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Bio-invasion - A threat to marine biodiversity

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Introduction

The modern era witnessed several unprecedented actions on the Earth by the human beings. We have appropriated half the planet's land surface for human uses, eliminated major chunk of the big fishes (especially predators) in the oceans, severely depleted the earth's stratospheric ozone layer, and increased atmospheric concentrations of green house gases. Every ecosystem in our planet now illustrates domination by human species and hence the argument that we have entered a new planetary era best described as the Anthropocene (Crutzen and Stoermer, 2000). Ever since humans began travelling over land and sea, assorted livestock, crops, pets, pests, and weeds have tagged along. Nearly every region of the globe has benefited economically from introduced species. Yet, new arrivals that become invasive have also created major problems in almost every ecosystem in the world.

Invasive Alien Species (IAS) are alien (non-native or exotic) species that occur outside their natural adapted ranges and threaten, or have the potential to threaten, the environment, health or economic production. Bioinvasion occurs when an alien organism is introduced into an environment and the ecosystem therein is disturbed. The invading organisms live in semblance with their predators and are controlled by ecosystem interaction in their natural environment. However, in the alien environment they can turn out to be pests. International organisations such as World Watch Institute consider bio-invasion as the second greatest threat to biological diversity, the first being habitat degradation. When an exotic species establishes a beachhead, it can proliferate over time and spread to new areas. It can also adapt - it tends to get better and better at exploiting an area's resources and at suppressing native species. According to the World Conservation Union (IUCN), effects of IAS on biodiversity are "immense, insidious and usually irreversible".

Vectors

Anthropogenic biological invasions are a leading threat to aquatic biodiversity in marine, estuarine, and freshwater ecosystems. In marine ecosystems, biological invasions occurred through a variety of mechanisms including maritime shipping, live seafood and bait shipments, aquaculture, ornamental fish trade, and the activities of education and research institutions (Godwin, 2004). Ocean going vessels provide substrate for settlement of species associated with fouling communities, protected recesses that can be occupied by both sessile and mobile fauna, and enclosed spaces that hold water in which everything from plankton to fish can become entrained (Wonham *et al.*, 2000). The ballast water, sediments and hull fouling associated with marine vessels act as primary vectors of marine bioinvasion.

Since the nineteenth century, ships have been using ballast water for safety, stability, propulsion and maneuverability, as well as to redress loss of fuel weight and water consumption, and to maintain structural stress at acceptable levels. The water may be discharged when the ship gets into a new port, discharging new organisms in the water along with it. Advances in shipbuilding have resulted in larger and faster vessels. This in turn has increased the chances of successful introduction of alien marine organisms to newer environments manifold. The success of bioinvasion mediated by ballast water depends on factors such as: (i) survival of organisms in extreme conditions during transport and deballast, (ii) adaptation to new environment, (iii) availability in large numbers for reproductive success, (iv) high level of competitiveness against possible antagonists, and (v) higher reproduction rates to compensate for the mortality that can occur during their dispersion (Anil *et al.*, 2002).

International seaways account to over 80% of world's commodities transportation. According to studies done under the Global Ballast Water Management Programme, shipping transfers about 10 billion tonnes of ballast water around the globe each year. It has been estimated that at least 7,000 different species are being carried in ballast tanks around the world (Global Ballast

Water Management Programme). Over two-thirds of recent, non-native species introductions in marine and coastal areas are likely due to ship-borne vectors (Ruiz *et al.*, 2000). These colossal loads of ballast water may transport viruses, bacteria, protists, algae, zooplankton, benthonic invertebrates and fishes among harbours at a faster pace.

Aquaculture and ornamental fish trade also contribute to marine bioinvasions. Species such as fish, shellfish and seaweeds raised in cages and pens may escape or be released into local waters. Species purchased as seafood may be later dumped or released into local waters. These species can carry diseases, parasites and other organisms.

Impacts

The consequences of species introductions should be better realised before the introduction of a species into a natural ecosystem. This thump rule is often ignored in many instances, often leading to serious ecological and economic cataclysms. Invading species can cause complex changes within the structure and function of their new ecosystem. Impacts include restructuring established food webs, importing new diseases to the new surroundings, and competition with indigenous organisms for space and food. Other ecological changes may occur when the invading organisms reproduce with native species, possibly altering the gene pool. This may lead to hybridization and homogeneity, which reduces biodiversity, the primary element associated with an ecosystem's adaptability to natural or human-induced changes. Specifically in the case of marine bioinvasion, the damages may be categorized as ecological, economic and human.

