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Potential ballast water transfer of organisms from the west to the east coast of India: Insights through on board sampling

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ABSTRACT

The possibility of translocation of organisms via ship's ballast water (BW) during a voyage from Hazira on the west coast to Visakhapatnam on the east coast of India was assessed. Samples of BW during the voyage and discharge and sediment collected subsequent to discharge of BW were collected and analyzed for different abiotic and biotic components. It was observed that the salinity did not change, whereas temperature and pH of BW increased marginally during the voyage. A marginal increase in the dissolved oxygen is observed during rough-very rough sea conditions. A sharp decline in the phytoplankton and zooplankton abundance observed in the initial ballast tank sample compared to natural seawater indicates the impact of ballast water pumping on the plankton community. Changes in the sea state during the voyage (slight-moderate to rough-very rough) resulted in a higher sediment suspension rate and suspended particulate matter and this coincided with higher bacterial abundance followed by increase in phytoplankton. An increase in the phytoplankton abundance in the discharge water could be attributed to the inoculum from the sediment. The abundance of zooplankton decreased from the start till the end of the voyage, with high numbers of dead zooplankton in the discharge sample.

1. Introduction

Ships' ballast water is a potential transfer mechanism (vector) of coastal marine species and is associated with at least one-third of the hundreds of documented marine invasions worldwide (Hewitt and Campbell, 2010). This vector made its debut in the mid-1850s, when coal shippers in England developed bulk carriers using efficient water ballast rather than cumbersome 'dry' ballast (Carlton, 1985; Davidson and Simkanin, 2012). Ballast water and fouling of ship's hull and sea chests have been recognized as the principal vectors of potential introduction of aquatic species, and is estimated to be responsible for the transfer of between 7000 and 10,000 different species of marine microbes, plants and animals globally each day (Carlton and Geller, 1993; Carlton, 1999; Gollasch, 2002). The introduction of vegetative and resting-stages of aquatic micro-organisms including potentially pathogenic forms such as *Vibrio cholerae* O1, O139 (Carlton and Geller, 1993; Ruiz et al., 2000) have also been identified with ballast water. Consequently, a precautionary approach suggests that every vessel transporting ballast water should be treated as a potential risk.

Since just 1 m^3 of ballast water may contain up to 50,000 zooplankton specimens (Locke et al., 1991, 1993; Gollasch, 1996; Kabler, 1996) and/or 10 million phytoplankton cells (Subba Rao et al., 1994), control of bioinvasion requires an understanding of the pathways. It is also noted that first step in this process is the initial introduction, the process by which organisms are transported from native to new habitats, outside their natural range (Wonham et al., 2001; Puth and Post, 2005). This results in primary introductions, which are followed by the secondary introductions as the species disperse from its new habitat (Wasson et al., 2001; DiBacco et al., 2012). Ballast water is a phyletically nonselective transport vector (Carlton and Geller, 1993), and variability among vessel type, source region, transit route, and duration can influence the nature, density, and viability of organisms being transported (Verling et al., 2005).

Intra-coastal ballast water transport is gaining increasing attention as a significant vector for the secondary transfer of non-indigenous organisms (Wasson et al., 2001; Cordell et al., 2009; Simkanin et al., 2009; Lawrence and Cordell, 2010). Intra-coastal vessels often have shorter voyages, and organism survivorship is greater on shorter voyages (Williams et al., 1988). Simkanin et al. (2009) examined intra-coastal ballast water transfer along with the presence of non-native species in receiving ports and suggested that intra-coastal transport may be a significant vector for the secondary spread of organisms. The pattern of inter-regional transfer of non-indigenous species within the EEZ of a country is largely unknown.

India has a coastline of nearly 7500 km with several ports situated on the east and the west coast. These ports receive ballast water both from transoceanic ships and from inter and intra-coastal transport, indicating possibilities of both primary and secondary introductions. Ballast water sampling studies carried out in several European ports have shown that

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most of the ballast water discharged originates from nearby sea areas indicating the importance of secondary introductions (Marquard, 1926; Essink and Kleef, 1988, 1993; Harbison, 1994; Gollasch, 1996; Gollasch and Leppäkoski, 1999; Ribera et al., 1996). Proper control and management of ship's ballast water is therefore a major environmental challenge. The IMO convention, Guidelines for risk assessment under regulation A-4 of the BWM convention (G7) provide for exemptions for ships on a voyage or voyages between specified ports or a voyage between specified ports or location and are granted to ships that do not mix ballast water or sediment other than between the specific port or locations.

Since the early 1980s several studies have undertaken ballast water sampling to understand the compositional changes in ballast water (Williams et al., 1988; Carlton and Geller, 1993; Hallegraeff, 1993; Rigby and Hallegraeff, 1993, 1994; Harbison, 1994; Macdonald and Davidson, 1997; Hay et al., 1997; Gollasch, 1996, 1998; Ribera et al., 1996; Lavoie et al., 1999; Olenin et al., 2000; Taylor and Bruce, 2000; Gollasch et al., 2000a, 2000b; Ruiz et al., 2000; Wonham et al., 2001; Murphy et al., 2002; Verling et al., 2005; Burkholder et al., 2007; Sun et al., 2010; Altug et al., 2012). The present study is the first of its kind from the tropical habitat around the subcontinent of India, where in on board sampling of ballast water was carried out during a voyage from Hazira Port, Gujarat (West coast of India) to Visakhapatnam port, Andhra Pradesh (East coast of India). Observations included quantification of bacteria, phytoplankton, zooplankton and physico-chemical parameters of ballast water from the ship's ballast tank while in voyage and ballast water discharged at the port.

