Preventing marine pollution

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Contents

Introduction

The marine environment is vulnerable to various types of pollution that reach the sea in different forms and from different sources, and which is the mostly the result of human activities on land. These activities include the disposal of waste directly to the sea or coast, discarded plastics and other residential waste, beach pollution, increasing the concentration of nutrients (nitrite and phosphate), industrial pollution (offshore agriculture, aquaculture, sewage discharge), oil spills, discarded fishing nets, pollution from ships, ballast water inputs, etc.

United Nations Convention on the Law of the Sea (Article 1.1.4.) defined marine pollution as "introduction by man, directly or indirectly, of substances or energy into the marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water and reduction of amenities".

This definition, formed in 1982, is part of a number of international conventions and programs that have been created to protect marine environment from pollution, improve and preserve marine resources.

In 1975, 16 Mediterranean countries and the European Community adopted the Mediterranean Action Plan (MAP), the first-ever Regional Seas Programme. This Programme functions through action plans, adopted by member governments in order to establish a comprehensive strategy and framework for protecting the environment and promote sustainable development. There are four European Regional Sea Conventions which covers EU marine regions or sub-regions and which express the commitment and political will of governments to tackle their common environmental issues through joint coordinated activities:

1. The Convention for the Protection of the Mediterranean Sea Against Pollution (The Barcelona Convention)
2. The Convention for the protection of the Marine Environment of the North-East Atlantic (the 'OSPAR Convention');
3. The Convention on the Protection of the Marine Environment in the Baltic Sea Area of 1992 (further to the earlier version of 1974) – the Helsinki Convention (HELCOM)
4. The Convention for the Protection of the Black Sea of 1992 – the Bucharest Convention.

In addition to these, among the conventions of exceptional importance for solving marine pollution problems are:

1. International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto and by the Protocol of 1997 (MARPOL)
2. The "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972", the "London Convention"
3. International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC)
4. International Convention for the Control and Management of Ships' Ballast Water and Sediments, 2004 (BWM Convention)

Marine pollution affects the changes in the physical and chemical characteristics of the sea and the ocean, biological communities and the overall health of the marine ecosystem. Measures to control pollution, prevention and improvement of conditions are essential to preserve the state of the sea and they represent one of the greatest challenges of the Integrated Coastal Zone management (ICZM).

Marine pollution is an international problem and its solution is only possible with the application of international recommendations and solutions. In countries with developed industry and tourism, the problem of pollution is more intense and requires greater prevention and action in line with international recommendations and protocols. Higher concentration of people in coastal areas and industrial pollution have caused that almost 80% of the pollution of the sea is land-based, while only 20% of pollution originates from the sea (ships, fishing, recreation, etc.).

Scope of the problem

The pollution of the sea and the ocean as a consequence of human activity is to a large extent created by various actions. The threat to marine organisms for decades has been eutrophication, overexploitation, global climate change, the spread of invasive species, coastal erosion etc. Lately, an increasing impact on the health of ecosystems and the living world has been the marine litter which, in addition to all mentioned, creates additional pressure for already endangered organisms, habitats and the overall ecosystem health of the world sea.

Marine habitats are spoiled with man-made debris, from the poles to the equator and from shorelines, estuaries and the sea surface to the depths of the ocean (Thompson et al., 2009). One of the major stresses comes from the input of excessive macronutrients (nitrogen, phosphorus) resulting in a change of the trophic status of a given body of water, which leads to eutrophication (Meyer-Reil and Köster, 2000). Nutrient pollution has different sources, among which most commonly are agricultural runoff, sewage discharges, nitrogen oxides from ships, industrial water etc. Eutrophication leads to biodiversity loss, ecosystem degradation, harmful algae blooms and oxygen deficiency in bottom waters. Hypoxic, as consequence of algal decomposition after algal blooms causes formation of “dead zones” in which fishes and other marine organisms cannot thrive.

Statuses of marine resources over the last 20 years have been increasingly subjected to overexploitation, detrimental fishing practices and environmental degradation. Overexploitation of marine fisheries resources is either known or suspected for almost all the commercial fish stocks of the world (Watson et al., 2013). In the Mediterranean and the Black Seas overexploitation has been recently shown to occur for the entire area and for specific regions (Tsikliras et al., 2013, Vasilakopoulos et al., 2014). In general, large slow-growing species with a later age at maturity are more vulnerable to fishing, exhibiting a larger decrease in abundance for a given fishing pressure (Gislason, 2003; Reynolds *et al.*, 2005). As European fisheries are no exception to the rule, much of the EU fisheries legislation aims to tackle with the problem of overexploitation (e.g. Council Regulations 1967/2006, 643/2007, 1224/2009, 404/2011), including the relatively recent Marine Strategy Framework Directive through its Descriptor 3 (Commission Decision 2010/477/EU) (Borja et al., 2013, Tsikliras et al., 2015). The number of overexploited or collapsed fish stocks in the Mediterranean Sea has been increasing at a rate of approximately 38 every 10 years between 1970 and 2010, while in the Black Sea, the equivalent figure is 13 stocks per decade (Tsikliras et al., 2015). Overexploitation leads to species extinctions, changes in biodiversity, and in synergies with other human-impacted activities to habitat loss. It is considered that overfishing has the greatest impact on sea fishes and invertebrates, with the lack of rigorous baseline data limits for the implementation of efficient management and conservation plans.

