

Επιστημονικά Θέματα και Ανακοινώσεις

**Μικροπλαστικά στο Θαλάσσιο Περιβάλλον
Περιβαλλοντική Απειλή με Επιπτώσεις στους Ωκεανούς και
στους Θαλάσσιους Οργανισμούς**

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Περίληψη :

Η παγκόσμια παραγωγή πολυμερών και πλαστικών προϊόντων καθημερινής χρήσης ήταν στα 280 εκατομμύρια τόνους το 2012. Η χρησιμοποίηση πλαστικών έχει μεταβάλλει σημαντικά την ποιότητα της ζωής του ανθρώπου και υπάρχουν αναρίθμητα προϊόντα και υλικά με μεγάλο φάσμα εφαρμογών. Τις τελευταίες δεκαετίες όμως αυξήθηκε δραματικά το ποσοστό πλαστικών στα αστικά και βιομηχανικά απόβλητα που κατακλύζουν το περιβάλλον. Σήμερα, εκατομμύρια τόνοι πλαστικών, απορρίπτονται μετά τη χρήση τους και ρυπαίνουν το έδαφος, τα υδάτινα συστήματα και τους ωκεανούς. Στατιστικές δείχνουν ότι μόνο το 30-50% των πλαστικών αποβλήτων ανακυκλώνεται. Η υψηλή ανθεκτικότητα των πλαστικών έχει ως αποτέλεσμα να διατηρούνται επί χρόνια και με αργό ρυθμό θρυμματίζονται σε μικρότερα κομμάτια, τα μικροπλαστικά (0.1-5 mm, microplastics) που ρυπαίνουν τις παραθαλάσσιες ακτές, τα ποτάμια, τις λίμνες και τις θάλασσες. Τα μικροπλαστικά είναι μικροσκοπικές ίνες ή σωματίδια από πλαστική ύλη, που με τον κυματισμό της θάλασσας και τα ωκεάνια ρεύματα διασκορπίζονται σε όλες τις περιοχές του πλανήτη.



Τα μικροπλαστικά λόγω του πολύ μικρού μεγέθους τους αποτελούν τους κύριους ρύπους των θαλασσών και εισχωρούν μέσω της διατροφής στους θαλάσσιους οργανισμούς ή με κατάπωση συσσωρεύονται στα στομάχια των θαλάσσιων πτηνών και άλλων θαλάσσιων ζώων. Η Μεσόγειος θεωρείται ότι δέχεται τη μεγαλύτερη ρύπανση από πλαστικά, σε σύγκριση με άλλες θάλασσες παγκοσμίως. Αναλύσεις σε ψάρια και θαλάσσιους οργανισμούς έδειξαν ότι περιέχουν μικροπλαστικές ίνες στο στομάχι τους και στους βιολογικούς ιστούς τους, γεγονός που επιβεβαιώνει ότι τα μικροπλαστικά σωματίδια εισέρχονται στην διατροφική αλυσίδα και τα οικοσυστήματα. Στην επισκόπηση αυτή εξετάζονται οι πολύπλευρες διαστάσεις της ρύπανσης του περιβάλλοντος από πολυμερή υλικά και ιδιαίτερα μικροπλαστικά, την απειλή στους θαλάσσιους οργανισμούς αλλά και στην υγεία του ανθρώπου. Επίσης, η επισκόπηση εξετάζει τις διεθνείς περιβαλλοντικές δράσεις και προγράμματα Θαλάσσιας Στρατηγικής της προστασίας και διαχείρισης του θαλάσσιου περιβάλλοντος στην Ευρωπαϊκή Ένωση. Ιδιαίτερα, τον περιορισμό της ρύπανσης των πλαστικών, της ανακύκλωσης των απορριμμάτων και την επιμόρφωση πληθυσμών ώστε να μειωθούν οι περιβαλλοντικοί κίνδυνοι στο μέλλον από τα πλαστικά και ιδιαίτερα τα μικροπλαστικά.

Πλήρες κείμενο της εργασίας στα αγγλικά [34 σελίδες]: αρχείο PDF, 4.7 MB

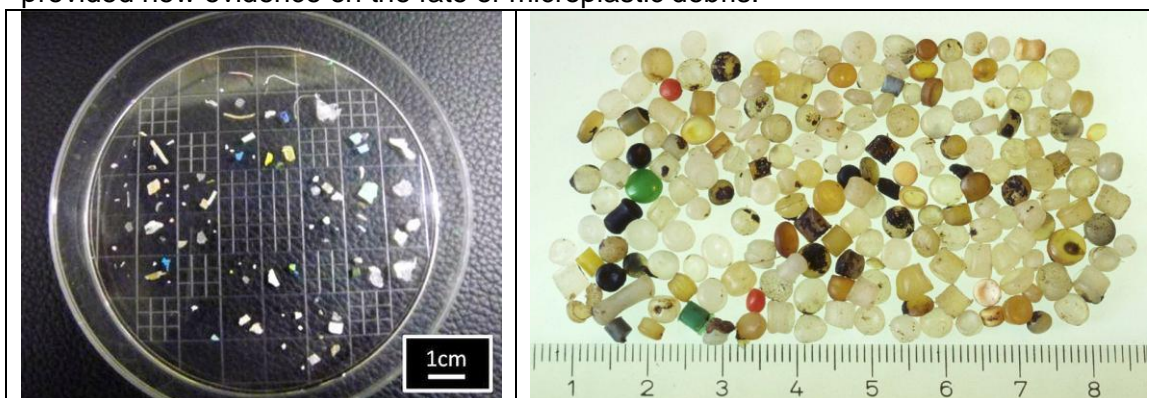
MICROPLASTICS IN THE MARINE ENVIRONMENT : UBIQUITOUS AND PERSISTENT POLLUTION PROBLEM IN THE WORLD'S OCEANS THREATENING MARINE BIOTA

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Abstract

Global polymer production in 2012 reached 280 Mtons. Although plastics can be recycled efficiently the majority of disposable plastic items have become a great source of environmental pollution. Limited and inappropriate waste management practices of plastics and irresponsible human behaviour increased the burden of municipal waste with single use plastics (bottles, cups, wrapping, etc) which pollute especially the marine environment. Studies showed that 80% of plastic waste in the regional seas and oceans is from land-based sources. An emerging environmental problem in the marine environment has been the increase of microplastics because of slow degradation of polymeric materials. Recent field and laboratory experiments as well as analytical monitoring in the marine environment and in marine species provided new evidence on the fate of microplastic debris.



