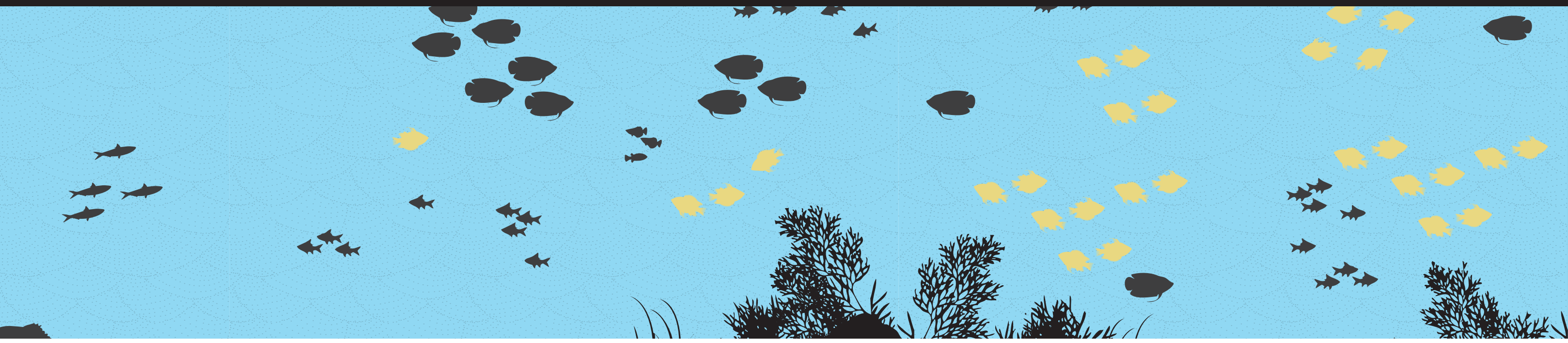

BIOLOGICAL INVASIONS OF MARINE ECOSYSTEMS

CONCERNS FOR TROPICAL NATIONS

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When more makes less

Human interventions on the Earths' natural systems are evident even in remote regions of the Antarctic and rain forests deep within the Amazon. In addition to human-induced climate change and habitat destruction, an emerging anthropogenic threat to biodiversity is the drastic species re-distribution (the movement of species from one place to another due to human intervention) at a global scale. This creates fertile conditions for biological invasions which in turn cause substantial economic and ecological losses.

What can possibly be wrong with something called 'biological invasions'?

Biological invasions involve two issues: the human-mediated transport of a species to an area where it does not naturally occur, and the economic or environmental damage resulting from this. Biotic communities the world over are being homogenised and restructured through biological invasions. This has the potential to cause large economic losses, particularly in countries that rely on natural resources and primary sources of production like agriculture, forestry, and fisheries for their development. Invasive species have increasingly been recognised as a problem the world over. A study in 2001 reports that on account of invasive species India suffers a loss of USD 116 billion in terms of economic and environmental services annually[1]. Can developing countries in biodiversity-rich areas afford to bear such costs? Human-mediated re-distribution of species has received little attention in the past in comparison to other anthropogenic impacts such as habitat loss, pollution, and greenhouse gas emissions. Whatever literature exists on human-mediated biological invasions largely focuses on terrestrial species. The aim of this paper is to highlight the processes and effects of human-assisted biological invasions on marine ecosystems, and suggest recommendations to address this socio-ecological problem.

In considering biological invasions, the following aspects need to be addressed:

1. The factors leading to a species getting established and spreading.
2. The processes by which introductions into an area take place. This would include all the methods by which species can be transported from one place to another through human interventions.
3. The impacts a species has on the ecosystem into which it is introduced.
4. The methods by which it can be controlled or eradicated. This would include policy and legal approaches.

THE PROCESS OF BIOLOGICAL INVASIONS

Addressing the problem of introduced non-indigenous species and devising management actions to control them requires an understanding of the stages involved in the process of biological invasion. The process of biological invasion by a species requires a series of transitions in order for it to overcome a dispersal barrier and establish itself in the recipient habitat (see figure on Pages 8-9). Biological invasions usually occur in two major phases: introduction and establishment (each with a few stages involved).

Introduction of species

The first step in the process of biological invasion is the relocation of a species from its native range into a new recipient system. Only a few species manage to survive transit. Natural transport, or dispersal (a fundamental of how ecosystems function) will not be considered here. Human-mediated transportation can be both intentional and accidental. Intentional transport involves introduction of new species for the purpose of agriculture, or aquaculture, as pets, for recreational purposes, for hunting or as ornamental species. Unintentional transport is by way of shipping and other transport mechanisms where organisms are inadvertently moved out of their home range, e.g., barnacles on a hull, mussels in ballast water, or rats on a ship.

Once a species is introduced into a recipient system, survival and dispersal of the species in its new habitat depends on several factors. These include the richness of the habitat in which it is introduced, similarities of the new habitat to the source environment of the introduced species, and the amount of disturbance. Nowadays, change in the disturbance regime of the recipient system is considered to be a very important factor.

Establishment and spread of species in the recipient system

Factors intrinsic to the species that aid its establishment and spread include high environmental tolerance, short generation times, rapid growth, a broad diet, early sexual maturity, high reproductive output, and rapid dispersal. Studies indicate that a fairly large proportion of species that are transported manage to survive and establish in the recipient system. About 80% of mammals and 50% of newly introduced birds establish themselves, and 65% and 50% respectively spread. Unfortunately, our understanding of the extent of introduction and survival of marine species is very poor.