The oceans cover three quarters of the Earth’s surface and play a vital role in the global climate system, generating oxygen and absorbing carbon dioxide from the atmosphere. It absorbs a significant portion of carbon and an overwhelming amount of excess heat. Through different debates and Conferences the scientists reported that the process of ocean acidification, from the absorption of more heat-trapping carbon dioxide emitted by fossil fuel burning, is occurring at a much more rapid rate than previously understood. The most common stressors on marine ecosystems amplified by climate change include: acidification of seawater, eutrophication and the spread of indigenous and/or invasive species into new habitats.

The introduction of invasive species is largely a consequence of maritime transport, one of the primary pathways for introduction of non-indigenous marine organisms (Mineur *et al.* 2009, Davidson *et al.* 2009, Wanless *et al.* 2010, Barnes 2002). Pollution and physical disturbance of the sea influence invasibility of species (Hobbs and Huenneke, 1992, D'Antonio et al., 1990, Sax and Brown 2000, Crooks and Suarez 2006, Lohrer et al., 2008). Recent studies showed that polluted marine habitats can favor invaders, while areas that are vulnerable to invasion due to anthropogenic activities, also tend to have abundant sources of potential invaders due to the strength and diversity of vectors (Crooks *at al.*, 2011)

Marine litter (debris) is defined as any persistent manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment (Coe and Rogers, 1997; Galgani et al., 2010). It includes the following categories: plastics, metals, sanitary waste, paper, cloth, wood, glass, rubber and pottery. While each category can pose problems in the marine environment, plastics, due to their lightweight and durable nature, have become the most prevalent, widespread element of marine litter (Derraik, 2002; Wright et al., 2013). Due to the extensive negative impact of marine litter to marine environment, it will be especially addressed in this paper.

Changes in marine ecosystem usually have several causes, and their joint effect with degrading pressures on the living world of the sea has a critical role in maintaining diversity of species, ecosystem health and achieving good ecological status. Seas and oceans hide huge quantities of waste under the surface, representing a global landfill for decades. Waste accumulation and poor pollution prevention is a threat that will increasingly cost the generations to come.

Types of marine pollution and sources

Marine Pollution by Wastes

Pollution of marine environment can be classified according to: their physic-chemical constitution (inorganic and organic); physical state (solid waste, drifting solids, gases, solutes) and persistence (biodegradable, pollutants which dissipate spontaneously (rapidly) and lose their damaging, and conservative or persistent pollutants). A major source of marine pollution is land-based and contributes to 80% of the total marine pollution. Air and land pollution are the major contributors to the growing marine pollution that hampering marine life, quality of environment and life on the land, as well.

Although there are many sources of marine pollution, among the biggest polluters of marine environment are:

- Discharge of untreated domestic wastes. This is one of the major sources of marine pollution.

This problem is worse in developing regions, where only a fraction of sewage is treated. Treatment facilities and infrastructure have not kept pace with population growth.

- Oil spills (hydrocarbons), POP-s (Persistent Organic Pollutants) and heavy metals.

Pops are highly toxic and stable organic chemical substances that can last for years or even decades before breaking down. Through a repeated and often seasonal process of evaporation and deposit, they can migrate to regions far away from the original source

- Marine litter.

The global production of plastics has increased from 1.5 million tons in 1950s to about 300 million tons currently, at an average rate of 4 per cent per annum and is expected to continue growing (Boucher and Friot, 2017). About 50 per cent of the plastics produced is for single use, and the literature estimates that 8 million tons (2.5 per cent) of the plastic produced are leaked into the oceans annually (PlasticsEurope 2016).

In the following part, the impact of some of the most important types and sources of marine pollution, as well as proposals for their prevention and reduction will be analyzed more detailed.

Floating litter

The dependence of the modern society on plastics - in particular packaging and single-use products - is increasing exponentially as is consequentially also the production of plastic waste (Zeri et al., 2018). The Mediterranean Sea is often referred to as one of the places with the highest concentrations of litter in the world. For floating litter, very high levels of plastic pollution are found, but densities are generally comparable to those being reported from many coastal areas worldwide (UNEP/MAP, 2017). Floating marine litter comprises the mobile fraction of debris in the marine environment, as it is less dense than seawater. The buoyancy and density of plastics may change during their stay in the sea due to weathering and biofouling (Barnes et al., 2009).

Floating marine litter items of different size (nano-, micro- to macro-litter) may be found floating at sea. The transportation of floating litter can be considered passive, mainly subject to surface currents or other movements of sea water. Beyond vertical mixing, waves and wind also affect the horizontal transport of microplastics (GESAMP, 2016). Ocean currents, waves, and winds control the transport of plastics, redistributing them at sea until they eventually wash ashore or sink. The high complexity and multiscale versatility of the dynamics of the upper mixed layer of the ocean, where the majority of plastics float, must be also taken into account (Liubartseva et al., 2016).

As plastic marine debris on beaches and floating in water is exposed to solar UV radiation it undergoes weathering degradation and gradually loses its mechanical integrity (Pegram and Andrady 1989). With extensive weathering plastics generally develop surface cracks (Cooper and Corcoran 2010) and fragment into progressively smaller particles (Qayyum and White 1993; Yakimets et al. 2004) (GESAMP, 2015).

