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Ballast Water and Sterilization of the Sea Water

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1. Introduction

Seventy one per cent of the earth's surface is covered by water; and ninety five point five per cent of the whole existing water is concentrated in oceans.

Generally, when we talk about water pollution or wastes dumped on sea, we think about products with varying degrees of toxicity (hydrocarbon, pesticides, etc.), or about innocuous products which, when their physicochemical conditions change and they are brought in a particular ecosystem, can be damaging to it (e.g.: a mass of water to a greater o lesser degree of salinity and/or temperature than the ones in the environment). However, the pollution and the alteration of an ecosystem can also be produced by the introduction of new allochthonous or foreign species.

Since human being started to sail, aquatic organisms have had the chance to travel in the hulls of vessel or in other surfaces: ropes, anchors, etc. (fouling). Therefore, those "unwanted travellers" have increased in last decades, with the recreational boat increase and with the transport of merchandise in great cargo ships, both in the hulls of vessel and into the ballast water.

If a vessel sails without cargo or partially loaded down, it will need ballast to keep its stability and safety.

Water is often used as ballast, but, when it is collected in origin, a series of organisms can travel into the water, normally members of the plankton community which could be stranger in the destination (allochthonous), and they might cause unwanted biogological pollution.

In order to avoid this possible pollution, we have to use a effective system to sterilize the ballast water.

Although the main methods to avoid the problems caused by ballast water have historically been mechanical, physical and chemical ones, on July 2007 the Marine Environment Protection Committee (MEPC) granted basic and final approval to a water sterilization system which does not use chemical products, based on the Advanced Oxidation Technology (AOT).

It's necessary the commitment of all the countries, the shipping companies, the industry and the scientific community to continue studying, developing and experimenting with efficient methods to sterilize the ballast water.

2. The planktonic community

Living beings that inhabit in oceanic waters can basically be classified in three communities: plankton, nekton and benthos. Normally, members of nekton and benthos are macroscopic, but members of plankton community are usually small and, by definition, they have little or no capacity to counteract the sea dynamic. That is why, until well into the 21st century, imagining an organism belonging to this community which was able to move enough in order to settle down in a different environment was difficult.

There is plankton in all the water of the earth. In seas and oceans, these animal and plant organisms, normally with a small size, are in every latitude and in the entire water column.

The components of this community have been clasified taking into acount several aspects or criteria, but not all the established classifications have a real rigor or scientific basis. Although, traditionally planktonic organisms have been divided into phytoplankton (autotrophs) and zooplankton (heterotrophic), in the latest classification, this distinction does not seem appropriate, since, among the autotrophic organisms, plants, some protists and bacteria are included, and there are animals, some protists and bacteria in the heterotrophic (Cognetti et al., 2001).

We can do a first classification in accordance with the permanence of the organisms in the community. As well, you can distinguish between holoplankton (Photo 1), formed by those organisms that throughout their life are part of the plankton, and meroplankton (Photo 2), constituted by those organisms that were part of the plankton during a period of their life and then became part of other communities (nekton or benthos).

In relation to its size, this type of classification was originally performed taking into account the dimensions of the mesh used for catches. Over time various authors have carried out these ratings, without reaching the final agreement, although currently, one of the most used is the classification proposed by Sieburth et al., 1978 (Table 1).

Category	Size	Organisms
Femtoplankton	0.02 -0,2 µm	Marine viruses
Picoplankton	0.2 – 2 µm	Bacteria; small eukaryotic protists
Nanoplankton	2 – 20 µm	Small flafellates; diatoms
Microplankton	20 - 200 µm	Foraminifera; rotifers; copepods nauplii
Mesoplankton	0.2 – 20 mm	Copepods; cladocera; ostracoda; chaetognaths; pteropods; tunicata; medusae
Macroplankton	2 – 20 cm	Heteropoda; chaetognaths; euphausiacea; medusae; salps; doliolids
Megaloplankton	20 – 200 cm	Ctenophores; salps; pyrosomes