The establishment of a naturalised population of a non-native species does not imply that the species has become an invasive. For a species to become invasive, it has to establish large populations and spread in its recipient system, thereby causing economic or environmental damage. If its numbers remain very low, obviously these impacts are missing.

METHODS OF INTRODUCTION OF NON-NATIVE SPECIES IN MARINE ECOSYSTEMS

Ships as vectors

Ocean-going vessels have long traversed the oceans of the world carrying a diverse variety of species in and on them, and are probably the best known examples of human-mediated transportation and dispersal of both marine and terrestrial species. The epifaunal assemblages that survive on the hulls of ships have been carried around the most through direct physical transport. However, one of the most significant global pathways of numerous recorded—and perhaps many more unrecorded—introduction of species in marine ecosystems is by way of ballast water. In order to maintain stability during transit, most ocean going vessels need to carry a substantial quantity of water in large tanks called 'ballast tanks'. Large cargo ships often carry millions of litres of ballast water which is filled at one port and may be discharged or exchanged at another. While filling ballast tanks close to ports, a large diversity of pelagic species such as microorganisms, phytoplankton, and zooplankton could get entrapped. Along with these, large numbers of propagules of different species in the form of larvae or fertilised eggs can also get entrapped. These adult and propagule forms are carried either long or short distances and the ballast water is emptied at the destination port. A substantial proportion of organisms and propagules die during transit. However, those that survive and make it to the new port could establish themselves in the recipient system (See figure on Page 4).

Studies that have tried quantifying the extent of biological transport facilitated by way of ballast water globally have conservatively estimated about 7,000–10,000 species to be transported per day[2]. This renders most global ports as the entry/source point for most marine biological invasions as well as stepping stones for facilitating the spread of marine invasives.

Introduction through aquaculture

Increasing demand for seafood in the world market and declining wild fish stocks have lead to a substantial boom in the aquaculture sector globally, with the countries of the tropics being the main producers. Technologies have been developed for the captive rearing of a few species which are generally more tolerant of disturbances and capable of surviving in captivity. This has led to the transportation of species beyond their natural range for the purpose of culturing. However, because of their ability to survive well under stressful conditions, many of these species are also superior competitors. The accidental or intentional release of such species can have severe economic and ecological impacts on the recipient systems. Marine bioinvasion risks that are associated with aquaculture activities arise from the direct introduction of non-indigenous species for culture and thereby their associated pathogens and harmful algae. Many case studies from across the world highlight the ecological and economic damage that the culture of non-indigenous species has on the recipient systems. Some notable species that were introduced for the purpose of aquaculture and which have subsequently invaded the recipient ecosystems are Mozambique tilapia (*Oreochromis mossambicus*), Nile tilapia (*Oreochromis niloticus*), Atlantic salmon (*Salmo salar*), African catfish (*Clarias gariepinus*), seaweeds (like *Codium fragiles* spp. *tomentosoides, Caulerpa recemosa var. cylindrica, Kappaphycus alvarezii*), and Pacific oyster (*Crassostrea gigas*).

