TRANSFER OF NON-INDIGENOUS AQUATIC SPECIES CONCERN AQUATIC RESOURCE USERS

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Summary

The introduction of non-indigenous organisms caused by anthropogenic activities has resulted in the establishment of many species outside their native ranges. As a result, ecosystems and dependent economies are at risk to become negatively affected by various invaders. It is assumed that the main vector for transportation of organisms is the unintentional transport with ships (ballast water and associated sediments as well as hull fouling). It has been estimated that on average 3000 to 4000 species are transported by ships intercontinentally and daily. One introduced species alone can cause severe harm to the local or regional economy and the ecology of the habitat it was introduced to. We provide here selected case histories of well documented invaders, including toxic phytoplankton, zooplankton, macroalgae, zoobenthos and human pathogens. Since it is well known that the eradication of an established introduced species in a new marine environment will be either very expensive or even impossible, efforts to prevent or minimize introductions should be given high priority. These should include (a) quarantine measures for planned introductions (aquaculture), and (b) effective, safe, economically viable, and environmentally sound treatment methods and/or management options for ballast water. As very first step to minimize the number of invaders the IMO developed guidelines to reduce the uptake of organisms and to carry out a mid-ocean exchange of ballast water. Mandatory legally binding regulations or guidelines minimizing the introduction of non-indigenous species would be of immense help to reduce future species introductions.

1. Introduction

The unintentional introduction of non-indigenous organisms through human activities such as shipping, live fish trade, and aquaculture has resulted in the establishment of many species outside their native ranges. As a result, ecosystems and those economies dependent on them are at risk of become negatively affected by various invaders.
The likelihood of an introduced species settling in a new habitat depends on a number of factors, primarily related to the biological characteristics of the species (such as physiological tolerance, reproductive strategy, and genetic variability) and to the environmental conditions prevailing at the time of introduction. Additional factors are climate, number of introduced specimens (size of the founder population), native competitors, and the availability of food. Species are more likely to establish in environments that are similar to those of their origin.

Observations have demonstrated that organisms need not to be harmful pests to cause severe damage. Some invaders affect native flora and fauna by competing for food, habitat, and other resources. The ecological worst case scenario would be the total replacement of a native species by an invader. This can affect species composition. As a result, the food web structure may be drastically changed by the introduction of a single species. Recent invasions and population explosions of non-indigenous species in various parts of the world that are causing ecological and economical damages are described by Carlton and Geller (1993), Hedgpeth (1993), Gollasch and Mecke (1996).

A recent summary of non-indigenous species in coastal waters of the North Sea revealed about 80 exotic species occurring in self-sustaining populations. The number is lower than in other enclosed seas or bays, for example the Chesapeake Bay (116 introduced species) and the San Francisco Bay with 253 introduced species. The majority of introduced species in the North Sea are invertebrates; predominantly crustaceans, polychaetes, and mollusks.

As early as 1994, it was recommended during a Conference and Workshop on Non-Indigenous Estuarine and Marine Organisms in Seattle, Washington, that educational programs should be developed to increase overall awareness of the risks associated with unintentional transfers of aquatic species, list pathways of introductions of species, and educate the general public on reporting procedures for new sightings of exotics.

2. Modes of Transfer of Aquatic Species

It is assumed that the main vector for transportation of organisms is, besides the introduction of species for aquaculture purposes, the unintentional transport on ships. Since the introduction of steel hulled vessels in the late nineteenth century, ballast water discharges have increased considerably throughout the world and the probability of successful establishment of self-sustaining populations of non-indigenous species increased with greater volumes of ballast water as well as with reduced ship travel times. The first suggestion of an unwanted species introduction with ships was made by Ostenfeld in 1908 after a mass occurrence of the Asian phytoplankton algae *Odontella* (*Bidulpphia*) *sinensis* in the North Sea in 1903. The first shipping studies including sampling of ships' ballast water appeared 70 years later by Medcof (1975) followed by those of Carlton (1985, 1987), Hallegraeff and Bolch (1991) and Subba Rao et al. (1994). Rosenthal (1980) reviewed the state of knowledge and the risks associated with the transplantation of non-indigenous species to fisheries and aquaculture, including ballast water as vector. An annotated bibliography on transplantation and transfer of aquatic organisms through various means (including ballast water) is presently under preparation, covering more than 15000 literature entries.

