A Review on Impacts of Invasive Alien Species on Indian Coastal Ecosystems

राष्ट्रीय जैव विविधता प्राधिकरण
2003
National Biodiversity Authority, India

Centre for Biodiversity Policy and Law

National Biodiversity Authority

2019

A Review on Impacts of Invasive Alien Species on Indian Coastal Ecosystems

• S. Sandilyan • B. Meenakumari
• T.T. Ajith Kumar • Rupam Mandal

Centre for Biodiversity Policy and Law
National Biodiversity Authority

2019

Authors

S. Sandilyan, B. Meenakumari, T. T. Ajith Kumar & Rupam Mandal

Citation

Sandilyan, S., Meenakumari, B., Ajith Kumar, T.T. and
Rupam Mandal. 2018. A review on Impacts of Invasive Alien Species on Indian Coastal Ecosystems. National Biodiversity Authority, Chennai.

Corresponding Author

Sandilyan, S. *<ssandilyan@gmail.com>*

ISBN No.: 978-81-932753-1-3

Published by

Centre for Biodiversity Policy and Law [CEBPOL]

National Biodiversity Authority,

5th Floor, TICEL Bio Park,

CSIR Road, Taramani

Chennai - 600 113

Website: www.nbaindia.org/cebpol

Layout and Design

N. Singaram

Information Technology Executive, CEBPOL

Contents

Acknowledgements

The success and final outcome of this report required a lot of guidance and support rendered from many researchers and well-wishers and we are privileged to thank them all.

We thank Shri T. Rabikumar, Secretary, National Biodiversity Authority (NBA) for his constant support, guidance and encouragement which made us to bring out the document.

We like to thank Ms. Maja Stade Aaronas, Norweigan Environment Agency for her support and encouragement.

We like to thank Dr. S. Chandrasekaran, Department of Plant Science, Madurai Kamaraj University, and Dr. Krishnan, National Academy of Agricultural Research Management (NAARM), Hyderabad, for helping us by providing photos of *Kappaphycus alvarezii* and *Carijoa riisei* respectively.

We like to express our special thanks to Dr. S. M. Vairavel, M.Sc., M.Phil., Ph.D, Consultant Biologist (Forest and Wildlife) and Freelance Editor for Scientific Journals and Dr. S Muthukumar, M.Sc., Ph.D, Head - Editorial Services, S4Carlisle Publishing Services, Chennai for their scientific support.

Special thanks to Mr. N. Singaram, IT Executive, Centre for Biodiversity Policy and Law (CEBPOL, NBA), Chennai, for helping to design the cover photo and layout.

I. Introduction

According to the Convention on Biological Diversity (CBD), an alien species is a species, sub-species or lower taxon, introduced outside its natural past or present distribution, which includes any part, gametes, seeds, eggs or propagules of such species that might survive and subsequently reproduce (CBD, 2002).

Invasive Alien Species (IAS) have been identified as one of the significant drivers of global biodiversity, which resulted in species and habitat loss worldwide (Sandilyan, 2016). Ever-increasing globalization and the ongoing environmental changes have facilitated the dissemination of invasive species significantly (Early *et al*., 2016).

All major groups including virus, fungi, algae, mosses, ferns, higher plants, invertebrates, fishes, amphibians, reptiles, birds and mammals have been recognized for their invasion potential in different habitats including wetlands. However, plants, insects and mammals comprise the most common types of invasive alien in terrestrial environment (Rejmanek and Richardson, 2000; Sujay *et al*., 2010), whereas in aquatic habitats, molluscs, fishes, algae, floating and submerged plants are the predominant taxa (Anil *et al*., 2002; Sandilyan, 2016). In general, invasive species are widely distributed in all kinds of ecosystems. Recent survey highlighted that 17% of the global land area is highly prone to invasion (except Antarctica and glaciated Greenland) (Early *et al*., 2016). The report also stated that 16% of globally important biodiversity-sensitive areas are highly vulnerable to bioinvasion (Early *et al*., 2016).

Studies have well established that invasive species can influence the species composition, community structure and functions of ecosystems by repressing or excluding native species, either directly by outcompeting them for resources or indirectly by changing the way that nutrients are cycled through the bio-geo system. Most of the time the whole ecosystem may be placed at risk through knock-on effects due to invasion, which results in irretrievable loss to native species that depends on the ecosystem (GISP, 2004; Levine *et al*., 2003).

Wetland habitats are highly prone to invasion, especially the coastal habitats which naturally provide several avenues for the invasion (Anil *et al*., 2002; Sandilyan, 2016). The major pathway for coastal invasion is through ballast water (e.g. *Karenia brevis*), natural calamity (e.g. Lion fish - *Pterois volitans*) accidental introduction/escape during unscientific coastal aquaculture (e.g. *Litopenaeus vannamei*) and seaweed culture (e.g. *Kappaphycus alvarezii*) (Figure 1) (Anil *et al*., 2002; Brigg *et al*., 2004). However, a number of studies

Figure 1. Regeneration of colonies of *Kappaphycus alvarezii* on coral reef in Gulf of Mannar after manual eradication, 2007.
Photo Courtesy: Dr. S. Chandrasekaran, Department of Plant Science, Madurai kamaraj University.

highlighted about the ballast water issues. Annually, 12 billion tonnes of ballast water is being exchanged throughout the world. A single bulk cargo ship of 200,000 tonnes can carry up to 60,000 tonnes of ballast water (Ibrahim and Manal, 2012; Raghunathan *et al*., 2013). Every day, nearly 7,000 marine and coastal species travel across the world's oceans by cargo ships, which silently carry more than 4,500^{+} different species including microbes, plants and small animals in their ballast water tanks. Among them some of the species can evolve as invasive species and cause deleterious impacts to the coastal ecosystem and lead to huge economic loss (WWF, 2009; Ibrahim and Manal, 2012).

A number of studies have pointed out that marine invasion is highly harmful to ecosystem functions, native species and human health, which may also cause huge economic and biodiversity loss (Anil *et al*., 2002).

For instance, studies highlighted that death of a large number of fishes, sea turtle, sea birds and marine mammals was reported due to harmful algal blooms (HABs) as a result of untreated ballast water discharge (Pierce and Henry, 2008). The HABs, commonly known as 'Red Tides', have been identified as a major health hazard. More than 300 algal species which cause red tides have been identified so far, and most of the species produce toxins that are harmful to marine organisms and human. For instance, the microscopic algae *Karenia brevis* can kill large numbers of fish and other marine organisms including dolphins (Pierce and Henry, 2008). During blooming *K. brevis* produces/liberates a collection of polyether neurotoxins called brevetoxins. This substance can easily dissolve in the environment and adversely affect the habitat and wildlife of the region. A study in southern Florida disclosed the large-scale mortality of fish, marine turtle, sea birds and mammals due to brevetoxins produced by *K. brevis* (Pierce and Henry, 2008).

Researchers clearly state that it is very difficult to control and eradicate the aquatic invasive species that have established themselves in open waters. Only few successful examples are available pertaining to eradication, especially if the invading species was detected at a very early stage inside enclosed areas such as an island or small bay. Using biocides to eradicate the invasive species is the only viable option recommended by experts (Ibrahim and Manal, 2012). On the other hand, prevention and management have been identified as an environmentally friendly way to manage the invasive species.

Obviously, the need of the hour is for scientific planning to find an early detection and eradication of invasive species in Indian coastal habitats. A group of experts (inter- and intra-science) including taxonomists, ecologists and resource managers should be established for better prevention and effective management of marine invasion. Formulating new strategies and action plans with updated technology will be highly helpful for better management.

Introduction to Indian coastal wetlands

India has a coastline of 7,516 km of which the mainland accounts for 5,422 km; Lakshadweep, Andaman and Nicobar coasts extend 132 km and 1,962 km, respectively. Studies conclude that nearly 250 million Indians live within a distance of 50 km from the coastal areas of India (Venkataraman, 2008). Interestingly several major cities of India are on/near the coastal zone (e.g. Chennai, Mumbai, Kolkata, Thiruvananthapuram) and provide livelihood to several million people. Such vital ecosystems support unique habitats such as estuaries, lagoons, mangroves, backwaters, salt marshes, mud flats, rocky shores and sandy stretches. The aforesaid unique habitat supports a number of endemic and IUCN threat category species as well as living fossils such as horseshoe crab *Tachypleus gigas* (Venkataraman, 2008; Sandilyan, 2009).

