The Ballast Water Problem:
Global Ecological, Economic and Human Health Impacts

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"I do not exaggerate the problem when I compare it to the scope and devastation wrought by natural disasters like hurricanes. It is less dramatic but just as destructive" Loy (2000).

Introduction & background

Natural dispersal of species and patterns of biogeography

Over the past millennia, aquatic species have dispersed throughout the oceans by natural means, carried by currents, ocean surface winds and attached to floating logs and debris (Figure One). Natural barriers, such as temperature and salinity regimes and landmasses, have prevented many species from dispersing into certain areas. This has resulted in the natural patterns of biogeography observed in the oceans today.

In particular, the pan-global tropical zone has separated the northern and southern temperate and cold-water zones. This has allowed many species to evolve quite independently in these latter zones, resulting in quite different marine biodiversity between the north and the south.

In tropical areas aquatic species have not faced the same barriers. This is exemplified by the relatively homogenous marine biodiversity spanning the huge area of the Indo-Pacific, from the east coast of Africa to the west coast of South America (Figure Two).

As ocean currents, climatic conditions and other environmental conditions change over time, and as species evolve, the natural patterns of dispersal and the resulting patterns of biogeography and bi-diversity also change, as part of a larger, ever-changing global eco-system.

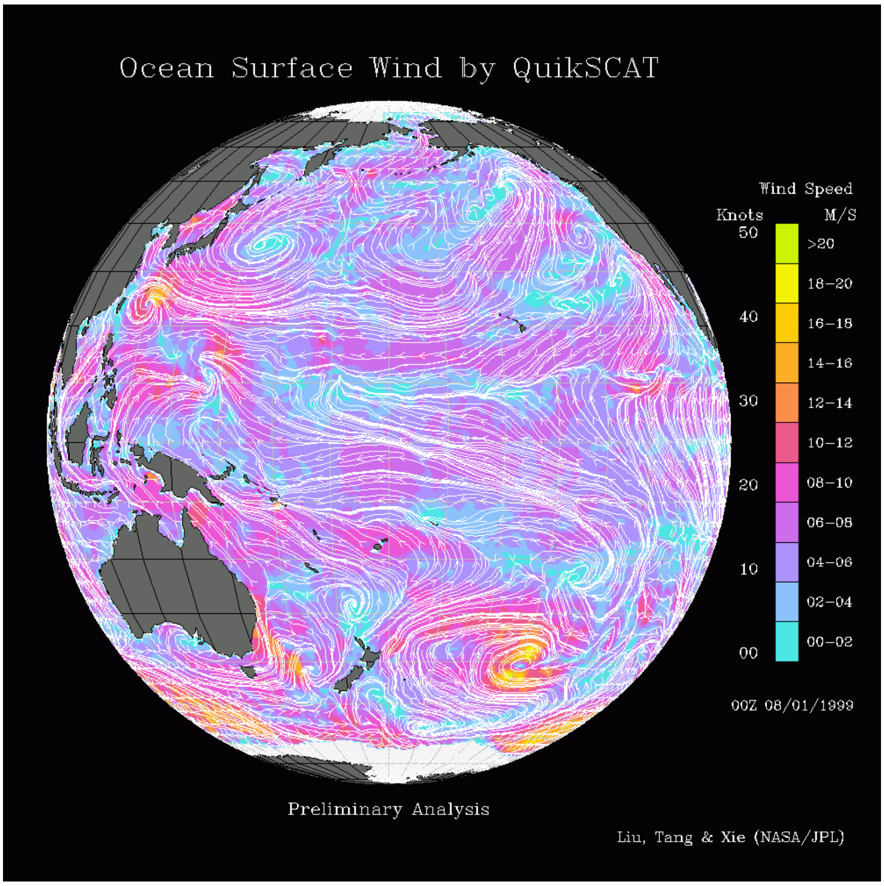


Figure One: *Ocean surface winds and circulation, which influence the natural dispersal of aquatic organisms (Source: IOC - GOOS).*

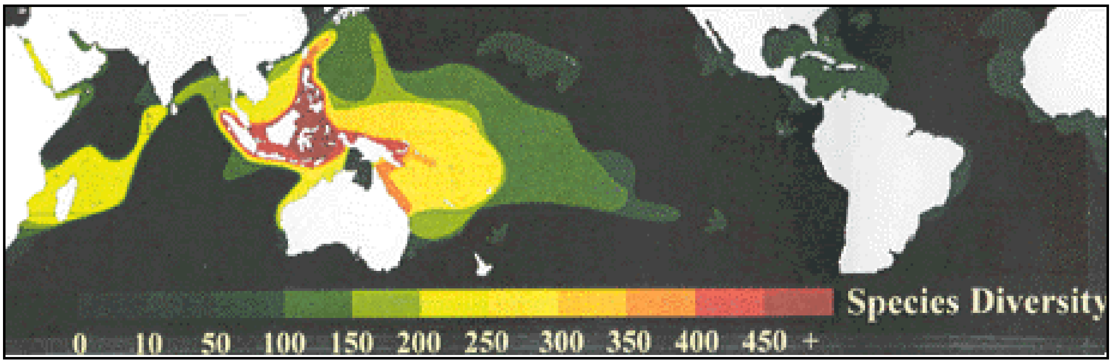


Figure Two: *An example of natural bio-diversity and bio-geography, in this case for corals (Source: Veron 1988).*

The influence of humans

Humans have of course aided the process of species dispersal for as long as they have moved from place to place and sailed across the seas. Historically, human mediated dispersal of aquatic species has been mainly through their attachment to the hulls of vessels. Over time, maritime activities via which aquatic species can be transferred to new areas have continued to expand. In modern times these include:

- canal developments - opening ‘transfer corridors’ through which species can invade new areas (e.g. the Suez canal),
- the movement of large marine structures such as drilling platforms and floating-docks;
- floating marine debris (e.g. discarded/lost fishing gear and plastics),
- the escape or release of species from private and public aquaria,
- intentional and accidental introductions for fisheries and aquaculture purposes,
- the movement of vessels between water bodies by land-transport (e.g. private recreational craft on trailers),
- species range expansion due to global climate change from the burning of fossil fuels (e.g. the spread of tropical species into the Mediterranean), and
- shipping.