2.1 Aquaculture at Risk from Transfers of Exotic Species

Modern aquaculture development in inland and coastal waters has been shown to be responsible for some of the exotic species occurring in new habitats mainly through unintentional transfer with live seed for stocking or brood stock. For example, several invertebrates have been transmitted to Ireland with seed oysters from France, and fish diseases and parasites have been introduced with live transport of fish either for culture, bait or the aquaria trade industry. More than 100 species have been documented as being transported with living oysters in the packing material or settling on the oyster shell. These may even include disease agents and parasites located in the tissues of the oysters. Several intergovernmental organizations including ICES, EIFAC, and IOE have prepared Codes of Practice and guidelines to reduce the risk of transfer of unwanted species. Negative effects on sport fishing and thereby the tourist industry can occur as well.

Aquaculture and fisheries are, however, also at high risk of transfer of parasites and diseases with ballast, particularly where culture facilities and fisheries are located near major shipping routes. The recent worldwide growth of aquaculture along such routes amplifies the probability of transfer, possibly rendering disease regulations for this industry partially useless.

Increasing aquaculture activities worldwide support the potential for unintentional spread of diseases and parasites which, after their establishment in new areas, may be distributed further by ballast water uptake.

2.2 Transfers via Sport Fishing and Fisheries

Another vector of unintentional species transfer is recreational fisheries. A large variety of organisms used as bait, including live seaweeds as packing material, and associated organisms, are transported frequently between watersheds and bays. Large numbers of live snails, bivalves, amphipods, isopods, harpacticoid copepods, marine mites, insect larvae, polychaetes, oligochaetes, nematodes, and foraminifers have been found in bait shops. In the Chesapeake Bay area this transport is believed to be responsible for the recent establishment of an Atlantic periwinkle. Sport fishing clubs are active in supporting hatchery programs to stock their favored fish into rivers in large numbers and often these come from outside the watershed.

2.3 Growing Importance of the Shipping Industry

Non-indigenous species are introduced not only with ballast water and associated sediments, but also as fouling organisms on the ship's hull. However, efficient biocidal anti-fouling paints currently used considerably reduce the number of fouling organisms on ships' hulls. Accordingly the major problem in transmission of harmful aquatic organisms resides with the transfer of ballast water from ships, in particular bulk carriers and container ships.

It has been estimated that the major cargo vessels of the world (total number 70000 in 1991)) are transferring about 10 billion metric tons (tonnes) of ballast water globally and annually, indicating the dimension of this problem. With the growing globalization of markets and trade, this volume is rising continuously. Ballast water may be taken in from eutrophic coastal or brackish estuarine habitats, containing hundreds of species which may survive voyages of several months. It has been demonstrated that on average 3000 to 4000 species are transported by ships intercontinentally and daily. Species discharged with ballast water near or in the next port of call may establish there and threaten native populations, fishing industries, and public health. About 500 species are estimated to have been transported via ballast water to habitats outside their native range and to have become established there. These include not only invertebrates but also fish species. One introduced species alone can cause severe harm to the local or regional economy and the ecology of the habitat it was introduced to.

In recent years shipping has become the most important vector for accidental species introductions, for the following reasons:

1. Shipping activities have increased over the past decades with corresponding

increases in amounts of transported and released ballast water.