The faster pace at which organisms are transported across marine habitats could change the native biodiversity and trophic structure. In the absence of predators, the aliens may establish their supremacy easily. In turn bioinvaders may displace native organisms by preying on them or out competing native species for food and habitat space.

The economic losses caused by marine invaders are a serious concern in many parts of the world. The fisheries, coastal industry and other commercial activities and resources are disrupted by the invading species. They may clog the coastal pipelines, drainage and other such places, disrupting the operations. For example, invasive species cost more than 140 billion US dollars in USA alone, where about 40 per cent of all imperilled species are at risk because of invasive species (McGrath, 2005). The invasion of the zebra mussel, *Dreissena polymorpha* was better studied in North America. 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. It has now spread, infesting more than 40% of the United States waterways. It fouls the cooling water intakes of the industry and the U.S. Coast Guard estimates that economic losses and control efforts cost the United States about $5 billion each year (Minchin, 2003).

When toxic organisms, diseases and pathogens are introduced through ballast water, it spreads illness and can cause even death of affected human beings. The health hazards are generally caused by build-up of toxins in the food chain caused by Harmful Algal Blooms (HAB). Ballast water has been considered one of the important vectors for the spread of toxic algae causing red tides and HABs can lead to fatality in human beings through paralytic shellfish poisoning (PSP) and cause health concerns through diarrhoeatic shelfish poisoning (DSP) (Anil *et al.*, 2002). Of late, HABs and human deaths caused by feeding contaminated marine food organisms have been recorded frequently from India. Novel occurrences of the human pathogenic *Vibrios*, e.g. *Vibrio parahaemolyticus, V. cholerae, V. vulnificus and V. mimicus* and the harmful algal bloom species *Alexandrium* spp. and *Gymnodinium nagasakiense* in the Indian coastal waters could be attributed to ballast water introductions (Subba Rao, 2005).

The global movements of ballast water by ships create a long distance dispersal mechanism for human pathogens that may be important in the worldwide distribution of microorganisms, as well as for the epidemiology of waterborne diseases. Only a few studies have been carried out on this subject, most of them involving ballast water containing crustacean larvae and phytoplankton. The epidemic cholera that is believed to be spread through ballast water and first reported from Peru in 1991, rapidly spread through Latin America and Mexico, killing over 10,000 people. In July of 1992, *Vibrio cholerae* was found in the USA and the Food and Drug Administration (FDA) determined that it came from ballast water of ships. Studies that can assess the probability that water ballast carries pathogenic microorganisms are extremely important, as is the examination of ships that arrive in the country. Treatment of the human infections caused by ballast water exists but none is completely safe and efficient (Takahashi *et al.*, 2008)

Indian Scenario

There are about 19 marine species that established spearhead in Indian waters (Table 1). In the Indian scenario, black stripped mussel *Mytilopsis sallei* has been reported from Mumbai and Visakhapatnam. This species is native of tropical and sub tropical Atlantic waters and is reported to have invaded the Indian waters sometime during 1960's. A native of European waters, Green Crab (*Carcinus meanasi*) is reported from the Indian Ocean (Sri Lankan coast), which may decline the preys (molluscs and crustaceans) of crabs in the region.

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). The Indo-Malaysian region can be identified as a centre of xenodiversity for biota from Southeast Asia, China, Japan, Philippines and Australian regions. Of the introduced species, the bivalve *Mytilopsis sallei* (Fig. 1) and the serpulid *Ficopomatus enigmaticus* (Fig. 2) have become pests in the Indian Seas, consistent with the Williamson and Fittertens rule which states that, on average, 1 out of 10 introduced species becomes invasive.

A fast-growing marine alga *Kappaphycus alvarezii* (Fig. 3), native of the Indonesia and Philippines, introduced to India for seaweed aquaculture in 1995 has already established its growth in many parts of Gulf of Mannar (GOM) Marine Biosphere Reserve (Pereira and Verlecar, 2005). This species has already exhibited its invasion and shadowing and smothering effects over the coral colonies and fears have been established by scientists that it may switch over to sexual reproduction by spores under favourable environmental conditions in future

(Chandrasekaran *et al.*, 2008). This demands continuous monitoring of species that have been introduced into the country for aquaculture operations, particularly in biodiversity-rich areas such as GOM.