Table 1. Classification of Planktonic organisms according to their size

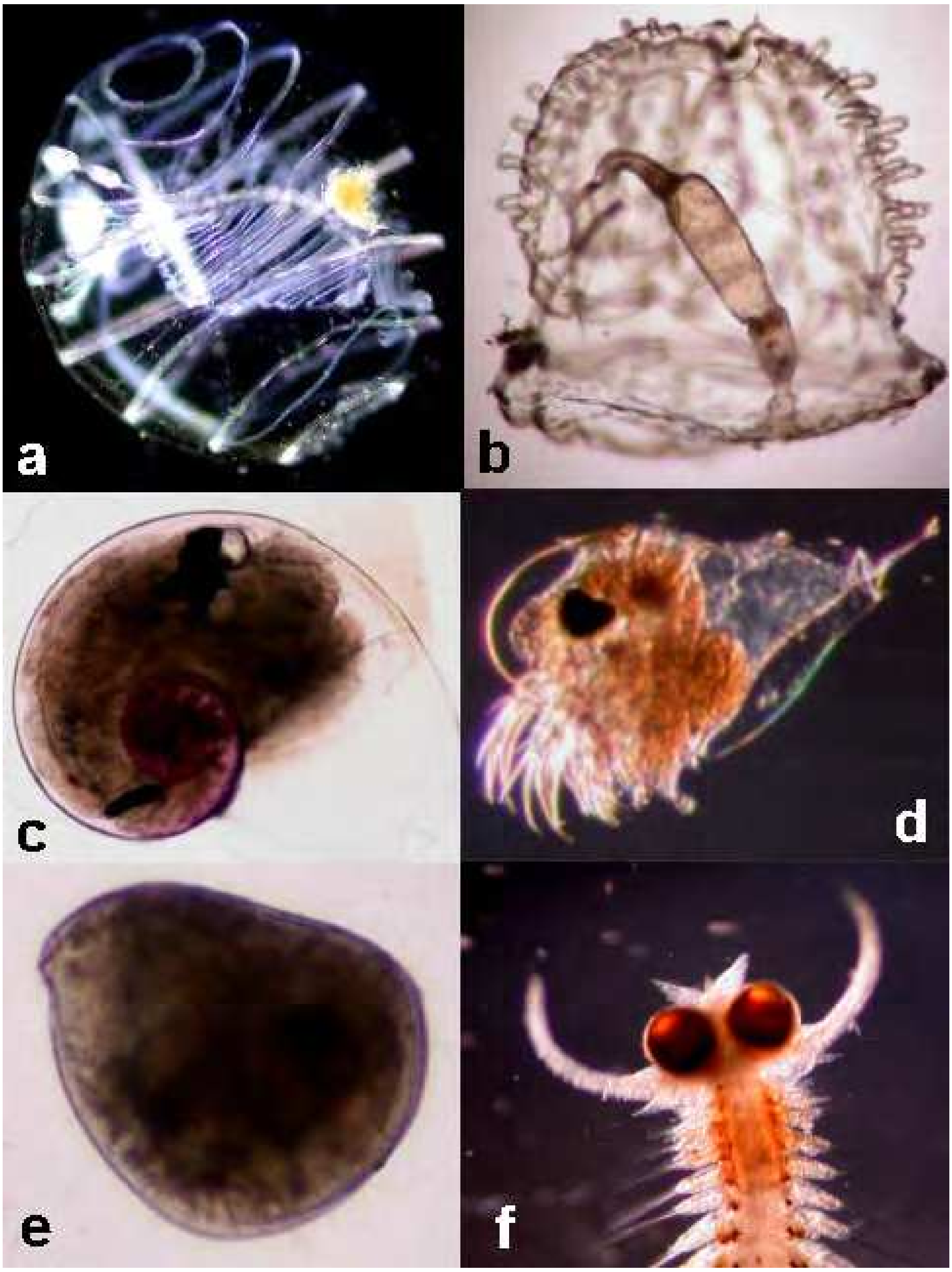

Photo 1. Components of the holoplankton: a) doliolid, b) hydromedusa; c) pteropod; d) cladocer; e) ostracod: and f) polychaeteo

