MARINE BIOINVASIONS FACT SHEET:

BALLAST WATER TREATMENT OPTIONS

Ships use ballast water to provide stability and maneuverability during a voyage. Water is taken on at one port when cargo is unloaded and usually discharged at another port when the ship receives cargo. Because organisms ranging in size from viruses to twelve inch fish living in the surrounding water or sediments are taken on board with ballast water, there is a potential for the introduction of non-native organisms - called bioinvaders, alien species, nonindigenous species or exotic species - into the port of discharge. A number of methods to prevent these unwanted introductions are discussed in this fact sheet.

Unfortunately no single ballast water management technique has been able to remove all organisms or all types of organisms from ballast tanks. A combination of different methods may prove to be more effective than one method alone, however little research has been conducted into this possibility. It is difficult to implement treatments because ship owners are understandably reluctant to install technology that is expensive, unreliable, or time consuming.

Criteria for Selecting a Treatment Method

- Safety of the crew and passengers
- Effectiveness at removing target organisms
- Ease of operating treatment equipment
- Amount of interference with normal ship operations and travel times
- Structural integrity of the ship
- Size and expense of treatment equipment
- Amount of potential damage to the environment
- Ease for port authorities to monitor for compliance with regulations

When evaluating ballast water treatment options a number of general factors must be considered including cost, enforcement, the effectiveness of the method, and the risks the treatment may pose to human health and the environment. The monetary cost of a treatment method includes the expense of the equipment, the crew needed to operate the treatment equipment, and the time needed for the treatment operation. Many treatment methods require that ships be retrofitted with the necessary equipment or that new ships have the equipment included in their design, both of which may be quite expensive. Because crew members have many tasks to perform on a ship, any crew that is needed to operate the treatment may decrease the number of crew members that are available for other ship operations. If a treatment method slows down the journey of a vessel or causes excess fuel consumption the journey will be more expensive. Any treatment method should provide means for port authorities to easily monitor whether or not the treatment has been performed and if it was effective. This allows for enforcement of any laws regarding ballast water treatment. Because many treatment methods work by killing the organisms in ballast water, the method itself may pose a risk to human health or to the environment if the treatment is not properly contained in the ballast tanks. These risks and costs need to be evaluated and compared to the risk of introducing species to a port.

Ballast Water Exchange

Current ballast water regulations usually recommend minimizing the risk of introducing non-native species by exchanging ballast water in the open ocean. This method is effective because organisms from coastal waters are unlikely to survive in the open ocean and vice versa. Drawbacks to this method are: (1) it is difficult to completely remove sediments and residual water from the bottom of ballast tanks; (2) organisms stuck to the sides of the tank or structural supports within the tank will not be readily removed; and (3) during stormy or rough seas it is unsafe for a ship to exchange ballast water. Thus, organisms remaining inside the ballast tanks may be discharged at a later time into ports and harbors if the exchange fails to remove all organisms.

Figure 1. Mid Ocean Exchange

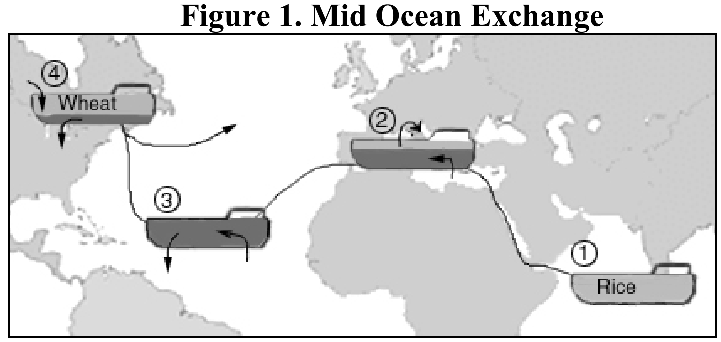


Figure 1 illustrates how ballast water exchange would work. A ship leaves a port in the Indian Ocean, travels through the Suez Canal, discharges cargo in the Mediterranean and takes up ballast water prior to crossing the Atlantic Ocean. Ballast water exchange would occur in the Atlantic prior to the ship entering the Great Lakes to pick up cargo, e.g. wheat for transport to the receiving port.