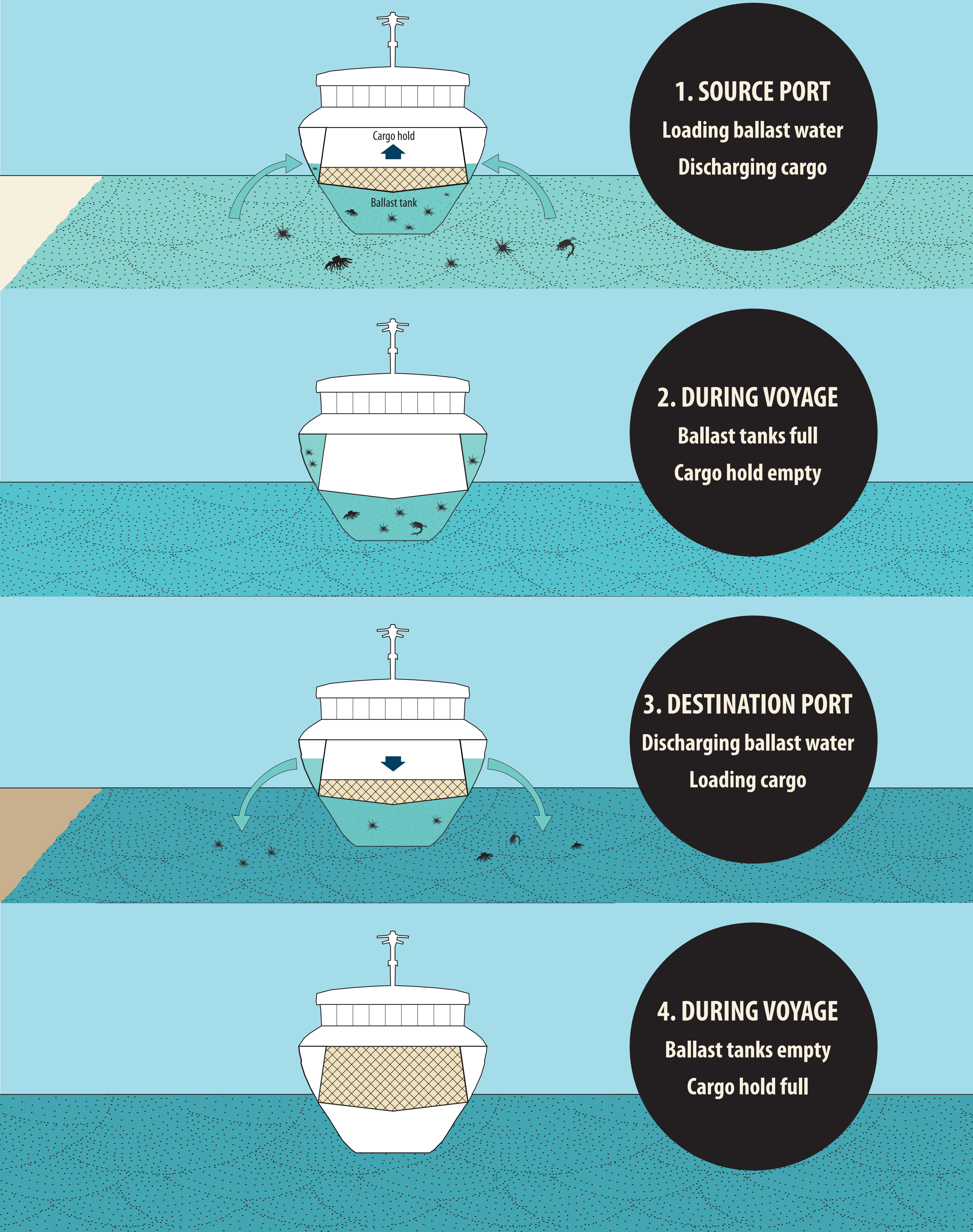
Ornamental fish trade

The ornamental fish trade is a relatively new entrant to the list of known vectors for the introduction of non-native species. While the introduction and establishment of a few freshwater ornamental species has been previously recorded, there is comparatively little information on marine species. A recent invasion of the Caribbean waters and the tropical Atlantic waters by the Indo-Pacific lionfish (*Pterois volitans)* and common lionfish (*Pterois miles*) has received substantial attention[3]. Another often unforeseen consequence of the aquarium trade is the free transfer of pathogens with tradable marine products. Pathogens are known to thereon successfully infect local indigenous species, which have no natural defense mechanisms against them, causing the outbreak of disease and even epidemics.

Live seafood trade

The introduction of marine bivalves into the USA through the trade for live seafood has been recorded. The extent of this elsewhere has not been documented.

BALLAST WATER TRANSPORT OF MARINE SPECIES



← *Large cargo ships often carry millions of litres of ballast water which is filled at one port and may be discharged or exchanged at another. While filling ballast tanks close to ports, a large diversity of pelagic species such as microorganisms, phytoplankton, and zooplankton could get entrapped. Along with these, large numbers of propagules of different species in the form of larvae or fertilised eggs can also get entrapped. These adult and propagule forms are carried either long or short distances and the ballast water is emptied at the destination port. A substantial proportion of organisms and propagules die during transit. However, those that survive and make it to the new port could establish themselves in the recipient system.*

ISLANDS AND BIOLOGICAL INVASIONS

Terrestrial biodiversity of island ecosystems is considered to be unique due to the high levels of endemism they exhibit. Prolonged geographic isolation of islands has limited immigration of new species; as a result, established species have evolved with fewer competitors, enemies and pathogens, rendering these systems susceptible to biological invasions. More than half of the 724 recorded animal extinctions in the last 400 years were of island species. The survival of indigenous communities of such islands that depend on the local biodiversity and their knowledge of it, could be seriously undermined by biological invasions. The fragile nature of the social-ecological systems of islands invites special focus and attention.

Unfortunately most of our understanding of the impacts of biological invasions on island systems is limited to terrestrial ecosystems. Due to their higher dispersal potential, and in the absence of obvious barriers, endemism in marine ecosystems usually happens at much larger scales than in terrestrial ecosystems.

Island groups of the Andaman and Nicobar in the Bay of Bengal, and the Lakshadweep in the Arabian Sea are two groups of oceanic islands in India that support substantial marine biodiversity. The islands of the Andaman and Nicobar, in addition, also support a high diversity of terrestrial endemic species and ecosystems. There needs to be stringent monitoring of species introduction, especially through ship ballasts, hull fouling, aquaculture, agriculture, horticulture, and as pets, and more focussed research needs to be undertaken on the impacts of existing invasive alien species.

COLA WARS AND INVASIONS

Kappaphycus alvarezii, referred to as the 'licorice algae', is among the largest tropical marine red algae that can grow up to 2m tall. A native of the Philippines, it is an economically important source of the gelling agent, kappa-carrageenan, which is used in industrial gums and other products such as ice cream, toothpaste, jellies, medicines, and paint as a smoothening agent. *K. alvarizii* has been introduced in 26 countries for large-scale culture, and the species has become a prolific biological invader in many of these countries.

Introduction of the species in India

In 1994, 10 grams of *K. alvarezii* was obtained from the Kochi University, Japan, by the Central Salt and Marine Chemical Research Institute (CSMCRI) for the purpose of carrying out large-scale culture of the species in order to produce kappa-carrageenan, an important ingredient in many commercial products. After trying out experimental studies (both field and lab-based) at Bhavnagar, Gujarat, the species was introduced in Mandapam in the Gulf of Mannar (Tamil Nadu) in 1995, a year after the introduction of the species to India.