2. The duration of ship voyages has decreased due to technical improvements resulting in faster ships. Consequently, the time a species has to spend in a ballast tank is much shorter today than in the past and this increases survival rate. In addition faster ships result in an increasing frequency of ship visits to ports, allowing multiple introductions in shorter intervals thereby enhancing the probability of arriving at suitable environmental conditions (e.g., season, weather) to support a founder generation. Multiple introductions certainly increase the probability for the successful introduction/establishment of an invader.
3. The number of marine organisms transported in ballast water seems to be increasing, partly due to larger size ships, larger ballast tanks, more frequent exchanges, more oxygen availability, and cleaner tanks. But even the anoxic sediments in ballast tanks are potential transport vectors, accommodating permanent cysts of toxic algae. While dinoflagellate blooms appear to be increasing worldwide, there is probably more than one factor involved in many cases: (a) changing environmental conditions (e.g., nutrient release leading to eutrophication) in both donor and recipient areas (e.g., climate change) and (b) due to transfers of species or strains (Bolch, 1993; Hallegraeff et al., 1990) that probably perform better in the recipient area. Therefore the probability of an effect of these species released from ballast water has increased.
4. The increasing trade by ships resulted in the construction of new ports providing additional sites and habitats along coasts for introductions of species and/or introductions from adjacent regions.
5. More favorable water quality conditions in ports due to improved environmental protection measures lead to richer fauna and flora in areas of origin, increasing the probability of their uptake and transport via ballast water.

2.3.1 Specific Issues Related to Ballast Water

Ballast water has been used since the late 1870s in cases where ships are not fully loaded in order to submerge the propeller and rudder in the water, to operate effectively and to control the trim and increase the stability. Ballast water is usually carried in segregated ballast water tanks or in emptied cargo holds. Ballast water is marine or fresh water taken on board in ports, waterways, and the open ocean. With the intake of ballast water organisms in the water are pumped on board into the ballast tanks. Sediments suspended in the water may settle to the bottoms of ballast water tanks or cargo holds containing water ballast. Vessels almost always carry ballast water when they are not carrying cargo. Loaded ships contain ballast water as well; even if they are loaded to the maximum, several tonnes of ballast water is carried. Depending on the construction of ballast water tanks and pipework, tonnes of residual water can remain in maximum emptied ballast tanks.

Depending on the economy of a country, it may be importing cargo (no or less ballast water necessary to be transported in fully loaded vessels) or exporting goods. Countries characterized by a surplus in exporting cargo usually will record empty vessels calling at their ports in order to load a cargo for their voyage. These vessels will carry large amounts of ballast water, especially if bulk carriers or oil tankers were employed, which has to be discharged in the ports and waterways.

Recently the results of European research activities were summarized. In total 1508 samples (1219 ballast water, 289 tank sediment) were collected on 550 ships. The total number of taxa determined during the 13 European shipping studies reviewed was 990. The diversity of species found included bacteria, fungi, protozoans, algae, invertebrates, and fishes.

Several studies have shown that living organisms were found in ballast water that was inside the tanks for weeks and/or months. Even water held in ballast tanks for 116 days contained living specimens of an amphipod species. In addition to the "long-term" survival of some organisms in ballast tanks, some species may form resting stages or cysts enabling survival during unfavorable conditions.

2.3.2 Specific Issues Related to Hull Fouling

Many of the non-indigenous species in the North Sea have been introduced with ships (47 introductions) and aquaculture activities (36 introductions), but ships are assumed to be the most important vector. Nearly two-thirds of the ship-mediated introductions were transported on ships' hulls.

As outlined by Chilton (1911) and Carlton (1979), the fouling community on ships is comprised not only of sessile organisms, but also of mobile organisms. Mobile organisms are transported for weeks or months amongst the fouling assemblage, for example in empty shells of barnacles, or in sheltered densely fouled areas of the hull. Neu (1932) assumed that ships initially fouled by mobile and sessile organisms in ports were cleaned during their voyages by washing away the mobile organisms due to strong water currents induced by the ships speed. Today, ships are faster and many reach a cruising speed higher than 10 m s^{-1}. However, mobile organisms, such as *Hemigrapsus penicillatus* (Decapoda, Reptantia), recently introduced to Europe and native to Asia, have been found in empty barnacle shells in the hull fouling. This decapod was first recorded from French Atlantic waters in 1994, probably introduced in 1993. In the late summer of 1993, the crab was sampled from a ship's hull during this shipping study. It is assumed that the crab was transported to Europe on the hull of the vessel investigated.