Modern shipping itself presents an array of opportunities for species to be transported to new environments, which may be grouped into four main categories – ship-borne water, fouling, ship-borne sediments and bio-films, as outlined in Figure Three and Table One.

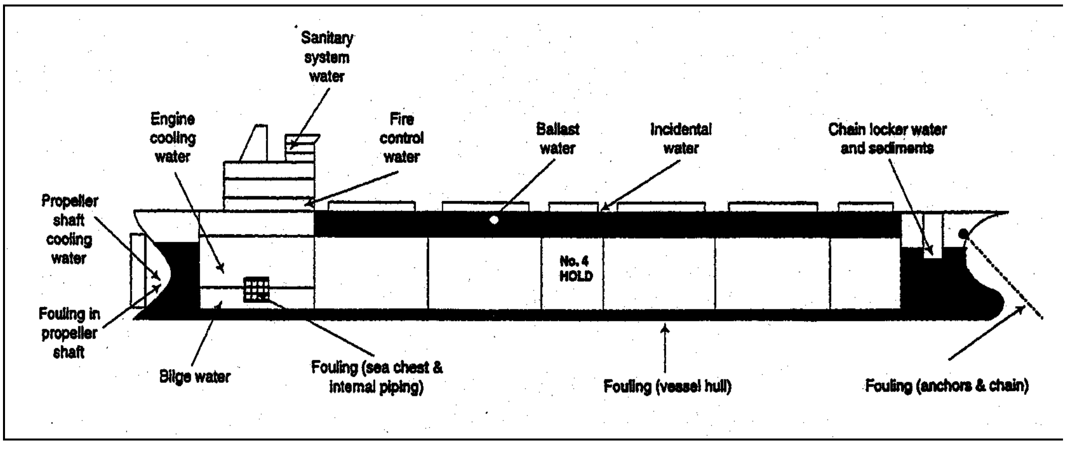


Figure Three: *Some ship-based vectors for the transfer of aquatic species.*

Table One: *Ship-based vectors for the transfer of aquatic species.*

Ship-borne Water	Fouling	Ship-borne Sediments	Bio-film
▪ Ballast water. ▪ Bilge water. ▪ Engine cooling water. ▪ Propeller shaft cooling water. ▪ Fire-control water. ▪ Sanitary system water. ▪ Chain locker water. ▪ Incidental water (e.g. deck wash).	▪ Hull fouling. ▪ Sea chest/ water intake fouling. ▪ Internal pipe fouling. ▪ Anchor and chain fouling. ▪ Propeller shaft fouling.	▪ Ballast tank sediments. ▪ Bilge sediments. ▪ Chain locker sediments.	▪ Ballast tank surfaces. ▪ Bilge surfaces. ▪ Internal pipe surfaces.

While it is vital that all of these vectors are addressed in an integrated and holistic management response, ships' ballast water is increasingly recognized as one of the major vectors that requires an urgent response.

Ballast water as a vector

Modern shipping cannot operate without ballast water, which provides balance and stability to un-laden ships. When a ship is empty of cargo, it fills with ballast to maintain stability, trim and structural integrity. The ballast is discharged when the ship loads cargo (Figures Four & Five).

A potentially serious environmental problem arises when this ballast water contains aquatic life. There are thousands of aquatic species that may be carried in ships' ballast water; basically anything that is small enough to pass through a ships' ballast water intake ports and pumps. These include bacteria and other microbes, micro-algae, small invertebrates and the eggs, spores, seeds, cysts and larvae of various aquatic plant and animal species.

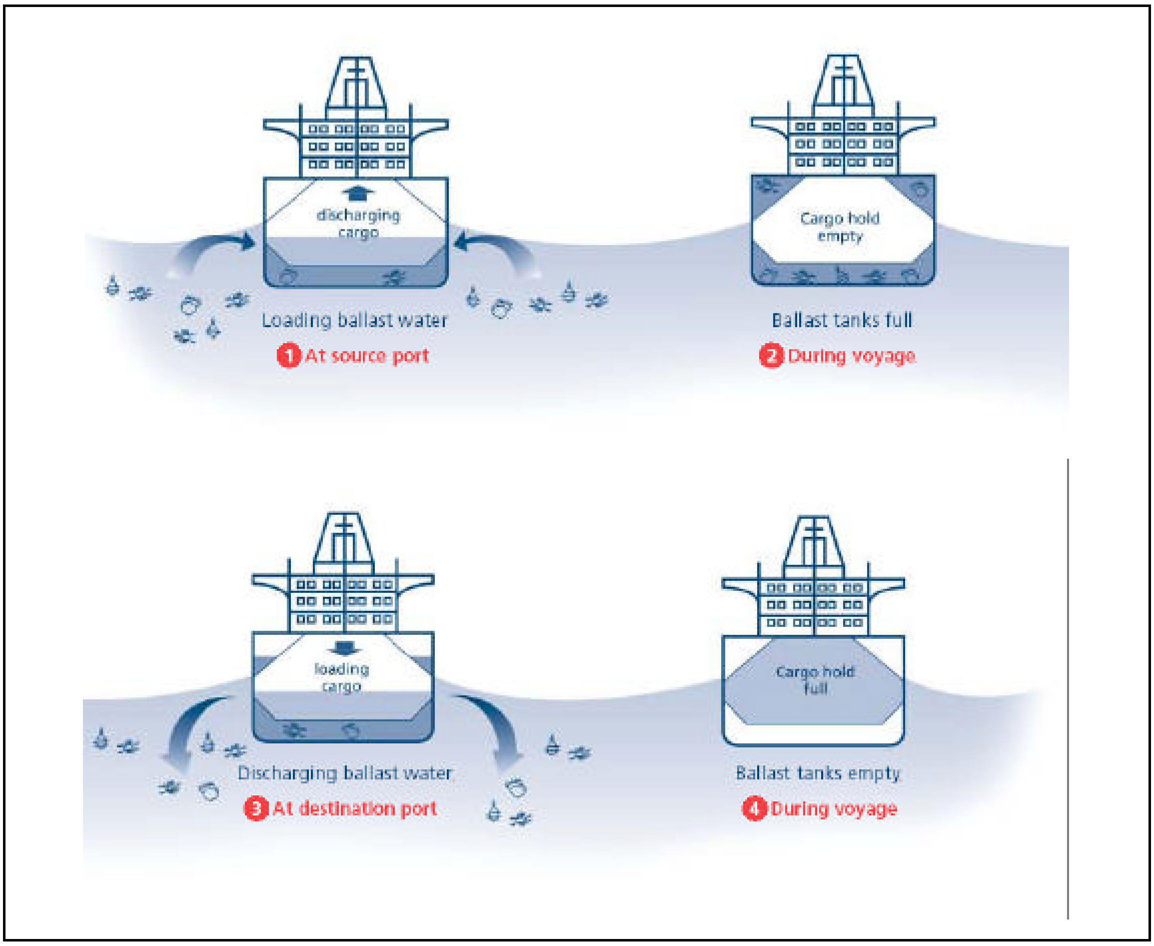
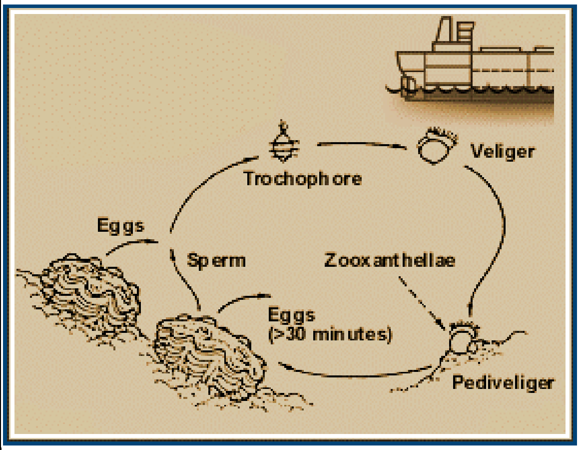