There are also advantages to ballast tank exchange. Because it is done while the ship is *en route*, relatively little time is lost during the voyage. No additional equipment or operator training is needed for ballast exchange so the capital costs are low and it is a simple process to implement. Enforcement of ballast exchange laws can occur to some degree because open ocean waters have higher salinity levels than coastal waters and this difference can be detected by port authorities. In addition, Battelle, a research institution, is developing a quick and easy test for determining if ballast water exchange has occurred.

The effectiveness of ballast water exchange could be improved by redesigning ballast tanks and pumping systems. Currently, most ballast tanks have one pipe that pumps water in both directions, but not at the same time. With the addition of another pipe, ballast exchange could be achieved by continual flushing of the tank with one pipe bringing water into the tank and another pipe allowing water to exit the tank. This would be a safer means of exchanging ballast because the tanks would contain water at all times.

Another means of improving current ballast tank flushing would be to remove the residual water and sediments from the bottom of ballast tanks. Pumps, which are relatively inexpensive, could be installed in the bottom of ballast tanks to remove these residual materials, thereby reducing the risk of introducing a non-native species. Ballast tanks could also be redesigned with a sloping bottom or other structure that allows sediment and water to drain into a pump.

Current ship designs often include structural supports and odd corners in the ballast tanks that trap organisms and ballast water. The possibility of trapping organisms in ballast tank structures could be reduced by designing ships that do not have these structures, redesigning these structures so they do not trap ballast water and organisms, or by installing small pumps in these areas to remove water during ballast exchange.

Biocide Treatment Terms

Biocide: A chemical such as bleach that kills organisms.

Oxidizing agent: Chemicals that destroy cell membrane through oxidization. A molecule that is electron deficient removes an electron from another molecule in this reaction. The process of rusting is an oxidation reaction.

Non-oxidizing biocide: Biocides can also be lethal through various other chemical means.

Ozone: This molecule, O_3, is very important in our upper atmosphere, where it shields us from harmful ultraviolet rays. In the lower atmosphere, however, it is the major component of smog and is a harmful pollutant. It is also often used as a biocide in water. Ozone is inherently unstable and dangerous to produce, but it is a very powerful oxidizing agent.

Chemical

Chemical biocides may be used to treat ballast water and prevent the introduction of non-native species. The specific type of biocide must be chosen very carefully to avoid harming humans or the environment. Biocides are usually shipped and stored in the form of a concentrated solid or liquid, so they can easily be stored onboard a ship. These are widely used industrial chemicals, so much data exists on their safety and effectiveness, although reactions between biocides and sea water that could produce harmful byproducts have not been extensively studied. The machines for applying biocides are reliable and need little maintenance, but their size may be a limitation when installing them aboard ships. A major concern with the use of biocides is the safety of the crew members who handle the chemicals. Because other dangerous chemicals that are used for lubricants and other functions on the ship must also be handled, training the crew to safely use biocides should be relatively simple. Another concern is whether residual biocides have the potential of corroding ballast tanks, pipes, pumps, and other structures. Some of the biocides that have been studied for ballast water treatment are discussed below.

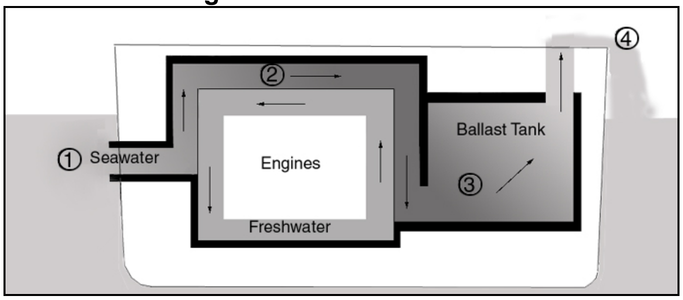
Two general types of biocides exist: oxidizing and non-oxidizing. Oxidizing biocides include chlorine, bromine, and iodine. These chemicals act by destroying cell membranes which leads to cell death. Chlorine is commonly used to treat municipal drinking water, but recent studies suggest that it may not be as safe to humans as once thought. There is also a possibility that oxidizing biocides may react with sea water to form toxic chemicals. Because of these reasons, it may not be safe to release water treated with oxidizing biocides into the environment.