Managing Aliens

A prerequisite for any attempt to control the introduction and spread by shipping of non-indigenous marine species into our waters is knowledge of the current distribution and abundance of introduced species in our major ports. Without adequate knowledge of the extent of the invasive species problem in any geographical area, management plans to prevent, control, and minimize their economic, and environmental impacts are inadequate (Anil *et al.*, 20002). Published scientific data on the ecological and economic impacts of invasion of alien fish species are not available in India. "While the introduction of exotic organisms is strictly monitored in most other countries, considering the threat to the local biodiversity and endemic organisms, quarantine measures in India are inadequate. There are no legal restrictions or standardised procedures for introduction and monitoring of species (Anil *et al.*, 2002).

Fig. 1. Bivalve, *Mytilopsis sallei*

Fig. 2. Serpulid, *Ficopomatus enigmaticus*

Fig. 3. Marine alga, *Kappaphycus alvarezii*

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. This programme aims to raise awareness among stakeholders and to remove barriers for effective ballast water management. 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.

Research related to ballast water treatment is underway in many countries and the options include, heating, filtration, ozonation, deoxygenation, gas super saturation, ultraviolet radiation, biocides. So far none of these have been able to address the issue in totality and scope for research and technology development is ample. Molecular tools that can identify the organisms in ballast water and markers that can substantiate the effectiveness of mid ocean exchange has potential implication in quarantine procedures and needs to be pursued. Unfortunately no single ballast water management technique has been able to remove all organisms or all types of organisms from ballast tanks. A combination of different methods may prove to be more effective than one method alone, however little research has been conducted into this possibility. It is difficult to implement treatments because ship owners are understandably reluctant to install technology that is expensive, unreliable, or time consuming. Successful intervention however, depends on well managed and synchronized actions of scientists, policy-making organizations, legislation-implementation bodies, local authorities, and the public.

Identification of suitable ballast discharge sites by each of the ports should be given priority. Indian coasts are studded with 12 major ports and large number of minor ports, which could function as gate ways for the transfer of marine bioinvaders. Further, presence of biodiversity-rich areas

Table 1. Marine invasive species recorded from Indian coastal waters
(Source: Anil *et al.*, 2002; http://www.globallastwaterindia.com)

Sl. No.	Species		Nativity	Record in Indian waters
1	Alga	*Monostroma oxyspermum*	Northeast Atlantic, Northwest Pacific	West coast
2	Hydroid	*Mercierella enigmata*	Australia	Indian Ocean
3	Anemone	*Eugymnanthea* sp.	--	East coast
4	Mussel	*Mytilopsis sallei*	Atlantic waters	East and west coasts
5	Wood-borers	*Lyrodus medilobata*	Indo-Pacific, Hawaiian Islands, Marshall Islands, New Zealand, Australia, Virginia, Bermuda	West coast
6		*Nausitora dunlopei*	Cochin	Goa
7		*Teredo fulleri*	Gulf of Mannar	Okha
8	Barnacles	*Balanus amphitrite var stutsburi*	West coast of Africa	West coast
6		*B. amphitrite hawaiiensis*	Malay Archipelago and Persian Gulf	Mumbai
10.	Isopod	*Cilicaea lateraillei*	Indonesia, the Philippines, Sri Lanka, S. Africa, Red Sea, Australia	Arabian Sea
11.	Amphipods	*Stenatho gallensis*	East coast of India	West coast
12.		*Maera pasifica*	East coast of India	West coast
13.		*Podocerus brasileusis*	East coast of India	West coast
14.		*Erichthonins brasileones*	East coast of India	West coast
15.	Crab	*Carcinus meanas*	Europe	Indian Ocean
16.	Bryozoa	*Barentsia ramose*	Pacific, California, Belgium	Indian Ocean
17.	Ascidians	*Styela bicolor*	Gulf of Siam, Java, North Australia, Banda Sea, Ambonia and the Philippines	Indian Ocean
18.		*Phallusia nigra*	Bermuda, Brazil, Red Sea, Gulf of Eden	Tuticorin harbour
19.		*Eusynstyela tincta*	Atlantic, Mozambique, Red Sea, Gulf of Suez, Africa, Sri Lanka	Tuticorin harbour

such as Andaman, Nicobar and Lakshadweep Islands necessitates close monitoring of our coastal waters for invasive species. For facing the challenges posed by the marine invaders, we need an effective legislation with frameworks rooted on prevention, public outreach and education, early detection and response, research and risk analysis and strategies for control and management.

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