

# A perspective of marine bioinvasion

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Bioinvasions are generally taken note of only when their impacts are felt. The impacts directly experienced by the society can be economical (loss of fishery or water as a resource) and human health related (for example, cholera epidemic, toxicity due to micro algal contamination). The ecological impacts, on the other hand, are complex and dependent on the interaction between the invader and the native community. The cost of invasion is generally related to how early one responds to the problem, and it increases with the lapse of time. Many cases of marine bioinvasion have been reported and their harmful effects on the ecosystem and human health have been documented. This paper provides an overview of the factors that influence the success of invasive alien species. Translocation of organisms through ships' ballast water is considered to be one of the important issues threatening the naturally evolved biodiversity, and consequences of such invasions are being realized increasingly in the recent years. International efforts underway to address this issue are brought out in this paper.

## A perspective of marine bioinvasion

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 and often undesirable imbalances in the ecosystem (Anil, Venkat, Sawant, *et al.* 2002). The IAS (invasive alien species) are serious threats to global biodiversity, second in importance only to habitat loss (Baltz 1991; Hayes and Sliwa 2003). Invasions are generally taken note of only when their impacts are felt. The impacts directly experienced by the society can be economical (loss of fishery or water as a resource) and human health related (for example, cholera epidemic, toxicity due to micro algal contamination). The ecological impacts, on the other hand,

are complex and dependent on the interaction between the invader and the native community. The cost of invasion is generally related to how early one responds to the problem, and it increases with the lapse of time.

Bioinvasions can be natural, intentional, or unintentional, and at times the impact is not easy to delineate due to multi-dimensional effects. Dispersion through propagation is the natural means of invasion and can be accelerated or facilitated by changes in the environment. At times, organisms are intentionally introduced for economic considerations. In India, more than 300 exotic species have been introduced (Qingran 1989). A vast majority of them are ornamental fish that remain more or less confined to the aquaria. Some others have been introduced in aquaculture and open water systems with varying degrees of success (Sugunan 1995). The tilapia, *Oreochromis mossambicus*, was first introduced into the pond ecosystem of the country in 1952. It has dominated and virtually eliminated all other fish species, including the stocked Gangetic carps, in a number of reservoirs in Tamil Nadu (Sugunan 1995). Table 1 provides a list of possible vectors that can bring about aquatic bioinvasion.

In marine environment, such intentional introductions take place due to the expansion of aquaculture/mariculture practices. Among the unintentional translocation of organisms in the aquatic environment, shipping has been marked as the major vector, due to the potential of organisms to get attached to the hull of the ship/sea chest and the possibility for organisms to be transported at various life cycle stages through ballast water. Ballast water is used to weigh down and/or balance the ships. It helps in the submergence of propeller and rudder for steerage. 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. Sea water loaded for ballast purposes contains a gamut of organisms and their propagules.

Table 1 Aquatic invasion facilitators

Vector	Role
Ships	Organisms inside the ballast tank and those attached to, or living on the, ship hull/sea chest
Fisheries (including aquaculture/public aquaria)	Either intentional or unintentional release (stock enhancement/increased productivity/pet fish industry)
Marine structures (off shore oil rigs/jetties/dry docks/buoys)	Organisms attached/living on the structures and colonization potential in virgin habitats, facilitating hopping to new destinations
Altering habitats (canals and reclamation)	Facilitating translocation of organisms to alien environments/influence of altered habitat in colonization
Research and education	Release of organisms, either intentional/accidental

A recent review shows that 205 taxa, not native to the Indian waters, have been introduced into the Indian waters since 1960 from various seas. The study also points out that maritime traffic could have acted as an important vector (Subba Rao 2005).

### Examples of marine bioinvasion

Many cases of marine bioinvasion have been reported and their harmful effects on the ecosystem and human health have been documented (Anil, Venkat, Sawant, *et al.* 2002). Few examples are as follows.