A 30-year circulation model using various input scenarios showed the accumulation of floating debris in ocean gyres and closed seas, such as the Mediterranean Sea, made up 7-8% of the total debris expected to accumulate (Lebreton et al., 2012). Locations that are particularly susceptible to litter accumulation are as follows: i) coastal areas; ii) areas close to terrestrial sources (e.g. sewage wastewater, river); iii) depressions in the seabed; and iv) low-energy environments (low currents, weak circulation) (IMO, 2016a).

Reports of floating plastic micro-debris in the North Atlantic were first published in the scientific literature in the early 1970s. These publications raised concerns about the likelihood of ingestion of plastic particles by organisms and the potential for adverse physical and chemical impacts. A number of further publications, some in the ‘grey’ literature, in the 1970s and 1980s confirmed the occurrence of plastic particles in the North Pacific, Bering Sea and Japan Sea. But, the topic was largely ignored by the wider scientific and non-scientific community for many years (GESAMP, 2015).

Only a few studies have been published on the abundance of floating macro debris in Mediterranean waters (Aliani et al., 2003; UNEP, 2009; Topcu et al., 2010, Gerigny et al., 2011, Suaria and Aliani, 2015, Liubartseva et al., 2016, Vlachogianni et a; 2017, Zeri *et al*., 2018), and the reported quantities measuring over 2 cm range widely from 0 to over 600 items per square kilometer.

The EU Marine Strategy Framework Directive (MSFD) (2008/56/EC) requires European Member States to develop strategies that should lead to programmes of measures to achieve or maintain Good Environmental Status (GES) in European Seas. MSFD sets the framework for Member States to achieve by 2020 GES for their marine waters, considering 11 descriptors; descriptor 10, focuses on marine litter, stating that GES is achieved only when "properties and quantities of marine litter do not cause harm to the coastal and marine environment".

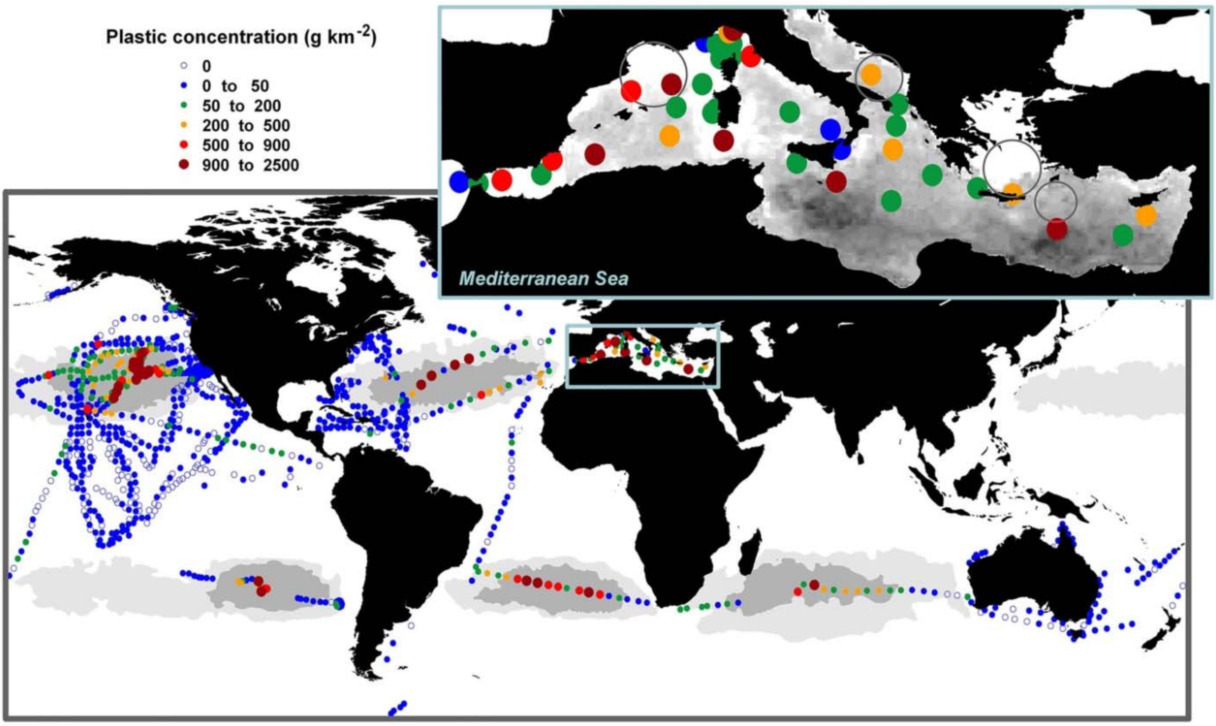

Figure 1. Plastic litter in global oceans. Source: Cozar et al., “Plastic Accumulation in the Mediterranean Sea”
(http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0121762)

Marine Pollution from Ships

International shipping, as the most efficient and cost-effective method of international transportation for most goods transports more than 80 % of global trade to peoples and communities all over the world. Besides facilitating commerce and helping to create prosperity among nations and peoples, shipping is important pollutant of marine environment. International Maritime Organization (IMO) is a specialized agency of the United Nations and global authority for the safety, security and environmental performance of international shipping. The IMO is trying to regulate, control and reduce pollution of sea and ocean from ships through various directives and laws. It resulted in the adoption of the first ever comprehensive antipollution convention, the International Convention for the Prevention of Pollution from Ships (MARPOL) in 1973. This Convention has changed over the last few decades to include a much wider range of measures to prevent marine pollution, and the original MARPOL Convention was amended many times in order to include requirements addressing pollution from chemicals, other harmful substances, garbage, sewage and, under an Annex VI adopted in 1997, air pollution and emissions from ships.