Indian coastal system also supports three Gulfs (Gulf of Mannar (East coast), Gulf of Kachchh and Gulf of Kambath (West coast)). Studies also highlight that Gulf of Mannar and Gulf of Kachchh ecosystems support rich coral diversity, which in turn harbours unique fish diversity (Venkataraman, 2008). Besides, the Indian coastal system also supports all the three major reefs (atoll, fringing and barrier). Such a unique coastal system harbours several endemic and endangered species and the list of species in Indian marine system is provided in Annexure A. Interestingly, the mangrove ecosystem of India alone supports 4011 species of flora and fauna (Annexure B), and most of them are endemic to the habitat. Indian mangroves also support several threatened species, for instance 17 different IUCN threat category water birds were reported (Sandilyan and Kathiresan, 2012).

Among the coastal habitats, estuaries, mangroves and coastal lagoons are rich in biodiversity, whereas the brackish water habitats support only few specialized species (Venkataraman, 2008). Some of the studies in India also concluded that there is a gradual reduction in species number in estuaries compared to adjacent seas and in-flowing river system. However, as far as Indian estuaries are concerned, this is not fully true (e.g. Venkataraman, 2008).

Indian coastal line encompasses almost all types of intertidal habitat such as hyper-saline and brackish lagoons, estuaries, coastal marsh, mudflats, sandy and rocky shores. On the other hand, the sub tidal habitats are also equally diverse. Interestingly, the existing biota in these habitats are highly influenced by the unique environmental factors of the habitats (e.g. salinity and temperature fluctuations). Thus, the marine fauna itself demonstrate gradients of change throughout the Indian coast (Venkataraman, 2008).

Introduction to coastal invasion

Coastal habitats are highly prone to invasion through several means. Among them, ballast water, natural calamities and accidental introduction are identified as big threat. Research community has identified several pathways for marine invasion and among them, the important pathways are discussed below.

Pathways of introduction

The pathways of marine introduction can be classified into two major groups: (a) intentional introduction (aquaculture) and (b) unintentional introduction through ballast water discharge and fouling of ship hulls. Besides, natural calamities such as tsunami, cyclone and flood also play a crucial role on marine invasion. However, the ballast water discharge can have more deleterious impact on marine diversity than intentional introduction and natural calamities (Anil *et al*., 2002).

Ballast water

Shipping moves over 80% of the world's cargo and transfers about 12 billion tonnes of ballast water throughout the global oceans each year. Ballast is defined as any solid or liquid that is brought on board ship to increase the draft and regulate the stability or to maintain stress loads (Anil *et al*., 2002; www1). Ballast water mainly helps in submergence of propeller and rudder for friendly steerage of the cargo ships. In earlier days, materials like rocks and metals were used as ballast. But, modern ships use sea water for ballasting (Anil *et al*., 2002). Normally, when a ship unloads the cargo, it takes marine water as ballast for the return trip in order to maintain the ship's stability and structural integrity. Whenever it again loads cargo, the ballast water is discharged into the adjacent place/port where it is going to load the cargo (Anil *et al*., 2002).

In general, the marine/ocean water loaded for ballast purposes contains a variety of organisms starting from microorganisms to smaller chordate and aquatic plants. Besides, it was reported that the vast majority of aquatic species die before they reach their destination or discharge point (Anil *et* *al*., 2002; Ibrahim and Manal, 2012). This is mainly because of the stressful ballasting and de-ballasting process and the environmental conditions prevailing inside ballast tanks that are quite unfriendly for the survival of the species (Carlton 2001; Ibrahim and Manal, 2012). Even in such hostile condition, some of the organisms manage to survive in the ballast water, but miserably fail to survive in the newly introduced marine habitat. It is mainly due to the environmental conditions and competition with native species (Carlton, 2001; Ibrahim and Manal, 2012). However, some of the individuals/ species are able to survive in this horrible journey and slowly establish a reproductive population in the new habitat and evolve as an invasive in due course of time. After the establishment, the invasive species outcompete native species and cause several problems to the habitat and livelihood of the coastal community (Carlton, 2001; Ibrahim and Manal, 2012). Due to this, ballast water is considered as one of the most important vectors for the spread of such notorious invasive species and has emerged as a big challenge for global m.arine diversity (Anil *et al*., 2002).

Natural calamities

In general, the role of natural disasters (tsunami and cyclone) in introducing invasive species in marine habitats is poorly documented. Globally very few studies are available so far, one study has reported that the 2011 earthquake of Japan triggered 133 feet tsunami waves which introduced more than 200 non-native species to the West Coast of the United States. Especially the occurrence/catch of knife jaws fish was frequent after the tsunami (www. Maritime). Besides, storms and hurricanes can also lead to marine invasion. A study by Nova South-eastern University's Oceanographic Center has discovered that storms can influence the flow of water in the Florida Straits and introduce the lionfish larvae and eggs from Florida to the Bahamas (Johnston and Purkis, 2015).

Pertaining to India, during 2015, the unprecedented north-east monsoon in Cuddalore district of Tamil Nadu introduced several invasive aquatic plant species to Pichavaram mangroves. The continuous discharge of water from the major tributaries washed away the choked invasive species aquatic plant species such as water hyacinth (*Eichhornia crassipes*), giant salvinia (*Salvinia molesta*) and water spinach (*Ipomea aquatica*) and dumped them into several parts of the creeks and channels of Pichavaram mangroves (Figure 2).

Figure 2. Mat of *E. crassipes* under mangrove vegetation in Pichavaram mangroves, 2015. Photo by: S. Sandilyan

However, due to the saline nature of the mangroves, the aforesaid aquatic plants could not survive after the monsoon (salinity level increase). Obviously, a long-term study is needed to assess the impacts of *E. crassipes*, *S. molesta* and *I. aquatica* in Pichavaram mangroves, with special reference to the role of these invasive plant species on dispersing heavy metals in this coastal system because the major rivers of this district are known for their heavy metal pollution (Sandilyan and Kathiresan, 2014).

Further, a study by Jyothi and Nair (1999) established the accumulation of heavy metals such as cadmium and lead in mangrove shrimp, crab and fishes. Thus, immediate removal of invasive species species from the mangroves will prevent the entry/dispersal of heavy metals in mangrove and marine food web.

II. Impacts of Invasive Alien Species on Indian coastal habitats

The coastal habitats of India known for diverse habitats such as backwaters, coral reef, estuaries, lagoons, mangroves, rocky coasts, salt marshes and sandy stretches play a crucial role on the ecological and economic prospective of the country (Saxena, 2012). Besides, it harbours commendable number of flora and fauna. Considering its floral diversity, it was reported that Indian coastal system supports 844 species of marine alga (seaweeds) belonging to 217 genera, 14 species of sea grasses, 69 species of mangroves and 451 floral species. On the other hand, it also support commendable group of fauna including 5 species of sea turtles, 26 species of sea snakes, 30 species of marine mammals, 47 species of tunicates, 200 species of corals and bryozoans, 451 species of sponges, 765 species of echinoderm, 1300 marine fishes, 2900 species of crustacean and 3370 species of marine molluscs (Saxena, 2012; India's Fifth National report, 2014). Interestingly, Indian coastal habitat supports several IUCN threatened categories of animals and also acts as a stopover site for thousands of migratory and resident water birds (Sandilyan, 2009).

However, the total number of recorded marine species (both plants and animals) is less than that of terrestrial habitats. This is because of the fact that marine diversity has not been fully understood due to logistic constraints in explorations and collection of specimen. However, it is also a fact that marine animals are more diverse than land animals at higher phyletic level (Saxena, 2012). Recent investigations have stated that Indian coastal diversity faces a huge threat due to large-scale invasion (e.g. Anil 2002; Raghunathan *et al*., 2013; Kamalakannan *et al*., 2014; Patro *et al*., 2015). Ironically, most of the invasion is not properly recognized and documented and, comparatively, few species have been studied to some extent so far.

Case Study 1:
Impact of *Kappaphycus alvarezii* on Indian corals

A number of marine algae (seaweed) often evolved as an invasive species in the introduced region and denature the natural diversity and ultimately affect services offered by the system. The seaweed *K. alvarezii* is identified as one of the worst invasive red algae. This native of Philippines was introduced into several parts of the world including India (Kamalakannan *et al*., 2014; Jacob and Reddy, 2015).