The quantity and the variety of beings which are part of the planktonic community depend on a lot of factors: the latitude, the season, the bathymetric level, etc. In oligotrophic oceanic water, the vertical tows of 50 metre of length samplings were carried out until surface show average values of approximately 320 ind.m^{-3} (Mingorance et al., 2004).

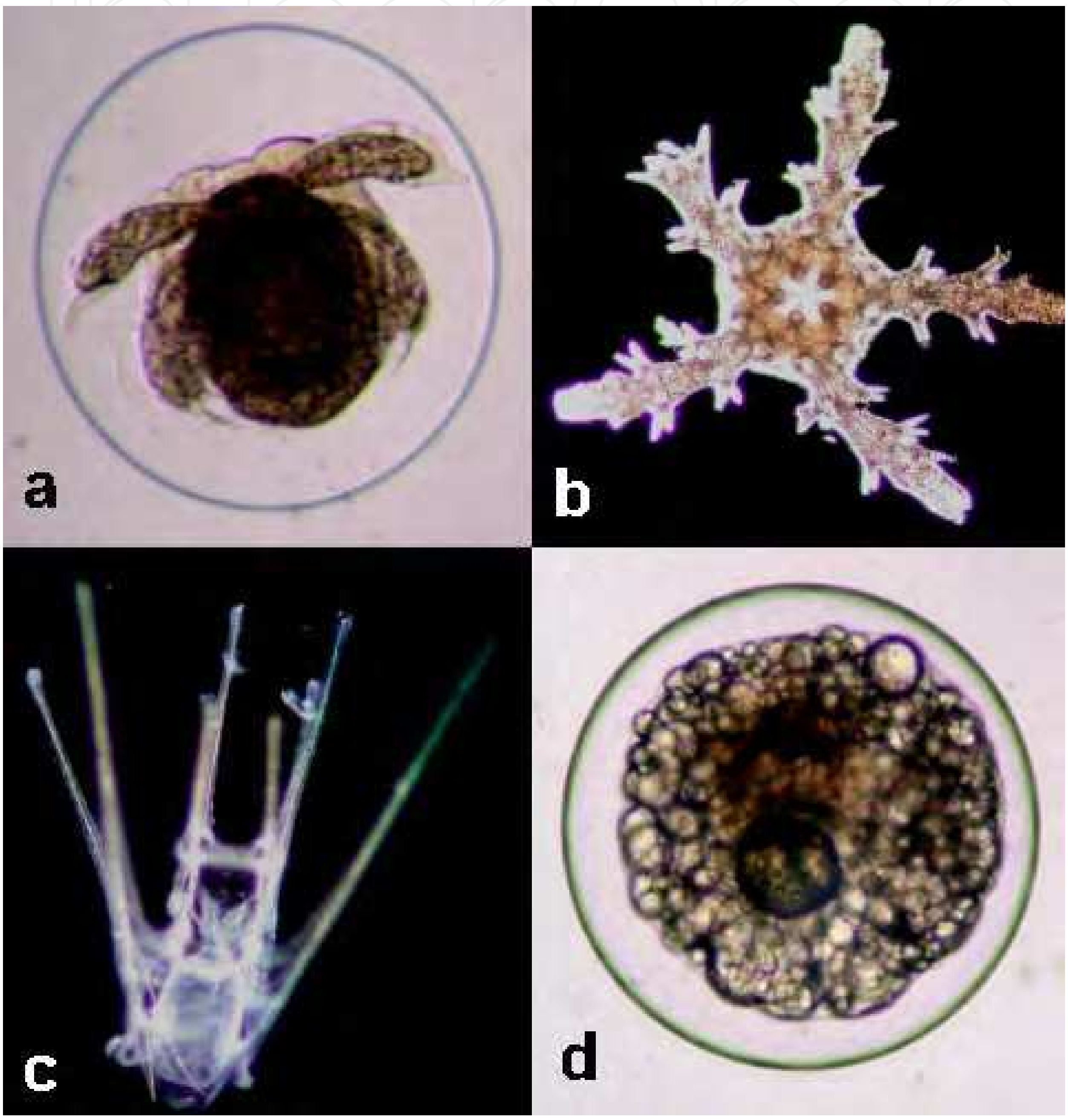

Photo 2. Components of the meroplankton: a) crustacea egg; b) ophiuroidea larvae; c) echinoderm pluteus larva; and d) fish egg

3. Biological pollution by ballast water

The first large enough boats to carry goods for trade appeared around 3500 B.C.; probably, the human being used boats of small size previously. From that moment the aquatic organisms could also travel: in the hulls of vessel (fouling), in the ropes, in the anchors, and so on (Photo 3).

Photo 3. The aquatic organisms have always travels in the hulls of vessel (fouling)

Nowadays, we try to minimize those "unwanted travellers" with the application of specific paints or with other methods like, for example, the utilization of ultrasounds. These measures are taken not only because they benefit environment but also because if the hull is clean, the vessel will have a greater energy saving and it will pick up more cruising speed.

The risk of possible biological pollutions could be caused not only by the organisms stuck in the hull of the vessel, but also because they travel accidentally in the water used to ballast the vessel when it goes without cargo.

The International Maritime Organization (IMO) define ballast water as "means water with its suspended matter taken on board a ship to control trim, list, draught, stability or stresses of the ship.".

The first materials used as ballast were stones, sand and other heavy objects, until sea water began to be used in the 19th century.

Throughout the 20th century and in this first decade of 21st century the transport by sea, both freight and passengers, has increased and the ships are becoming faster and with greater capacity. Moreover, the involuntary transportation of microorganisms has also increased among different places of the planet.