This extensive review provides scientific evidence for sources, distribution and fate of plastic pollution of the marine environment and the emerging threat of microplastics (0.1-5 mm). Microplastics are found to every level of the food web, from primary producers (microalgae) to higher trophic-level organisms. The ingestion of microplastics has been documented by many scientific studies for vertebrate and invertebrate marine species. As top predators, seabirds are considered sentinels of the state of marine environmental pollution by plastics, since large quantities are found in their stomachs. Microplastics are part of the overall marine litter issue, which is attracting attention not only from national and international authorities, but also from NGOs, the media, scientists, consumers, the plastics industry and others. Environmental plastic waste and microplastics are important factors in the EU Marine Strategy Framework Directive. This review presents selected national and international efforts and environmental programmes dealing with marine waste pollution and the emerging threat of microplastics pollution

Keywords : Marine pollution; Marine litter; plastic pollution; microplastics; marine biota; seabirds; persistent chemical pollutants

1. Introduction: Polymer Technology and Modern Life

In the last decades polymer technology and the production of countless plastic items have moulded the activities of modern human civilization and transformed the quality of life for most humans. Plastics are employed in myriad applications where they actually conserve natural resources. There is no human activity where plastics do not play a key role from clothing to shelter, from food to cosmetics and pharmaceuticals, from transportation to communication and from entertainment to health care. Plastic items have amazing properties, they are lightweight, high strength, flexible, transparent and easy of processing into any shape.

World production of polymers has reached 288 million metric tons (Mtons) per year in 2012. The countries or regions with the highest production of polymer products in 2012 was China (23.9%), Europe (20.4%), USA +NAFTA (20%), Rest of Asia (16%), Middle East +Africa (7%) and Latin America (5%).^{1,2}

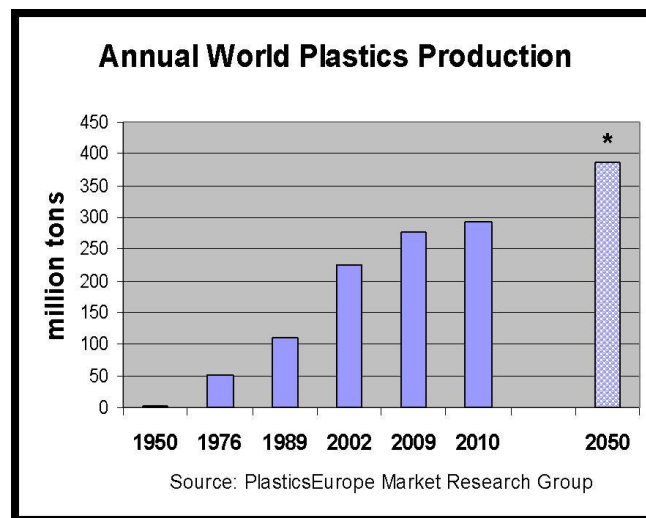


Figure 1. Annual world plastics production grew four times from 1989 to 288 Mtons in 2010 and edging to 400 Mtons by 2050.

[<http://www.plasticsnews.com/article/20120830> , accessed 29.4.2014]

In 2012 European countries produced 45.9 Mt of polymer materials subdivided into the main categories: 40 % packaging, 22% appliances, furniture, sport, health etc, 20% building and construction, 8% automobile, 5% electrical and electronic equipment. The great variety of polymers, their excellent properties, low price and versatility lead to the growth of single-use disposable plastics. This was the result of direct outgrowth of chemical industries developed during World War II and quickly polymer items became symbolic of the convenience of modern day living. Although plastics can be recycled quite efficiently the majority of disposable plastic items have become a great source of environmental pollution all over the world.^{3,4} Plastic bags, bottles, utensils, cups, fishing nets and so many others are polluting soil, rivers, lakes, regional seas and oceans. Plastic pollution is having a significant environmental impact particularly on marine life and coastlines.⁵⁻⁷

According to the European Association of Plastics Manufacturers, world plastics production is increasing by 3-4% every year. The types of polymers mostly produced included thermoplastics, polyurethanes, thermosets, elastomers, adhesives, coatings, sealants and PP-fibres. The most important classes of plastics that are commonly encountered in the marine environment are.^{8,9}

a) Low-density polyethylene (LDPE LLDPE) Plastic bags, six-pack rings, bottles, netting, drinking straws, b) High-density polyethylene (HDPE) Milk and juice jugs, c) Polypropylene (PP) Rope, bottle caps, netting, d) Polystyrene (PS) Plastic utensils, food containers, e) Foamed Polystyrene, and polyurethanes (PU) Floats, bait boxes, foam cups, furniture foam, Polyacrylonitrile (PAN), (C₃H₃N)_n Fibres, sails for yachts, g) Nylon (PA) Netting, fibres and traps, h) Thermoplastic Polyester (PET) Plastic beverage bottles, i) Poly(vinyl chloride) (PVC) Plastic film, pipes bottles, cups, j) Cellulose Acetate (CA), Cigarette filters.

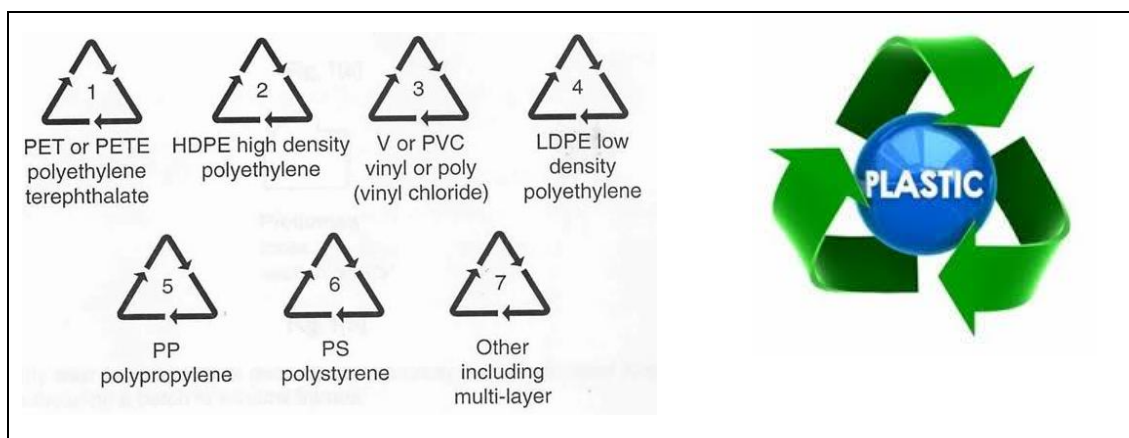


Figure 2. All types of polymers have resin codes by international legislation on every consumer item (food packaging, toys, clothes, etc). Compared with other materials (wood, glass and metals) plastic polymers can be recycled.