Past invaders in the North Sea regions were mostly transported on ship hulls. During British and Australian investigations it was indicated that hull fouling also might have been the most important vector for species introductions in the past. Even a species new to science was found in hull samples of one ship.

2.4 Aquarium Trade and Tourism

There are many examples of transmission of foreign species via the aquarium trade (Lubbock and Polunin, 1975). Florida is an often cited state that is heavily involved in the intercontinental trade of tropical fish, while Hong Kong is another "turntable" for Asia, sometimes also a cause for concern about human health (Dudgeon and Yipp, 1983); and a tropical green alga, *Caulerpa taxifolia*, was accidentally introduced to the Mediterranean Sea in the 1980s (see below). Negative impacts on the biodiversity and a tremendous growth rate brought this alga, commonly used in aquaria, into focus

(Lubbock and Polunin, 1975; Dudgeon and Yipp, 1983).

Caulerpa spp. are robust, fast growing and easy to handle in seawater aquaria. For example, it is common in pet shops in northern Germany and in other European countries as well. Several aquarium journals list *Caulerpa taxifolia* in their "buy and sell" sections. It is easy and cheap to order the algae by mail. One liter of *Caulerpa* wet weight from the Mediterranean Sea (an approx. 5 meter long rhizoid) costs about US$7, including packing and mail. In Germany about 5 tonnes of *Caulerpa* spp. are sold each year, mainly originating from the tropics and the Mediterranean Sea.

Caulerpa taxifolia has spread throughout the Mediterranean from one single point introduction (probably via the Monaco aquarium). It occurred subsequently in small harbors along the French and Italian coasts (Meinesz and Hesse, 1991; Boudouresque et al., 1992, Meinesz et al., 1993; Villèlle and Verlaque, 1995) and has now also reached the eastern part of the Mediterranean Sea (Israel). The main vectors are pleasure boats, which pick strands up from the bottom via their anchors and release these into the next marina where these thalli proliferate and grow to the extent that dredging is needed to clear the harbor basins. Disposal of the dredged *Caulerpa* meadows without release to the aquatic environment is a costly problem.

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Biographical Sketch

Dr. Stephan Gollasch was involved in the first European ship sampling program on ballast water, tank sediments, and ship hull fouling (1992–1996). His Ph.D. is worldwide the first thesis based on ship sampling of ballast water. He was further involved in a risk assessment study on the Baltic Sea (carried out for the Nordic Council of Ministers), and the EU Concerted Action Introductions with Ships. Since 1999 Dr. Gollasch jointly coordinates a research initiative on species survival during long-term voyages of ocean-going vessels with a Canadian colleague in the framework of the German–Canadian Cooperative Research initiative. Since 2001 he has been the chairman of ICES Working Group on Introductions and

Transfers of Marine Organisms and ICES/IOC/IMO Study Group on Ballast and other Ship Vectors. He is further the convener of the Baltic Marine Biologists Working Group on Non-indigenous Estuarine and Marine Organisms.

Professor Harald Rosenthal is national member of the ICES WGITMO; Chairman of the WG on Environmental Interactions on Mariculture of ICES; has chaired the ICES Workshop on Principles and Practice of Coastal Zone Management in Relation to Fisheries and Aquaculture; coordinates on behalf of the Federal Government, the bilateral cooperation programs on aquatic sciences with Canada and Israel, and has worked—over the last 12 years—on an annotated worldwide bibliography on transfers and transplantations of alien aquatic species (including ballast water). Professor Rosenthal was the coordinator of the EU Concerted Action Introductions with Ships.