Large-scale culture of the algae at Mandapam, Tamil Nadu

K. alvarezii was first cultured in confined conditions, employing perforated polythene bags to prevent its accidental spread. The algae produced by this method were stunted and the polythene bags suffered wear and tear. Next, a semi-confined method using net bags was tried, which was replaced later by unconfined open culture on rafts. In 2002, the technology of *Kappaphycus* production was transferred to Pepsi Foods Limited (PFL), which promoted a buy-back system from Self-Help Groups (SHGs) and local community members in the region. Currently SHGs and individuals of four coastal districts are involved in the production of this algae.

Conflict of interest in the assessment of risk

The CSMCRI had introduced the species to India after obtaining necessary permits from the Ministry of Agriculture, Government of India, through the Department of Agriculture & Co-operation, Directorate of Plant Protection, Quarantine & Storage. PFL had carried out an EIA in 1999–2001 to understand the natural occurrence of *Kappaphycus* in and around the Palk Bay. In 2002 and later in 2008, after the technology transfer to PFL, CSMCRI carried out a project to evaluate the impacts of *K. alvarezii* culture on the adjoining ecosystems. The studies revealed that except three sites in the Krusadai Island, the species was not encountered in and around the region.

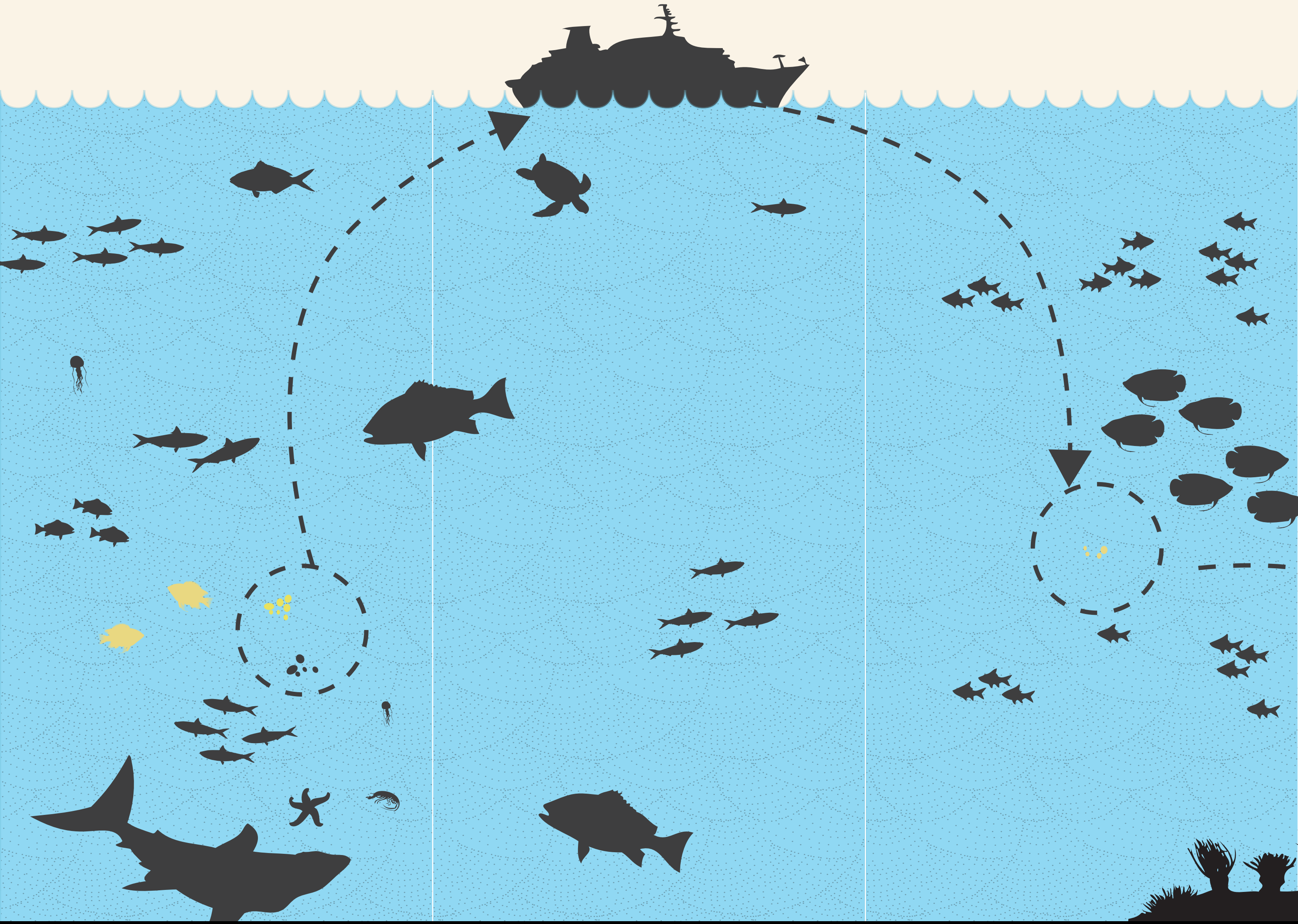
Spread of K. alvarezii in the Gulf of Mannar

While mariculture of *K. alvarezii* was being promoted in India, there was mounting evidence of the invasive properties of the species from other parts of the world. *K. alvarezii* is known to outcompete local varieties of algae in the Mediterranean and to have invaded coral reefs in Hawaii undermining their ecological and economic functions. However, independent studies conducted by other scientific institutions in the country between 2008 and 2010, in the Gulf of Mannar indicate that the species has managed to spread and establish itself on corals within the Marine National Park in at least three islands[4,5,6]. Independent studies and transparency in data collection and analysis are important to verify so called 'unbiased' trials and assessments which often are carried out by proponents themselves.