Europe's waste plastics is estimated to increase from 24.9 million tonnes (Mt) to 30.6 Mtons (2012-2015). Recycling of plastics and energy production in European countries (EU 27 states plus Norway and Switzerland) is approaching 60%. In 2012, 26 % of plastics were recycled, 35% were used for energy recovery (burning waste for electricity or converting non-recycled plastic waste into synthetic gas or fuel oil) and 38% was going for landfill disposal. In some countries (Germany, Austria, Switzerland, etc) there is a ban on plastics landfill disposal. European Union countries aim at zero plastics landfill by 2020.¹⁰

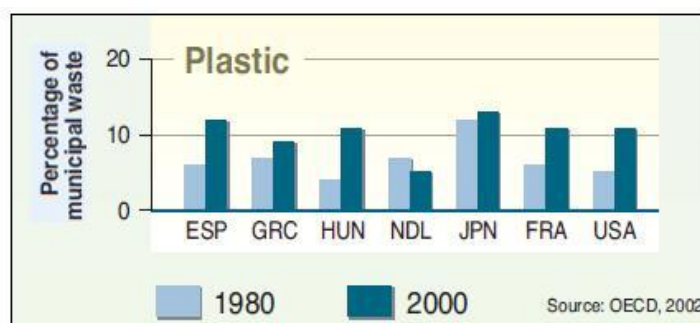
According to Environmental Protection Agency (EPA), in 2012 the U.S produced 32 Mtons of plastic waste representing 13% of the total Municipal Solid Waste (MSW). But, only 9 % of the total plastic waste generated in 2012 was recovered for recycling. Of all these plastic waste, 14 Mt were containers and packaging items, about 11 Mt durable goods (automobiles, furniture, equipment, electrical appliances, etc, these materials are counted separately from MSW), and almost 7 million tons as nondurable goods (plates, cups,

etc). Plastic bags, sacks, and wraps are items that are recycled at about 12%. It is estimated that 1,800 U.S. businesses handle or reclaim post-consumer plastics. Plastic packaging is preferable because is more lightweight than its alternatives (glass, paper or metal) and require less fuel to transport.¹¹



Figure 3. Plastics recycling technology currently involves a great number of industries and a huge investment in developed countries. Recycling bottles from PET and HDPE has become a highly profitable business.

In the last decade there is a new trend of global trade in recycling waste plastics. Exported waste plastic is a valuable commodity. The export trade is driven by a strong market demand for secondary material, not by an intent to dump waste. Most of the demand for waste plastics now comes from emerging economies in Asia (especially China). The lower labour and energy costs (compared to the industrial countries) provides a competitive advantage to reprocessors and manufacturers in Asia. China absorbs the majority (over 70%) of globally traded recovered plastics. China's declared imports of recovered plastic have increased at 500kt-1000kt per year over recent years (for less than 5 million tonnes in 2005). China's major markets for plastic waste are Europe, North America and Japan.¹² The European Union Statistical Office (2011) reported exports of around 3.36 million tonnes (Mt) of "waste, parings and scrap of plastic" to destinations outside the EU, mainly to East Asia countries. 87% of plastic waste destined to China and Hong Kong, and the rest for India and Malaysia. The majority of plastic for recycling consisted of polyethylene (1.6 Mt).¹³



*Spain, Greece, Hungary, Netherlands, Japan, France, United States of America
Figure 4: Increased Plastic Percentage within the Municipal Waste in selected OECD Countries [<http://www.unep.org/ietc/ourwork/wastemanagement/projects/wasteplasticsproject/tabid/79203/default.aspx> , accessed 19.5.2014]

Municipal Solid Waste (MSW) tends to be generated in much higher quantities in wealthier regions of the world. Members of the Organisation for Economic Co-operation and Development (OECD), a group of 34 industrialized nations, lead the world in MSW generation, at nearly 1.6 Mtons per day. The list of top 10 MSW-generating countries includes four developing nations (Brazil, China, India, and Mexico) in part because of the size of their urban populations and adopting high-consumption lifestyles. The USA with its highly developed and consumer society leads the world with 621,000 tons MSW per day and China close second, at some 521,000 tons/day. Approximately, 25% of the world's MSW is diverted to recycling, composting, digestion, which are waste management options environmentally superior to landfills and incineration. Recycling rates vary widely by country, the USA recycled, approximately, 34% in 2010, and similar increases have been seen in other countries, especially industrial ones.¹⁴ The growing interest in MSW recovery is the result of national and international regulations and of markets for post-consumer materials. The global market for scrap metal and paper is at least \$30 billion per year, according to the World Bank. The UN Environment Programme (UNEP) estimates the market for waste management, from collection through recycling, to be some \$400 billion worldwide. Yet UNEP also estimates that to "green" the waste sector would require, among other things, a 3.5-fold increase in MSW recycling at the global level.¹⁵ Municipal Waste Management in all developed countries has become a worldwide issue for environmental sustainability.¹⁶⁻¹⁸

2. Environmental Pollution by Persistent Plastic Materials

The increasing applications of polymers in everyday products inevitably resulted in the widespread presence of plastic waste in the natural environment. Plastics in the last decade represent 50-60% of municipal solid waste (MSW), 30-40% of industrial waste and between 15- 25% of all hospital waste in developed countries.¹⁷ Plastic bags is one example of massive throw away items that pollute the environment and especially oceans. Total number of plastic bags used worldwide annually is 1 trillion. Total number of plastic bags in China every year 3 billion. (<http://www.statisticbrain.com/plastic-bag-statistics/>). It is estimated that 80% is used in North America and Europe. Only in the US it is estimated that 100 billion grocery bags are thrown away. Also, in the US, the total number of plastic water bottles sold annually are 30

