranean (Fos-su-Mer), bacteria concentrations followed a similar pattern with no differences between control tanks (n=2) and exchanged tanks (n=2) after exchange (T2). This further suggests a different dynamic for Mediterranean sourced ballast. Overall, we observed an increase in total bacteria in a few control tanks. For the exchanged tanks, the incubation effect appeared in 3 tanks, whose voyages were all in summer; furthermore, 2 of those tanks were from the same ship, indicating more likely an effect of the ballasting spot instead of a growth effect. Murphy *et al*. [5] found that some crustacean taxa were more abundant in shallow than in deeper ballast waters. Here, the overall result across voyages was a uniform distribution, even though stratification was observed for a few individual tanks, usually with higher numbers in surface waters. Seasonal effects have previously been documented [2], where bacterial abundances were higher in warm seasons than in cold ones. Here, spring concentrations of bacteria were found to be significantly higher than for the other seasons. No taxonomical identification was conducted in this study, such that our data cannot address the dynamics of individual taxa. Specific components (genotypes) of the bacteria may behave differently from the total, and there is likely to have been considerable compensatory changes in genotypes both through time and as a function of exchange.

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