Lessons learnt and the way forward

The case-study of *K. alvarezii* raises important questions about ethical practices in scientific trials, and highlights the need to introduce stringent and transparent protocols for the introduction of new marine species in non-native waters. While the idea of introducing *K. alvarezii* as an alternative livelihood for resource-dependent communities may be well-intended, the scientific information and research that currently supports and justifies its introduction is weak and unsubstantiated. If immediate measures are not undertaken to check the spread of large-scale culture, atleast till satisfactory trials establish its non-invasive nature, we could be facing a frightening prospect of a social conflict and an ecological disaster.

THE PROCESS OF BIOLOGICAL



1.
Species in its natural habitat

The species occur in their natural home range and may not be dominant or superior competitors.

The natural range is limited by barriers to dispersal (either physical or environmental).

Their populations are kept in check by local environmental parameters, competing species, predators, and diseases.

2.
Transport of species

Species are intentionally or unintentionally moved beyond these natural barriers by humans.

Relocation could be by way of movement of adult organisms or of propagules, larvae, spores, etc.

Intentional transport is for the purpose of culturing the species for economic benefits, e.g., as pets, for hunting, etc.

Unintentional transport is by way of ships, dormant propagules of pathogens, through food products, etc.

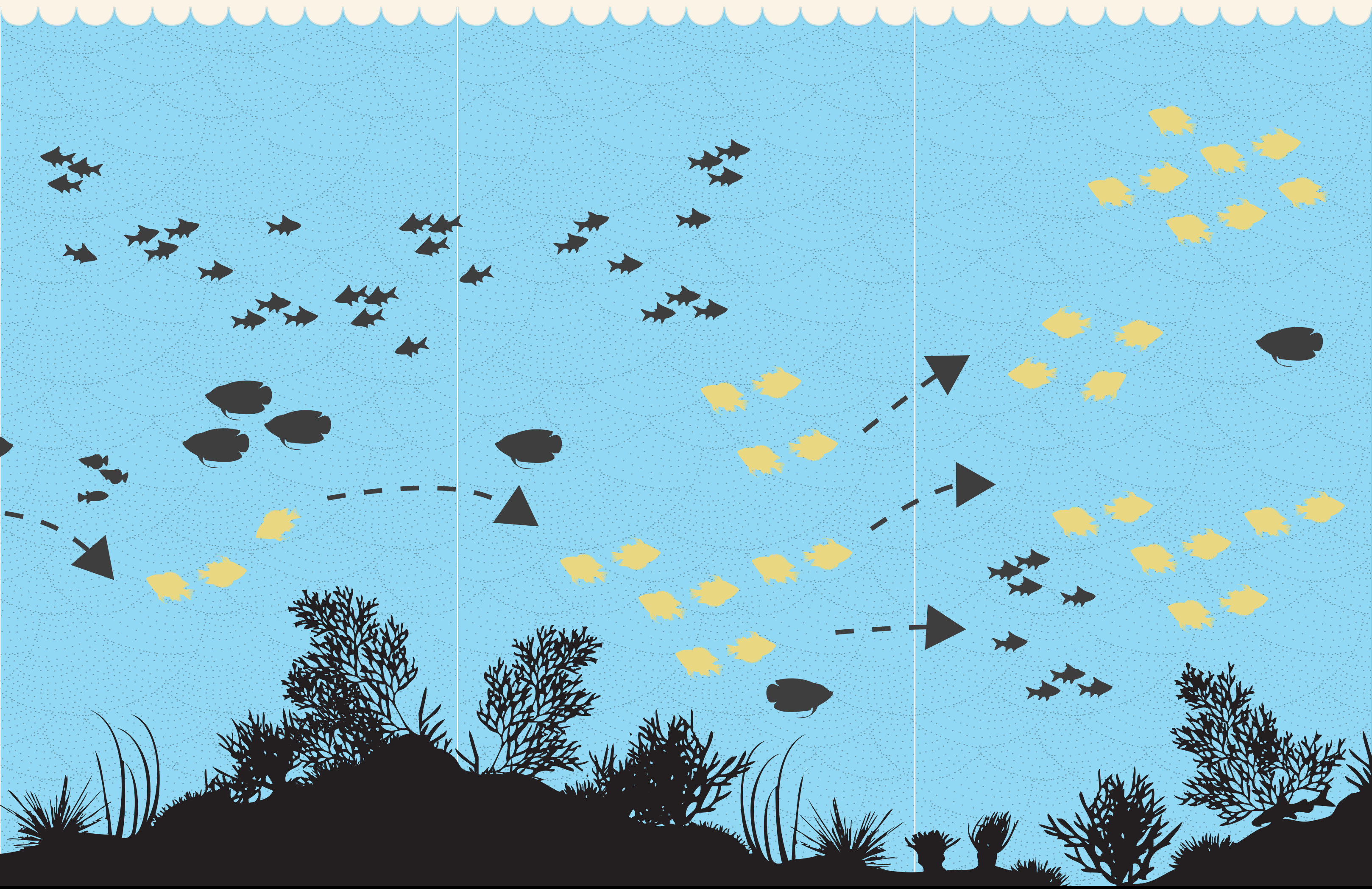
3.
Introduction into a new territory

Transported species enter the recipient systems either as propagules or directly as adults.