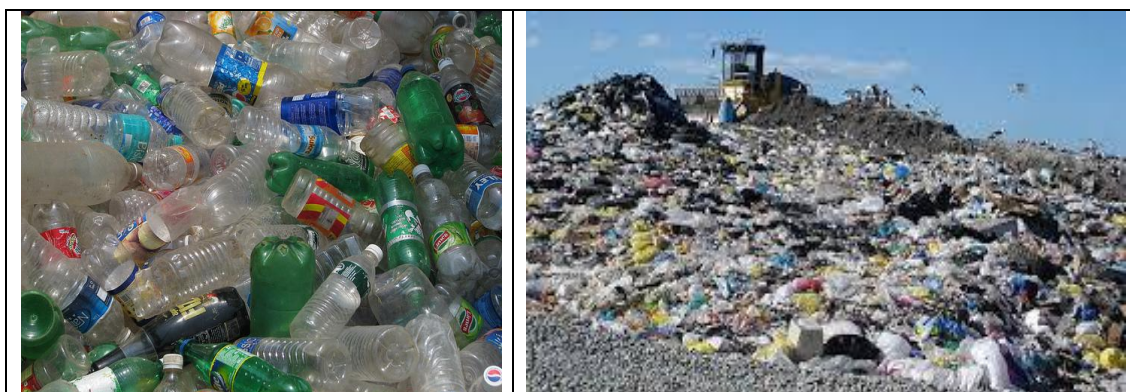


Figure 5. 80% of plastic bottles, packaging, fishing nets and other plastic materials reach the marine environment from land-based sources.

Biodegradable plastics are also an option that should be considered. Biodegradable plastic is one in which the “degradation results from the action of naturally occurring microorganisms such as bacteria, fungi, and algae,” whereas a compostable plastic “undergoes degradation by biological processes during composting to yield carbon dioxide, water, inorganic compounds, and biomass at a rate consistent with other known compostable materials and leaves no visible, distinguishable, or toxic residue” Although conventional plastics are not biodegradable, there is increasing trend for manufacturing new plastics which can biodegrade when exposed to landfill conditions and, such as polyhydroxylalkanoate (PHA) and polylactic acid (PLA) based plastics. However, they are not yet the perfect solution to disposable plastics. Most bioplastics today are derived from plant sources such as corn and molasses, thereby representing a competition for the food supply of humans and farm animals. Not figuring in the various externalities from environmental pollution and human health effects, biodegradable plastics currently are more expensive than conventional plastics. However, as oil prices rise and technologies to produce biodegradable plastics advance, this may change in the near future.^{19,20}

3. Marine Pollution by Plastics

In the last decades, limited or/inappropriate waste management practices and irresponsible human behaviour in throwing rubbish resulted in large masses of single use plastics released into the natural environment. Inevitably the majority of these non-degradable and persistent solid plastics have entered the marine environment and the world’s oceans. Another important finding of the last decade is that most plastic debris in the marine environment originated from the ocean-based fishing industry (plastic nets and other fishing equipments). Also, marine tourism and large numbers of holiday facilities in coastal areas produce massive numbers of plastic waste. These plastic debris accumulate in the ocean surface, on the seabed and in coastal recreation areas. Plastics are heavier than sea water and inevitably 70% are known to eventually sink accumulating in the seabed sediments.²¹



Figure 6. Land-based sources and the fishing industry are responsible for most of plastic debris at the sea [<http://www.plasticgarbageproject.org/>]

Although most of the plastic materials are persistent and do not biodegrade easily, under the influence of solar UV radiations, high temperature, wave and air friction, do degrade and fragment into small particles, termed microplastics. Our oceans eventually serve as a sink for these small plastic particles and in one estimate, it is thought that 200,000 microplastics per km² of the ocean's surface commonly exist.²²



Figure 7. Fishing nets and other plastic items pollute the marine environment.. *Marine debris collection at the GGP.* Photo: Lindsey Hoshaw [Great Pacific Garbage Patch, http://plastic-pollution.org]

Plastic pollution may enter river, lakes, regional seas and eventually oceans through drainage systems, sewage treatment overflow during high-volume rain events.^{23,24} The polymers can be degraded into microplastics in the water but also may form on land by UV degradation and fragmentation or road abrasion of larger plastic items through damage by vehicles and transport along concrete pathways.²⁵ PE and PP microbeads, used in many consumer facial cleansers, have been identified as potential contributors to marine pollution.²⁶ Textile laundering facilities are also potential sources of

microplastic fibers and particles from sandblasting media have been suspected to pollute the marine environment.^{23, 27}

In 1972 Carpentered and co-workers were the first researchers to become alarmed by the polymer marine litter in coastal water and the implications for marine biota. They observed that polystyrene (PS) spherules averaging 0.5 mm diameter (range 0.1-2 mm) were abundant in the coastal waters of southern New England. The PS spherules have bacteria on their surfaces and contained PCBs, apparently absorbed from ambient seawater, in a concentration of 5 ppm. Also, they suggested that ingestion of the microplastic particles may lead to intestinal blockage in smaller fish.²⁸

Marine mammals are among those species that are most affected by entanglement in plastic debris. Also, marine birds suffer the most from ingestion of plastics. Organisms can also be seriously absorbed by floating plastic debris, or the contaminants may derive from plastic additives that are leached to the environment. Recent studies emphasize the important role of microplastics as they are easily ingestible by marine organisms, such as plankton species, and form a pathway for contaminants to enter the food web. Toxic chemical leached from plastics tend to bioaccumulate in those organisms that absorb them, and chemical concentrations are often higher at higher trophic levels. This causes a threat to the basis of every food web and can have serious and far-reaching effects, even on non-marine species such as polar bears and humans, who consume marine-grown food.²⁹

Microplastics is the dominant type of anthropogenic pollution, ubiquitous and persistent pollutants in the marine environment. A recent study investigated the presence of plastic pollution in the Laurentian Great Lakes ecosystem. Sample counts varying from 0 to over 450,000 plastic particles per km². Based on dense urban populations adjacent to the lakes that employ combined sewage overflow, and the convergence of lake currents near sample sites. Microplastic spheres may be microbeads used in consumer product applications, such as those used in facial cleansers.³⁰

