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From Balance to Burden: The Global Impact of Ballast Water

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SUMMARY

Ballast water is essential for the safe and efficient operation of ships, helping them stay balanced during voyages. However, when released without proper treatment, it can introduce a wide range of invasive aquatic species, harmful pathogens, and pollutants into new environments. Real-world examples—like the zebra mussel invasion in the United States, Asian kelp spreading in Australia, and cholera outbreaks linked to marine shipping—highlight the serious environmental, economic, and public health risks caused by discharging untreated ballast water. This study explores the various methods used to treat ballast water, discussing their benefits and limitations. It also sheds light on the challenges ship operators face and examines future innovations in treatment technologies. Most importantly, the research points out that it requires eco-friendly, non-chemical solutions and the use of multiple treatment methods to effectively manage ballast water and protect marine ecosystems.

INTRODUCTION

Eighty percent of the world's cargo is carried by ships, which employ ballast water—seawater that is pumped in and out to stabilize loading and unloading operations and to help set the ship's buoyancy. By reducing hull stress brought on by shifting sea and cargo conditions, this procedure guarantees safe navigation. However, it also plays a significant role in the worldwide spread of aquatic species and other contaminants. In 2004, the International Convention for the Control and Management of Ship's Ballast Water and Sediments was adopted by the International Maritime Organization (IMO), the United Nations' specialized agency in charge of shipping safety and security as well as preventing ship-related marine and atmospheric pollution. The Ballast Water Management (BWM) Convention officially came into effect on September 8, 2017. It's also known as the BWM Convention. At least 7000 distinct marine species are said to be transported in BW every day all over the world. Exotic species can modify communities and genetic structure, among other aspects of biological organization.

Ballast water: process and ecological concerns

Ballast water is a significant volume of water that is placed into a ship to help with trim adjustment, list fixing, draft control, and preserving stability or hull stresses within allowable bounds. When there is an uneven distribution of cargo or when the cargo hold is empty, ballast water is kept in the ballast tank. As ballast water, either freshwater or seawater can be utilized, although seawater is typically employed. The size of the cargo vessel determines how much ballast water is transported.

Ballasting is the process of pumping seawater into the ballast tanks while the ship is empty, usually at the departure port. The pipes and ballast pumps have coarse-mesh screens that eliminate large material but allow microscopic creatures to pass through. Since most water is drawn from harbours, estuaries, and coastal regions that are abundant in plankton, there is a significant probability that it will infiltrate the ballast water. The organisms that are present in the ballast tanks survive for days or weeks during the **transport phase** since the water stays there during the journey. In certain situations, they may even reproduce or form cysts (dinoflagellates). They become a vector for invading species if left untreated. **Deballasting:** To lower draft for safe navigation or while loading cargo at the arrival port. Ballast water from the tanks is pumped back into the sea during discharge. A new marine environment is created by releasing this water, which contains creatures that are not native to the original port. This can bring infections, dangerous germs, and invasive species if left untreated. Significant ecological changes have resulted from this process globally.

Key changes observed

One of the most significant risks to the world's seas is ballast water, which can have detrimental effects on the environment, the economy, and public health. One of the main routes for the transmission of potentially invasive alien species is ballast water, including the following:

Impact of Invasive Species Introduced via Ballast Water

The ***Dreissena polymorpha*** (zebra mussel). These species originally come from the Caspian and Black Seas in Europe. Administered through ballast water into North America's Great Lakes They had spread to many of the inland waterways within a few years of their discovery. Destroyed ecosystems, displaced native mussels, and clogged water intake pipes. Between 1989 and 2000, the economic loss in the United States alone was estimated to be between $750 million and $1 billion. By 2022, zebra mussels were reported to be found in 31 states in the USA (Benson *et al.*, 2022).

The comb jelly (***Mnemiopsis leidyi***), originally found along the Atlantic coast of North America, made its way across the ocean not by choice—but by accident. It hitched a ride in the ballast water of ships and was unknowingly released into the Black Sea. Over the next 20 years, this small yet resilient creature slowly spread its reach, moving into nearby waters like the Aegean Sea, the Sea of Azov, the Sea of Marmara, and eventually the Caspian Sea. What began as an unintentional introduction has now become a widespread presence in multiple marine ecosystems. Over time, this species' density in the Black Sea rose to 1 kg of biomass per m^2. Its consumption of zooplankton and fish larvae caused its stocks to decline, which in turn affected the ecosystem's food chain and caused the anchovy and sardine fisheries to collapse. Every year, the local fishing industry takes a major hit—losing around $250 million—all because of an unexpected invader: the North American crested jellyfish. This seemingly harmless creature disrupts marine ecosystems, competing with fish for food and damaging fish populations, leaving fishermen struggling to make ends meet.