- *Mnemiopsis leidyi*, an opaque comb jellyfish, about 10 centimetre 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 tonnes; 10 times the total annual fish catch from all the world's oceans (Pearce 1995).
- 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 transoceanic ships that discharged freshwater ballast containing planktonic larvae or young adults (Ahlstedt 1994). It has now spread, infesting more than 40% of the United States waterways. It fouls the cooling water intakes of the industry, and may have five billion dollars in control measures since 1984 (Globalballast 2001).
- Black-striped mussel, *Mytilopsis sallei*, has been reported from Mumbai and Visakhapatnam (Karande and Menon 1975; Raju, Rao, and Viswanadham 1988). This species is a native to 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 invaded Australian waters.
- *Vibrio cholerae* 01 and 0139 are the causative bacteria for the human epidemic cholera, and can be transported through ballast water (Ruiz, Rawlings, Dobbs, *et al.* 2000). There is a strong evidence linking cholera epidemic and climate (Colwell 1996; Lobitz, Beck, Huq *et al.* 2000; Ruiz, Rawlings, Dobbs, *et al.* 2000). As the bacteria are capable of forming associations with plankton, their survival and sojourn in the ballast water tanks are much easier.
- The impact of HAB (harmful algal blooms) on human health, fishery resources, and marine ecosystems is recognized increasingly in the past two decades. Many causes, both natural and anthropogenic, have been attributed to the geographic spread of HAB. Ballast water carried by the ship has

also been identified as one of the responsible vectors. In the 1970s, the PSP (paralytic shellfish poisoning), a toxin syndrome caused by consumption of seafood contaminated by certain HAB species, was mostly recorded in the northern hemisphere. Since then, there has been a cumulative global increase in the recorded distribution of the causative organisms and the confirmed appearance of PSP toxins in shellfish at levels above the regulatory limit for human consumption (GEOHAB 2001).

## Success of marine bioinvasion

Versatility in terms of resistance to grazers and predators, high tolerance to abiotic factors, high rate of reproduction and/or fast vegetative growth, capability of hermaphroditic reproduction, and ability to hibernate or rejuvenate under unfavourable/favourable conditions are some of the features that determine the success of invasion by an organism.

The European *green crab*, *Carcinus maenas*, which has invaded west coast of North America, South Africa, and Australia has fewer parasites in the regions of introduction, which has helped in its successful establishment (Torchin, Lafferty, and Kuris 2002). Such facilitation is enhanced due to the lack of specific predators in the introduced environment. A recent trend in the invasion literature (Colautti, Ricciardi, Grigorovich, *et al.* 2004) relates the success of NIS (non-indigenous species) with the number of co-occurring enemies (that is, enemy release hypothesis or ERH). The ERH assumes: (1) NIS are affected by fewer enemies than those in the source region, (2) NIS are less affected by enemies native to the invaded region, (3) enemies co-introduced with their hosts will behave similarly in the invaded and source regions, and (4) release from natural enemies of the source region results in increased vigour and advantage over the competitors in the invaded region.

Altering the environment has also been shown to influence the invasion success. Examples of such catastrophes are reported from the Black Sea and the Mediterranean Sea. A review on biological invasions as a component of global change in stressed marine ecosystems (Occhipinti-Ambrogi and Savini 2003) points out that stressed environments are easily colonized by alien species; understanding the links between human and natural disturbance and massive development of MS will help prevent marine bio-invasions that are already favoured by global oceanic trade.

Pacific oyster (*Crassostrea gigas*) took nearly 17 years before a large population of several million oysters became established on natural mussel beds in the northern Wadden Sea and eastern North Sea. A report (Diederich, Nehls, van Beusekom, *et al.* 2005) indicates that further invasion will depend on high late summer water temperatures. Spider crab (*Hyas araneus*) has recently been reported as one of the first known benthic invasive species in the Southern Ocean Antarctic Peninsula (Tavares and DeMelo 2004). The warming Antarctica is

being exposed to two complimentary forces: (1) human-mediated transport of exotic species (Barnes 2002); and (2) polar warming (Gille 2002), leading to changes in the barrier formed by the circumpolar freezing temperatures. Combination of these two forces can have unpredictable consequences for Antarctic marine biota and this clearly points out that the invasion pathways can be influenced by global climate change.

## Role of ballast water in marine bioinvasion

Shipping is the backbone of global economy and facilitates transportation of 90% of the commodities. A single bulk cargo ship of 200 000 tonnes can carry up to 60 000 tonnes of ballast water. It is estimated that 2-3 billion tonnes of ballast water is carried around the world each year. Translocation of organisms through ships is considered to be one of the important issues that are threatening the naturally evolved biodiversity, and consequences of such invasions are being realized increasingly in the recent years.

The IMO (International Maritime Organization), a specialized agency for the United Nations, is responsible for the international regulation of ship safety and prevention of marine pollution. It has been working through its member states to tackle the problem of ballast water since 1973. It adopted the International Convention for the Control and Management of Ships Ballast Water and Sediments in 2004. The main management measure recommended under the existing IMO ballast water guidelines is the 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.