When cargo ships (bulk carriers, ore carries, tankers, among others) (Photo 4) must sail without cargo (with ballast) they need big volumes of ballast water, which is pumped before undertaking the trip with the empty vessel. If the ballast tanks are segregated, in other words, they transport exclusively sea water, and the vessel travel with ballast, organisms (virus, bacteria, animals and plants), normally belonging to the planktonic community, can accidentally go on board.

Photo 4. Carrier need ballast (water) when they travel without cargo in order to keep their stability

It's estimated that 10.000 million tons of ballast water are transfered among different places on the earth every year. Each vessel can transport from several hundred of liters until 100.000 tons of ballast water, it depends on its dimensions and purposes, and various studies suggest that the shipping industry is responsible for transfering more than 10 millions tons of ballast water every year among different places on the planet (Rigby et al., 1999).

Around 3000 species of animals and plants are estimated to travel daily by this way (IMO, 1998), and, though the survival rate of these species is low in a different habitats from the own one, as less than 3% of them really settle in new habitat, invading species are the direct cause of the 39% of known extinctions and of the loss of biodiversity.

As well, the speed of current vessels displacements is another factor that favors the prosperity of these organisms, because a lot of them wouldn't survive a long period of time in the darkness of the ballast tanks. That's why it's important that there aren't eggs, spores or organisms which can pollute that ecosystem in the ballast water throwed away in the destination place.

Ballast water is recognized as the most important vector of transoceanic and interoceanic movements of low deep water and of coastal organisms (IUCN, 2000).

