Marine bioinvasion: Concern for ecology and shipping

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Marine bioinvasion – introduction of marine organisms alien to local ecosystem through ship hulls and ballast water – has serious consequences to native biota, fishery and general coastal ecosystem. Over 80% of the world cargo is mobilized transoceanically and over 12 billion tones of ballast water is filled at one part of the ocean and discharged at the other. These ballast waters offer conducive situation for bacteria, viruses, algae, dinoflagellates and a variety of macro-faunal larval/cyst stages to translocate to alien regions, usually along the coasts of the continents. As an example, there are over 18 species of animals and plants documented along the Indian coasts as those that might have got invaded and established. They can cause deleterious effects to local flora and fauna through their toxigenic, proliferative and over-competitive characteristics. This article points out the threats arising out of marine bioinvasion and various technological developments needed to deal with this unavoidable scourge in global shipping transport.

BIOINVASION refers to introduction of an alien organism(s) into an ecosystem. When in its native environment, the invading organism lives in semblance and is controlled by ecosystem interactions. Once in an alien environment, introduced species can turn out to be a threat, bringing about untold, often undesirable imbalances in the ecosystem. The two major pathways of marine bioinvasion are intentional, for aquaculture gain or unintentional introduction, through a ship's ballast water discharge and fouling of ship hulls. Shipping moves over 80% of the world cargo and transfers about 12 billion tons of ballast water throughout the global oceans each year[1,2]. The impact of unintentional invasion includes changes in biodiversity and restructuring of the food web. The introduction of new species can have a direct impact on the society and human health by affecting the fisheries and causing health hazards. The health hazards are generally caused by build-up of toxins in the food chain caused by Harmful Algal Blooms (HAB) (Figure 1). HAB is popularly referred to as 'Red Tides' and their incidences have been rising the world over. Ballast water has been considered one of the important vectors for the spread of these organisms. The toxic effects of these harmful algae can lead to fatality in human beings through paralytic shellfish poisoning (PSP) and cause health concerns through diarrhoeatic shelfish poisoning (DSP). Human death due to PSP has been recorded in India[3]. India being one of the major maritime countries, is susceptible for bioinvasion from the rest of the world oceans and hence warrants a close watch.

Ballast is any material used to weigh down and/or balance the ships. It helps in submergence of propeller and rudder for steerage. For thousands of years, ships carried rocks and/or metal as solid ballast. Ships of modern times use sea water for ballasting. When a ship empties its cargo, it takes in water as ballast to maintain its stability and structural integrity. Conversely, when it loads cargo, the ballast water is discharged usually in the vicinity of ports just prior to loading the cargo from an exporting country. Sea water loaded for ballast purposes contains a gamut of organisms and their propagules. In the wild, natural processes control their sustenance. However, their hostage status in the dark ballast waters leads to alterations in physiological and population structure of these organisms.

Changes in the composition of the population may occur in four different ways (Figure 2). Three of the four possibilities (marked with a 'tick') can lead to an invasion. In an alien environment, the capability of introduced organisms to establish and its rate is geographically variable and is influenced by the biokinetic range of temperature and salinity, and usually controlled by the local ecology. It is pertinent to note that marine bioinvasion concern is a two-way traffic, i.e. what is native to us can be risky and alien to others and vice versa.

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Many cases of marine bioinvasion have been reported and their harmful effects on the ecosystem and human health have been documented. For example:

(1) *Mnemiopsis leidyi*, an opaque comb jellyfish around 10 cm long, entered the Black Sea in early 1980s as a stowaway in ballast water on a ship from the United States. *M. leidyi*, which had until then lived in bays along the eastern seaboard of the United States, encountered no predators in the Black Sea but food in plenty. It devoured the eggs and larvae of a wide variety of fish that led to a collapse of the fishing industry. The fish catch fell by 90% in six years. By 1990, the total biomass of *M. leidyi* in the Black Sea had reached an estimated 900 million tons, ten times the total annual fish catch from all the world's oceans[4].

(2) The zebra mussel, *Dreissena polymorpha*, was first discovered in North America in Lake St Clair, Michigan in 1988. This species is native to Europe and is believed to have been introduced in 1983 or 1984 from trans-oceanic ships which discharged freshwater ballast containing planktonic larvae or young adults[5]. It has now spread to infest more that 40% of the United States waterways, fouls the cooling water intakes of the industry and may have cost US$ 5 billion in control measures since 1984 (ref. 2).

(3) Black-stripped mussel, *Mytilopsis sallei*, has been reported from Mumbai and Visakhapatnam[6,7]. This species is a native of tropical and subtropical Atlantic waters and is reported to have invaded the Indian waters sometime during 1960s. It has also spread to Hong Kong and threatened Australia.