The International Convention on Ballast Water Management for Ships will require all new ships to implement a Ballast Water and Sediments Management plan (IMO News 2004). All new ships will also have to carry a Ballast Water Record Book and will be required to carry out ballast water management procedures to a given standard. Existing ships will be required to do the same but after a phase-in period.

The convention includes ballast water exchange standard (based on the logic that the organism from the open ocean waters is less damaging to the coastal habitats) and a ballast water performance standard (based on the quality of ballast water that can be discharged).

*Ballast water exchange standard* states that ships performing ballast water exchange shall do so with an efficiency of 95% volumetric exchange of ballast water. For ships exchanging ballast water by the pumping through method, pumping through three times the volume of each ballast water tank shall be considered to meet the standard described. Pumping through less than three times the volume may be accepted, provided the ship can demonstrate that at least 95% volumetric exchange is met.

*Ballast water performance standard* states that ship conducting ballast water management shall discharge less than 10 viable organisms per cubic metre greater than or equal to 50  $\mu\text{m}$  (micrometres) in minimum dimension and less than 10 viable organisms per millilitre less than 50  $\mu\text{m}$  in minimum dimension and greater than or equal to 10  $\mu\text{m}$  in minimum dimension. Discharge of the indicator microbes shall not exceed the specified concentration.

Under Ballast Water Exchange, all ships using ballast water exchange should, whenever possible, conduct water exchange at least 200 nautical miles from the nearest land and in water at least 200 metres in depth, taking into account guidelines developed by the IMO. Ships unable to conduct ballast water exchange as above can do so as far from the nearest land as possible, and in all cases at least 50 nautical miles, from the nearest land and in water at least 200 metres in depth. All ships shall remove and dispose of sediments from spaces designated to carry ballast water in accordance with the provisions of the ship's ballast water management plan. Parties to the convention are given the option to take additional measures before ships would be allowed to enter their ports. Such additional measures are subject to criteria set in the convention and to the IMO guidelines yet to be developed, and may also include additional controls applicable to discharge and/or uptake areas of ballast water.

Meeting ballast water performance standard, as stated in the convention, will require development of suitable technologies. A conservative estimate indicates such technologies would cost from 100 000 dollars to 300 000 dollars. If these are to be installed in ships (75 000) and if an average of 200 000 dollars is considered, the BWT (ballast water treatment) would cost 15 billion dollars. The running cost is estimated to be 666 million dollars, considering a cost of 3.7 cents/tonne with an average of 40 000 tonnes/ship for 75 000 ships for six exchanges a year. The technology that will be acceptable will have to prove its worth with reference to biological performance; power requirements and predictability; temperature and energy efficiency; operational and maintenance issues; by-products and residuals; and environmental acceptability. There are several technological options that are under consideration to treat ballast water (Raaymakers 2003; Matheickal and Raaymakers 2004) and some of the options that are being pursued are given below.

### ***Ballast water treatment systems***

*Ballast water treatment by filtration* Self-cleaning screen-filtration systems are one of the technological options for ballast water management. The technologies currently available off the shelf are not designed to meet the requirements of normal ballasting operations. Considerable modifications and system re-engineering have to be done to develop a dedicated ballast water filtration system. Several alternative technological options for pathogen inactivation (for example,

ultraviolet, ultrasound) would require a pre-filtration stage for removal of larger particles in ballast water. It appears that identification of suitable filtration material, which is corrosion resistant, will also play an important role. Technological advancements to filter smaller-sized particles (for example, 10  $\mu\text{m}$  and above), which can be effective in the removal of dinoflagellates and its cysts, need to be pursued.

*Ballast water treatment by ozonation* Ozone is used for disinfection in a number of applications ranging from grey water treatment, treatment of potable water to those related to industrialized process such as aquaculture and electricity production. Application of ozone as an option to treat ballast water has to address concerns of corrosivity of ozone-treated sea-water and the footprint requirement of the installations.

*Ballast water treatment by heat* The option of heating ballast water to a temperature sufficiently high to minimize or eliminate the translocation of harmful organisms is also under consideration. The treatment is environmentally attractive since waste engine heat can be used and could be better than ocean exchange. However, in ships where there is no waste heat available, this treatment method could turn out to be expensive. It also appears that this method may not be adequate (under the existing conditions in ship) to address the threats from bacteria and viruses. Vertical gradient variation in temperature inside ballast tanks is an important concern that needs careful consideration while using heat treatment.