Another recent review (2014) examined more than 100 peer-reviewed studies investigating microplastic pollution in plankton samples, sandy and muddy sediments, vertebrate and invertebrate ingestion, and as marine chemical pollutants. A series of other papers have investigated polymer litter at sea, especially their slow decay at sea and their ingestion by marine species. Fibres accounted for 75% of particles on average, although near shore samples had more fibre content than offshore. While elevated microplastic concentrations near urban areas are consistent with land-based sources, the high levels in a certain point appeared to be the result of oceanographic conditions that trap and concentrate debris.³¹

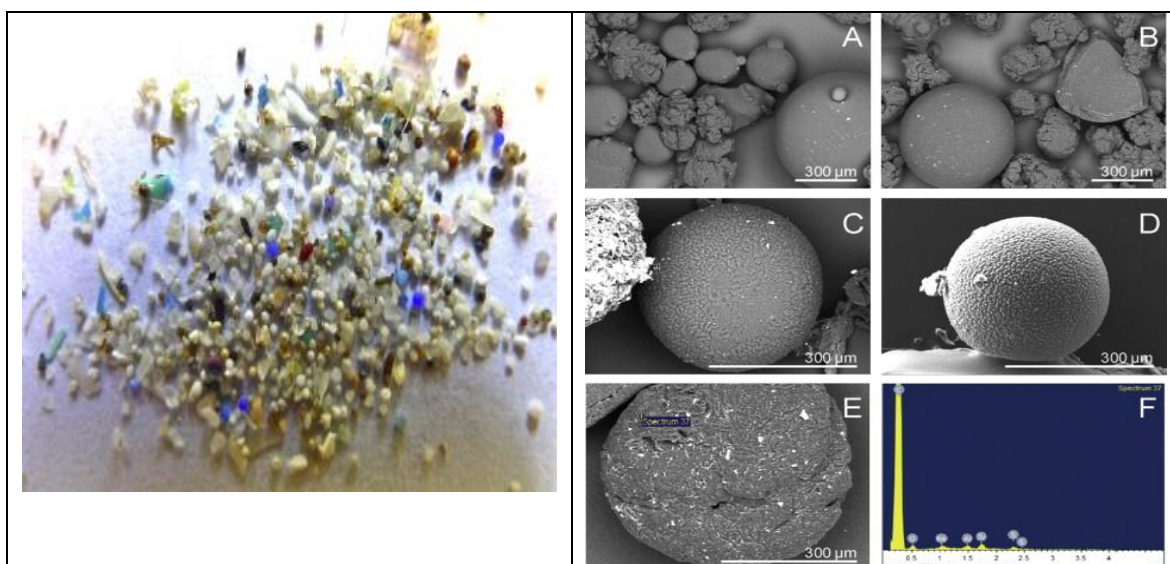


Figure 8. Microplastics. (Left) Particles with color variations, size <1 mm collected in Great Lakes. Right (A). SEM image containing PE microbeads, (B) PE microbeads, (C & D) SEM image of spherical fragments after HCl wash. (E) SEM image of blue spherical fragments. (F) Elemental analysis (fragment E) showing polymeric material.

4. Degradation of Polymers into Microplastic in the Marine Environment

Marine plastic pollution is widespread as a result of the increasing MSW that is thrown away every year. Larger plastics eventually undergo some form of degradation and subsequent fragmentation leads to the formation of small plastic pieces. The most-used polymer types polyethylene and polypropylene although non-biodegradable, once in the marine environment, they start to break down by photo-oxidative degradation (UV solar radiation and oxygen), followed by thermal and/or chemical degradation. The light-induced oxidation which breaks the covalent C—C bonds is orders of magnitude higher than other types of degradation that weakens the plastic material. Oxygen, ozone, nitrogen oxides and other oxidative chemical species, through free radical mechanism, continue the fragmentation (cracking and debonding) of polymer chains.^{32,33}

In the last phase degraded plastics become brittle enough to fall apart into powdery fragments due to the friction caused by sea waves, the winds and the high temperature. Further, plastic particles are susceptible to microbial action in the marine environment which extent its biodegradation. The longevity of plastic is estimated to be hundreds to thousands of years, but is likely to be far longer in deep sea and non-surface polar environments.³⁴

Another aspect of plastic debris and microplastic pollution in the marine environment is the adsorption of persistent chemical pollutants into their pores. Hydrophobic chemical pollutants in seawater may adsorb onto plastic debris and especially by microplastics which have high surface areas. Studies showed that microplastics have accumulated in marine regions and in oceans

and sediments worldwide with maximum concentrations reaching 100.000 particles per cubic meter.³⁵⁻³⁷ The majority of these pollutants are persistent, and have high toxic potential. Some plastic debris acts as a source of toxic chemicals: (added during manufacturing) and leaching in the marine environment. Plastics also act as a sink for toxic chemicals. Plastic absorbs persistent substances, such as polychlorinated biphenyls (PCBs) and dioxins, from the water or sediment and is leached when is ingested by a great variety of marine species.³⁸

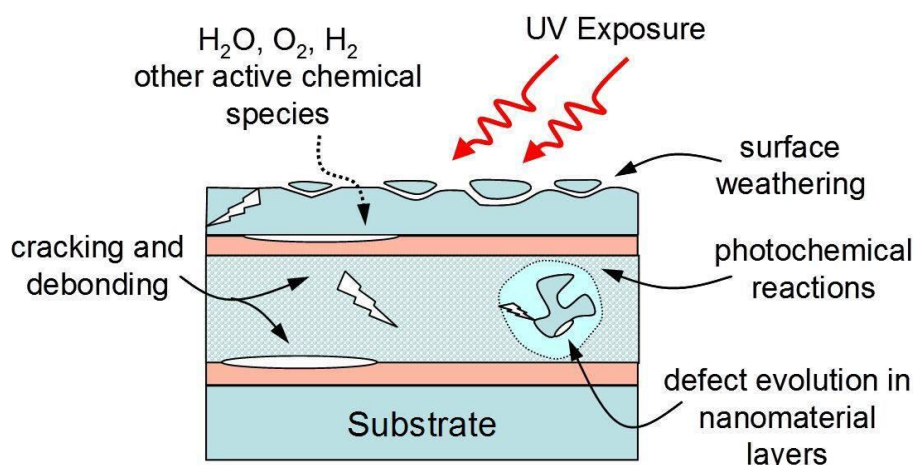


Figure 9. Degradation of structures containing polymer-oxide interfaces in outdoor environments [<http://dauskardt.stanford.edu/people/sisaacson.html>]