The Regional Strategy for Prevention of and Response to Marine Pollution from Ships (2016- 2021) (Decision IG.22/4) was developed with the aim to prevent;

Shipping is principal to our well-being, with around 90% of European Union international trade going by sea and more than 3.7 billion tonnes of freight a year being loaded and unloaded in EU ports (Özdemir, Ü et al., 2016). If not correctly controlled, the effect on the environment could be destructive, as ships often carry large volumes of hazardous cargo and generate a significant amount of pollutants throughout their life cycles (EMSA, 2008). According to the IMO, marine pollution caused by ships are affected by factors such as operational pollution and accidental pollution. Operational pollution implies discharge of sewage, tank residues, bunker oils and garbage, as well as the exchange of ballast water, emissions from vessels' engines and pollution due to anti-fouling paints on ships' hulls, dumping of garbage and solid waste, resulting of oil and waste water after deck washing operations, pouring of cargo into the sea, giving directly to the sea of raw sewages (Özdemir, Ü et al., 2016).

Shipping accidents are unexpected events that result in financial loss and properties, damages and either loss of people. Several reasons as human errors, technical failures, natural conditions, shipping factors, route conditions and cargo related factors play role in these accidents. The effects of accidents vary from minor injuries to fatalities and from insignificant damage to very severe damage to the environment and property. The cost of accidents, including fatalities and injuries, damage to property and the environment, prevention and mitigating measures, and insurance accounts for a considerable share of transport costs (Mullai & Paulsson, 2011, Ceyhun, G.C, 2014).

Historically, ships were a major source of plastic pollution of the sea due to the maritime tradition of dumping garbage at sea (Hagen, 1990). Merchant ships were estimated to deposit 639,000 plastic containers daily worldwide in 1982 (Horsman, 1982). Patruno (2008) gives detailed information related to the number and crossing intensity of ships in the Mediterranean area. 200,000 of merchant vessels of any size and type cross the Mediterranean annually, from which 10,000 are estimated to be oil tankers; every year 61,000 vessels transit the Strait of Gibraltar, 42,000 transit the Straits of Canakkale and Karadeniz, while 14,500 transit the Suez Channel.

According to IMO's 2012 Report named International Shipping Facts and Figures Information Resources on Trade, Safety, Security, Environment, measures introduced by IMO have helped ensure that the majority of oil tankers are safely built and operated and are constructed to reduce the amount of oil spilled in the event of an accident.

A very important segment of marine pollution is sulphur pollution, as a result of the high concentration of sulphates in liquid fuels used by ships. Sulphur emissions from shipping due to the combustion of bunker fuels with high sulphur content contribute to sulphur dioxide pollution and problems of acidification of seas and oceans. EU Directive 1999/32/EC defines maximum sulphur content of heavy fuel oil and gas oil, and that all member States should take all necessary steps to ensure that gas oils, including marine gas oils, are not used within their territory as from 1 January 2008 if their sulphur content exceeds 0,10 % by mass (10 parts per million - p.p.m). In contrast to the Directive, a few developed countries, including the United States, the United Kingdom and Norway, limit the sulphur content of marine fuel in their national waters to within 1,000 p.p.m. Most developing countries, including India and China, permit dirtier fuels with 35,000 p.p.m. of sulphur.

Marine Oil Pollution

Pollution of the marine environment by oil spill is a critical problem with worldwide ecological consequences. Approximately 3.5 million tonnes of petroleum hydrocarbons enter the marine environment annually, either directly or indirectly from anthropogenic and natural, terrestrial, atmospheric and marine sources (Samiullah, Y., 1985). There are two major sources of oil pollution. The first is the deliberate release of oil residues directly into the sea, and the second is accidental spillage consequent upon collision, shipwreck, or misuse or malfunction of equipment. The control of the first source and the prevention of the other is the essence of protecting the sea from pollution by oil or oil spills. However, accidents are the most common consequence of human error that is difficult to predict.

After oil reach the sea from its source, it spreads to the thinner and thinner layer that covers the sea surface. Depending on the composition and density of oil, as well as the weather conditions (winds, waves, currents, etc.) the influence of the oil pollution both to the environment and the living world of the sea could be different. If oil reaches the shoreline or coast, it interacts with sediments in shallow littoral area, intertidal zone, beach sand and gravel, vegetation, marine and terrestrial habitats of wildlife and humans, causing erosion, as well as contamination. The effect of oils pills also depends on the selected clean-up techniques and its effectiveness.

Oil pollution represents the worst chemical pollution with often catastrophic consequences that last for decades after spillage. All organisms that come into contact with oil have significant consequences, among which the most endangered are seabirds, larger mammals, planktonic organisms and fishes. The environmental impacts of oil comprise physical and chemical alterations, as well as the toxication of marine habitats.