Figure Four: *The ballast water cycle (Source: GloBallast Programme, IMO).*

Figure Five: *Routine ballast water discharges from bulk carrier in port (Source: CSIRO Australia)*

The problem is compounded by the fact that virtually all marine species have life cycles that include a planktonic stage or stages. Even species in which the adults are unlikely to be taken on in ballast water, for example because they are too large or live attached to the seabed, may be transferred in ballast during their planktonic phase (Figure Six).



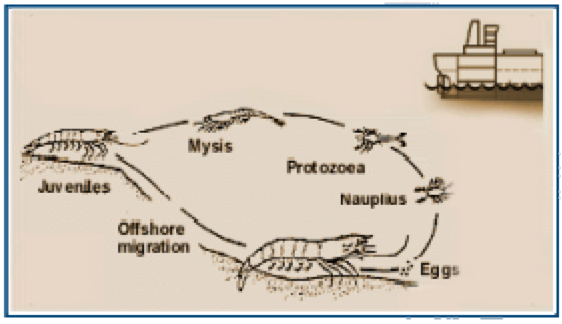


Figure Six: *Clam and prawn life cycles showing examples of planktonic stages that can be entrained when ship takes on ballast water (Source: GloBallast Programme, IMO).*

As a result, it is estimated that at least 7,000 to possibly more than 10,000 different species of marine microbes, plants and animals may be carried globally in ballast water each day (Carlton 1999).

The commencement of the use of water as ballast, and the development of larger, faster ships completing their voyages in ever shorter times, combined with rapidly increasing world trade, means that the natural barriers to the dispersal of species across the oceans are being reduced. In particular, ships provide a way for temperate marine species to pierce the tropical zones, and some of the most spectacular introductions have involved northern temperate species invading southern temperate waters, and vice versa.

Shipping is vital to the global economy and moves over 80% of the world's commodities. However, in doing so it also transfers approximately 3 to 5 billion tonnes of ballast water internationally each year (Andersen 2002 Pers. Comms). A similar volume may also be transferred domestically within countries and regions each year, bringing the total global ballast water movements to around 10 billion tonnes per year (Rigby 2002 Pers. Comms). An analysis of global shipping traffic provides a clear visual indication of the extent of world trade and the broad 'reach' of shipping as a vector for transporting aquatic species (Figure Seven).