Ozone is an oxidizing biocide that has been used to disinfect water supplies since the late 1800's. Ballast water is treated as it flows through a device that bubbles ozone gas into the water. Most of this gas dissolves into the water, decomposes and reacts with other chemicals in the ballast water to kill organisms. Ozone gas is toxic to humans and contributes to smog in the lower atmosphere, so any ozone that does not dissolve must be destroyed before it is released into the atmosphere. Ozone is especially effective at killing microscopic organisms, but is not as effective at eliminating larger organisms. Combining ozone with a treatment method that successfully eliminates larger organisms would be more effective than using ozone as a solitary treatment. The main drawback to ozone treatment is the large size of the ozone generators needed to treat a large volume of ballast water. Reactions between ozone and components of sea water may also result in toxic chemicals that should not be released into the environment.

Non-oxidizing biocides include numerous chemicals that act by interfering with a necessary life function such as metabolism or reproduction. Most pesticides fall into this group of chemicals. Some of these biocides degrade into non-toxic chemicals within a few days, so if they are applied towards the beginning of a voyage they should have little effect on the environment when ballast water is released. Because of the time needed for deactivation, non-oxidizing biocides may not be the best option for shorter voyages.

One non-oxidizing biocide is gluteraldehyde, an organic compound that kills a wide variety of organisms and is used in industry, for example to sterilize medical equipment. Gluteraldehyde has the advantage of being metabolized quickly when released in the environment to carbon dioxide, a safe chemical.

Figure 2. Heat Treatment



1. Sea water is pumped in to flush ballast tanks. 2. The sea water is heated (shown in a darker shade) by freshwater used to cool the ship's engines. 3. The heated sea water is pumped into the ballast tanks, killing many of the organisms. 4. The treated ballast water is pumped overboard.

Heating ballast water to temperatures between 35°C (95°F) and 45°C (113°F) and maintaining that temperature for a long enough period of time is effective at killing larger organisms, such as fish, but not as effective at killing microorganisms. Ballast water is heated by using the engine cooling system, either by using ballast water to cool the engine or by flushing ballast tanks with the heated water that was used as coolant. This is a very efficient method because coolant water is necessary and would most likely be discharged into the ocean if it were not used to treat ballast water. Another benefit to this method is that there are no resulting chemical byproducts. A similar method is used in heat exchangers used to cool houses instead of using air conditioners with a reverse process being used to minimize heat loss during the winter.

The main drawback to either of the methods for heating ballast water is that they require the installation of pipes to bring the ballast water in contact with heat. Treatment is limited by the amount of heat provided by the engines, so the amount of ballast water to be treated must be compared to the heat released by the engines. In some cases, it may be necessary to be filter out dead organisms before releasing the heated ballast water into the environment.

A number of factors need to be considered before using heat treatment on a specific ship or a particular voyage. The voyage must be long enough to allow water to reach the specified temperatures for the necessary amount of time. Because the temperature of ballast water is affected by the ambient water temperature, this method may not be as useful in colder waters since more energy would be needed to raise ballast water to the necessary temperature. Another consideration is the possibility of ballast tank corrosion from the high temperatures. Because ballast tanks of newer ships are coated with a protective epoxy that can withstand temperatures up to 80°C (176°F), they are less likely to corrode than those of older ships. However, if the epoxy wears away the uncovered surface may corrode. Regardless, because heating only occurs for a short period of time as compared to the lifetime of the ship, corrosion may not actually be a major concern with this treatment method.

A study in Australia modified a ship to flush ballast tanks with heated water from the engine's cooling system while letting ballast water overflow onto the deck then into the ocean. Ballast water reached temperatures of close to 40°C (104°F) and most organisms perished. In this study 90% of the original ballast water was washed overboard so this method is especially effective because it kills organisms with heat and also flushes the ballast tanks.

Filtration

Ballast water can be filtered before it enters the tanks or while it is being discharged. The advantage to filtering as water is pumped into the tanks is that organisms that are filtered out may be retained in their native habitat. If ballast water is filtered while being discharged, proper disposal of organisms is required to eliminate accidental introductions. One of the main drawbacks to filtration is that it requires specialized equipment which may be expensive to purchase and install. The cost of filtration increases as smaller particles, and organisms, are removed from ballast water. Since the size of filters used to treat ballast water are not likely remove microorganisms, another treatment method would have to be used to remove microbial invaders. New technologies are developing ways to increase the flow rate through filters and prevent organisms from clogging filters, making this method of treatment more useful.