K. alvarezii has more commercial importance; *'kappa carrageenan'*, commonly called as 'carrageenans,' a product from *K. alvarezii,* is widely used in food, confectionery, soft drinks and beverage industries and is also highly used in the non-food industries such as textiles and cosmetics (Jacob and Reddy, 2015). Due to this huge demand, globally the algae are being intentionally introduced into several marine habitats across continents (Kamalakannan *et al*., 2014). However, recent studies in India disclose that *K. alvarezii* poses serious threats to native corals and associated diversity and ultimately alters the habitat in an irreparable way (Woo, 2000; Smith, 2003; Kamalakannan *et al*., 2014).

Indian coastal system harbours 830 species of marine algae (seaweed); the maximum number of species belongs to Rhodophyta (422), Chlorophyta (217) and Phaeophyta (191) (Reddy *et al*., 2014). The exotic seaweed '*K. alvarezii*' was introduced in 1990s by the CSIR-Central Salt and Marine Chemicals Research Institute, Gujarat. Consecutively, it was introduced into the Palk Bay at the southern tip of India (Namboothri and Shankar, 2010). This species was introduced in the Gulf of Mannar Biosphere Reserve for cultivation in the mid-1990s. Besides, as per the Tamil Nadu state government GO [G.O. Ms. No.229, E&F (EC.3) Department dated 20.12.2005], cultivation of *K. alvarezii* is allowed only in the sea waters of North of Palk Bay and South of Tuticorin coast (Edward and Bhatt, 2012). But in due course of time *K. alvarezii* escaped from cultivation sites and successfully established its colony in the neighbouring areas, which has paved the way for its invasion into the coral reef ecosystem of Kurusadai Island of Gulf of Mannar (Kamalakannan *et al.*, 2014). In this region, a large-scale production of this seaweed for industrial procurement was promoted by the Pepsi Holdings India Private Limited (Pepsi Co) in 2000 (Narayanakumar and Krishnan, 2013). In successive years they motivated the fishermen community in and around the fishing hamlets to take up seaweed farming, and successfully materialized their mission with the help of Women Self-Help Groups (SHGs). They also arranged institutional financial support with the State Bank of India and National Bank for Agriculture and Rural Development (Narayanakumar and Krishnan 2011; 2013), and it is continuous till date with the support of the state government (Jacob and Reddy, 2015). Further, it was reported that an average of at least two members from a family in this region are involved in seaweed industry-related work. Obviously, seaweed culture has now provided a potential employment-generating and income-earning activity, which is practised by more than a thousand members of SHGs in Ramanathapuram district alone and is now slowly spreading to adjoining coastal districts (Narayanakumar and Krishnan, 2011). It was also reported that India receives an annual turnover of Rs. 2 billion by exporting the processed weed (Jacob and Reddy, 2015).

Due to this high commercial worth, the invasion impacts of *K. alvarezii* on coastal ecosystem were not recognized by policy makers and park managers and they probably failed to notice the harmful side of the seaweed. But later, insight and intensive investigations on the coral habitat disclosed that *K. alvarezii* smothers corals of this island and leads to the degradation of the native corals (Chandrasekaran *et al.*, 2008; Kamalakannan *et al.*, 2014). After the impacts were identified, during the year 2008 and in early March 2009, manual removal (hand plucking) of the *K. alvarezii* from the coral habitats (intertidal zone of Kurusadai Island) was carried out by the state forest department (Chandrasekaran *et al*., 2008; Kamalakannan *et al*., 2014). A research team from the Department of Plant Sciences, Madurai Kamaraj University, selected nine removal points where the alga was completely removed and the places were marked with GPS during the year 2007. The team selected 1 m^2 quadrat to monitor the regeneration potential of the *K. alvareziir* for which they adopted Rueness *et al*., (1987) method to estimate the biomass (daily growth rate). After 175 days the place was again surveyed completely for final measurements. The result showed that there was a significant increase in *K. alvarezii* cover in this region. The investigation concluded that after the removal process, there was a vigorous re-growth and predominant establishment of *K. alvarezii* in the habitats and it may be due to counterproductive mechanism exhibited by the species (Figures 3 – 5) (Kamalakannan *et al*., 2014). Further, the study concluded that the sexual reproduction through spores is rare and not viable in this habitat and they observed asexual reproduction by vegetative fragmentation. Obviously fragmentation resulting from manual removal and the tidal currents highly facilitated the dispersal of fragments into new areas, and such broken fragments can easily attach to the nearby substratum, that is, the corals. The strong regeneration ability of this species leads to re-establishment of the colony in Kurusadai Island of Gulf of Mannar (Kamalakannan *et al*., 2014).

In general, invasive species are known for their role as an 'ecosystem modifier' and they can change and maintain a new biotic and abiotic condition, which will favour their growth and continuous expansion in a habitat (Crooks, 2002). Here in the case of *K. alvarezii*, the unscientific control/management strategies exacerbate the issues (Kamalakannan *et al*., 2014).

However, till date, there is no detailed study about the direct impact of *K. alvarezii* in every trophic level in Gulf of Mannar region. It is worth to mention here that it is almost impossible to eliminate an established alien species from a marine habitat (Thresher and Kuris, 2004). Therefore, long-term effects of the species should be properly studied. The state government GO [G.O. Ms. No.229, E&F (EC.3) Department dated 20.12.2005] also clearly mentions that in the event of any adverse impact during environmental impact assessment studies, permission for cultivation in the Coastal Regulation Zone area would be withdrawn. Considering the adverse impact of *K. alvarezii* on the marine environment and resources, in particular coral reefs, seagrass beds and associated fisheries, the G.O. has to be revisited and action may be taken up to stop cultivation in the Gulf of Mannar and Palk Bay (Edward and Bhatt, 2012).

Figure 3. Dispersal of *K. alvarezii* colony due to the discarded fragments during manual removal in Gulf of Mannar, 2007.

Figure 4. Covering of *K. alvarezii* on coral,

Figure 5. Dome-like growth of *K. alvarezii* which suppresses the growth of the native corals in Gulf of Mannar
Photo Courtesy: Dr. S. Chandrasekaran, Department of Plant Sciences, Madurai Kamaraj University.

Case Study 2:
Invasion of snowflake coral (*Carijoa riisei*)

Indian coastal system also harbours a wide range of coral reefs. The major reefs are located in the Gulf of Kachchh, Gulf of Mannar, Andaman and Nicobar Islands, Lakshadweep and some minor reefs at Maharashtra (Malavan) and Goa (Grande Island) (Figure 6 - 7) (Patro *et al.,* 2015). Surfing reports highlighted that invasive speices pose a serious threat to the existing corals, which harbour 25% of total marine biodiversity and contribute to 10% of total fishery production (Raghunathan *et al.,* 2013; Patro *et al.,* 2015).

Besides, some of the exotic corals invaded into Indian coastal habitat have been identified to accelerate the degeneration process of native corrals. The snowflake coral (*C. riisei*) is one such species, native of tropical Western Atlantic and Caribbean, emerging as a potential threat to Indian coastal diversity (Raghunathan *et al.,* 2013; Patro *et al.,* 2015). Recent surveys reveal the occurrence of *C. riisei* on native coral species in several parts of Indian coastal system including Goa, Gulf of Mannar, Andaman and

Nicobar Islands (Raghunathan *et al.,* 2013; Patro *et al.,* 2015). Besides, it was reported that, this coral can establish its colony on a variety of substratum including metal, concrete, plastic, rope and shipwrecks apart from the native corals (Patro *et al.,* 2015). To support this, the recent investigations confirm the occurrence of this species amid barnacle clusters on the rocky reef of the coast at Thiruvananthapuram and Kanyakumari coastal regions (www.The Hindu).

The invasion of *C. riisei* was first reported on 10 May 2009 in Kundol region of Nicobar Islands by the Zoological Survey of India (ZSI). The island is uninhabited by humans after the December 2004 earthquake-cum-tsunami, which has resulted in the unchecked growth of *C. riisei* colonies in several parts of the island. The ZSI reported that 100 m long abandoned jetty was completely covered to a depth of 3–20 m (Raghunathan *et al*., 2013). *C. riisei* had an erected growth up to a maximum length of 40 cm with several intermediate branches. The density of the colonies recorded 6 to 13/m^2 area and the maximum colonies found were at a depth of 10–20 m in Kundol region (Raghunathan *et al*., 2013). In subsequent years, *C. riisei* was reported at Wandoor Jetty in Mahatma Gandhi Marine National Park, Andaman (Dhivya *et al*., 2012) followed in the Gulf of Mannar and the Gulf of Kachchh regions (Patro *et al*., 2015; www.The Hindu).