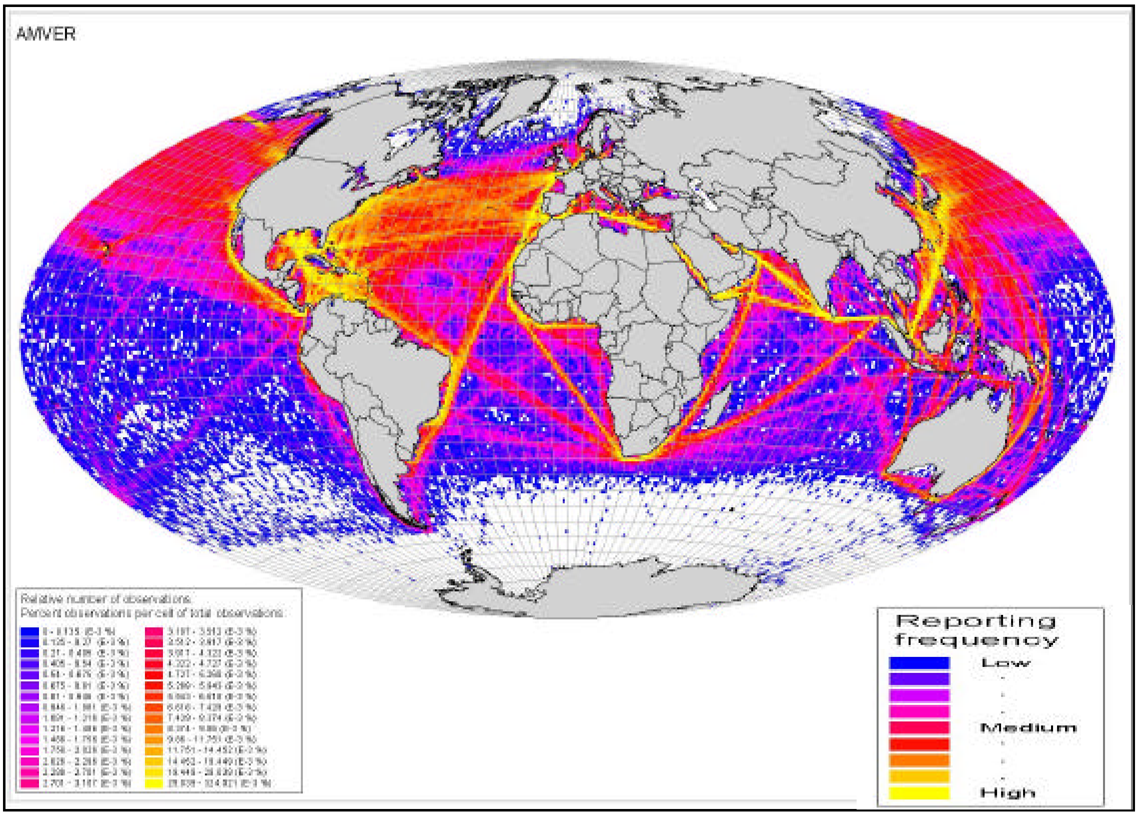


Figure Seven: *Cargo vessel traffic densities based on AMVER (2001) (Source: DNV).*

Impacts

The vast majority of aquatic species carried in ballast water do not survive the voyage, as the ballasting and de-ballasting cycle and environmental conditions inside ballast tanks can be quite hostile to organism survival. Even for those that do survive a voyage and are discharged, the chances of surviving in the receiving environment may be further reduced, depending on environmental conditions and predation by and/or competition from native species. However, when all factors are favourable, an introduced species may survive to establish a reproductive population in the host environment. It may even become invasive, out-competing native species and multiplying into pest proportions.

As a result, whole ecosystems are being changed. In the USA, the European Zebra Mussel *Dreissena polymorpha* has infested over 40% of internal waterways and is a major problem for industry, fouling all available hard surfaces, including cooling water intake pipes. In southern

Australia, New Zealand and the Mediterranean, the Asian kelp *Undaria pinnatifida* is invading new areas rapidly, displacing the native seabed communities. In the Black Sea, the filter-feeding North American jellyfish *Mnemiopsis leidyi* has on occasion reached densities of 1kg of biomass per m^2. It has depleted native plankton stocks to such an extent that it has contributed to the collapse of entire Black Sea commercial fisheries. In several countries, introduced, microscopic, 'red-tide' algae (toxic dinoflagellates) have been absorbed by filter-feeding shellfish, such as oysters. When eaten by humans, these contaminated shellfish can cause paralysis and even death. The list goes on, hundreds of examples of severe aquatic bio-invasions across the globe. Impacts caused can be divided into three main categories; ecological, economic and human health, although they are all inter-linked and influence each other.

Ecological impacts

Should an introduced species become a successful invader in its new environment, it can cause a range of ecological impacts. These include:

- competing with native species for space and food,
- preying upon native species,
- altering habitat,
- altering environmental conditions (e.g. increased water clarity due to mass filter-feeding),
- altering the food web and the overall ecosystem, and
- displacing native species, reducing native biodiversity and even causing local extinctions.

The United Nations Environment Programme has identified invasive species in general as the second greatest threat to global bio-diversity after habitat loss and this was re-iterated at the World Summit on Sustainable Development in 2002.

An important feature of the ecological impacts of harmful aquatic bio-invasions is that they are virtually always irreversible, and generally increase in severity over time. In this regard it is worth comparing the impacts of aquatic bio-invasions with those of a better-known form of ship-sourced pollution, major oil spills (Figure Eight). In a major oil spill, the ecological impacts are most likely to occur very quickly, be catastrophic and acute, and highly visible. However, impacts will decrease over time as the oil degrades and clean up and rehabilitation activities are undertaken. With an aquatic bio-invasion, the initial impacts may be non-existent to minor, and invisible. However, as the population increases, the impacts will increase over time, in an insidious, chronic and irreversible manner.

Unlike oil spills, for which humans have developed a huge range of response and clean-up options, once an invading species has established a viable population in a new environment, it is almost always impossible to remove. There are no recorded cases of successful control and eradication of aquatic invasive species that have established in open waters. The extremely limited cases of successful control and eradication have been when the invading species was detected at a very early stage, inside enclosed waters such as a marina or small bay, that could be closed-off and treated with biocides (e.g. the striped mussel in Darwin Harbour, Northern Australia – Pyne 1999).

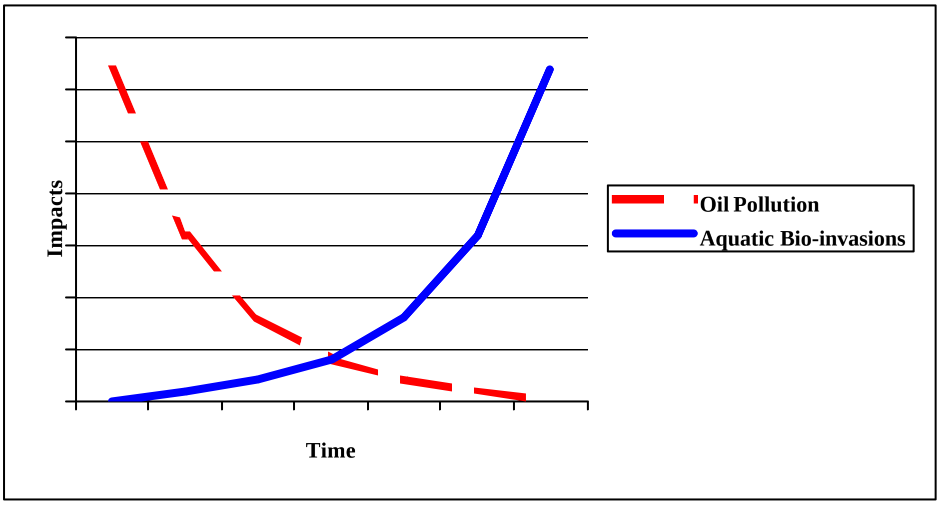


Figure Eight: *Impacts over time, major oil spill versus aquatic bio-invasions.*

Economic Impacts

Many aquatic invasive species can cause major economic impacts on human society. Direct economic losses to society can be caused by aquatic bio-invasions in a number of ways, including:

- Reductions in fisheries production (including collapse of the fishery) due to competition, predation and/or displacement of the fishery species by the invading species, and/or through habitat/environmental changes caused by the invading species.