Plastics spherules have the potential to absorb on their surface and transport chemical pollutants and in this way can act as vehicles to transfer chemical pollutants into the tissues of marine biota. Japanese scientists analysed abdominal adipose of oceanic seabirds (short-tailed shearwaters, *Puffinus tenuirostris*) collected in northern North Pacific Ocean. They detected polybrominated diphenyl ethers (PBDEs) which are not present in the natural prey (pelagic fish) of the birds, but were present in plastic found in their stomachs. The finding suggests the transfer of plastic-derived (absorbed) chemicals from ingested plastics to the tissues of marine-based organisms.³⁹

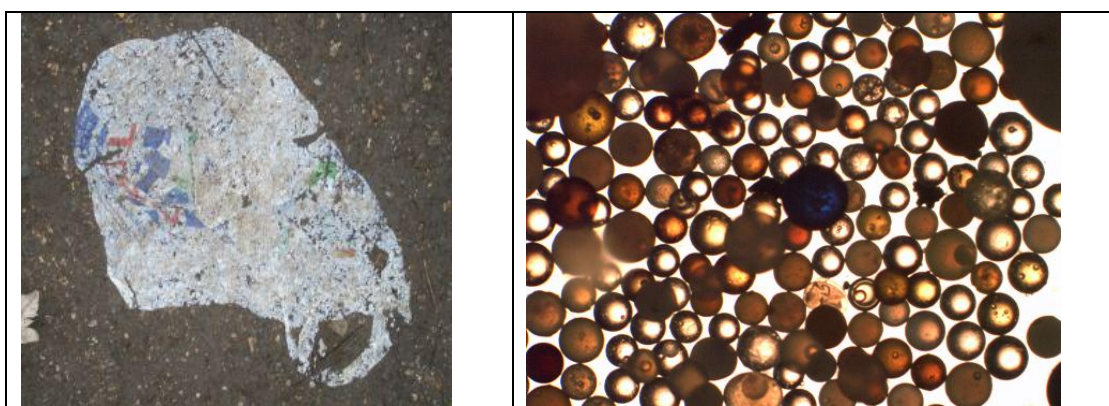


Figure 10. Biodegradation of PE bags from fermented corn starch, cane sugar and wheat starch [<http://workjournal.archipelago.gr/?=1607>]. Microplastics spherules pollute the marine environment.

Most of the degraded plastic become a source of microplastics released to the environment in the form of small size pellets (their size is >5 mm, or in μm , 10^{-6} m). Researchers studied the example of facial cleansers, toothpaste and hand cleansers (tiny exfoliating beads) that are used by millions of people for cosmetic and cleansing purposes. Contain small size plastics. These cleansers contain PS or PE particles (in μm size) that directly enter sewage systems and are found mainly as solid waste in the coastal environment. These bits plastic are too small to be caught by wastewater treatment plants after they wash down the drain and instead end up in the ocean, where they may become a hazard to marine life.^{40,41}

5. Microplastics in Surface Seawater and in Marine Species. Plankton samples and floating microplastics

The small size of microplastics inevitably contribute to spreading tiny particles in the various environmental compartments. Microplastics are found to every level of the food web, from primary producers (microalgae) to higher trophic-level organisms (such as marine invertebrates). The small size of microplastics (0.1-5 mm) plays a vital part to be ingested by low trophic fauna, with uncertain consequences for the health of the organism (internal abrasion, blockage of vital organs, etc).^{42,43}

A study of microplastics took place in 40 stations of NW Mediterranean Sea. Sampling focused on the surface seawater layer (called neustonic) where microscopic zooplankton organisms inhabit. The study observed high concentrations of microplastic particles (size 0.3–5 mm) of various compositions: (filaments, polystyrene, thin plastic films). The average ratio between microplastics and mesozooplankton weights was 0.5 for the whole survey. Scientists suggested that the high concentration of microplastics might induce a potential confusion for zooplankton feeders.⁴⁴

The initial evidence in the 1970s of synthetic microplastic fibres were reported in membrane-filtered water samples from the marine environment. In the last decades scientists have used surface plankton samples to diagnose the presence of floating plastics in pelagic areas⁴⁵⁻⁴⁸ Furthermore, these samples indicated a significant increase in the abundance of microplastics (mainly fibrous and 20 μm in length) during the periods 1960–1970s and 1980–1990s.⁴⁹

Numerous surveys were taken place in the North Atlantic Ocean and Caribbean Sea for pelagic plastic debris and microplastics. More than 80% of samples collected (surface tows) plastic particles smaller than 10 mm. Analysis of these plastics showed that were less dense than seawater and the majority were polyethylene and polypropylene pellets.^{50,51} Microplastics were observed also in the isolated archipelago of the Equatorial Atlantic Ocean. Most plastic items had secondary sources and were fragments, threads and rubber crumbs. Microplastics accumulate near (<100 m) of the seamount. Researchers suggested that plastic items can be autochthonous or transported over large oceanic distances and one probable source was the small but persistent fishing fleets using this area.⁵² From the extensive data on surface net tows in North Atlantic Ocean during the period 1991-2007 (18.000 net tows), the pelagic microplastics were investigated in more details. The

sizes of 2-6 mm were in the 60% of the microplastic samples.⁵³ Surface seawater (neustonic) samples were collected at 48 sites in the South Pacific subtropical gyre (in March 2011). The results show an increase in surface abundance of plastic pollution with the average abundance and mass was 26,898 particles per km² and 70.96 g.km⁻², respectively. Almost 90% of the plastic pollution was found in the middle third of the samples with the highest value of 396,342 particles per km² occurring near the centre of the predicted accumulation zone.⁵⁴