Based on the available literature it is clear that all the vital coral harbouring zones (Andaman and Nicobar Islands, Gulf of Mannar and Gulf of Kachchh), or in other words all the marine national parks of India, as well as Arabian Sea, Bay of Bengal and Andaman Sea have been witnessed the invasion of this species (Raghunathan *et al*., 2013) even though there are no detailed studies/ reports about the extent of damage caused by the species in the above-said areas. However, 10 different areas in Vembar and Keelakarai group of islands in Gulf of Mannar region were studied by Padmakumar et al., (2011). The investigations revealed that 2.16% of the reef area of Poovarasanpatti Island was infected by *C. riisei*. Especially the cup corals of this region got affected by this invasion. However, the degree of damage caused by *C. riisei* is yet to be studied. It is time to undertake a coordinated and concerted research to monitor the reef health in all sites where the invasion of *C. riisei* has been reported, respect to conserve the fragile reef ecosystem of the country (Patro *et al*., 2015). It is worth to mention here that the ZSI in collaboration with the Department of Environment and Forests, Andaman and Nicobar Administration, has set up 10 permanent monitoring plots in the major reef areas of Andaman and Nicobar Islands to continuously monitor the changes in the coral reefs (Raghunathan *et al*., 2013); such monitoring programmes should be extended to other coral habitat zones of India with a collaboration with nearby research stations and universities that will provide vital data in the near future.

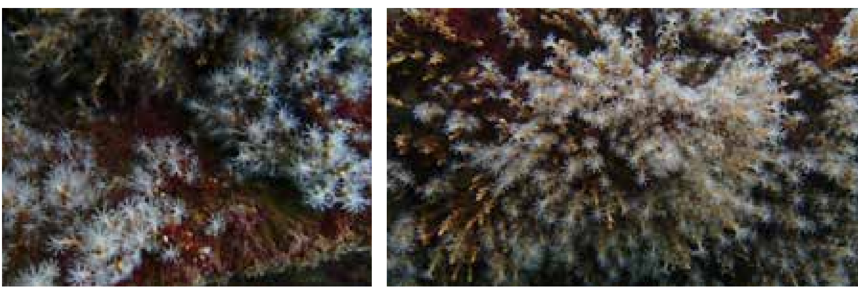

Figure 6. Snowflake coral, *C. riisei* growing on the shipwreck ecosystem in Grand Island, Goa

Figure 7. Polyps of *C. riisei* from Grand Island, Goa, Photo courtesy P. Krishnan, National Centre for Sustainable Coastal Management, Anna University Campus, Chennai

Case Study 3:
Impacts of *Litopenaeus vannamei*

Shrimp farming reached a spectacular growth in the mid-1980s in India (Balasubramanian *et al*., 2016). During that period, the Indian prawn and shrimp culture highly depended on the native species such as *Macrobrachium rosenbergii* and *Penaeus monodon.* In the early 1990s, *P. monodon* accounted for 70% of the globally farmed shrimp. But after the introduction of exotic shell fish, *L. vannamei* (Figure 8), the native species slowly faded out from the culture and natural habitats (Brigg *et al*., 2004), besides the outbreak of White Spot Syndrome Virus (WSSV) in *P. monodon,* leads huge loss. Due to this, culturing shift from *P. monodon* (native tiger prawn) to *L. vannamei* was considered as the most important event in prawn culture industry (Balasubramanian *et al*., 2016). The entry of *L. vannamei* attracted farmers because of its fast growth, low incidence of native diseases, specific pathogen-free (SPF) nature, ability to tolerate high density and low salinity, availability of domesticated strains and also being motivated by corporates (Singh *et al.,* 2014). Indian aquaculture sector leaped to a remarkable height during 2014–2015 with export revenue crossing US $5 billion mainly because of *L. vannamei* (Makesh *et al*., 2016).

Figure 8. *Litopenaeus vannamei,* Photo by Google images

The benefits of the introduced exotics are usually immediate, while the adverse effects are evident only after a long incubation period (Makesh *et al.,* 2016), *L. vannamei* stands as a recent example for this. Now the cultivators are dejected about the outbreak of new diseases. Earlier in the year 2003, the Ministry of Agriculture & Farmers' Welfare permitted two firms to import limited numbers of *L. vannamei* pathogen-free brood stock to India (Makesh *et al.,* 2016). Later it was found that the quarantine of the imported animals by the firms themselves was under high-risk category. However, in the year 2009, the ministry conducted Import Risk Analysis with the help of the Indian Council of Agricultural Research, and the Centre for Agriculture and Bioscience International. The committee disclosed that in Indian condition *L. vannamei* can transmit several new diseases including Taura syndrome virus, Yellow head virus, infectious myonecrosis virus (Makesh *et al*., 2016). Further, the committee recommended to the Government of India to establish quarantine facilities under public sector with restriction on the culture practices (low risk), and to establish SPF multiplication centre-cum-quarantine under public–private partnership with restricted permits for culture. Besides, a dedicated quarantine centre for *L. vannamei* called 'Aquatic quarantine facility for *L. vannamei*' was established in Chennai and the facility started its operation in 2009 (Makesh *et al*., 2016) even though there were surfing reports about the incidents of disease outbreaks. Besides, recent risk assessment studies revealed that this exotic shrimp species has the potential to cause some ecological impacts, such as reducing aquatic biodiversity and also spreading alien pathogens. Moreover, it may also cause some unwanted socioeconomic issues (Singh and Lakra, 2011). Recent studies have confirmed the occurrences of *L. vannamei* in the wild (Balasubramanian *et al.*, 2016). As stated earlier, large numbers of *L. vannamei* cultured in Marakkanam, a town in Viluppuram district of Tamil Nadu, managed to escape from the stocking ponds and entered into the adjacent marine area during 2015 monsoon flood (personal observation). Establishment of wild population in coastal system will cause an imbalance in ecosystem integrity and biodiversity. It has also been reported that this species has become a regular component of inshore catches; now the occurrence may be low but in due course of time it will be increased (Balasubramanian *et al*., 2016). Besides, chances for hybridization with native shell fishes are higher and if it occurs, it will lead to gene dilution. However, it is too early to discuss about the disease caused by the species in the wild.

Obviously, the invasion chance of *L. vannamei* is higher, because it is known for its fast growth and low incidence of regional diseases (Singh *et al*., 2014). Besides it is known for its competition ability with the native species for habitat and food (Briggs *et al*., 2004). However, a detailed long-term study is highly required and the study should cover all aspects of these issues.

III. Impacts of Ballast water on Indian coastal systems

Research in the year 2008 found that marine invasive species have been reported in 232 marine Eco regions (i.e. 84% of the world's coastal system) (WWF, 2009). The study also identified international shipping as being the major introduction pathway for these species. Eariler studies also established that a number of major ports are prone to large-scale introduction of invasive species. For instance, every year three new species have been reported from Port Phillip Bay (Melbourne, Australia) and up to one species every 9 weeks from San Francisco Bay (WWF, 2009).

A number of studies have pointed out that marine invasion is highly harmful to native species, ecosystem functions and human health, which will also cause huge economic and biodiversity loss (Anil, 2002). For instance, the USA spends nearly USD 8.4 billion to manage Asiatic clam, quagga mussels (Ibrahim and Manal, 2012). Eariler studies highlighted that, massive death of fishes, sea turtle, sea birds and marine mammal was reported due to harmful algal blooms (Pierce and Henry, 2008). The other common impacts of invasive species are given in Table 1.

Table 1. Impacts of invasive alien species that invaded through ballast water

Ecological Effects	Economic Impacts	Public Health Concerns
Predation	Industrial water users	Cholera risk
Parasitism	Nuclear power plants	Paralytic shellfish poisoning
Competition	Other water sports	Harmful algal blooms
Introduction of new pathogens	Damage to dams	
Genetic changes	Fishing	
Habitat alterations		
Species shifts/loss of biodiversity		

Source: National Aquatic Nuisance Species Task Force, 2001.

Health hazards

As mentioned earlier 300 algal species have already been identified so far which can cause red tides, and most of the species produce toxins which are harmful to marine organism and humans. For instance, the microscopic algae *K. brevis* can kill large numbers of fish and other marine organisms including endangered dolphins. During blooming, *K. brevis* produces/liberates a collection of polyether neurotoxins called brevetoxins. This substance can easily dissolve in the environment and adversely affect the habitat and wildlife of the region. A study in southern Florida disclosed the large-scale mortality of fish, marine turtle, sea birds and mammals due to brevetoxins produced by *K. brevis* (Pierce and Henry, 2008).