- Impacts on aquaculture (including closure of fish-farms), especially from introduced harmful algae blooms.

- Physical impacts on coastal infrastructure, facilities and industry, especially by fouling species.

- Reduction in the economy and efficiency of shipping due to fouling species.

- Impacts and even closure of recreational and tourism beaches and other coastal amenity sites due to invasive species (e.g. physical fouling of beaches and severe odours from harmful algae blooms).

- Secondary economic impacts from human health impacts of introduced pathogens and toxic species, including increased monitoring, testing, diagnostic and treatment costs, and loss of social productivity due to illness and even death in affected persons.

- Secondary economic impacts from ecological impacts and bio-diversity loss.

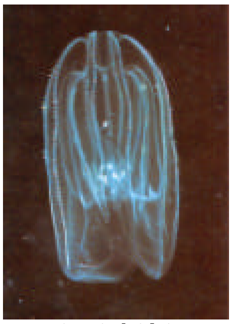
- The costs of responding to the problem, including research and development, monitoring, education, communication, regulation, compliance, management, mitigation and control costs.

Two classic examples of major economic impacts from aquatic bio-invasions are the European Zebra mussel *Dreissena polymorpha*, which has been introduced from the Black Sea to the North

American Great Lakes, Ireland and parts of the European Atlantic coast; and the North American Comb Jelly *Mnemiopsis leidyi*, which has been introduced to the Black Sea.

The Zebra Mussel is an encrusting species that forms large clumps of individual mussels grouped tightly together, fouling all available hard surfaces in mass numbers. It displaces native aquatic life, alters the native habitat, ecosystem and food web and causes severe fouling problems on infrastructure and vessels. Perhaps of most economic significance, is the fact that it blocks industrial water intake pipes, sluices and irrigation ditches. It is estimated that cost of attempting to clear Zebra Mussels from industrial facilities in the USA alone was between US$750 million and US$1 billion between 1989 and 2000 (O'Neil 2000).

The severe economic and ecological impacts of North American Comb Jelly provide one of the starkest case studies of the potential negative effects of ballast water introductions.


Mnemiopsis leidyi

Native to American waters, *Mnemiopsis* was first recorded in the Black Sea in 1982, introduced via ships' ballast water. It feeds by actively hunting zooplankton and exhibits massive fluctuations in population density in response to environmental conditions. It is a superfluous feeder, consuming up to ten times its own weight per day and regurgitating excess ingested food (Kremer 1979). The reproductive success of *Mnemiopsis* is facilitated by the fact that it is a self-fertilising, simultaneous hermaphrodite.

By 1988 the jellyfish reached an estimated total biomass throughout the Black Sea of 1.10^9 tonnes wet weight, greater than the world's total annual fish landings (Sorokin 2001). It is believed to have contributed substantially to the near collapse of commercial fisheries in the Black Sea through reduction of plankton resources.

Mnemiopsis reduced fisheries production by more than US$200 million a year in the Black Sea and by more than US$40 million a year in the Sea of Azov in the late 1980's. These figures were for certain fish species only and did not include the flow-on effects of inactive fishing fleets, ports and factories, which are considered to have been much worse (Zaitzev & Ozturk 2002). Of great concern, *Mnemiopsis* has recently been transferred in ballast water to the Caspian Sea as well.

Other example of the economic impacts of invasive aquatic species include the closure of fisheries and fish farms during outbreaks of harmful, introduced algae (and the subsequent implementation of expensive monitoring and quality-control programmes) and the closure of recreational and tourism beaches due to fouling by harmful algae blooms (Figure Nine).

Figure Nine: *Mucous generated by a harmful algae bloom fouling a beach and making it unusable (Source: The Argus).*

Added to these are the ever-increasing costs to coastal and port States, flag States and industry of responding to the ballast water 'problem', including research and development, monitoring, education, communication, regulation, compliance, management, mitigation and control costs.

One study has estimated that the total cost of all invasive species (including terrestrial) is in the vicinity of US$138 billion per year in the USA alone (Pimental et al 2000). The global economic impacts of invasive aquatic species have not been quantified but are likely to be in the order of tens of billions of US dollars per year or more.

Human health impacts

Casale (2002) states, "For six hundred years leaders in the health and maritime industries have recognized the international transport of disease as a public health threat. As early as the fourteenth century it was understood that plague epidemics moved along maritime trade routes. The concept of quarantine originated in Venice. Ships were required to stay at anchor off shore for forty days (a quaresma) and were not allowed to enter the port until there was reasonable assurance the ship was disease free.

Although there was no understanding of the germ theory in the 1300s, the effects of disease transmission were well known. In 1347 several ships returned to Venice from Constantinople and the Black Sea bringing Bubonic Plague, the Black Death, to a population that was immunologically vulnerable. By 1348 the disease had spread to Paris and was transmitted to London within a few months. All aspects of society were thrown into turmoil; including religion, government, trade and agriculture. During the course of this epidemic the population of Europe was decimated, with the mortality rate reaching over sixty five percent in many cities. Historians report that it had significant effects on the economy of Europe for two hundred years (Univ. of Virginia 1999). "

In modern times, despite effective quarantine procedures that have addressed the conventional modes of ship-transported human diseases, shipping remains a potentially significant vector for pathogens and toxic organisms, through ballast water. Scientific research has established that human pathogens are transported in ballast water of ships (Ruiz et al 2000). Public Health professionals were astonished to discover that *Vibrio cholera* could invade some species of algae, then enter a dormant state awaiting favourable conditions that facilitate its re-emergence as an infectious agent (Monroe & Colwell 1996)."