Depending on their ability to adapt to the new biotic and abiotic parameters, and the continuity of the supply of propagules, the species may or may not succeed in surviving in the new territory.

The species are released from a variety of biotic and abiotic constraints that they experienced in their native home range.

INVASION IN MARINE SYSTEMS



4.
Survival and reproduction

The species try to get acclimatised in their new home range, and only a small proportion of the introduced species manage to survive.

The species start interacting with other species in their host environment, and may succeed in outcompeting the native species.

Species that survive may or may not require continuous propagule supply to establish a reproductively viable population.

5.
Establishment of populations

Once they are able to successfully reproduce (either asexually or sexually) in their new environment, the populations begin to establish themselves.

Only a small proportion of the species that survive manage to establish a reproductively viable population.

Sustained disturbances, lower biodiversity, better competitive success, lack of natural predators, release from diseases, etc., improve the survival capacity of the introduced species.

6.
Dispersal and spread

Species that manage to establish reproductively viable populations in the new territory spread further away from the area in which they were introduced, by way of dispersal and physical movement.

Superior dispersal and colonisation potential (than the local indigenous species) is required for enabling long-distance dispersal .

Species that are capable of both sexual and asexual reproduction (budding, pores, larvae) are known to disperse more than species that require physical movement.

MARINE BIOINVASION: THE INDIAN SCENARIO

The understanding of biological invasion of marine ecosystems in developing countries like India is still very rudimentary. There are a handful of studies that have focussed on marine invasions. The table below summarises our current understanding of the processes of bioinvasion in marine ecosystems of India.

Species	Information	Source
Alga: *Monostroma oxyspermum*	Native of northeast Atlantic/ northwest Pacific, and was introduced to the west Coast of India. Reported in the year 1980.	Untawale, A.G., V.V. Agadi and V.K. Dhargalkar. 1980. *Mahasagar - bulletin of the National Institute of Oceanography* 23: 179–181.
Bivalve: *Mytilopsis sallei*	Native of Panama, Atlantic Ocean. First reported from India in 1971 from the Vishakapattinam Harbour. Currently recorded from Mumbai Port too.	Ganapathi, P.N., M.V.L. Rao and A.G. Varghese. 1971. On *Congeria sallei* Recluz, a fouling bivalve mollusc in the Visakhapatnam Harbour. *Current Science* 40: 409–410.

Bryozoa: *Barentsia ramose*	Recorded from the eastern Pacific and North Atlantic, and later reported from the Indian Ocean.	Satyanarayana Rao, K., M. Saraswathi and P.V. Bhavanaraya. 1988. *Marine biodeterioration: Advanced techniques applicable to the Indian Ocean* (eds. Thompson, M.F., R. Sarojini and R. Nagabhushanam). Pp. 57–79. New Delhi: Oxford and IBH.
Ascidian: *Styela bicolor*	Native of Southeast Asia and north Australia. The species was first recorded from the east coast of India in 1981.	Renganathan, T.K. 1981. On the occurrence of a colonial ascidian, *Didemnum psammathodes* (Sluiter, 1895) from India. *Current Science* 50: 1008.
Ascidian: *Phallusia nigra*	Native of the Atlantic. The species has been recorded from the Tuticorin Port in 1998.	Meenakshi, V.K. Occurrence of a new ascidian species—*Distaplia nathensis sp*. nov. and two species—*Eusynstyela tincta* (Van Name 1902), *Phallusia nigra* (Savigny, 1816) new records for Indian waters 1998. *Indian Journal of Marine Sciences* 27: 477–479.
Ascidian: *Eusynstyela tincta*	Recorded from northeast Indian Ocean (Gulf of Suez and Red Sea) from the Tuticorin Port in 1998.	Meenakshi, V.K. Occurrence of a new ascidian species—*Distaplia nathensis sp*. nov. and two species—*Eusynstyela tincta* (Van Name 1902), *Phallusia nigra* (Savigny, 1816) new records for Indian waters 1998. *Indian Journal of Marine Sciences* 27: 477–479.
28 species of marine/ estuarine species of fin and shellfishes	A comprehensive review of the species introduced into India for aquaculture purposes since 1963 identifies at least 28 such species that have been introduced into India.	Singh, A.K. and W.S. Lakra. 2006. Alien fish species in India: impact and emerging scenario. *Journal of Ecophysiology and Occupational Health* 6: 165–174.
15 species of polychaetes	Based on a survey of the Mumbai port.	Gaonkar, C., S.S. Sawant, A.C. Anil, K. Venkat and S.N. Harkantra. 2010. Mumbai harbour, India: Gateway for introduction of marine organisms. *Environ. Monit. Assess.*: 163(1-3): 583–589.
18 species of marine flora/ fauna	Provides a review of marine bioinvasion in India focusing on ships as vectors.	Anil, A.C., K. Venkat, S.S. Sawant, M. DileepKumar, V.K. Dhargalkar, N. Ramaiah, S.N. Harkantra and Z.A. Ansari. 2002. Marine bioinvasion: Concern for ecology and shipping. *Curr. Sci.*: 83(3): 214–218.