(4) Green crab, *Carcinus meanas*, a native of Europe, is found in Sri Lankan waters. The molluscs and crustacean population on which this crab preys upon can, therefore, be affected.

(5) *Vibrio cholerae* 01 and 0139 is the causative bacteria for the human epidemic cholera, and can be transported through ballast water[8]. There is strong evidence linking cholera epidemic and climate[8–10]. As the bacteria are capable of forming associations with plankton, their survival and sojourn in the ballast water tanks are much easier.

A list of organisms which could have been translocated into our waters from other ports and between the coastal locations of India, is given in Table 1. There could be more such examples and their elucidation is needed.

India is dotted with 12 major ports and a number of minor ports. These serve as gateways for marine bioinvasion. In addition to introduction of alien species in these marinas, the threat of its spread to neighbouring environments and the coral reefs of Andaman, Nicobar and Lakshadweep islands is a distinct possibility. In light of this, it is essential to monitor all the ports simultaneously and adopt suitable ballast water-management protocols, first to delineate the already invaded species and then to check such invasions in the future.

During transportation, changes in composition of ballast water can occur, influencing the nature of biota and shifts in dominant species. Compositional changes in ballast water can happen due to the following reasons:

(1) Stagnation inside the ship will curtail the ballast water ventilation. Therefore, there is no fresh oxygen supply. Living organisms need oxygen for their biochemical functions. Bacteria require the same for decomposing non-living organic substrates in the water. In the absence of replenishment, the oxygen in ballast water, depending on the duration of voyage, will be depleted, leading to prevalence of sub-oxic or anoxic conditions.

Figure 1. Toxin accumulation pathways during the outbreak of harmful algal blooms.

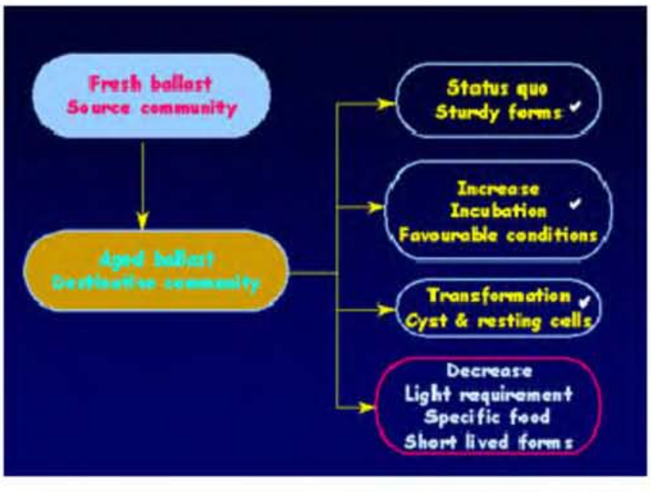

Figure 2. Four scenarios of change in community structure of organisms in ballast water through voyage.

Under these conditions, there will be shifts in the composition of species, with tolerant ones predominating.
(2) Prevalence of low oxygen conditions can lead to lowering of oxidation potential and pH in ballast water, which can promote leaching of metal ions toxic to organisms from particles, sediments and corrosion-resistant paint of the ship. Changes in physico-chemical characteristics of ballast water lead to alterations in speciation of metal ions and thereby affect their precipitation equilibria, and nature and extent of toxicity.
(3) Oxygen depletion may result in the accumulation of remains of organisms in water in particulate form. This together with inorganic colloids, formed from either *in situ* coagulation or present originally in ballast water, can lead to the formation of sediments that settle at the bottom. Presence of particulate and dissolved organic matter can facilitate proliferation of bacteria and virus that may withstand drastic changes in physico-chemical conditions.

When the ballast water, that has possibly undergone changes mentioned above, is discharged at a port or a coastal region, it can influence the local biology since this water is low in oxygen and may contain toxic metal ions. The latter can harm the biota, at least temporarily, before this water is carried away from the discharge point and diluted by mixing with the local waters. However, the most harmful effects of this discharge will come in the form of diseases to the local organisms from bacteria and virus transported from the place of origin or formed during the transportation.

The Indian seas, Bay of Bengal and Arabian Sea, are hydrographically and biogeochemically different. Therefore, if water from one port bordering Bay of Bengal, which may favour the growth of certain organisms, is carried through the ballast over to another distant one on the west coast of India that might house diverse species of organisms, then the transportable organisms, including bacteria in the ship's ballasts can reach the second port from the first and may prove ecologically symbiotic or disastrous to biota in the recipient port. Therefore, it is important to study the effects of possible bioinvasion among maritime ports within our country, that will also help us to modify and strengthen our strategies on ecological conservation.