Some cholera epidemics appear to be directly associated with ballast water. One example is an epidemic that began simultaneously at three separate ports in Peru in 1991, sweeping across South America, affecting more than a million people and killing more than ten thousand by 1994. This strain had previously been reported only in Bangladesh.

In addition to bacteria and viruses, ballast water can also transfer a range of species of micro-algae, including toxic species that may form harmful algae blooms or 'red tides'. The public health impacts of such outbreaks are well documented and include paralytic shellfish poisoning, which can cause severe illness and death in humans (Figure Ten).

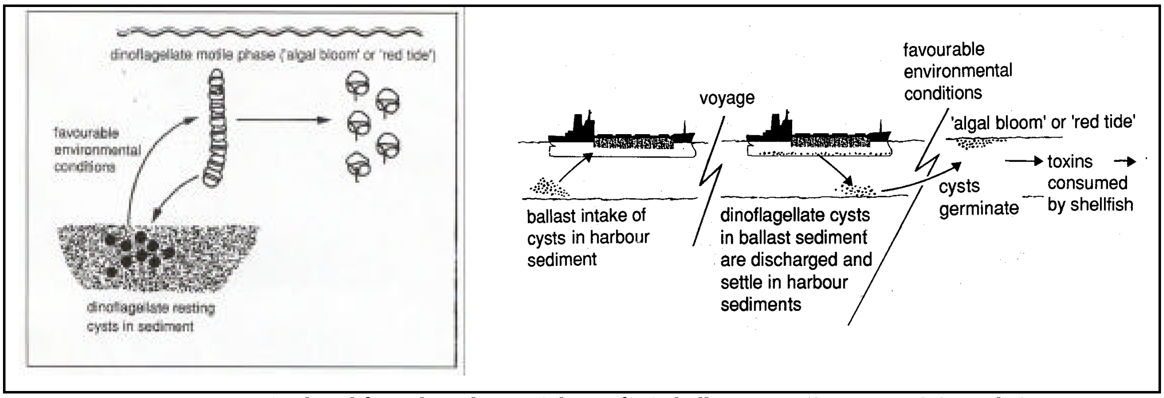


Figure Ten: *Toxic algae life-cycle and potential transfer in ballast water (Source: BRS Australia).*

The human health implications of ballast water transfers distinguish this issue starkly from other ship-based environmental issues. Nobody has ever died directly from the effects of a ship-sourced oil spill, people may fall ill and die from ballast water introductions.

Are all bio-invasions harmful?

It is true that not all introduced species have negative impacts. Many introduced species establish viable, long-term populations in the invaded environment without causing major ecological or other disturbances. Many of the small bryozoans (sea squirts) and small Goby fishes found introduced around the world fit this category. They may be called 'benign' invaders.

It is also possible for introduced species to have positive socio-economic impacts, although these are usually minimal. One example is the introduction of the Asian marine snail *Rapana thomasiana* to the Mediterranean. In the 1990's Turkey exported more than 1,000 tonnes of edible *Rapana* meat per year back to Asia, supporting a small-scale coastal fishery.

The question of whether or not invasive species are perceived as being negative, benign or positive, is to a large extent a philosophical one, and one that is dependent on the time-scale being considered. It also depends on whether one considers human activity, including modern shipping, to be just another part of the natural world, or if somehow, human activities should be considered as being 'apart' from nature.

In a geological time-scale, it could be argued that changes to the global distribution of aquatic species from human activities, including transfers by shipping and ballast water, are well within the range of natural variation caused by plate tectonics, natural changes in global environmental conditions and biological evolution, and are somehow a natural part of the Earth's dynamic state.

However, from a purely anthropogenic standpoint, viewed within a human time-scale, there can be no doubt that the majority of case studies conclude that most aquatic bio-invasions around the world have drastic negative impacts, in terms of socio-economic considerations.

The extent of invasions – a truly global problem?

The rate of aquatic bio-invasions appears to have increased at an exponential rate over the last two hundred years and shows no sign of levelling off (Carlton 2001). The data presented in Figure Eleven is typical of most areas where investigations have been carried out.

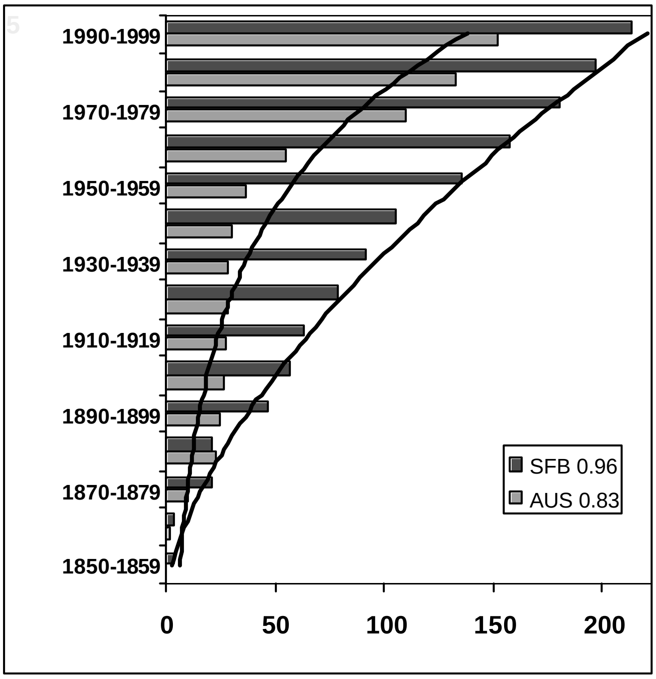


Figure Eleven: *The exponential increase of marine bio-invasions. Cumulative number of invasive species in San Francisco Bay (SFB) and Australia (AUS) (Source: CSIRO Australia).*

It appears highly likely that a significant proportion of the apparent increase in aquatic bio-invasions is a direct result of increased observer effort. As scientists, governments and industry have become more aware of the issue, greater effort is being put into field surveys and monitoring, which of-course is likely to increase the number of detected and reported invasions. However, scientists are now beginning investigations to differentiate between apparent and actual patterns of bio-invasion and to remove observer bias (Ruiz et al 2000). It seems likely that even when the effects of increased observer effort are removed, the 'actual' or 'real' trend in the occurrence and frequency of new aquatic bio-invasions will still be upward at an exponential rate.