This problem appeared for the first time before the IMO on 1988. In September of that year, Canada presented a report about a research related to the existence and the effects of foreign organisms (the Zebra Mussel, *Dreissena polymorpha*) in the vessel ballast unloaded in the Great Lakes between Canada and the United States from the Black Sea in the mid-1980s in the Marine Environment Protection Committee (MEPC), and, for more than 15 years, IMO has discussed about an agreement to regulate a better treatment of ballast water.

Throughout history, there were a lot of situations when these unexpected, unwanted and involuntary "travelers" have been detected.

In the port with the great traffic in the world, San Francisco Bay, 212 allochthonous species have been found (Garcia Varas, 2007).

In a bay in Oregon State (United States of America), 367 marine organisms from Japanese fauna were detected four years later than some ships from that country had released ballast water in the above-mentioned bay (UNESCO).

A planktonic Asian alga, specifically a diatom, which is able to reproduce very easily, invaded the North Sea on 1903, and it has been spreading to the Southern coast of United Kingdom (Boalch & Harbour, 1977).

The *Pfiesteria piscicida*, a dinoflagellate species of the genus *Pfiesteria,* which can have 24 different shapes and some of them produce a series of toxins, that are inocuous for human being but they are associated with injuries and with mortality of many fishes, was discovered on 1988 in North Carolina, after it had been brough into the ballast water (Rublee et al., 2005).

And, there are not only cases of planktonic beings: European green crab (*Carcinus maenas*) is a crustacean of about 8 centimeters long (in adult phase), it is quite voracious and practically omnivore. It has been introduced by ballast waters in Hawaii, both United States coasts, Panama, Madagascar, the Red Sea, India, Australia and Tasmania (Jaquenod de Zsögön, 2005).

In the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992, an entire chapter of Agenda 21 was dedicated to the seas and oceans protection. Subsequently, the IMO announced, from 1993 to 1997, directives to avoid the transfer of unwanted aquatic organisms and pathogenic agents from ballast water and from sediment unloading, but, the problem is that, unlike hydrocarbon spillage and other forms of sea pollution caused by shipping traffic, marine species and exotic organisms, they are very difficult to eliminate.

The A.868(20) resolution, which was approved on November 27, 1997 as an appendix of the MARPOL agreement, entitled "Directives to the control and management of ballast water of vessels in order to minimize the transfer of damaging aquatic organisms and pathogenic agents", and its objective is to achieve that all the world fleet would sterilize the ballast water as soon as possible. In addition, it asks governments for promoting urgent measures to apply these directives and to spread them in shipping sector.

Members of the femtoplankton, picoplankton, nanoplankton, microplankton (Photo 5) and mesoplankton (Photo 6) (0.02 μm - 20 mm holoplankton), as well as of the meroplankton corresponding to the sizes, travel daily in the ballast water. That's why an efficient sterilization is so important.