Samples collected in surface seawater in the Mediterranean Sea indicated that it is also threatened by microplastic pollution. Studies in 2010 showed that 90% of the samples contained plastic debris (sizes 0.3-5 mm), which were mostly fibres, polystyrene fragments and plastic films. Microplastics concentrations increased 5 times before a strong wind event than after, suggesting that wind stress might redistribute plastics in the upper layers of the water column and prevent them from being sampled by the surface tows. An average concentration of 0.116 particles/m² was observed.⁵⁵ Another survey for microplastics in the Mediterranean Sea collected 41 samples (Sept. 2011-Aug. 2012, Gulf of Lion, Eastern Spanish coast, Balearic Islands, Sardinia, Corsica). Sample collection was performed using a surface net tow of 330 µm mesh size. The concentrations of micro-plastic debris (0.33-5 mm) were measured in term of particles number and particles mass per surface unit. The average values of micro-plastics measured were 130,000 parts/km² and 58,000 mg/km² respectively. A qualitative analysis revealed the presence of fragments (77% in mass), thin films (13%), foams (7%), pellets (2%) and lines (2%). The average concentrations of meso-plastic debris (5-50 mm) reached the number of 5,500 parts/km² and the mass of 120,000 mg/km², mostly fragments (57%) and thin films (34%). The results revealed that plastic debris are widely distributed in Western Mediterranean Sea and are of the same order of magnitude with those measured in the North Atlantic or North Pacific subtropical gyres.⁵⁶

The European Marine Strategy (EU Marine Strategy Framework Directive, MSFD 2008/56/EC to establish framework for good environmental status in the marine environment by 2020) standardised sampling methodologies for microplastics in order to make future data comparable. Recently, the western Sardinian coast was investigated for abundance and distribution of microplastic fragments (using Manta Trawl) and their relation with phthalates and organochlorinated compounds in the neustonic habitat. Results showed high average plastic abundance (0.15 items/m³), comparable to the levels detected in other areas of the Mediterranean Sea. Contaminant levels show high spatial and temporal variations in which hexachlorinatedbenzene (HCB) is the contaminant with the lowest concentration while polychlorinatedbiphenyls (PCBs) showed the highest levels.⁵⁷

High amounts of microplastic fragments were observed in the Pacific Ocean by special tows performed in the 1980s.⁵⁸ Surface plankton tows were carried out in Southern California coastal waters before and after storm events which resulted in high plastic/plankton ratio. Also, sampling of microplastics was performed throughout the water column. Higher amounts of

microplastics were sampled after a storm, especially close to the shore, which reflects the inputs from land-based runoff and re-suspended sediments⁵⁹ Sampling in the Western Pacific Ocean identified plastic and polystyrene fragments in surface plankton tows (most of them in sizes 3 mm).⁶⁰ Specific surface survey in the South Pacific Subtropical Gyre (SPSG), revealed that 95% the samples contained plastic fragments and microplastics (1-5 mm).⁶¹ The North Pacific subtropical gyre (NPSG, corresponding to centres of plastic accumulation resulting from the convergence of ocean surface currents) showed maximum plastic concentrations from individual surface net tows 10⁶ pieces per km⁻². These concentrations decreasing with increasing distance from the predicted centre of accumulation. Outside the NPSG the median plastic concentration was 0 pieces per km⁻². Researchers utilizing all available plankton net data collected in the Eastern Pacific Ocean since 1999, estimated a minimum of 21, 290 tones of floating microplastic.⁶²

6. Microplastics in Sandy Beaches and in Sediments

Plastic resin pellets are large-sized microplastics, which are industrial raw material transported to manufacturing sites for production of a wide range of plastic products. Resin pellets have being reported in marine waters worldwide and accumulate in depositional environments, including sandy beaches. Sources of pellets are both marine and land-based and include spillages during handling and transfer and losses during transportation.⁶³

From the 1970s many studies reported the presence of microplastics, in the form of plastic pellets in sandy beaches in New Zealand, Canada, Malta, Bermuda, Mediterranean Sea, Lebanon and elsewhere. Pellets were translucent (size 2-5 mm) showing deterioration due to weathering. Large numbers of stranded pellets indicated that a massive spill most likely occurred during shipping. Some of the PE pellets observed in the Mediterranean Sea were embedded in tar.⁶⁴⁻⁶⁶ Already from the 1970s scientists observed and studied the presence of **plastic resin pellets** which were distributed worldwide. Nowadays, microplastics are reportedly present on six continents, and higher amounts are commonly related to densely populated areas.^{67,68}



Figure 11. Plastic pellets in sandy beaches (Pre-production plastic pellets, or 'nurdles' on the windward side of South Sokos Island, Hong Kong. Photograph: Alex Hofford/EPA).

The study of plastic pellets in beaches showed that mostly are fibres and other materials (frequently polyester and acrylic) suggesting that the plastics were produced by sewage effluents, including wastewater from washing machines. Polyvinylchloride (PVC), polyester and polyamide comprised, approximately, 80% of the total sampled fragments and were generally more common at downwind sites.^{9,23} A study on the Belgium coast, observed that the sediment from beaches, harbours and sub-littoral habitats were contaminated with microplastics (size 38 μm –1 mm). The sediment cores from sandy beaches revealed that microplastic deposition tripled over the last 20 years.⁶⁹ Similar studies were conducted in Lagoon of Venice that identified 10 different polymers (sizes 30-500 μm). Polystyrene and polypropylene (determined by FT-IR) are the prevalent types.^{70,71} The presence of small-sized plastics on Hawaiian beaches is expected because the archipelago is located in the NPCG. All of the sediment samples from the islands were contaminated, primarily by plastic fragments (87%) but also by resin pellets (11%).⁷²

Many coastal zones in many places of the world show signs of widespread disposal of plastics. Under the direction of scientists local communities worked to determine the concentrations of micro-plastics in 125 beaches on three natural protected islands in the Canary Current: Lanzarote, La Graciosa, and Fuerteventura. The study found that microplastics pollution reached concentrations greater than 100 g of plastic in 1l of sediment.⁷³