This case study can be carried out in two modes: (1) Intense studies on biodiversity in and around the ports identified. These studies should monitor physico-chemical conditions, microbial and other higher organisms. Nature and type of marine species and their densities are of paramount importance. (2) Continuous monitoring of changes in physico-chemical properties and the resultant

Table 1. Inter- and intra-translocation of organisms in Indian waters

Common name	Species	Native of	Introduced to	Reference
Alga	*Monostroma oxyspermum*	Northeast Atlantic, Northwest Pacific	West coast of India	11
Hydroid	*Mercierella enigmata*	Australia	Indian Ocean	12
Anemone	*Eugymnanthea*	?	East coast of India	13
Mussel	*Mytilopsis sallei*	Atlantic waters	East coast and west coast of India	6,7
Wood-borer	*Lyrodus medilobata*	Indo-Pacific, Hawaiian Islands, Marshall Islands, New Zealand, Australia, Virginia, Bermuda	West coast of India	14
	Nausitora dunlopei	Cochin	Goa	15
	Teredo fulleri	Gulf of Mannar	Okha	15
Barnacles	*Balanus amphitrite* var *stutsburi*	West coast of Africa	West coast of India	16
	B. amphitrite hawaiiensis	Malay Archipelago and Persian Gulf	Mumbai	17
Isopod	*Cilicaea lateraillei*	Indonesia, the Philippines, Sri Lanka, S. Africa, Red Sea, Australia	Arabian Sea	18
Amphipod	*Stenatho gallensis*	East coast of India	West coast of India	19
	Maera pasifica	East coast of India	West coast of India	19
	Podocerus brasileusis	East coast of India	West coast of India	19
	Erichthonins brasileones	East coast of India	West coast of India	19
Bryozoa	*Barentsia ramose*	Pacific, California, Belgium	Indian Ocean	20
Ascidian	*Styela bicolor*	Gulf of Siam, Java, North Australia, Banda Sea, Ambonia and the Philippines	East coast of India	21
	Phallusia nigra	Bermuda, Brazil, Red Sea, Gulf of Eden	Tuticorin harbour	22
	Eusynstyela tincta	Atlantic, Mozambique, Red Sea, Gulf of Suez, Africa, Sri Lanka	Tuticorin harbour	22

Table 2. Technological options under consideration for ballast water-treatment/management

Technology	Principle	Constraint
Filtration	Particle elimination	Maintenance of adequate filtration rates to cater to large volume and flow. Elimination of micro-sized organisms (< 50 μm) yet to be realized under practical conditions.
Ozonation	Disinfectant	Effectiveness and operational hazards need to be evaluated. May produce adverse corrosive effects.
Heat	Thermal shock (elevation of temperature to 40–45°C)	Persistence of spores and thermophiles. Additional heating or waste heat availability in ship's engine room. Needs design consideration.
Deoxygenation	Removal of dissolved oxygen under high vacuum	Cysts and spores can continue to thrive. Needs design consideration.
Gas supersaturation	Under low hydrostatic pressure multicellular organisms suffer from embolism and haemorrhage	Effect depends on vascularization of organisms. May not affect dinoflagellates. Removal of passivation film in the tanks, promote sulphur-reducing bacteria leading to increased corrosion.
Chemical treatment	Biocide	By-product should be non-toxic. Setting up of treatment systems on-board. Health risk.
Ultraviolet radiation	Irradiation	Effectiveness to be evaluated. May require a pre-treatment system to filter out sediments associated with ballast water.
Ship design and operational issues	Continuous flow through exchange of ballast water	Design consideration for old vessels.

changes in microbes/animals/phytoplankton in water being carried in the ship's ballasts, from the source port to the recipient port, during the transit.

A few institutions, including the National Institute of Oceanography have been addressing the issue of alien species in our waters. Studies on alien species or strains or types of bacteria, viruses, fungi, phytoplankton and zooplankton are not available. There are difficulties in proving the origin of these groups conclusively. A concerted effort must begin on these groups not only to recognize the incidences, but also to understand their adaptability and impact in and around our waters. This is particularly important to pin-point the causes of depletion, migration, overall changes in population dynamics as well as epizootics among the native communities. With the advent and ease of applying molecular detection techniques, the visibly impossible task of documenting and proving the invasion events is becoming a reality that needs to be encouraged.