Another study stated that *K. brevis* turned lethal to humans who consumed the infected shellfish such as mussels, clams and oysters (Pierce and Henry, 2008). The filter-feeding mechanism of shellfish leads to the accumulation of the neurotoxins and toxic metabolites in their body when they feed on *K. brevis* (Pierce and Henry, 2008). If the infected shellfish is consumed by humans, it would cause several impacts which are commonly known as Paralytic Shellfish

Poisoning (PSP) or Neurotoxic Shellfish Poisoning (NSP). The symptoms of NSP include gastrointestinal disorders, itching sensation on lips, reversal of hot and cold sensation, rapid heartbeat, loss of balance and lack of coordination (Pierce and Henry, 2008). Human deaths due to PSP/NSP have been reported from several countries including India (Anil *et al*., 2002; Ibrahim and Manal 2012). Besides, it was reported that *K. brevis* produces toxins which can travel though air and cause respiratory, eyes, nose and skin irritation, dry cough and sometimes lead to asthma (www2; Pierce and Henry, 2008).

Ecological Impacts

The invasive species which enter through ballast water cause several ecological impacts in the marine habitats. Throught their invasion, they compete with native species for space and food, sometimes preying upon native species too. Most of the time, invasive species turn the natural environment of the habitat highly suitable for them (e.g. increased water clarity due to mass filter-feeding). Besides, invasive species altering the food web and displacing native species result in poor native biodiversity and even cause local extinctions (Anil *et al.,* 2002; Ibrahim and Manal. 2012). For instance, the European Green crab *Carcinus maenas* which established a colony in Sri Lankan waters emerged as a threat to native molluscs and crustacean population (Anil *et al.,* 2002). The other major impacts caused by the well-known invasive species are given in Table 2.

Economic Impacts

Direct economic losses can be caused by a number of marine invasive species, for instance, reductions or complete collapse in fisheries production due to competition, predation and displacement of the commercially important fish species through invasion (Ibrahim and Manal, 2012). Sometimes the introduced harmful algae blooms will also affect the aquaculture ponds adjacent to the costal system and cause huge economic loss. Marine invasive species can alter the coastal infrastructure by fouling species which affect the efficiency of shipping due to fouling. Often the nearby recreational /t ourism sites are affect by physical fouling and severe odours from harmful algae blooms (Ibrahim and Manal, 2012).

Number of species can cause a huge economic loss to the introduced sites. For instance, the zebra mussel *Dreissena polymorpha*, native to Europe, entered the USA around 1983. It has now spread to infest more that 40% of the US waterways, and fouls the cooling water intake of the industry; to get rid of the problem, the US government has spent USD 5 billion since 1984. Besides, the USA also spends USD 805 million to manage green crab, shipworm and aquatic plants and USD 8.4 billion to control/manage Asiatic clam, quagga mussels and West Nile virus (Ibrahim and Manal, 2012). The impacts of common invasive species invaded through ballast water are given in Table 2.

Table 2. Impact of the invasive species invaded through ballast water

Species	Impacts
Undaria pinnatifida (Sea mustard/Wakame)	Displaces native algae and marine life. Alters habitat, ecosystem and food web and also affects commercial shellfish stocks through space competition and alteration of habitat
Vibrio cholerae	Outbreak of Cholera epidemics
Cercopagis pengoi (Fishhook water flea)	Forms very large populations that affect the zooplankton community and clog fishing nets and trawls
Eriocheir sinensis (Chinese mitten crab)	Burrows into river banks and dykes causing erosion and siltation. Preys on native invertebrate and fish, causing local extinctions during population outbreaks. Interferes with fishing activities
Neogobius melanostomus (Round Goby)	Competes for food and habitat with native fishes including commercially important species, and preys on their eggs and young. Spawns multiple times per season and survives in poor water quality
Mnemiopsis leidyi (Sea walnut)	Feeds excessively on zooplankton, altering food web and ecosystem function
Asterias amurensis (Northern Pacific seastar)	Feeds on shellfish, including commercially valuable scallop, oyster and clam species

Carcinus maenas (Littoral crab)	Displaces native crabs and becomes a dominant species in invaded areas. Consumes and depletes wide range of prey species. Alters inter-tidal rocky shore ecosystem
Dreissena polymorpha (Zebra mussel)	Displaces native aquatic life. Alters food web and habitat, causes severe fouling problems. Blocks water intake pipes

Source: www4.

Issues to be addressed

India harbours 12 major ports and more than 180 non-major ports which are important gateways for marine invasion. Interestingly, the Indian Sea, Bay of Bengal and the Arabian Sea are hydrographically and bio-geochemically different which will be highly prevent the smooth establishment of colonies of exotic species in this region (Anil *et al.,* 2002). Besides, it has been identified that most of the Indian coastal habitats are ecologically sensitive and support important species including horseshoe crabs and marine turtles (BWC, 2004).

Pertaining to ballast water research, only few institutions like the National Institute of Oceanography have been addressing the issue. Studies on exotic bacteria, viruses, fungi, phytoplankton and zooplankton are not available or poorly studied in India (Anil *et al.,* 2002). So far, a handful of invasive species have been identified from Indian marine system (Table 3). Continuous monitoring and field survey are the need of the hour to list out species and its impact. It is essential to monitor all the ports and adopt suitable ballast water management protocols in order to protect the coastal diversity and economy of India (Anil *et al.,* 2002).

Table 3. Alien species reported in Indian marine waters

Group	Species name	Invasion status
Alga	*Monostroma oxyspermum*	A
	Kappaphycus alvarezii	I
Hydroid	*Mercierella enigmata*	A
Anemone	*Eugymnanthea*	A
Mollusca	*Mytilopsis sallei*	A
	Tenellia adspersa	A
	Eualetes tulipa	A
Isopod	*Cilicaea lateraillei*	A
	Cirolana hardfordi	A
	Paradella dianae	A
	Sphaeroma serratum	A
	Synidotea laevidorsalis	A
Bryozoa	*Barentsia ramose*	A
	Amathia verticillata	A
Anthozoa	*Carijoa riisei*	I
Barnacles	*Balanus amphitrite var stutsburi*	A
	B. amphitrite hawaiiensis	A
Ascidian	*Ascidia sydneiensis*	I
	Botrylloides chevalensis	A
	Botrylloides leach	A
	Botrylloides magnicoecum	A
	Corella eumyota	I
	Didemnumpsammathodes	A
	Diplosoma swamiensis	A
	Distaplia nathensis	A
	Ecteinascidia venui	A
	Ecteinascidia.krishnani	A
	Eudistoma lakshmiani	A
	Eudistoma viride	A

Group	Species name	Invasion status
Ascidian	*Eusynstyela tincta*	I
	Eusynstyela tincta	A
	Herdmania momus	I
	Herdmania pallida	A
	Lissoclinum fragile	I
	Microcosmus curvus	A
	Microcosmus squamiger	I
	Perophora formosana	A
	Phallusia nigra	I
	Phallusia polytrema	A
	Phallusia arabica	I
	Polyclinum indicum	A
	Polyclinum madrasensis	A
	Styela bicolor	A
	Styela canopus	A
	Symplegma oceania	A
Amphipod	*Elasmopus rapax*	A
	Erichthonins brasileones	A
	Jassa falcata	A
	Jassa marmorata	A
	Maera pasifica	A
	Monocorophium acherusicum	A
	Paracaprella pusilla	A
Amphipod	*Podocerus brasileusis*	A
	Quadrimaera pacifica	A
	Stenatho gallensis	A
	Stenothoe valida	A

Group	Species name	Invasion status
Cirripedia	*Amphibalanus reticulatus/Balanus reticulatus Utinomi*	A
	Fistulobalanus pallidus	A
	Megabalanus tintinnabulum	A
Copepoda	*Cosmocalanus sp*	A
	Euterpina acutifrons	A
	Nannocalanus minor	A
	Paracalanus sp	A
	Tortanus sp	A
Decapoda	*Litopenaeus vannamei*	A
	Tenellia adspersa	A
Wood-borer	*Lyrodus medilobata*	A
	Nausitora dunlopei	A
	Teredo fulleri	A
Fishes	*Pterois volitans*	A

Note: A- Alien; I: Invasive

Source: Anil *et al*. 2002; Abdul Jaffar Ali and Sivakumar, 2007; Tamilselvi *et al.* 2011; Prakash *et al.* 2012; Raghunathan et al 2013; Kamalakannan et al 2014; Abdul Jaffar Ali and Tamilselvi, 2016; Jebakumar *et al.* 2015 & 2017; Dhanya. A. M 2017; Roy and Nandi.2017.