Undaria pinnatifida, or Asian kelp These species are native to Northern Asia. introduced via ballast water to Australia, New Zealand, and portions of Europe. By removing native seaweed and affecting fish and invertebrate habitats, these species formed dense submerged forests.

Killer shrimp Initially indigenous to Eastern Europe, especially the Danube River, now it is found throughout the Great Lakes and certain regions of Western Europe. It has been connected to the mortality of a number of native species, such as native shrimp and juvenile fish. According to studies, it is extremely adaptive and can withstand a broad variety of salinity, oxygen levels, and temperatures. This species, which is well-known for its aggressive colonization strategies, was mostly brought to new areas by ships' ballast water discharge.

Economic impact

The impact of ballast water on fisheries and aquaculture can be sustainable, as can the losses resulting from the overloading of ship hulls, floating signage, and port infrastructure. Commercially significant species may face competition from invasive species, which could lower their numbers and make them harder to capture. Fishermen may catch fewer fish as a result, and companies' revenues may decline. Invasive species mitigation and management can be costly.

Disease spread

It has been found that numerous diseases that pose a hazard to human health, including Enterobacteria, Vibrio spp., and Escherichia coli, can be transferred to various locations in ballast tanks in addition to invasive species. Additionally, ballast may include dangerous infections and illnesses that could affect the health and survival of fish populations. These have the potential to significantly deplete fish stocks, disrupt the food chain, and contaminate water with diseases that directly cause human illness. Ballast water is linked to several serious cholera outbreaks. One of the most devastating began in 1991, when ships introduced the bacteria into three ports in Peru. It rapidly expanded throughout South America from that point. By 1994, the outbreak had claimed more than 10,000 lives and infected over a million people. What made it even more alarming was that this particular strain of cholera had previously only been seen in Bangladesh—until ballast water carried it across oceans.

Ecological

Predation, parasitism, competition, the introduction of new infections, genetic modifications, habitat changes, species shifts, and biodiversity loss are the main ecological effects associated with invasive species. Ballast water movement around the world contributes to the spread of waterborne diseases that impact humans and other creatures by spreading chronic human pathogens. Exotic species invasions are a problem in many countries, including Africa, the United States, Australia, and several European countries. These invasions can result in changes to ecosystem function, nutrient cycles, and water quality. By raising the risk of infections and parasites, several invasive species carried by ballast water can endanger public health.

Making Our Oceans Safer: How Ships Treat Ballast Water

In addition to carrying goods, ships frequently bring along unwelcome passengers, including bacteria, invasive species, microscopic organisms, and larvae, when they traverse the world's oceans. These can be dangerous when released into unfamiliar surroundings and infiltrate ships through ballast water, which is seawater pumped in for balance. Ballast water must therefore be treated before being released.

The main methods now used to purify ship ballast water are as follows:

1.Filtration: The First Line of Defence

In many systems, it is the initial step. How well the system works largely depends on the mesh size used for filtering (Bailey *et al.,* 2022). Large particles and marine life, such as plankton and crabs, are captured by large mesh screens or sophisticated filters. Some ships include two-stage filters: larger ones for garbage and seaweed, then smaller ones to capture smaller creatures. Weight and maintenance can be decreased with the use of special materials like ceramic filters or crumb rubber. Although it's a good place to start, different approaches are frequently used because it doesn't get rid of the smallest offenders.

2. Hydro cyclones: Consider a fast-moving vortex inside a pipe. A hydro cyclone is that. It rapidly spins water, causing heavier particles to be thrown to the sides and eliminated. Sand, grit, and some creatures can be effectively removed with it, but not microscopic microorganisms. It frequently precedes or complements other therapies.

3. Ultrasound (Sonication): Ships break down microscopic organisms in the water by using high-frequency sound waves. It is particularly effective on soft-bodied organisms such as some bacteria and brine shrimp. However, it typically plays a supporting role because its power decreases with higher volumes.