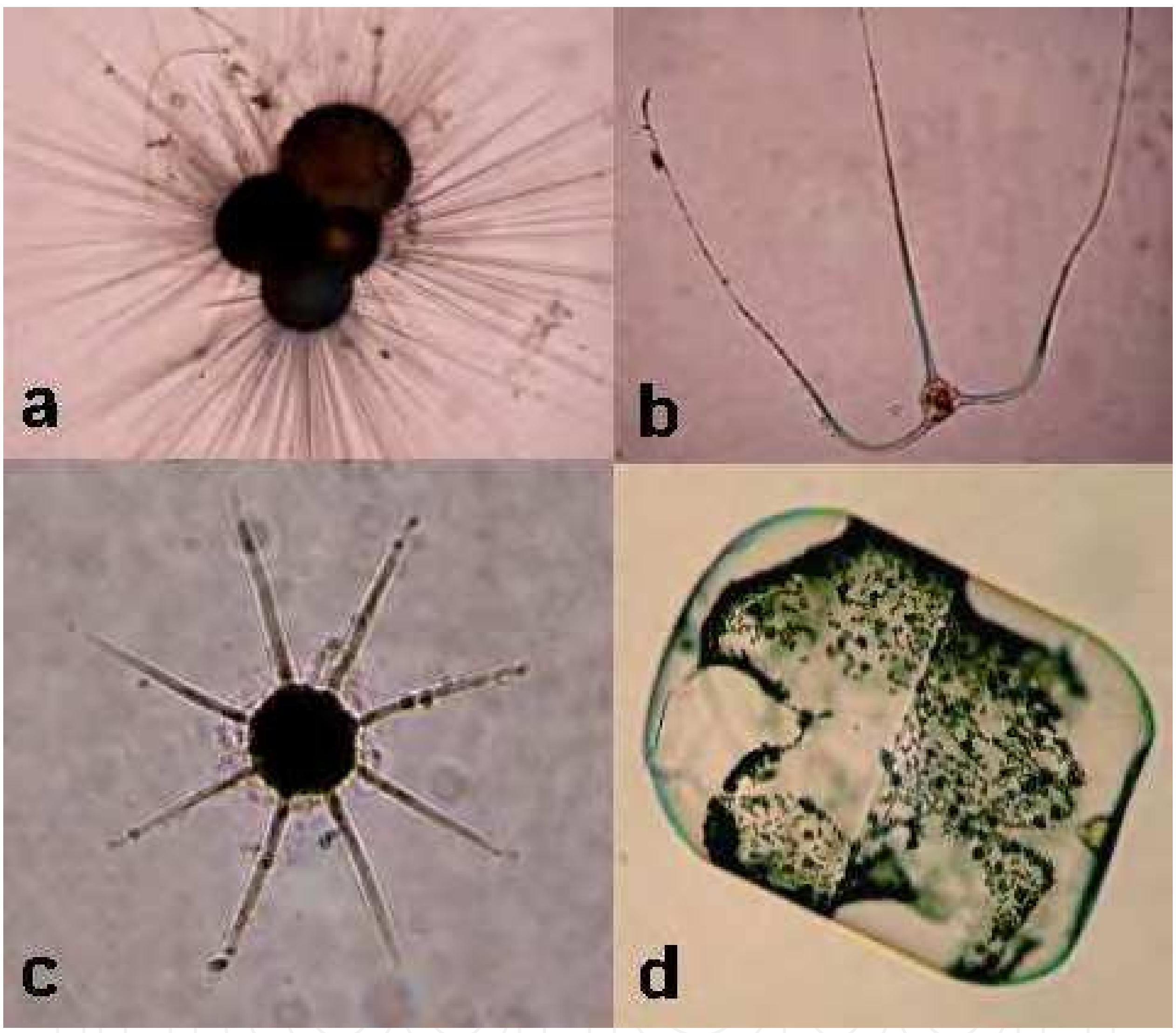

Photo 5. Microplankton: a) Globigerinida (foraminiferan); b) dinoflagellate; c) radiolarian; and d) diatom

According to a research done in North Tenerife (Canary Islands), a place is considered a oligotrophic area compared to the thickness of mesozooplankton which is in other places and other latitudes, an average thickness of 313.06 ind.m^{-3}.

A 60.000 tons oiler carries around 25.000 tons of ballast water in a travel with heavy sea, as 1 m^3 of sea water weights 1.020 g, 25.000 tons represent approximately 24.509.804 m^3. Therefore, if an oiler sucked up 24.000.000 m^3 of ballast water, it could pick up about 7.512 millions of organisms belonging to this community (Mingorance et al., 2009).

Photo 6. Copepods are usually the dominant members of the mesozooplankton

4. Sterilization of ballast water

Throughout time, mechanical methods as well as physical, chemical and biological ones have been considered, in order to solve the potentials problems of biological pollution, which could be caused by ballast water.

4.1 Mechanical methods

Mechanical methods can be the filtration, the reballasting, the dilution and the cyclonic separation, among others.