2. Materials and methods

The on board sampling of ballast water was taken up on a bulk carrier. The dead weight tonnage of the ship was 129,237 and gross tonnage was 67,713. The total ballast water capacity of the ship was 55,994 m^3 with 23 ballast tanks on board. The sampling was undertaken from Hazira port (21.0837°N; 72.6283°E), Gujarat (West coast of India) to Visakhapatnam port (17.6831°N; 83.2399°E), Andhra Pradesh (East coast of India) during December 2009, while the ship was sailing in full ballast. The natural seawater (source ballast water) into the ballast tanks was taken from the outer anchorage at Hazira after emptying the cargo. Cleaning history of ballast tank was not known. At Hazira, the discharge port for cargo, it takes about 3–4 days for unloading in addition to 11–12 days of voyage from Visakhapatnam to Hazira. There is a possibility top side tank exposed to sunlight could be dried out because of humid tropical temperature ranging from 29 to 32 °C in this case. In Visakhapatnam, at the time of cargo loading, the ballast tank was emptied completely, sediment accumulation was minimal and we could sample the sediment.

The sea conditions reported during the voyage were slight-moderate, moderate, rough and rough-very rough as per the Beaufort scale (Table 1). The tropical cyclone 05B hit the Northern Indian Ocean with maximum sustained winds of 40–50 mph during 5th and 6th days of this voyage (Table 1) which lasted for 12 days.

2.1. Sample collection

The samples of ballast water during the voyage were taken from ballast tank ST-4 (Star board Topside Tank) by opening the cover of the manhole of the ballast tank. The manhole was opened for a very short time during the sampling to avoid organisms concentrating at the manhole opening, the zooplankton sample were collected with net towing in the entire water column of the tank and not by collecting with a bucket at the opening of the manhole. Zooplankton collection was done first during every sample collection as they would be the first one to concentrate at the manhole opening. The depth of the tank was about 5 m. Before sailing out from Hazira, the seawater from the outer anchorage was sampled (natural seawater – SW) by using a Niskin sampler of 10 l capacity for the analyses of all the parameters.

During voyage the samples from the ballast tanks were collected twice daily at 0900 h and 1700 h (BWS1 to BWS19). During the rough sea conditions (Day 5 and 6) we could collect the samples from the ballast tank. On day 5 (December 10, 2009) there was a depression due to the cyclonic storm and on day 6 (December 11, 2009) at 0530 IST this was upgraded to deep depression and at 1430 IST to a cyclonic storm. On day 7 (December 12, 2009) at 2330 IST the cyclonic storm was downgraded to a deep depression and it made a land fall over Sri Lanka coast. During this duration, the ship was not moving and captain was holding the ship away from the actual track of the storm. The ship being a bulk carrier (overall length – 263 m) and it was not moving with high speed, it was not rolling and we were allowed to take the sample. As mentioned earlier that the tank was not filled up to the top, the water was not overflowing on the deck. The samples (DISC1 to DISC4) were also collected during discharge at the Visakhapatnam port from the same tank which was sampled during the voyage until the entire ballast water was deballasted. At the time of cargo loading the ballast tank was emptied completely and very little ballast water was remaining in the ballast tank, only in the crevices of the tank bottom due the paneling of the tank bottom with steel panels. Sediment samples were also collected after the tank emptied on discharge of the ballast water. The physical parameters, salinity, temperature and pH were measured using multiparameter probes. 125 ml glass bottles were used to collect and fix samples for the estimation of dissolved oxygen content (DO) (Parsons et al., 1984). The samples for suspended particulate matter (SPM) were collected in 1 l plastic bottles. The settling rate of suspension sediment was estimated by deploying an acrylic pipe of 7.5 cm (inner diameter) diameter sealed from the bottom at a depth of 3 m in the tank. The entire volume of water from the pipe was decanted into a PVC bucket after every 24 h for the analyses of suspended particulate matter. Samples for nutrients were collected in

Table 1
Details of sampling dates, voyage days and in-tank samples collected during the voyage and discharge sampling, as well as weather and sea conditions during the voyage (Mod: Moderate; V. Rgh: Very Rough; SW: Source water; BWS1 to BWS19: Ballast water sample 1 to 19; DISC1 to DISC4: Discharge sample 1–4).

Date	Days	Samples	Position		Wind		Swell height (m)	Sea descriptive terms	Sea state
			Latitude	Longitude	Direction	Force			
6-Dec-09	1	SW	AT HAZIRA ANCHORAGE		N	5	1.5	Slight–moderate	3–4
7-Dec-09	2	BWS1, BWS2	19° 45′ N	072° 19′ E	N	5	2	Moderate	4
8-Dec-09	3	BWS3, BWS4	15° 28′ N	073° 33′ E	N	5	2	Moderate	4
9-Dec-09	4	BWS5, BWS6	11° 17′ N	075° 28′ E	N	5	2	Moderate	4
10-Dec-09	5	BWS7, BWS8	07° 31′ N	077° 48′ E	NE	6	4	Rough	5
11-Dec-09	6	BWS9, BWS10	06° 04′ N	081° 34′ E	NE	6	4	Rough	5
12-Dec-09	7	BWS11, BWS12	07° 20′ N	083° 08′ E	SW	5	2.5	Moderate	4
13-Dec-09	8	BWS13, BWS14	07° 12′ N	083° 09′ E	SW	5	2	Moderate	4
14-Dec-09	9	BWS15, BWS16	11° 58′ N	083° 14′ E	NE	7	4	Rough–very rough	5–6
15-Dec-09	10	BWS17, BWS18	16° 41′ N	083° 20′ E	NE	6	2	Rough	5
16-Dec-09	11	BWS19, DISC1, DISC2	AT VIZAG PORT		NE	3	0.5	Slight	1
17-Dec-09	12	DISC3, DISC4	AT VIZAG PORT		NE	3	0.5	Slight	1

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