IV. Knowledge Gaps and Research Needs

Overall, a little or no knowledge is available on coastal habitat biodiversity before and after the bioinvasion which is a major knowledge gap.

Non-availability of detailed studies in coastal habitat related with invasive species is another major concern.

Non-availability of experts (Taxonomist / Ecologist) lead to identify the marine invasive species. More number of trained personnel should be appointed in quarantine division to prevent the entry of invasive species through trade and ballast water.

The Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA) 2003 pointed out some of the important areas to be addressed by the CBD signatories:

a. Patterns and processes characterize the distribution and spread of invasive alien microorganisms in all wetlands including coastal
b. How do genetic traits and hybridization affect the likelihood of a species becoming invasive?
c. What are the key factors driving ecosystem resistance to invasions and the capacity to recover from invasions?
d. What are the high-priority taxonomic difficulties that should be addressed first?
e. Mode of prediction of invasiveness

f. How can invasive species be distinguished from the consequences of other stresses such as loss of habitat and hydrological connectivity, flow regulation, loss of riparian functions, and water pollution?

g. Coordination between institutes involved in research on this aspect and a lead centre can monitor the activities: Efforts from Government of India are the need of the hour on this issue.

These gaps in the knowledge are a real threat in the invasive species management in the wetlands of India. Further, the SBSTTA (2003) has recommended developing useful conceptual models to undertake experimental research, prevention, management, monitoring and control of invasive species in wetland ecosystem. Aforesaid issues are the important knowledge gaps pertaining to Indian aquatic invasive species management.

V. Recommendations

There has been no detailed and in-depth study in India to quantify the economic and biodiversity loss as a result of marine invasion. On the other hand, several developed countries contribute to major research and legal framework in order to prevent the biological invasions in and around marine habitat (Miller, 2004). For example, a number of rodent species in the islands of UK have been completely eradicated after continuous monitoring and eradication programmes, and the successful details of the methodology of such programmes are hosted by the concerned researchers (Thomas *et al.,* 2017).

Ballast water management and recommendation

A number of ballast water management plans have been identified by the researchers including chemical, physical, mechanical and biological mode of elimination of organism from the ballast tanks (Ibrahim and Manal, 2012). Even ballast water exchange, treatment or retention on board is recommended for the best management practices. However, several ballast water treatment methods have some negative feedbacks both to the ecosystem and to the ship industry (Ibrahim and Manal, 2012).

However, the Global Environment Facility through the United Nations Development Programme funded the International Maritime Organization (IMO) to initiate the Global Ballast Water Management Programme (GloBallast). Countries like Brazil, China, India, Iran, South Africa and Ukraine were identified for the initial phase of this programme (Anil *et al.*, 2002). The main agenda of IMO is to reduce the transfer of harmful marine species in ballast water by assisting the countries to implement existing IMO voluntary guidelines for the control and management of ships' ballast water. The GloBallast (GEF-UNDP-IMO GloBallast Partnerships Programme) is also involved in the preparation of new international convention on ballast water (Anil *et al*., 2002). In this connection, an International Convention for the Control and Management of Ships' Ballast Water and Sediments was adopted by consensus at a Diplomatic Conference at IMO in London on Friday 13 February 2004 (Ibrahim and Manal, 2012). The Convention is widely accepted by several governments and the global shipping industry. Unfortunately, the convention has not yet entered into force even after several years of its adoption (WWF, 2009). However, recent news confirms that the Convention entered into force on September 8, 2017 (India is not a signatory), marking a landmark step towards halting the spread of invasive aquatic species (www3). Ballast Water Management Convention will not only minimize the risk of invasions by alien species through ballast water, but also provide a global level-playing field for international shipping, providing clear and robust standards for the management of ballast water (www3). As per the guidelines, every ship should maintain a ballast water record book along with an International Ballast Water Management Certificate. Ships will also need to install an on-board system to treat ballast water and eliminate unwanted organisms. The convention also certified more than 60 on-board systems. Obviously the entry of the convention into force is a vital step towards ballast water management (www3).

Key functions of National Biodiversity Action Plan of India on Invasive Alien Species issues

So far there has been no exclusive legislation and concrete policy in India to deal with the invasion issues. However, the National Biodiversity Action Plan (NBAP) sheds some light on this issue and pointed out some key functions (Raghunathan *et al*., 2013). The NBAP pointed out the following key points for invasive species regulation and management:

1. Develop a unified national system for regulation of all aquatic introductions and carrying our rigorous quarantine checks
2. Strengthen domestic quarantine measures to contain the spread of invasive species to neighbouring areas
3. Promote intersectoral linkages to check unintended introductions and manage the spread of invasive species
4. Develop a national database on invasive species in India
5. Develop appropriate early warning and awareness system in response to new sightings of invasive species
6. Provide priority funding to basic research on managing invasive species
7. Support capacity building for managing invasive species at different levels with priority on local area activities
8. Promote restorative measures of degraded ecosystems using preferably locally adapted native species for this purpose
9. Promote regional cooperation in the adaptation of uniform quarantine measures and containment of invasive exotics
10. Demarcate habitat specificity and distribution of invasive species with their distribution trend
11. Monitor water current movement and regular analysis
12. Cooperate actively among the concerned central and state government departments (research and policy) as well as agriculture, livestock, fisheries, forests, water resources, tourism, commerce, shipping, environment and rural development while involving lead institutions and non-governmental organizations on a case-by-case basis
13. Draft socioeconomic degradation with the help of impact parameters

14. There are three major methods by which to prevent species invasions: interception based on regulations enforced with inspections and fees; treatment of material suspected to be contaminated with invasive species; and prohibition of certain commodities in accordance with international regulations

15. Early detection of potential invaders is usually critical in determining whether eradication is feasible

16. Eradication is the final stage followed by the failure of prevention step

17. Invasive species control uses many of the same techniques as eradication such as mechanical (e.g. pulling weeds), chemical (e.g. using toxic baits against vertebrates or poisons against plants), habitat management (e.g. sanitation, habitat removal, barriers, grazing, flooding and prescribed burning) and prescribed hunting of invasive vertebrates. Biological control can be another very cost-effective measure but careful assessment of the environmental impacts of biocontrol agents is necessary before introduction. As with eradication, the integration of several control methods often provides the most effective management strategy (Raghunathan *et al*. 2013; NBAP 2014).

VI. Conclusion

Globally, several studies have concluded that marine habitats and their biodiversity face major losses due to biological invasion. The invasive problem affects the marine system in several ways including altering genetic composition of the native species to the denaturing of the ecosystem. Researchers and policy makers have identified the major pathways for the entry of invasive species in all aquatic ecosystems and are concerned about the poor regulation/control (SBSTTA, 2003). According to several researchers, the species introduced for aquaculture, ornamental aquarium trade and ballast water is the leading pathway of entry of invasive species in several aquatic ecosystems, and apparently they are the major source of income, food and livelihood for local communities (Anil *et al.*, 2002; SBSTTA, 2003; Sandilyan, 2016). On the other hand, invasive species play a vital role in demolishing the natural system through which local communities depend on (SBSTTA, 2003). Pertaining to a developing country like India, exotic species are considered an easy option for commercially important agriculture, forestry and fisheries-related activities. In the policy level, we should give priority and promote the native species (SBSTTA, 2003).

Globally, limited success has so far been reported in the prevention, eradication and control of invasive species in wetland ecosystems including marine, which indicates the vulnerability of the system (SBSTTA, 2003). Population growth and associated anthropogenic pressure on coastal habitat will very soon exacerbate the issues in a country like India.

In general, invasive species management is not an easy task; it needs a combination of various methods and technique (e.g. physical, chemical, biological, legal). It is better to give the privilege on prioritize the prevention, control and suppression/management (Raghunathan *et al*., 2013). The need of the hour is to establish a regulatory authority to deal with invasive species issues under Ministry of Environment, Forest and Climate Change. Further, establishment of a national institute with special branches for invasive species management is also needed. Such an institute should concentrate on adherence to the guidelines by traders and other stakeholders, creating awareness among public and policy makers, and encouraging research in the management aspects (Sandilyan, 2016).

References

Anil, A. C., Venkat, K., Sawant, S. S. *et al*., 2002. Marine bioinvasion: Concern for ecology and shipping. *Current Science* 83(3):214-218.

Balasubramanian, CP., Gopal, C, Anand, SS *et al* .2016. Ecological integrity and biodiversity of native ecosystem with special reference to the introduction of exotic whit shrimp, *Penaeus vannamei.* "Abstract on Inter National conference on Aquatic Exotics: Trends, Challenges and Polices" (28-30 March 2016) at University of Kerala, Thiruvananthapuram, India. Pp;6-7.