The filtration, which in the ballast water case need to be carried out as water is loaded on board, makes it possible to eliminate big particles as macroscopic algae, but it doesn't prevent from loading small organisms. Wastes would be left in the ballast intake area, but the necessary cost for this infrastructure could be very high.

Reballasting consist of doing the change of ballast water in deep waters, with 2000 meters or more sounding line, but it avoids the superficial water, the dredging areas and the places where there are illness or plankton outbreaks. This method keeps the chances of carrying allochthonous organisms at the place of destination.

Dilution caused by overflowing has to be done on the high sea; through the entry of water with the ballast pump and then we allow it overflows by the deck, at least a third of tank total volume. This method entails the risk of organisms wouldn't be entirely expelled.

In the cyclonic separation, ballast water goes into the inside of a chamber with circular flow; it goes through a venturi passage which is between the interior chamber and the separation chamber. The centrifugal helicoidal action propels particles toward the walls and it moves them to the chamber of sediments, they go through the clean water to outflow pipe. Sediments are constantly purged through the sediments return pipe.

4.2 Physical methods

The physical methods include the water treatment with ultraviolet radiation, heat treatment, ultrasonic treatment or water treatment with ions generated electronically.

The effect of the water treatment with ultraviolet radiation changes, it depends on the kind of organisms, because some of them are very resistant to UV radiation; it could be a very effective method if it were combined with the filtration. It has not toxic or damaging side effects for pipes, pumps or coating.

The heat treatment involves rising the ballast water temperature above 40º C for 8 minutes, since these conditions are lethal to practically all the organisms. Reaching this temperature depends on there being heating sources on board in order to treat the ballast water during the crossing.

The ultrasonic treatment for liquids uses high frequency energy to cause a vibration in the liquid. When the liquid is exposed to these vibrations, it causes cavitations (formation, expansion and implosion of microscopic gas bubbles in the liquid). As the ultrasonic energy goes into the liquid, the gas bubbles grown until they have a critical size and they implode. If the cavitation is sufficiently intense, it will break the cytoplasmic membranes.

The electrolytic generation of metallic ions, specifically copper and silver ions, has, in principle, a highly effectiveness to sterilize the water, but some organisms can increase their tolerance to high concentrations of copper and silver, so this turns the utilization of this method into a useless issue. Furthermore, the concentrations of these elements in the water could cause adverse environmental consequences. The application of this system has yet been rejected some time ago.

4.3 Chemical methods

Chemical treatments (basically the addition of disinfectants and biocides), the effect of which is oxidizing the organic matter, like, for example, chlorine, are refused for use, because water treated by this way keep certain biocide characteristics that could affect later other species.

4.4 Biological methods

On February 13, 2004, IMO adopted at London the Ballast Water Management Convention (BWM-2004) with the participation of 74 countries; the standards approved are compulsory from 2009 to 2016, depending on the year of vessel construction and the capacity of its ballast tanks. Therefore, vessel should have a specific ballast water management plan, which would be included in the documentation related to its operations.

Nevertheless, the 18th article of this Convention establish that it will come into effect 12 months later than the date when, at least, 30 states, whose merchant fleets represent the 35% or more of the world merchant fleet gross tonnage, will have ratified it.

Until February, 2010, 22 countries had ratified the Convention, but their fleets represented the 22.65% of the world merchant fleet gross tonnage.

In addition, this Convention won't be applied in the case of vessels which wasn't build for carrying ballast water, vessels that just carry ballast water in sealed tanks, vessels in a geographical area which only operate under the jurisdiction of that area, vessels which, although they were from another country, they operate under the jurisdiction of a geographical area or war vessels.

Since the approval of BWM-2004 Convention, the industry has been looking for solutions. It has mainly tried biological methods, which are effective and accessible from the point of view of economic costs, but also for their material installation on board. As well, according to these guidelines, the Swedish *Seatrade* awards to Countering Marine & Atmospheric Pollution have recognized two ballast water treatment systems: *PureBallast* on 2005 and *OceanSaver* on 2006.