The Algonorth experiment is a $1.3 million project in the Great Lakes that is designed to measure the effectiveness of ballast water filtration. A filtration unit, a testing laboratory, and peripheral equipment such as a trolley for towing a plankton net through a ballast tank were installed in 1996. A back washing mechanism cleans the filters and collects organisms to prevent their accidental release. In addition to removing larger organisms with the filtration method, another experiment will study which pathogens are carried in ballast water and evaluate whether filtration with fine-meshed filters removes pathogens.

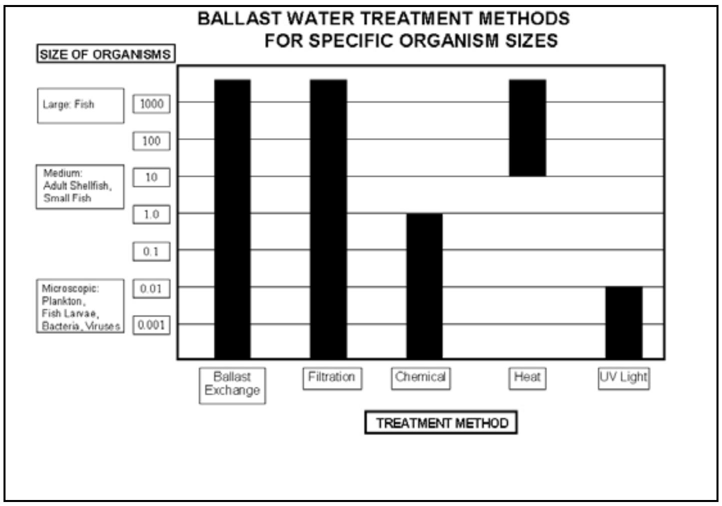
Other Methods

Other methods for treating ballast water are being investigated. These methods need much more research and development before they will be applied to ballast water treatment.

Ultraviolet (UV) light is currently used in hospitals, homeless shelters, and prisons to kill microorganisms and prevent the spread of disease. UV lamps are being studied for use in municipal water treatment plants as a replacement for chlorine. This method is most effective on microorganisms, so would need to be combined with another method to effectively remove all potential bioinvaders from ballast water. One of the main drawbacks is that UV light is ineffective in water containing suspended matter, so ballast water may need to be filtered before treatment.

Although many methods are being investigated, no treatment has been found that cost effectively prevents all living organisms from being transported through ballast water. Figure 3 shows the sizes covered by the various methods. Some treatments may need to be accompanied by another treatment that covers another category of organism. For instance, UV treatment may be accompanied by filtration. Filters of different sizes are also needed in order to cope with the volume of water exchanged. Larger material must be filtered out, in other words, before the water can be filtered by a finer mesh.

Figure 3.



A number of other physical methods for removing unwanted organisms from ballast water have been examined including acoustics, electric pulses, and magnetic treatment. Specific acoustic frequencies kill specific organisms, so acoustic treatment may be effective at removing target organisms but not the wide range of organisms found in ballast water. Magnetic forces have been shown to kill certain invertebrates, such as zebra mussels, in laboratory tests. This method has not been tested on a wide variety of organisms in sea water so its effectiveness for treating ballast water is yet to be determined. Electric pulses may be sent through ballast water killing most organisms. The risk to the crew and the expense and size of the equipment needed to generate these pulses are the major drawbacks to this method of ballast water treatment.

Conclusions

Ballast water is one of the major pathways of biological invasion throughout the world. Removing organisms from ballast water is a promising way to prevent the introduction of bioinvaders that cause ecological and economic harm. Because no one method has yet been proven to remove all organisms from ballast water, more research must be conducted into improving existing treatment methods, developing new methods, and determining the effectiveness of combining ballast water treatment methods.

Until recently, preventing ballast water release of non-native species was a low priority. As a result, many of the treatment options are still in the experimental stage. Because installing new technologies or retrofitting ships is expensive, ship owners are reluctant to use a new technology unless it is proven effective. This, in turn, has created further delays in adopting regulations and implementing changes in how ships manage ballast water releases.

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