Briggs M, Funge-Smith S, Subasinghe R, Phillips M.2004 Introductions and movement of Penaeus vannamei and Penaeus stylirostris in Asia and the Pacific. Food and Agriculture Organization of the United Nations, Regional Office for Asia and the Pacific. RAP Publication 2004/10, 1– 12 pp

BWC, 2004. dgshipping.gov.in//201405020431325319835notice_msl_b.Accessed on 8/9/16.

Carlton, J. T., 2001. Introduced species in U.S. coastal waters: environmental impacts and management priorities. Pew Oceans Commission, Arlington, Virginia, iii + 28 + (1) pp. http:// www.pewoceans.org/ reports/introduced_species.pdf.

CBD (Convention on Biological Diversity), 2002. Decision VI/23 (Annex, footnote): Alien species that threaten ecosystems, habitats and species. Document UNEP/CBD/COP/6/23. Convention on Biological Diversity Secretariat, Montreal, Canada. Available from https://www.cbd.int/decision/cop/?id=7197, (accessed 11.01.15).

Chandrasekaran, S., Nagendran, N. A., Pandiaraja, D., Krishnankutty, N. and Kamalakannan B. 2008. Bioinvasion of *Kappaphycus alvarezii* on corals in the Gulf of Mannar, India. *Current Science*, 94, 1167–1172.

Crooks, J. A. 2002. Characterizing ecosystem-level consequences of biological invasions: the role of ecosystem engineers. Oikos, 97, 153 –166.

Dhanya. A. M 2017. Non-indigenous sea slug Tenellia adspersa in the southeast coast of the Arabian Sea, India. Current Science, 113(1); 24-26.

Dhivya P, Sachithanandam V, Mohan PM. 2012. New record of *Carijoa riisei* at Wandoor Mahatma Gandhi Marine National Park (MGMNP), Andaman and Nicobar Islands, India. *Indian J Mar Sci* 41(3):212–214.

Early, R. *et al* 2016. Global threats from invasive alien species in the twenty-first century and national response capacities Nature Communication.DOI: 10.1038/ncomms12485.

Edward, JKP and Bhatt, J.R.2012. A note on bio-invasion of *Kappaphycus alvarezii* on coral reefs and seagrass beds in the Gulf of Mannar and Palk Bay. Bhutt *et al* (eds,), in Coral reefs in India - status, threats and conservation measures. pp 281-288. Available on https://www.mangrovesforthefuture.org/.../Coral-Reefs-in-India-Status-Threats-Conser. Accessed on 2/8/16.

GISP 2004. *Africa Invaded: The Growing Danger of Invasive Alien Species*. Global invasive Species Programme, Cape Town. http://www.gisp.org/downloadpubs/gisp%20africa%202.pdf

Ibrahim, A.M. and Manal, MAC. 2012. Ballast Water Review: Impacts, Treatments and Management.Middle-East Journal of Scientific Research 12 (7): 976-984.

India's Fifth National Report to the Convention on Biological Diversity.2104. https://www.cbd.int/doc/world/in/in-nr-05-en.pdf. Accessed on 22/11/17..

Jacob, CT and Reddy, CA. 2015. Implementation of the Access and Benefit Sharing provisions of the Biological Diversity Act, 2002: A case study on Red Seaweed (*Kappaphycus alvarezii). Asian Biotechnology and Development Review;*17(3); 37-49.

Jebakumar,JPP; Ganesan Nandhagopal; Shunmugavel Ragumaran; Bose Rajanbabu; Vijaya Ravichandran., (2015). First record of alien species Eualetes tulipa (Rousseau in Chenu, 1843) from the Royapuram fishing harbour at Chennai, India. BioInvasions Records. 4 (3): 201–204.

Jebakumar,JPP, Ganesan Nandhagopal, Bose RajanBabu, Shunmugavel Ragumaran, Vijaya Ravichandran, Agnese Marchini, Dan Minchin. (2017). The bryozoan Amathia verticillata (delle Chiaje, 1822) fouling harbours of the southeast coast of India: re-evaluating its status. BioInvasions Records, 6 (3): 211–216.

Johnston, M. W., & Purkis, S. J. 2015. Hurricanes accelerated the Florida–Bahamas lionfish invasion. *Global Change Biology 21*, 2249–2260. DOI: 10.1111/gcb.12874.

Jyothi, A. K. and Nair, V. R. 1999. Concentration of metals in shrimps and crabs from Thane and Basse in creek systems, Maharashtra. *Indian Journal of Marine Science*, 28: 92–95.

Kamalakannan, B., Joyson Joe Jeevamani, J., Nagendran, AN., *et al*. 2014. Impact of removal of invasive species *Kappaphycus alvarezii* from coral reef ecosystem in Gulf of Mannar, India. *Current Science*, 106(10);1401-1408.

Levine, J.M., Vila, M., D'Antonio, C., Dukes, J.S., Grigulis, K. & Lavorel, S. 2003. Mechanisms underlying the impact of exotic plant invasions. *Phil. Trans. Roy. Soc*., 270, 775–781

Makesh, M., Alavandi, S.V. and Vijayan, KK. 2016. Prevention of exotic diseases through introduction of alien aquatic species in brackish water aquaculture in India. Abstract on Inter National conference on Aquatic Exotics: Trends, Challenges and Polices" (28-30 March 2016) at University of Kerala, Thiruvananthapuram, India. Pp;12-15.

Miller, M.2004. The paradox of US alien species law. In Harmful Invasive Species: Legal Responses (eds Miller, M. and Fabian, R.), Environmental Law Institute, Washington, DC, USA. pp. 125–184.

Namboothri, N., Shankar, K. 2010. Corals or coke: between the devil and the deep blue sea. *Current Conservation* 4:18–20.

Narayanakumar, R and Krishnan, M. 2011. Seaweed Mari Culture: An economically viable alternative livelihood option for fishers. "*Indian Journal of Fisheries*, 58(1); 79-84.

Narayanakumar, R and Krishnan, M. 2013. Socio-economic assessment of seaweed farmers in Tamil Nadu - A case study in Ramanathapuram District. "*Indian Journal of Fisheries*, 60(4): 51-57.

National Aquatic Nuisance Species Task Force, 2001. www.anstaskforce.gov.

NBAP (National Biodiversity Action Plan. 2014. https://www.cbd.int/doc/world/in/in-nbsap-v3-en.pdf. Accessed on 4/01/17.

Padmakumar, K., Chandran, R., Yogesh Kumar, J. S. and Sornaraj, R. 2011. *Carijoa riisei* (Cnidaria : Octocorallia : Clavulariidae), a newly observed threat to Gulf of Mannar coral biodiversity?. *Current Science,* 100(1), 35–37.

Patro, S., Krishnan, P., Gopi, M. *et al*. 2015. Snowflake coral, *Carijoa riisei* from Grand Island, Goa: a case of invasion of an alien species or re-establishment of a native species?. *Current Science*, 109 (6); 1028-1030.

Pierce, R. H. and Henry, M. S. 2008. Harmful algal toxins of the Florida red tide (*Karenia brevis*): natural chemical stressors in South Florida coastal ecosystems. *Ecotoxicology*, 17(7): 623–631. doi:10.1007/s10646-008-0241-x.

Prakash, S., Balamurugan, J., Ajith Kumar, TT and Balasubramanian, T. .2012. Invasion and abundance of reef inhabiting fishes in the Vellar estuary, southeast coast of India, especially the lionfish Pterois volitans Linnaeus.Current Science, 103(8);941-944.

Raghunathan, C., Venkataraman, K., Satyanarayana, Ch. and Rajkumar. R. 2013. An Invasion of Snowflake Coral *Carijoa riisei* (Duchassaing and Michelotti 1860) in Indian Seas: Threats to Coral Reef Ecosystem. K. Venkataraman *et al*. (eds,), in Ecology and Conservation of Tropical Marine Faunal Communities_pp 381-393.

Reddy *et al*. 2014. The seaweed resources of India. In: A. T. Critchely, M. Ohno and D.B. Largo (eds.). World Seaweed Resources (in DVD format), ETI Information Services Ltd., Wokingham, Berkshire, U. K.

Rejmanek, M. and Richardson, D.M., 2000, What makes some conifers more invasive? Proceedings of the Fourth International Conifer Conference

Roy MKD, Nandi NC .2017. Marine Invasive Alien Crustaceans of India. J Aquac Mar Biol 5(2): 00115. DOI: 10.15406/jamb.2017.05.00115.