A very illustrative and detailed example of the impact of oil spill exists for the Baltic Sea area. The EU coast of the Baltic Sea and its approaches include the coastlines of Sweden, eastern Denmark, north-eastern Germany, Poland, Finland, Estonia, Latvia and Lithuania. In the period 1998-2007, all open sea areas of the Baltic Sea, except for the Kattegat, were classified as being ‘disturbed by hazardous substances’. 98 of the 104 coastal assessment units were classified as being ‘disturbed by hazardous substances’, while only 7 out of the 144 assessment units were considered to be ‘under-disturbed by hazardous substances’. The main basin of the Baltic Sea, together with certain parts of the Kiel and Mecklenburg Bights, were the areas most disturbed by hazardous substances (HELCOM 2010). The EMSA reported that 75 ships were involved in incidents at the Baltic Sea in 2009. This number includes sinkings, groundings, collisions, fires/explosions and other types of accidents. 89 vessels were involved in incidents in 2010, which is an increase of 19% compared to 2009, but significantly lower than the 120 incidents that were reported in 2008 (EMSA 2010 , EMSA 2011). According to Hänninen and Rytkönen (2006), around 80% of all accidents that took place in the Baltic Sea are due to human factors, such as improper handling of the cargo, inadequate supervision and navigational errors, and machine breakdowns and other technical problems.

Jeftic, 1998 give an assessment of the oil pollution for the Black Sea area, where from total input of 111,000 tonnes, 53,000 tonnes (48%) enters via the Danube River. A further 30,000 tonnes is derived from domestic sources, 15,400 tonnes from industrial sources, and only 136 tonnes from accidental oil spills. The point is that the land-based sources of oil input are likely to the most significant even in marine areas having heavy tanker traffic (GESAMP, 2001). A significant amount of oil spilled into the sea comes from other sources, including seepages from the natural environment, discharges from refining, distribution and retail operations as well as end users of oil products. Waste disposal on land, together with the illegal dumping/discharge of waste oil, represents a substantial source of pollution to the sea from land run-off (IPIECA 2005).

Ballast waters

The uptake of ballast water is a traditional way of ensuring that a ship is perfectly balanced and stable even when unloaded. It is taken on board in one place and discharged back into the sea in another place, possibly thousands of miles away from its place of intake. This process, known as ballasting, was long thought to be environmentally innocent. However, increased understanding of intra-ecosystem dependencies has revealed that organisms living in the ballast water could prove to be harmful for the particular ecosystem they are discharged into, because of their potential to alter, *inter alia*, prevailing predator-prey relationships or structures of micro-organism communities. While discharge of ballast water has not yet been prohibited completely, regulatory efforts have been made to manage its handling and treatment adequately (Tsimplis, 2004, Kachel, 2008).

Many oil tankers clean their tanks or unload contaminated ballast water whilst at sea. Although environmental standards for these operations are quite strict, especially in MARPOL special areas, compliance rates are very low in some areas of the world (Kachel, 2008).

In order to prevent the spread of potentially harmful aquatic organisms and pathogens in ships' ballast water International Maritime Organization (IMO) adopted The Ballast Water Management Convention or BWM Convention in 2004. The BWM has two main management standards (D-1 and D-2) - ballast water exchange should be done in the open ocean (>200 miles from shore, or at least 200 m depth) and reduction of abundance of marine organisms in ballast water (maximum amount of viable organisms allowed to be discharged).

The impact of ballast water on the marine ecosystem and the diversity of species are multiple. Primarily, in coastal ecosystems, transfer of species by ships is a dominant mechanism of invasions by non-indigenous species (NIS), and has driven the observed increases in newly detected invasions over the past century (Fofonoff et al., 2009, Ruiz et al., 2000).). In European Seas, more than 1000 alien species have been identified (Werschkun *et al*., 2014). Vilà et al., (2009) have identified a list of the 100 most impacting species introduced into European waters. The transfer of invasive species not occur only over larger distances, between continents, but also as a secondary spread in regional seas (David et al., 2013). The most unwanted species that have already spread beyond the place of its natural habitats, are the bacteria of cholera, toxic algae, and some larger organisms such as the Round Goby, European Green Crab, Mitten Crab, Zebra Mussel or North Pacific Seastar (Paavola, M, 2005, Sapota). These organisms can displace native species from their own environment and became dominant component of the invaded biota, causing irreversible ecological disruptions, economic damage and species extinction.

There are currently 23 treatment systems homologated by the IMO to meet IMO-D2 standards. However, these systems cannot be applied to all ships due to great limitations of space on board and power and retrofitting capacities. In addition, the installation costs of these systems may reach $2-3 million (Pereira and Brinati, 2012). According to the IMO briefing, some delegations expressed concerns regarding the implementation of the BWM Convention due to lack of approved technologies, limited shipyard capacity, time availability and the costs involved. The International Maritime Organization (IMO) suggests that the consequence of ballast water is one of the most significant global ecological and economic risks (IMO, 2013).

Impacts of marine pollution

The impact of marine pollution on biodiversity, economics and human health depends on a number of factors. The type and intensity of pollution (marine litter, shipping, oil spills, eutrophication, etc) cause a different range of impact ranging from medium to catastrophic.

When it comes to pollution from solid waste, sewage effluents or oil spills, the impact of pollution is much greater in the coastal benthic area due to the greater diversity of species and habitats compared to the pelagic area. Sensitivity analysis suggests the biomass of large reef fish decreased by 25% to 50% in areas most affected by the spill, and biomass of large demersal fish decreased even more, by 40% to 70% (Ainsworth et al., 2018). Same study showed that recovery of high-turnover populations generally is predicted to occur within 10 years, but some slower-growing populations may take 30+ years to fully recover.