The International Maritime Organization (IMO), with funding provided by Global Environment Facility (GEF) through the United Nations Development Programme (UNDP), has initiated the Global Ballast Water Management Programme (GloBallast). Six countries (Brazil, China, India, Iran, South Africa and Ukraine) have been identified for the initial phase of this programme. Mumbai has been chosen as the demonstration site for this activity in India.

The IMO has an overall objective of reducing the transfer of harmful marine species in ships ballast water, by assisting countries to implement existing IMO voluntary guidelines for the control and management of ships' ballast water in order to minimize the transfer of harmful aquatic organisms and pathogens. The GloBallast is also involved in the preparation of new international convention on ballast water currently being developed by IMO. Some of the techniques that are being considered are summarized in Table 2.

The main management measure recommended under the existing IMO ballast water guidelines is ballast exchange at sea. It is widely recognized that this approach has many limitations, including serious safety concerns and the fact that translocation of species can still occur even when a vessel has undertaken complete ballast exchange.

One of the problems currently faced by the global R&D and shipping communities is that there are currently no internationally agreed and approved standards and in particular, effectiveness standards for the evaluation and approval of new ballast water-treatment systems that are being developed and those available. These aspects have to be evaluated. Thus, in addition to delineating the ecological consequences of alien species bioinvasion, it is extremely important that alternative, effective ballast water-treatment methods are soon developed.

1. *Ballast Water News*, GloBallast, IMO, GEF, UNDP, 2000, 1.
2. *Stopping the Ballast Water Stowaways*, Global Ballast Water Management Programme, IMO, March 2001.

3. *Harmful Algae News*, IOC, UNESCO, 1998, 17.
4. Pearce, F., *New Sci.*, 1995, **2003**, 38–42.
5. Ahlstedt, S. A., *J. Shellfish Res.*, 1994, **13**, 330.
6. Karande, A. A. and Menon, K. B., *Bull. Dept. Mar. Sci. Univ. Cochin*, 1975, **7**, 455–466.
7. Raju, G. J. V. J., Rao, K. S. and Viswanadham, B., *Marine Biodeterioration Advanced Techniques Applicable to the Indian Ocean* (eds Thompson, M. F., Sarojini, R. and Nagabhushanam, R.), Oxford and IBH, New Delhi, 1988, pp. 513–525.
8. Ruiz, G. H., Rawlings, T. K., Dobbs, F. C., Drake, L. A., Mullady, T., Huq, A. and Colwell, R. R., *Nature*, 2000, **408**, 49–50.
9. Colwell, R. R., *Science*, 1996, **274**, 2025–2031.
10. Lobitz, B., Beck, L., Huq, A., Wood, B., Fuchs, G., Faruque, A. S. G. and Colwell, R. R., *Proc. Natl. Acad. Sci. USA*, 2000, **97**, 1438–1443.
11. Untawale, A. G., Agadi, V. V. and Dhargalkar, V. K., *Mahasagar Bull. Natl. Inst. Oceanogr.*, 1980, **23**,179–181.
12. Chandramohan, P. and Aruna, Ch., *Recent Developments in Biofouling Control* (eds Thompson, M. F., Sarojini, R. and Nagabhushanam, R.), Oxford and IBH, New Delhi, 1994, pp. 59–64.
13. Raju, P. R., Rao K. M. and Kalyansundaram, N., *Curr. Sci.*, 1974, **43**, 52–53.
14. Santhakumaran, L. N., *Mahasagar Bull. Natl. Inst. Oceanogr.*, 1986, **19**, 271–273.
15. Santhakumaran, L. N., *ibid*, 1985, **18**, 57–61.
16. Wagh, A. B., *J. Bombay Nat. Hist. Soc.*, 1974, **70**, 399–400.
17. Bhatt, Y. M. and Bal, D. V., *Curr. Sci.*, 1960, **11**, 439–440.
18. Venugopal, V. P. and Wagh, A. B., *Biol. Oceanogr.*, 1987, **5**, 133–136.
19. Venugopal, V. P. and Wagh, A. B., *Mahasagar Bull. Natl. Inst. Oceanogr.*, 1986, **19**, 213–215.
20. Satyanarayana Rao, K., Saraswathi, M. and Bhavanaraya, P. V., *Marine Biodeterioration Advanced Techniques Applicable to the Indian Ocean* (eds Thompson, M. F., Sarojini, R. and Nagabhushanam, R.), Oxford and IBH, New Delhi, 1988, pp. 57–79.
21. Renganathan, T. K., *Curr. Sci.*, 1981, **50**, 1008.
22. Meenakshi, V. K., *Indian J. Mar. Sci.*, 1998, **27**, 477–479.

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