4. Hydrodynamic Cavitation: The physics of collapsing bubbles is used in this technique. Special nozzles cause tiny bubbles to grow and burst when water passes through them. These tiny explosions produce shockwaves that kill tiny organisms and rip apart cells. It is low-maintenance and environmentally friendly, but it is less effective against bacteria; thus, it is frequently combined with chemicals or UV light.

5.Chemical Disinfection: Ships employ specialized marine-safe chemicals to eradicate what filtering is unable to, much like we do at home. By targeting the membranes of cells, oxidizing biocides such as ozone and chlorine kill them. Although strong, they can also be caustic, corrosive, odorous, and possibly dangerous if not handled properly. Non-oxidizing biocides, such as glutaraldehyde, disrupt an organism's ability to reproduce or metabolize. They are preferable for longer trips because they take longer to operate.

6. Oxygen Depletion: For survival, certain species require oxygen. So why not remove it? This technique removes oxygen from the water by pumping in inert gases like nitrogen. Although it helps stop corrosion and is safe for ships, short trips are not a good fit for it because it takes days to start working.

7. UV Therapy: Bacteria on your hands and in ballast tanks can be effectively eradicated by ultraviolet (UV) radiation. Microbes are rendered incapable of reproducing when their DNA is damaged by UV radiation. Particularly after filtration (which makes room for the light to function), it is efficient, fast, and clean. It doesn't leave behind any chemical residue; however, it performs worse in murky or dirty water.

Challenges in Ballast Water Management

The majority of systems are unable to completely remove certain microorganisms from ballast water, primarily cysts or spores, and they are resistant to common treatments like ultrasound, chemical disinfectants, and ultraviolet light. This is one of the major challenges effecting the efficient and widespread use of ballast water treatment systems. Before becoming active and causing the introduction of new species into the environment, these adaptive forms can endure severe environments for prolonged periods of time. The cost of installing and maintaining these systems is another significant obstacle. For example, some cutting-edge technologies, such as ozone chlorine dosing, require specialized infrastructure and equipment in order to maintain treatments like ozone heat. Internal ballast tank corrosion from chlorine can result in additional maintenance problems. IMO establishes international standards for ballast water, but some nations, such as the United States, have their own rules and regulations in addition to the Coast Guard's. This puts shipowners in a difficult situation because they must install systems that satisfy both sets of requirements, which causes delays, confusion, and increased costs.

Future Strategies and Innovations

Depending on the level of investment, governments around the world are expected to implement several advanced measures to manage ballast water (BW) more effectively. These include the use of laser treatment systems integrated with two-tier filtration, as well as the deployment of ceramic filters enhanced with graphene-functionalized silver for improved microbial removal. Additionally, establishing a robust biodiversity monitoring system will play a key role in controlling and preserving local ecological balance. Enhancing port state management is also crucial—ports and local authorities must conduct thorough inspections of BW records, collect water samples, and enforce stricter regulations when issuing or renewing BW management certificates. Furthermore, alternative ship designs should be explored and adopted, moving away from conventional methods to build more sustainable and environmentally responsible vessels for the future. Another strategy to prevent DBP generation during on-dock ballast water treatment is the use of nonoxidizing biocides, such as naphthoquinone, glutaraldehyde, and lysoglycerophosphocholine (Sayinli *et al*., 2021).

CONCLUSION

Maintaining proper ballast water levels helps ships sail smoothly and reduces the risk of accidents. But it plays an important role in the spread of disease, invasive species, and ecological disturbances. when they are released into water without proper treatment. These cause several consequences, like fishery collapse, biodiversity loss, and effects on human health. Although several treatment methods have been developed, all the treatments have their own limitations. One of the most important ways to reduce the harmful impact of ballast water on marine ecosystems is through proper treatment technologies. Ballast Water Management Systems (BWMS) play a key role in this process by treating the seawater that's pumped into ships' ballast tanks—removing or killing unwanted organisms before the water is discharged elsewhere. Even though there are several methods, the best treatment is the one that doesn't use chemicals. These non-chemical methods don't release any pollutants into the environment, and they don't affect the environment. To control the number of organisms, a single treatment is not enough; two or more treatments are used together.

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