It is known that many fish species have different behaviour strategies as a result of adverse effects of the environment or pollution in order to increase the chances for survival. Research carried out on species from Engraulidae and Clupeidae families show that anchovy, pilchard and sprat (*Sprattus sprattus*) have a reproduction tactic ensuring the survival and sufficient number of surviving eggs and larvae i.e. their reproductive traits are characterised by high plasticity (Alheit, 1989). This means that their spawning tactics are based on the ability to quickly change one or more reproductive characteristics (batch fecundity, spawning frequency, age or length at first reproductive maturity) whenever environmental conditions require so (Millán, 1999). Fish eggs and larvae are typically vulnerable to toxic oil compounds due to their small size, poorly developed membranes and their position in the water column. Marine pollution causes high embryonic mortality, lethal or sub-lethal physiological effects, larvae growth reduction, brain cell damage and inability to escape predators (Booman et al. 1996).

Hydrocarbons may accumulate through direct uptake from the water by gills or skin, uptake of suspended particles or through ingestion through food. In all cases, there is potential for bio-magnification of toxins (Ainsworth et al., 2018). Extent of the harm caused by oils spills depends on: i.) the intensity of animal exposure to the source of pollution, ii.) age, health, reproductive characteristics, lifestyle, mobility and physiological state of the individual and iii.) the duration of the pollution and the manner of its removal (composition and additional influence of the substances for the removal of oil).

The biggest impact of oil spillage is certainly on species that are poorly mobile (like sea turtles and marine mammals). Sea turtles and marine mammals are usually slow-growing, late-maturing, and long-lived, and generally do not reproduce every year, making populations particularly vulnerable to declines and slow to recover when threats are reduced (Musick 1999). Oil and other chemicals on skin and body may result in skin and eye irritation, burns to mucous membranes of eyes and mouth, and increased susceptibility to infection. On the other hand, animals that are air breathers (whales, dolphins, manatees and sea turtles) must come to the surface frequently to take a breath of air, and may be exposed to volatile chemicals during inhalation, as well. Ingestion or absorption of oil may result in gastrointestinal inflammation, ulcers, bleeding, diarrhea, damage of organs such as the liver or kidney, reproductive failure or death. Influence of the pollution depends on the crude oil's composition, as it may contain benzene, toluene, xylene and polycyclic aromatic hydrocarbons (see below), all of which are highly toxic. These substances tend to bioaccumulate in fish and shellfish, as well as in sediments, posing a long-time threat to benthic organisms. Birds get coated and their feathers lose their waterproofing qualities; causing them to sink and drown.

Marine pollution by marine litter has both environmental and economic impacts and presents risks to marine life, human health and safety. The types and sizes of marine litter determine the impact and fate of these materials in the ocean (e.g. submerged, floating, within a sensitive habitat).

Floating litter may eventually sink to the seafloor, due either to an increase in weight because of absorbed water and/or the settlement of living organisms. Microplastics may also reach sediments through ingestion by filter-feeders, zooplankton and fishes; some of these reach the seafloor after their death, or become components of 'marine snow'. Plastic litter readily accumulates persistent organic pollutants (POPs) which have a greater affinity for the hydrophobic surface of plastic than for seawater (IMO, 2016b).

In addition to the aforementioned, floating litter enables the transport of certain invasive or foreign organisms, while some microorganisms might use plastic as a food source leading to biodegradation of debris (PlasticsEurope.org, 2010).

Reports revealed that all known species of sea turtles, about half of all species of marine mammals, and one-fifth of all species of sea birds were affected by entanglement or ingestion of marine debris. The frequency of impacts varied according to the type of debris; over 80 % of the impacts were associated with plastic debris while paper, glass and metal accounted for less than 2 % (GEF, 2012). Species for which the greatest number of papers exist reporting incidence of entanglement or ingestion of marine litter were *Chelonia mydas* (Green Turtle), *Eubalaena glacialis* (North Atlantic Right Whale) and *Caretta caretta* (Loggerhead Turtle).

Marine litter on beaches has been shown to affect behavior of intertidal organisms such as the gastropod *Nassarius pullus* (Aloy et al., 2011) and adversely affect the ability of turtle hatchlings to reach the sea (Ozdilek et al., 2006).

The loss of economic revenue can be substantial. Understanding the full economic significance of the impacts of marine litter still remains relatively limited, however it is well known that every year, marine litter results in tremendous economic costs and significant losses for the economic sectors involved, such as tourism and recreation, fisheries and aquaculture, maritime transport and navigation, and infrastructure and services for individuals, local communities and enterprises (Mouat et al, 2010; Leggett et al, 2014).

Vlachogianni, 2017 reported important calculations and losses in economy sector caused by marine litter. For the fisheries sector the average annual cost of marine litter per vessel reaches € 5,378 (cost of repairs of damages, loss of revenue due to the smaller catch, loss of time spent on clearing and repairing nets, etc., reported by fishermen per fishing vessel per year), an amount much higher than the one reported for EU vessels. On average, the annual direct and indirect marine litter related costs for the aquaculture sector were assessed to be € 3,228 per aquaculture farm unit. The total annual cost of managing marine litter reported by 38 harbours and marinas in the Adriatic-Ionian macroregion was € 323,550 with an average annual cost of € 8,518 per harbour. The average annual amount per tourism related business of varying size and type was calculated to be € 5,685 per year, which can be considered as a substantial expense. The total cost of removing beach litter reported by the 32 municipalities was € 6,724,530 per year, with an average of € 216,920 per year per municipality. On average, the municipalities spent some 5% of their budget for marine litter cleanup operations.