Rueness, J., Mathisen, H. A. and Tananger, T. 1987. Culture and field observations on *Gracilaria verrucosa* (Huds.) Papenf. (Rhod ophyta) from Norway. *Bot. Mar.,* 30, 267–276.

Sandilyan, S., 2009. Habitat Quality and Waterbird Utilization Pattern of Pichavaram wetlands Southern India. Ph.D. Thesis. Bharathidasan University, Tiruchirapalli, India.

Sandilyan, S.2016. Occurrence of ornamental fishes: a looming danger for inland fish diversity of India. *Current Science*, 110 (11): 2099-2104.

Sandilyan, S., Kathiresan, K., 2012. Mangrove conservation: a global perspective. *Biodivers Conserv* 21 (14), 3523e3542.http://dx.doi.org/10.1007/s10531-012-0388-x

Sandilyan, S. and Kathiresan, K. 2014. Decline of mangrove: A threat of heavy metal poisoning in Asia. Ocean and Coastal Management, 102: 161–168.

Saxena, A.2012. Marine Biodiversity in India: Status and Issues. Published by Uttar Pradesh State Biodiversity Board. www.upsbdb.org/pdf/Souvenir2012/ch-14.pdf. Accessed on 30/12/16.

SBSTTA.2003. Pilot assessments: the ecological and socio-economic impact of invasive alien species on island ecosystems. UNEP/CBD/SBSTTA/9/INF/33. Available on https://www.cbd.int/doc/meetings/.../sbstta-09-inf-33-en.doc.

Singh, A.K., Ansari, A., Srivastava, S.C., Verma, P and Pathak, A.K. 2014. Impacts of Invasive Fishes on Fishery Dynamics of the Yamuna River, India. *Agricultural Sciences* 5: 813-821. http://dx.doi.org/10.4236/as.2014.510086.

Singh, A.K. and Lakra, W.S. 2011. Risk and benefit assessment of alien fish species of the aquaculture and aquarium trade into India. *Reviews in Aquaculture* 3: 3–18.

Smith, J. E. 2003,., 153 Invasive macroalgae on tropical reefs: impacts, interactions, mechanisms and management. *J. Phycol.,* 39, 53.

Sujay, Y.H., Sattagi H.N. and Patil, R.K.2010. Invasive alien insects and their impact on agroecosystem *Karnataka J. Agric. Sci., 23(1) : (26-34) 2010.*

Surendra, B., Muhammed, A. A., & Raju, Solomon AJ. 2013. Invasive Alien plant species assessment in urban ecosystem: a case study from Andhra University, Visakhapatnam, India. International Research Journal of Environment Sciences, 2(5), 79–86.

Tamilselvi,M., Sivakumar, V., Ali, HAB and Thilaga R.D.2011. Distribution of Alien Tunicates (Ascidians) in Tuticorin Coast, India. World Journal of Zoology 6 (2): 164-172.

Thomas, S., Vamham, K and Havery, S.2017. Current recommendation procedures for UK (bait station) rodent eradication projects(version 4.0) Royal Society for the protection of Birds, Sandy, Bedfordshire.

Thresher, R. E. and Kuris, A. M. 2004. Options for managing invasive marine species. *Biol. Invasions,* 6, 295–300.

Venkataraman, K. 2008. Coastal and Marine Wetlands in India. In Sengupta, M. and Dalwani, R. (eds). 2008. *The 12th World Lake Conference* Proceedings of Taal 2007:: 392-400.

Wafar M, Venkataraman K, Ingole B, Ajmal Khan S, Loka Bharathi P. 2011. State of Knowledge of Coastal and Marine Biodiversity of Indian Ocean Countries. *PLoS ONE* 6(1): e14613. https://doi.org/10.1371/journal.pone.0014613

Woo, M. 2000. Ecological impacts and interactions of the introduced red alga Kappaphycus striatum in Kaneohe Bay, Oahu. Master thesis, Department of Botany, University of Hawai'i, Honolulu,

WWF.2009. Silent Invasion – The spread of marine invasive species via ships' ballast water. WWF International, Gland, 2009. (www.wwf.de/fileadmin/fm-wwf/Study_Silent_Invasion.pdf. Accessed on 8/10/16.).

Ballast water net reference

www1 https://www.tc.gc.ca/eng/marinesafety/oep-environment-ballastwater-defined-249.htm.

www2 https://start1.org/red-tide/. Accessed on 16/9/16.

www3 http://www.maritime-executive.com/features/invasive-species-doubts-five-years-after-japans-tsunami. Accessed on 16-3-16.

www4 http://wwf.panda.org/about_our_earth/blue_planet/coasts/coral_reefs/coral_importance/

www5 http://www.thehindu.com/todays-paper/tp-national/snowflake-coral-a-serious-threat-to-biodiversity/article8066192.ece. Accessed on 2/8/16.

Annexure A

Marine plant species reported from India

Sl. No	Types/life forms of Plants	Number of Species
1	Diatoms	200+
2	Dinoflagellates	90+
3	Macro algae	844
4	Seagrasses	14
5	Mangroves	39
	Total	**1187**

Source: Wafar *et al*. (2011).

Marine Protista from India

Sl. No	Types/life forms of Plants	Number of Species
1.	Protozoa	532+
2.	Foraminifera	500+
3.	Tintinnids	32+
	Total	**1064**

(Protists are eukaryotic organisms that cannot be classified as a plant, animal, or fungus)
Source: Wafar *et al*. (2011).

Marine animals reported from India

Sl. No	Types	Number of Species
1	Porifera	486+
2	Cnidaria	842+
3	Ctenophora	12+
4	Platyhelminthes	350
5	Annelida	338
6	Chaetognatha	30+
7	Sipuncula	35
8	Echiura	33
9	Gastrotrocha	75
10	Kinorhyncha	10
11	Tardigrada	10+
12	Crustacea	3498
13	Mollusca	3370
14	Bryozoa	200+
15	Echinodermata	765
16	Hemichordata	12
17	Protochordata	119+
18	Pisces	2546
19	Reptiles	35
20	Mammals	25
	Total	**12791**

Source: Wafar *et al* (2011).

Annexure B

Sl. No	Groups	No. of Species
Plants		
1	Mangroves	39
2	Mangrove associates	86
3	Sea grasses	11
4	Marine algae	557
5	Bacteria	69
6	Fungi	103
7	Actinomycetes	23
8	Lichens	32
Animals		
1	Prawns and lobsters	55
2	Crabs	138
3	insects	707
4	Molluscs	305
5	Other invertebrates	745
6	Fish parasites	7
7	Fin fish	543
8	Amphibian	13
9	Reptiles	84
10	Birds	426
11	Mammals	68
	Total number of Species	**4011**

Source: Sandilyan and Kathiresan (2012).

NOTE

NOTE

About CEBPOL

Government of India in collaboration with the Norwegian Government has established "Centre for Biodiversity Policy and Law (CEBPOL)" at the National Biodiversity Authority (NBA), an autonomous and statutory body of the Ministry of Environment Forest and Climate Change towards strengthening of expertise in Biodiversity Policy and Law in India. This programme is executed by the NBA in collaboration with Norwegian Environment Agency through the Royal Norwegian Embassy, New Delhi, India.

The Centre aims to provide advice and support to the Government of India and Norway on Biodiversity Policy and Law related issues including complex negotiations on Access and Benefit Sharing and Traditional knowledge as well as governance issues relating to biodiversity at the National and International level. The Centre proposes to help NBA in the effective implementation of International agreements on conservation, sustainable use and the associated access and benefit sharing components of it.

CEBPOL is set up as a specialized Centre of Excellence in Biodiversity Policy and Law to network, organize and consolidate expertise on issues of Biodiversity Policy and Law in India and Norway. The Centre, located at NBA, would function as an independent think tank on Biodiversity Policy and Law. In addition, CEBPOL aims to contribute to the effective implementation of the Biological Diversity Act 2002 and Rules 2004.

Contact:

The Secretary

Centre for Biodiversity Policy and Law

National Biodiversity Authority

5th Floor, TICEL BIO PARK, CSIR Road

Taramani, Chennai-600 113, Tamil Nadu

Email: secretary@nba.nic.in

Website: www.nbaindia.org/cebpol

राष्ट्रीय जैव विविधता प्राधिकरण • National Biodiversity Authority, India • 2003

Ministry of Environment Forest and Climate Change
Government of India

Norwegian Embassy

NORWEGIAN ENVIRONMENT AGENCY