← *Two species of Indo-Pacific predatory lionfishes [*Pterois volitans *(left) and* P. miles*] were introduced to the Western Atlantic through the marine aquarium trade. The species have spread rapidly along the shallow coastal regions of southeast USA and also as far as Jamaica in the south and Bermuda in the east. Being voracious predators with few natural enemies, they are reported to have significantly reduced recruitment of native species of fish including important fish guilds like herbivores. Herbivore populations in the Bahamas have been decimated up to a depth of 60 metres leading to a simultaneous increase in algal cover and reduced recruitment of corals and sponges in these regions.*

LEGAL INSTRUMENTS PERTAINING TO BIOLOGICAL INVASIONS

Global instruments

With increasing acknowledgement of the threats posed by marine bioinvasions, a few international instruments that range from legally binding treaties to broad technical guidelines have been developed. Many of these are species-specific, refer to a specific vector (such as ballast water or aquaculture, etc.), or address a particular type of environment or harm.

A few such instruments that operate at the global scale are summarised in the table below.

Many of the existing international legal instruments are voluntary, not binding, and focus on the prevention of unwanted species introductions. Few actually address issues of eradication and control. Many of the treaties are ambiguous about the obligations of the signatories, and provide no measurable indicators for assessing implementation. Further, there are few effective rules on liability and restoration for possible damage generated by invasive alien species.

Legal instrument	Provisions
Article 8(h) of the Convention on Biological Diversity (CBD).	Requires that signatories "as far as possible and as appropriate, prevent the introduction of, control or eradicate those alien species which threaten ecosystems, habitats or species".
United Nations Convention on the Law of the Sea (UNCLOS) in 1982 first recognised the issue of species introductions through ballast waters. India ratified the Convention in 1995 with the Department of Ocean Development as the nodal agency.	The Rio Declaration called upon nations to prevent, reduce, and control the intentional or accidental introduction of species to marine environments, and has outlined twenty-seven key principles with the *precautionary approach* and the *polluter pays* principle being the most important.
Article 196 of the UN Convention on the Law of the Sea (UNCLOS).	The law requires Parties to take all measures necessary to prevent, reduce, or control pollution of the marine environment resulting from the intentional or accidental introduction of alien or new species to a particular part of the marine environment, which may cause significant and harmful changes thereto.
United Nations Environment Programme's (UNEP) Regional Seas Programme (RSP). India is a signatory to the South Asia Seas Programme since 1995. The Secretariat is located at the South Asia Cooperative Environment Programme (SACEP), Sri Lanka.	Regionally, environmental protocols for four conventions developed under this programme contain specific requirements to prevent introductions to marine and coastal ecosystems (Eastern African Region, Wider Caribbean Region, Southeast Pacific, and Mediterranean).
Resolution VII/14 on Invasive Species and Wetlands of the Ramsar Convention in 1991.	Has recognised the threat of invasive species to terrestrial and marine wetland ecosystems. Parties are urged, where necessary, to adopt legislation or programmes to prevent the introduction of "new and environmentally dangerous alien species" into their jurisdiction, and to develop capacity for identifying such alien species, including those tested for agricultural and horticultural use.

International Maritime Organization (IMO). India is one of the six participating countries (along with Brazil, China, Iran, South Africa, and Ukraine) that is implementing a pilot project for the management of ballast water. However, we still lack stringent regulations for the management, monitoring, and regulation of ballast related activities within local law.	The IMO has developed guidelines on the management of ballast water and sediments through the GloBallast (Global Ballast Water Management Programme) in partnership with the Global Environment Facility (GEF). The programme is aimed at assisting developing countries in managing bioinvasions through ballast water. The programme also addresses the impacts of pathogen invasions through ballast water on human health. The guidelines proposed by the IMO are voluntary, however, through the Marine Environment Protection Committee (MEPC) the IMO has been working towards developing a legally binding instrument.
The 1995 FAO Code of Conduct for Responsible Fisheries and the 1994 ICES/EIFAC Code of Practice on the Introductions and Transfers of Marine Organisms.	Policies have been developed for ongoing introductions or transfers of species for commercial purposes such as aquaculture, mariculture, or ornamental fishery which have already become established as a commercial practice. There are also guidelines on the measures to be taken prior to introductions, and measures to prevent unauthorised introductions.

Legal instruments in India — or the lack thereof

India does not have a binding policy that specifically addresses the issue of biological invasions of marine ecosystems, or for that matter, any ecosystem. There are however, a set of legal instruments that deal with specific aspects of species introduction in terrestrial ecosystems. These are:

a. The Prevention and Control of Infectious and Contagious Diseases in Animals Act, 2009

b. The Plant Quarantine (Regulation of Import into India) Order, 2003

c. The Destructive Insects and Pests Act, 1914

d. The Plants, Fruits and Seeds (Regulation of Import into India) Order 1989

e. Livestock Importation Act, 1898

These legal instruments are highly specific and their jurisdictions can be extended or amended to specifically regulate the introduction of marine species and other pathogens through aquaculture, mariculture, and ornamental fish trade. The initiatives undertaken at the global level need to be complemented by regulatory mechanisms by the member states. India needs a more comprehensive legal mechanism to specifically address the problem of human-mediated biological invasions.

Some existing laws of the Indian government that have implications for regulating biological invasions are:

a. ***Wild Life (Protection) Act, 1972***: Various sections of this Act (Section 11(a) & 11(b) and Section 12) permit the Chief Wildlife Warden to allow the hunting, eradication, and translocation of animals that are dangerous or diseased, as well as for the purpose of scientific management of populations. Section 62 of the WLPA also empowers the Central Government to declare species as vermin (provided the species are not listed under Schedule I or Part II of the Schedule II list). These sections of the Act can have substantial implications for eradicating/managing invasive species.

b. ***The Biological Diversity Act, 2002***: It provides clearances on the use of biological resources especially for commercial purposes. However, there are instances where the National Biodiversity Authority has provided clearances for the large-scale culture of established invasive species such as the seaweed *Kappaphycus alvarezii*.