*Ballast water treatment by de-oxygenation* A high-speed ballast water treatment system that uses a vacuum chamber to remove dissolved oxygen from ballast water, resulting in low oxygen condition within the ballast tank/hold, is also explored as a possible technology.

*Ballast water treatment by electro-ionization* Electro-ionization technology has been used in freshwater treatment applications but has never been tested with marine or brackish water samples. Claims that have been patented include a kill of over 90% of the bacteria in 300 litres of water within just 2-minute contact time treatment and kill of all detectable organisms in 15 minutes of contact time treatment. This works on electro-ionization magnetic separation technique.

*Ballast water treatment by gas supersaturation* Gas supersaturation is known to affect multicellular organisms, especially when subjected to low hydrostatic pressure. The organisms may suffer from embolism and haemorrhages. Optimization of a technique using this principle can have application in ballast water treatment. However, it is to be noted that the effect depends on vascularization of the organism and may not affect organisms such as dinoflagellates. Gas supersaturation may also aid in removal of passivation film in the tanks, and promote sulphur-reducing bacteria and corrosion.

*Ballast water treatment by chemicals* Use of potential biocides, both natural and chemical, is being explored. The most immediate concern for this pathway is the impacts of the product thus developed on the non-target organism

once discharged into the environment and the bioaccumulation. The biocide developed will have to go through rigorous environmental safety check.

*Ship design and operational issues* A design of ballast system that would permit continuous flow through exchange of ballast water is a possibility that is being explored.

## The future

In most of the cases, the emphasis in bioinvasion research has been on incursion management. Hicks (2003) points out that aquatic bioinvasion research has been mostly reactive or curative and grossly inadequate in preventative research (investigations designed to put one on the front foot by pro-prediction, risk assessment, and decision-support systems). The mantra of bioinvasion management should be 'prevention is better than cure'. If an aquatic invasion is prevented then the battle is won; the other options have their own limitations.

Invasion detections always take place with reference to natural history of the habitat. In most of the situations, invasions become apparent only when the effects/presence are visible. Historical data and description of fauna and flora of a geographic region are the vital basis for the determination of bioinvasions. Lack of linkage to a potential invasion pathway in several exploratory investigations leads to recording of organisms as mere new reports from the area of collection. Rising awareness of marine invasion impacts has led to protocols that intensively explore habitats of possible introduction (for example, ports/drilling platforms). The aim of such protocols is to detect the rare, so as to provide incursion management a practical control option. Useful reference in this context is the protocol developed by the Center for Research on Introduced Marine Pests (Hobart, Tasmania, Australia) (Hewitt and Martin 2001). This was adopted by the Global Ballast Water Management Programme (executed by the IMO) in its pilot project to track invaders in six countries (Brazil, China, India, Islamic Republic of Iran, South Africa, and Ukraine) through port biological baseline surveys. This protocol is being suitably adopted for the expansion of the initiatives in India.

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## References

- Ahlstedt S A. 1994  
Invasion and impacts of the zebra mussel in the United States  
*Journal of Shellfish Research* 13: 330-333



Anil A C, Venkat K, Sawant S S, Dileepkumar M, Dhargalkar V K, Ramaiah N, Harkantra S N, Ansari Z A. 2002

**Marine bioinvasion: concern for ecology and shipping**

*Current Science* 83 (3): 214-218

Barnes D K A. 2002

**Biodiversity, invasions by marine life on plastic debris**

*Nature* **416**: 808-809

Baltz DM. 1991

**Introduced fishes in marine systems and inland seas**

*Biological Conservation* **56**: 151-177

Colwell R R. 1996

**Global climate and infectious disease: the cholera paradigm**

*Science* **274**: 2025-2031

Colautti R I, Ricciardi A, Grigorovich I A, MacIsaac H J. 2004

**Is invasion success explained by the enemy release hypothesis?**

*Ecology Letters* 7: 721-733

Diederich S, Nehls G, van Beusekom J E E, Reise K. 2005

**Introduced pacific oysters (*Crassostrea gigas*) in the northern Wadden Sea: invasion accelerated by warm summers?**

*Helgolander Marine Research* **59**: 97-106

Gille S T. 2002

**Warming of the Southern Ocean since 1950s**

*Science* **295**:1275-1277

GEOHAB (Global Ecology and Oceanography of Harmful Algal Blooms). 2001

**Global ecology and oceanography of harmful algal blooms**

In *Science Plan*, edited by P Gilbert and G Pitcher

Baltimore and Paris: SCOR (Scientific Committee on Oceanic Research) and IOC (Intergovernmental Oceanographic Commission). 86 pp.