When the international community first began to discuss the ballast water issue at IMO in the late 1980s, only Australia, Canada and the USA were actively involved. These three countries were suffering known impacts from aquatic bio-invasions and the rest of the world, particularly the ballast water exporting nations, considered it to be largely a problem for those countries only.

While this perception still persists to a certain extent, ongoing studies all across the world are demonstrating that virtually no corner of the globe where there is shipping activity has escaped from the harmful effects of ballast water introductions. The port biological baseline surveys being conducted by the GEF/UNDP/IMO Global Ballast Water Management Programme (GloBallast) at six demonstration sites around the world, are showing that this is truly a global problem. For example the survey conducted in Odessa in the Black Sea in 2001, an area that had previously been well studied for invasive aquatic species, detected no less than 12 exotic species previously undetected in the region, including blooms of the dinoflagellate algae *Gyrodinium cf aurelu* (Alexandrov 2002). Similar results are being found in other areas, both from studies in port and coastal waters and sampling of ships' ballast tanks. A poster produced by the GloBallast Programme 'Ten of the Most Unwanted' provides an indication of the global extent of the problem (see also Annex I), although even this is a small sub-sample of the true global scale of aquatic bio-invasions.

Has the horse already bolted?

A common question in the ballast water 'debate' is whether or not all potentially invasive species have already been transferred to all potentially invadable environments, i.e. 'Has the horse already bolted and is it too late to close the stable door?'

Given the long history of shipping, the current extent of global trade (Figure Seven), and the exponential 'J' curve associated with the apparent ongoing increase in aquatic bio-invasions (Figure Eleven), this is an entirely reasonable question. Any 'J' curve must reach an asymptote at some stage. Despite the vastness of global bio-diversity, potentially invasive species are finite in number, and despite the expanse of global geography, potentially invadable sites are also finite.

A definitive answer to this question remains to be provided by the scientific community. What is clear is that as a result of globalisation, implementation of free trade arrangements and ongoing economic development, maritime transport is continuing to increase at a phenomenal rate. Some studies predict that global shipping will increase four-fold in the next 15 years (European Commission 2002). Review of the journal 'Port Development International' shows that virtually every major port in the world is under-going or has planned expansion works, and that numerous new ports are being developed at 'greenfield' sites all around the world. Shipping patterns are undergoing significant changes, including:

- an overall expansion in volume, frequency and global coverage,
- opening-up of new areas that may not have been exposed to shipping previously (e.g. new ports near resource development projects, often in developing countries),
- increases in the number of vessels and changes in the types and sizes of vessels sailing existing trade routes,
- the establishment of new shipping routes between new trading partners, and
- an increase in the size and speed of vessels along with advances in ship design, construction and operation.

All of these factors lead to the obvious conclusion that despite the already significant extent of aquatic bio-invasions, the risk of further invasions is ever-increasing. The range of variables influencing the likelihood of any one ship-voyage resulting in a harmful bio-invasion is huge, including the presence/absence of species in the ballast-uptake port, seasonal environmental and biological conditions, the type of ship and its ballast tank arrangements, the length and nature of the voyage, any ballast water management practices applied, environmental and biological conditions at the receiving port and many other factors.

Despite several scientific hypotheses having been advanced regarding the invasive 'potential' of species and the invasion 'susceptibility' of environments, the range of possible combinations of all factors is such that there are no ecological laws that can be truly verified or falsified. Aquatic bio-invasions can only be characterised by multi-causality, and multiple hypotheses can operate simultaneously, depending on the situation. Under one set of circumstances a particular species may have low invasive 'potential' and a particular environment may have low invasion 'susceptibility', yet under another set of circumstances the scenario may well be reversed.

Every change in shipping patterns, whether in global terms or in relation to a single ship on a specific voyage, alters the risk scenario for aquatic bio-invasions. When the 'finite' number of potentially invasive species is combined with the 'finite' number of potentially invadable sites, along with the range of possible transfer scenarios, environmental conditions and other influencing variables, the number of possible successful-invasion combinations and scenarios rapidly appears to begin to approach 'infinity'.

It may be concluded then, that while many horses have indeed already bolted, there are still many inside the stable and there is still time to close the door. In addition, the global extent of aquatic bio-invasions that have already manifested is an added reason to take action to prevent further transfers. The problem of secondary transfers from already invaded sites is an ever-increasing one - many of the horses that have already bolted are now well ensconced in new stables – an important management objective must be to prevent them from bolting from those stables as well.

Conclusion

The introduction of invasive aquatic species into new environments by ships' ballast water, attached to ships' hulls and via other vectors has been identified as one of the four greatest threats to the world's oceans. The other three are land-based sources of marine pollution, overexploitation of living marine resources and physical alteration/destruction of marine habitat.

The ecological, economic and even human health impacts of aquatic bio-invasions are significantly more severe than all other forms of ship-sourced pollution. Ballast water transfers and aquatic invasive species are perhaps the biggest environmental challenge facing the global shipping industry this century.

The problem of ballast water and aquatic bio-invasions must be addressed on an international basis involving cooperation between all countries and the shipping and port industries because:

- Shipping is an international industry and must cross jurisdictional lines to conduct trade.

- Coastal States are in-extricably linked by natural circulation and currents and by shipping.

- Action by individual countries and companies would therefore be of limited effectiveness.

References

Alexandrov, B. 2002. *Preliminary results of investigations of the problem of exotic species invasion into the Black Sea – the Odessa port example.* CIESM Workshop on Ship-transported alien species in the Mediterranean and Black Seas, Istanbul, Turkey 6-9 November 2002.

Carlton, J. T. 2001. *Introduced species in US coastal waters – environmental impacts and management priorities.* Pew Oceans Commission, Arlington, Virginia.

Carlton, J. T. 1999. The scale and ecological consequences of biological invasions in the world's oceans, pp. 195-212. in: Odd Terje Sandlund, Peter Johan Schei, and Åuslaug Viken, editors, *Invasive Species and Biodiversity Management.* Kluwer Academic Publishers, Dordrecht, 431 pp.