In the *OceanSaver* System, during the ballast, the water goes through a 50 µm filter to eliminate the particles and organisms with a big size; this also helps to reduce the number of sediments that are piled up on the ballast tanks. Subsequently, the water is sterilized with a cavitation device, which breaks most of the organic matter, and then we add purify nitrogen and hydroxide ions generated by electrolysis.

In the *PureBallast* System, during the ballast, the water also goes through a 50 µm filter to eliminate the particles and organisms with a big size. Then, the water goes to the advanced oxidation unit (AOT unit), which contains catalyst of titanium dioxide and which, when is exposed to the light, it generate active oxygen and hydroxide radicals; the creation of those radicals doesn't depend on the water physico-chemical conditions (salinity, cloudiness, etc.); the radicals, whose life just last some milliseconds, break the cytoplasmic membrane of the organisms cells that have gone through the filter without using chemical products or generating damaging waste. The rest of the filtration is given back to sea, in the same place where ballast water was taken.

During the unballast, the water goes again through the advance oxidation unit to be sterilized again, but it doesn't go through the filter in order to there won't be possibility of unloading any kind of organic remains.

This treatment removes more than the 99.999% of the organisms with a size of more than 10 microns, and it can get the same percentage in the concentration of *Escherichia coli* (Alfa Laval, 2008). Thank to its modular design, it could adapt itself to several kinds of vessels and it can sterilize between 25 and 5.000 m^3/h (MEPC, 2006).

The Marine Environment Protection Committee (MEPC), in the meeting celebrated from 9 to 13 July, 2007, at the Horticultural Halls, London, agreed on giving the basic and final approval *PureBallast* System, created by Alfa Laval, and proposed by Sweden and Norway.

5. Conclusion

More than 3000 species of bacteria, animals and plants travel daily into the ballast water, 10 million tons of ballast water are transported every year among different places on the planet and more than 7.500 millions of organisms can travel into the ballast water in a oiler carries of average size (60.000 tons). So it's indispensable to apply always the principle of prevention, and to achieve that water would be sterilize effectively, in order to avoid species germane to an ecosystem arrive and establish themself in another ecosystem, which would be different to the own one.

Mechanical, physical, chemical and biological methods have been developed and tested to minimize the transport of organisms into the ballast water, but, some of these methods have also turned out to be damaging to marine environment, because, when a problem was being solved, other ones appeared: for example, the introduction of chemical products in the environment.

The organisms transfer in the ballast water is, in the first decade of 21st century, the fourth most serious environmental problem worldwide. To avoid it, IMO approved a ballast water sterilization system based on the Advanced Oxidation Technology (AOT), which complies with the rules of this institution and which came into effect on 2009.

This agreement is very important for trying to avoid the arrival of invading species in the oceanic ecosystems; nevertheless, it's also necessary the commitment of all the countries, the shipping companies, the industry and the scientific community to study, develop, bring into operation and experiment with efficient methods to sterilize these waters.

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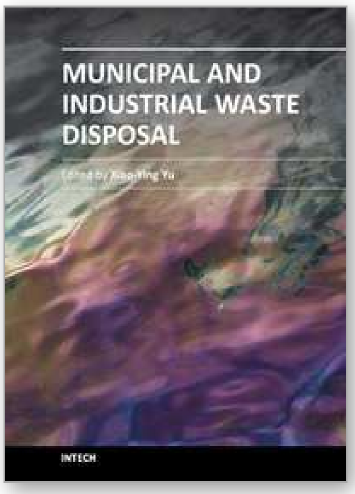

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This book reports research findings on several interesting topics in waste disposal including geophysical methods in site studies, municipal solid waste disposal site investigation, integrated study of contamination flow path at a waste disposal site, nuclear waste disposal, case studies of disposal of municipal wastes in different environments and locations, and emissions related to waste disposal.