Marine pollution in the Adriatic Sea

The Adriatic Sea is a semi-enclosed basin with poor seawater flows and a long retaining of water masses, making it vulnerable and highly sensitive to persistent pollution, especially when it comes to plastic waste. Tourism, as a strategic sector of the eastern Adriatic coast (Albania, Montenegro, Croatia) is based on the purity of Adriatic Sea.

The coastal population around the Adriatic basin is more than 3.5 million people; the largest cities are Bari, Venice, Trieste and Split. Fisheries and tourism are the two most important sources of income. In 2000 the total landings of fisheries for the whole basin reached 110,000 tons (Mannini et al., 2012). The increased concentration of population and the intensive economic activities, combined with the riverine inputs from large drainage basins (such as the Po), have led to a deterioration of the marine environment of the Adriatic Sea.

The global growth of cruise tourism has brought increasing concern for the pollution of the marine environment. Marine pollution from sanitary wastewater is a problem especially pronounced on large cruise ships where the number of people on board may exceed 8,000 (Perić *et al.*, 2016). The United Nations Environment Programme (UNEP) has identified tourist ships as one of the principal pollution sources of marine ecosystems (Allsopp et al., 2005).

Estimations of waste from cruise ships vary from 2.6 to 3.5 kg/person/day (USEPA, 2008) and is managed in accordance to MARPOL. In addition to solid waste, air pollution from marine diesel engines is another threat to marine environment, biodiversity and human health. Marine diesel engines use heavy fuel oils containing large concentrations of sulphur and ash forming metals (Agrawal et al., 2010). Within the Mediterranean, cruise and passenger ship CO2 emissions are estimated to be up to 10% of all ship emissions (Faber et al., 2009). This makes the cruising the highest CO2 contributor in tourism (Amelung and Lamers, 2007).

The Adriatic Sea is crossed by important oil transport routes from the Otranto Strait to the north Adriatic ports (Trieste, Venice, Omišalj and Koper), transporting around 58 x 106 t of oil annually (Lončar and Maradin, 2009; MZOPU 2010). International shipping activity is increasing because of important industrial centers, especially in Italy. Some of these are also transit ports for Central Europe (Trieste, Venice, Koper and Rijeka), and some new transit ports are gaining significance such as Ploče, Bar and Vlorë. Joint study performed by the Joint Research Centre (JRC, 2006) reported for the Adriatic Sea a total of 257 ship-made oil spills in 1999, 263 in 2000, 184 in 2001 and 244 in 2002, with the number of detected oil spills in Croatian waters ranging from 24 to 68 (Morović and Ivanov, 2011). The released ballast waters in the Adriatic is estimated to be 8 106 t in 2003 (Krstulović et al., 2004; MZOPU, 2010), 80% of which was discharged in the Italian Adriatic ports, while the rest is shared between Koper (Slovenia) and the Croatian ports (Morović and Ivanov, 2011). There are several papers published recently related to potential risk of aquatic organisms via ballast water, with detailed list of HAOP species found in Adriatic ports (Mozetič et al., 2017, Cabrini et al., 2018, David and Gollasch, 2018, Romanelli et al., 2018).

It is estimated that total water exchange through the straits of Otranto can take between one to five years (Cushman-Roisin et al., 2001; Leksikografski institute, 1979). It is highly influenced by the surrounding landmass and riverine input, particularly the river Po which drains the industrial centres of Milan and Turin and is considered to be one of the most endangered regions of the Mediterranean (Horvat et al., 1999). Therefore, each type of sea pollution in the Adriatic has specific consequences and lifetime, which, depending on its characteristics and sources, in some cases can cause irreversible consequences.

Pollution of Adriatic and Ionian seas, as a consequence of marine litter was analyzed in detailed through DEFISHGEAR –EU funded project. Assessment showed that average beach litter density is i 0.67 items/m^2 (average: 658 items/ 100m; range: 219-2914 items/100m); average density of floating macro-litter (items > 2.5 cm) in coastal Adriatic waters obtained by small-scale vessels was found to be 332 ± 749 items/km^2; average seafloor litter density found at regional level by bottom trawl surveys was 510 ± 517 items/km^2 (range: 79-1099 items/km^2) and 65 ± 322 kg/km^2 (range: 3-339 kg/km^2) (Vlachogianni et al., 2017).

Monitoring activities of floating litter in Adriatic and Ionian seas showed that the abundance of macroplastics in the enclosed gulfs (Kotor, Split, Trieste, Venice) of the Adriatic Sea shows some increasing trend in parallel to the population density, albeit not significant; nor is it higher than the macroplastics abundance observed in offshore waters. Possible explanations are considered the sea-based sources of macro plastics as well as the different buoyancy features of various macroplastic items most probably related to their polymer types and shape. With the exception of fisheries, no other apparent sea-based source of floating plastics could be discerned. In addition, macroplastics' compositional differences between inshore and offshore waters infer that items' properties (polymer type and shape) are also important in determining their distribution. (Zeri et al., 2018).