While these legal instruments have been successful in protecting certain species and ecosystems in some instances, in others they actually hinder the removal of invasives. For instance, the Wild Life (Protection) Act, 1972 protects the spotted deer in the Andaman Islands, where it is an invasive[7]. Removal of mammal, bird, and plant invasives has to be done most importantly in protected areas where bans on hunting and trapping apply.

There are a range of other legislations that govern the use of natural ecosystems, such as laws that govern agriculture, fisheries, aquaculture, and related activities. However, it is clear that a specific policy and legislation is required to deal with invasive species.

A new policy requires a nuanced approach to biodiversity protection where our knowledge of nature's patterns and processes, particularly the dynamics of species assemblages, informs our management decisions.

The legal instrument should have the flexibility to allow for remedial action to be taken when a species considered endangered in one context (and under a national law) can easily become a biological invasive in another context within the same national boundaries.

MONITORING INVASION

Monitoring of marine ecosystems is a critical component of detection and early eradication of biological invaders. Very often, it is the local community members who first witness the establishment and spread of a species and their subsequent impacts on ecosystems and their own livelihoods. *Oreochromis mossambicus* (Mozambique tilapia) (seen in the adjacent image), a hardy species of fish introduced into India to improve the fisheries productivity of its brackish and freshwater systems has become a serious threat to the local biodiversity. Citizen programmes such as the volunteer-run monitoring of fish catch from the Mutukadu lagoon in Tamil Nadu, India, initiated by the Madras Crocodile Bank Trust and Dakshin Foundation should be encouraged. This programme aims to understand the impacts of invasive species such as the Mozambique tilapia on local ecosystems. Initial results reveal that the species dominates the fish biomass of the lagoon.

RECOMMENDATIONS AND FUTURE DIRECTIONS

Biological invasion of marine ecosystems is a topic of growing concern in many countries, and tropical developing countries with rich biological diversity need to be supported in investing greater effort and attention in understanding this phenomenon and in designing strategies to deal with it.

1. The regulatory framework in India needs to address the problem of biological invasives through the following steps:

- Review the existing legal framework concerned with forests, agriculture, fisheries, maritime trade, coastal aquaculture, etc.

- Identify lacunae and provisions in the existing legislation that make it difficult to control and eradicate invasives.

- Develop a separate policy that deals specifically with biological invasions such as introduction of a new species into India, stringent regulations on ballast water management, and locality- and context-specific policies to control biological invasion (this needs to consider de-listing species from protected schedules of conservation laws and permitting eradication measures in protected areas).

- Develop an extensive inventory of alien invasive species to analyse patterns of introduction, source floras and faunas, and to develop a risk assessment system.

2. Effort should be invested in building and consolidating the available expertise to specifically monitor the social, ecological, and economic impacts of biological invasions in India. India also needs greater awareness generation amongst civil society about the problems of invasive species.

3. Our knowledge of the impacts of biological invasions on both terrestrial and marine ecosystems is rudimentary. Interdisciplinary research drawing from the disciplines of ecology, environmental sciences, biology, social sciences, and economics needs to be undertaken to understand the scales and impacts of biological invasions on marine ecosystems.

4. Databases should be developed that provide up-to-date information on the current status of alien invasive species in India. These sites could be interfaced with existing regional and global databases.

5. Involvement of citizen scientists in monitoring/generating invasive species atlases.

6. Cost-benefit estimates of utilising and eradicating invasive species should be carried out, and the potential of involving users and local communities in the monitoring and control of invasive species needs to be explored.

7. Specific programmes that deal with island ecosystems of India, particularly the Andaman and the Nicobar Islands, and the Lakshadweep group of islands need to be developed.

REFERENCES

1. Pimentel, D. et al. 2001. Economic and environmental threats of alien plant, animal and microbe invasions. *Agriculture, Ecosystems and Environment* 84: 1–20.

2. Carlton, J.T. 1999. The scale and ecological consequences of biological invasions in the world's oceans. In: *Invasive species and biodiversity management* (eds. Sandlund, O.T., P.J. Schei and P. Viken). Pp. 195–212. Kluwer Academic Publishers, Dordrecht, The Netherlands.

3. Albins, M.A. and M.A. Hixon. 2008. Invasive Indo-Pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral reef fishes. *Marine Ecology Progress Series* 367: 233–238.

4. Pereira, N. and X.N. Verlecar. 2005. Is Gulf of Mannar heading for marine bioinvasion? *Current Science* 89 (8): 1309–1310.

5. Chandrasekaran, S., N. Arun Nagendran, D. Pandiaraja, N. Krishnankutty and B. Kamalakannan. 2008. Bioinvasion of *Kappaphycus alvarezii* on corals in the Gulf of Mannar, India. *Current Science* 94 (9).

6. Namboothri, N. and K. Shanker 2010. Corals or cola – *Between the devil and the deep blue sea. Current Conservation* 4(1): 18–20.

7. Ali, R. 2004. The effect of introduced herbivores on vegetation in the Andaman Islands. Current Science 85(8): 1103–1112.

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