Globallast. 2001

**Stopping the ballast water stowaways**

London: International Maritime Organization. 8 pp.

[Global Ballast Water Management Programme, March 2001, International Maritime Organization]

Hayes K R and Sliwa C. 2003

**Identifying potential marine pests—a deductive approach applied to Australia**

*Marine Pollution Bulletin* 46: 91-98

Hewitt C L and Martin R B. 2001

**Revised Protocols for Baseline Port Surveys for Introduced Marine Species: survey design, sampling protocols and specimen handling**

Hobart, Australia: CSIRO Marine Research. 46 pp.

[Center for Research on Introduced Marine Pests, Technical report no. 22,

CSIRO Marine Research, Hobart, Australia. 46 pp.

Hicks G R F. 2003

**Turning the Tide: is aquatic bioinvader research heading in the right direction?**

[12th International Conference on Aquatic Invasive Species, Windsor, Ontario,

Canada, 9-12 June 2003, hosted by the Ontario Ministry of Natural Resources,

Abstracts page 9, 159 pp.

IMO News. 2004

**IMO adopts new convention to counter ballast water threat**

International Maritime Organization, London. Issue 1: p. 5

Jhingran A G. 1989

**Role of exotic fishes in capture fishery waters of India**

In *Conservation and Management of Inland Capture Fisheries Resources of India*, edited by A G Jhingran and V V Sugunan

Barrackpore: Inland Fisheries Society of India, CIFRI (Central Inland Captured Fisheries Research Institute). 275 pp.

Karande A A and Menon K B. 1975

***Mytilopsis sallei*, a fresh immigrant in Indian harbours**

*Bulletin of the Department of Marine Science University Cochin*, VII 2:455-166

Lobitz B, Beck L, Huq A, Wood B, Fuchs G, Faruque A S G, Colwell R R. 2000

**Climate and infectious disease: use of remote sensing for detection of *Vibrio cholerae* by indirect measurement**

*Proceedings of the National Academy of Science USA* 97:1438-1443

Matheickal J and Raaymakers S (eds). 2004

**GloBallast Monograph Series No. 15**

London: IMO (International Maritime Organization)

[Proceedings of the *Second International Ballast Water Treatment R&D Symposium*, 21-23 July 2003, IMO, London]

Occhipinti-Ambrogi A and Savini A. 2003

**Biological invasions as a component of global change in stressed marine ecosystems**

*Marine Pollution Bulletin* 46:542-551

Pearce F. 1995

**How the Soviet seas were lost**

*New Science* 2003: 38-42

- Raju G J V J, Rao K S, and Viswanadham B. 1988  
**Recruitment of the fouling Bivalve, *Mytilopsis sallei* (Recluz), on metallic and non-metallic surfaces at Visakhapatnam harbour, India**  
In *Marine Biodeterioration: advanced techniques applicable to the Indian Ocean*, pp. 513-525, edited by M F Thompson, R Sarojini, and R Nagabhushanam  
New Delhi: Oxford and IBH. 826 pp.
- Raaymakers S. 2003  
**GloBallast Monograph Series No. 5**  
London: International Maritime Organization  
[Proceedings of the First International Ballast Water Treatment R&D Symposium, 26-27 March 2001, IMO, London]
- Ruiz G H, Rawlings T K, Dobbs F C, Drake L A, Mullady T, Huq A, Colwell R R. 2000  
**Global spread of microorganisms by ships**  
*Nature* **408**: 49-50
- Subba Rao, D. V. 2005  
**Comprehensive review of the records of the biota of the Indian seas and introduction of non-indigenous species**  
*Aquatic Conservation: Marine and Freshwater Ecosystems* 15: 117-146
- Sugunan V V. 1995  
*Reservoir Fisheries of India*  
[FAO Fisheries Technical Paper 345]  
Rome: Food and Agriculture Organization. 423 pp.
- Tavares M and DeMelo G A S. 2004  
**Discovery of the first known benthic invasive in the Southern Ocean, the North Atlantic spider crab *Hyas areaneus* found in the Antarctic Peninsula**  
*Antarctic Science* 16 (2): 129-131
- Torchin M E, Lafferty K D, and Kuris A M. 2002  
**Parasites and marine invasions**  
*Parasitology* **124**: S137-S151