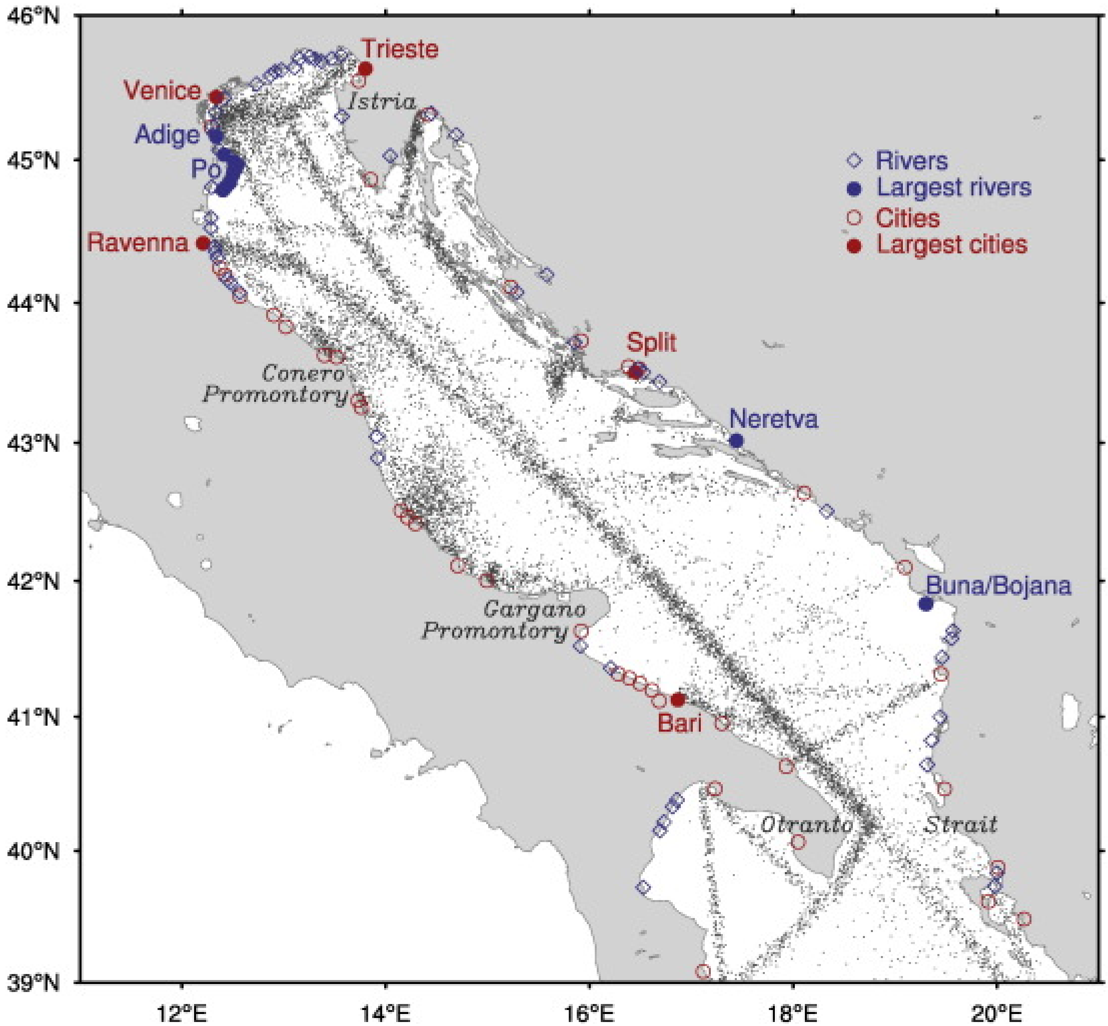

Figure 2. Spatial distribution of the floating debris inputs into the Adriatic Basin: shipping lanes (gray scatter plot); rivers (open blue diamonds), the largest rivers (closed blue circles); cities (open red circles); and the largest cities (closed red circles). Source: Liubartseva et al, 2016.

It is important to note that there is no specific national legislation or directives relating to marine litter in the region of Adriatic Sea. Of course, there are general legal regulations and by-laws relating mainly to waste management as well as on port waste. Marine waste goes beyond national borders, so it is obvious that a coordinated response is needed to address the marine waste issue of each country in the Adriatic and its coastal zone. Collaboration with partner countries will affect the exchange of ideas, experiences, techniques and knowledge, creating a favorable environment for future cooperation and joint activities in the Adriatic.

Conclusions and recommendation

Very extensive sources of pollution, types and characteristics of pollutants, the range of impacts to marine environment and humans, causes the whole range of measures and recommendations with the aim of reducing additional environmental pressures.

In addition to respecting of international conventions and implementation of best practices in the field of waste reduction, preventive measures in reducing the risk of oil spills, action at local level is of greatest importance. One of the proposed measures is the persistent training of young people and general population, referring to risks of marine pollution to human health and the environment; media support in promoting the preservation of the sea and the ocean as the basis for a healthy and sustainable future. Also, since in many countries there is no legal framework that recognizes specific types of pollution (such as marine litter pollution), the impact on decision-makers and authorities is crucial to seriously and safely addressing pollution issues.

Since marine pollution doesn't recognize the territorial boundaries, in addition to the importance of reduction of local factors of marine pollution, international cooperation and contribution to the international framework and data sharing have been recognized as an indispensable measure in resolving marine pollution issues.

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