Casale, G. A. 2002. *Ballast water – a public health issue?* Ballast Water News, Issue 8: Jan – March 2002. GloBallast Programme, IMO London.

Hamza, W. 2001. *Report on the analysis of the ballast water samples collected from the gas carrier (Al-Hamra).* Report to the National Gas Company Limited, United Arab Emirates.

Kremer, P. 1979. Predation by the ctenophore *Mnemiopsis leidyi* in Narragansett Bay, Rhode Island. *Estuaries 2.*

McLaclan-Karr, J, Vahid, Y & Raaymakers, S. In press. *Invasive aquatic species in the ROPME Sea Area – Case Study.* GloBallast Programme, IMO London.

Monroe PM and RR Colwell. 1996. Fate of *Vibrio cholerae* 01 in seawater microcosms. *Water Research.* 30:47-50.

O'Neill, C. R. 2000. Cited in: Carlton, J.T. 2001. *Introduced species in US coastal waters – environmental impacts and management priorities.* Pew Oceans Commission, Arlington VA.

Ruiz G. M. et al. 2000. Global spread of microorganisms by ships. *Nature.* 2000. 408(Nov): 49.

Ruiz G. M. et al. 2000. Invasion of coastal marine communities in North America : apparent patterns, processes and biases. *Annu. Rev. Ecol. Syst.* 2000. 31:481-531.

Pyne, R. 1999. The Black Striped Mussel infestation in Darwin: a clean-up strategy, in: Hillman, S. P (ed.) 1999. *The Ballast Water Problem – Where to from Here? Proceedings of a workshop held 5-6 may 1999, Brisbane, Australia*. EcoPorts Monograph Series No. 19. Ports Corporation of Queensland, Brisbane.

Pimentel, D., Lach, L., Zuniga, L. and Morrison, D. 2000. Environmental and economic costs of nonindigenous species in the United States. *BioScience 50:53-65*

Sorokin, Y. 2001. *The Black Sea.* Backhuys Publishers.

University of Virginia. 1994. Plague and Public Health in Renaissance Europe. *The Institute for Advanced Technologies in the Humanities.* University of Virginia.

Zaitzev, Y. & Ozturk, B. 2002. *Exotic Species in the Aegean, Marmara, Black, Azov and Caspian Seas*. Turkish Marine Research Foundation, Istanbul.

Annex I:

Some Examples of Notorious Bio-Invasions Attributed to Ships' Ballast Water

Species	**Origin**	**Area invaded**	**Impact**
Asian Kelp *Undaria pinnatifida*	Northern Asia	Southern Australia, New Zealand, West Coast of USA, Europe and Argentina	Grows and spreads rapidly, both vegetatively and through dispersal of spores. Displaces native algae and marine life. Alters habitat, ecosystem and food web. May affect commercial shellfish stocks through space competition and alteration of habitat.
Cholera *Vibrio cholerae (various strains)*	Various strains with broad ranges	South America, Gulf of Mexico and other areas	Some cholera epidemics appear to be directly associated with ballast water. One example is an epidemic that began simultaneously at three separate ports in Peru in 1991, sweeping across South America, affecting more than a million people and killing more than ten thousand by 1994. This strain had previously been reported only in Bangladesh.
Cladoceran Water Flea *Cercopagis pengoi*	Black and Caspian Seas	Baltic Sea	Reproduces to form very large populations that dominate the zooplankton community and clog fishing nets and trawls, with associated economic impacts.
European Green Crab *Carcinus maenus*	European Atlantic Coast	Southern Australia, South Africa, USA and Japan	Highly adaptable and invasive. Resistant to predation due to hard shell. Competes with and 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.
Mitten Crab *Eiocheir sinensis*	Northern Asia	Western Europe, Baltic Sea and West Coast North America	Undergoes mass migrations for reproductive purposes. Burrows into river banks and dykes causing erosion and siltation. Preys on native fish and invertebrate species, causing local extinctions during population outbreaks. Interferes with fishing activities.
North American Comb Jelly *Mnemiopsis leidyi*	Eastern Seaboard of the Americas	Black, Azov and Caspian Seas	Reproduces rapidly (self fertilising hermaphrodite) under favourable conditions. Feeds excessively on zooplankton. Depletes zooplankton stocks; altering food web and ecosystem function. Contributed significantly to collapse of Black and Asov Sea fisheries in 1990s, with massive economic and social impact. Now threatens similar impact in Caspian Sea.
North Pacific Seastar *Asterias amurensis*	Northern Pacific	Southern Australia	Reproduces in large numbers, reaching 'plague' proportions rapidly in invaded environments. Feeds on shellfish, including commercially valuable scallop, oyster and clam species.
Round Goby *Neogobius melanostomus*	Black, Asov and Caspian Seas	Baltic Sea and North America	Highly adaptable and invasive. Increases in numbers and spreads quickly. 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

Species	Origin	Area invaded	Impact
Toxic Algae (Red/Brown/Green Tides) *Various species*	Various species with broad ranges	Several species have been transferred to new areas in ships' ballast water	May form Harmful Algae Blooms. Depending on the species, can cause massive kills of marine life through oxygen depletion, release of toxins and/or mucus. Can foul beaches and impact on tourism and recreation. Some species may contaminate filter-feeding shellfish and cause fisheries to be closed. Consumption of contaminated shellfish by humans may cause severe illness and death.
Zebra Mussel *Dreissena polymorpha*	Eastern Europe (Black Sea)	Western and northern Europe, including Ireland and Baltic Sea; eastern half of North America	Fouls all available hard surfaces in mass numbers. Displaces native aquatic life. Alters habitat, ecosystem and food web. Causes severe fouling problems on infrastructure and vessels. Blocks water intake pipes, sluices and irrigation ditches. Economic costs to USA alone of around US$750 million to $1 billion between 1989 and 2000.

Note: There are hundreds of cases of harmful aquatic bio -invasions, the above are provided simply as examples only.

See also GloBallast poster – 'Ten of the Most Unwanted' – http://globallast.imo.org/awareness