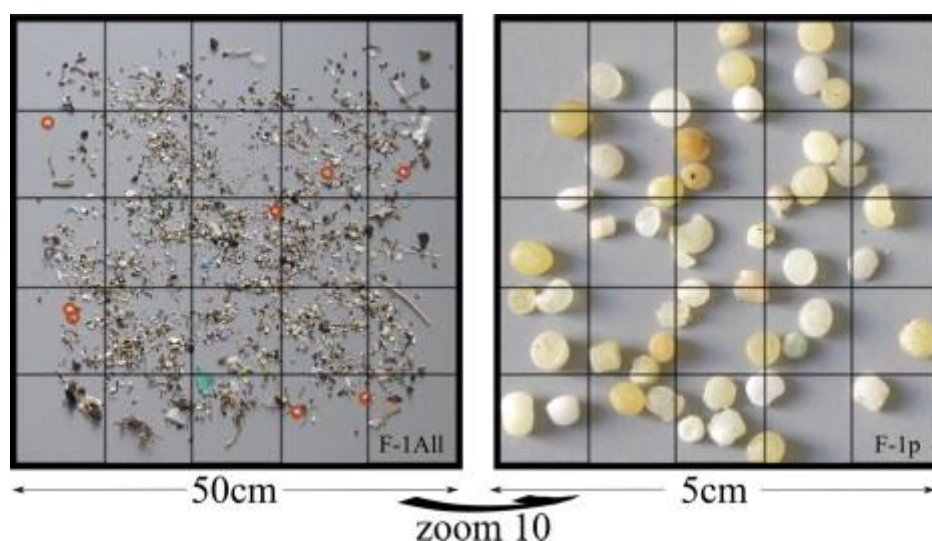


Figure 12. Microplastics measurements in the Canary Islands.⁷³

7. Microplastics in Deep Sea Sediments

Microplastics have been reported in the water column and marine sediments worldwide.^{49,69} The concentrations varied from 3/m³ (particles per cubic meter) in water to 8/kg in sediments. But there were also very high, hot-spot concentrations of 102,000/m³ in water and 621,000 particles/kg in sediments.⁷⁴ Accumulation zones of floating plastic debris and microplastics, the so-called garbage patches, are located far from any continental margin. To resolve the problem scientists investigated the presence of microplastics in pristine marine environments: by collecting sediment samples of deep sea.

The sediment samples from deep-sea locations worldwide were analysed for the presence of microplastics by means of a new and highly efficient extraction technique using a high density salt solution. Studies showed that microplastics (size <1mm) are present in the water column and seabed. Sediment from 4 deep sea locations was analysed. Average abundance of up to 1 microplastic per 25 cm³ was observed. The depths from where these microplastics were recovered range from 1176 to 4843m.⁷⁵

Studies showed that microplastics are distributed throughout the water column, sediments, and the deep sea, with highest concentrations along populated coastlines and within mid-ocean gyres.⁷⁶ The observed microplastics in the global oceans and the extent of microplastics pollution to the marine environment is still largely unknown.²² Also, scientists are worried about the influence of global warming in the increase of microplastics pollution. Observations show that Arctic sea ice from remote locations contains concentrations of microplastics at least two orders of magnitude greater than those that have been previously reported in highly contaminated surface waters, such as those of the Pacific Gyre. The findings indicate that microplastics have accumulated far from population centres and that polar sea ice represents a major historic global sink of man-made particulates. The potential for substantial quantities of legacy microplastic contamination to be released to the ocean as the ice melts therefore needs to be evaluated, as well as the physical and toxicological effects of plastics on marine life.⁷⁷

8. Microplastics in Vertebrates and Invertebrates: ingestion of microplastics

The ingestion of microplastics has been documented by many studies for vertebrate and invertebrate marine species.

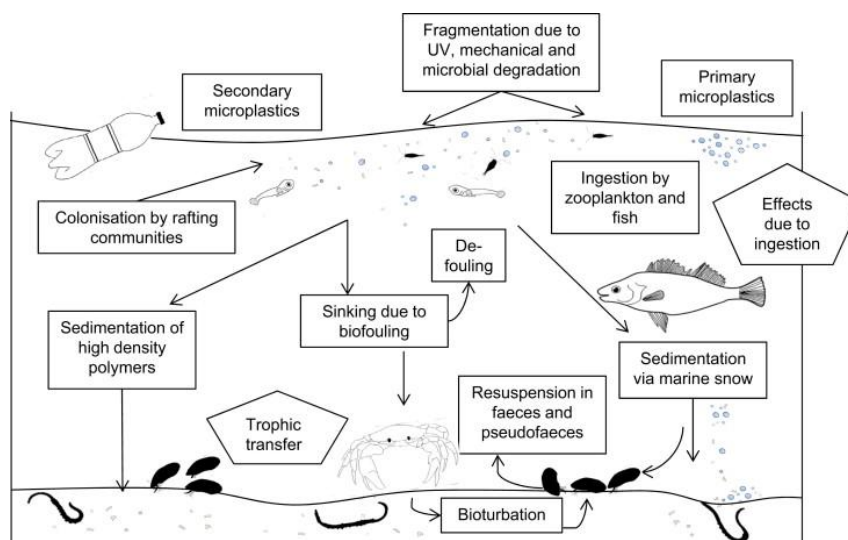


Figure 13. Potential pathways for the transport of microplastics and its biological interactions [Wright SL, Thompson RC, Galloway TS. The physical impacts of microplastics on marine organisms: A review. *Environ Pollut* 178:483-492, 2013]

Recent studies have identified potential effects of plastic particles mainly in invertebrates and fish, including: 1) transport of persistent,

bioaccumulating and toxic (PBT) substances from plastics; II) leaching of additives such as phthalates from the plastics; III) physical harm.⁷⁶ Very few studies observed the ingestion and occurrence of microplastics in large marine vertebrates which are filter feeding, such as baleen whales or sharks.⁴⁸

Scientific concern over the ingestion of microplastics emerged when synthetic plastic fragments were found in the gastrointestinal content of the planktivorous fish in the North Pacific Central Gyre. The study showed that the average number of plastic pieces ingested (1–2.79 mm) increased with the fish size. Another important observation is that the colours of the plastics collected in the same marine environment during sampling are in similar percentages to those of the ingested plastics.⁷⁸ Pelagic and demersal fish inhabiting the coastal waters around the United Kingdom were also found with synthetic and semi-synthetic plastics from sewage sources in their digestive tracts. Most of the ingested microplastics were polymer fibres (68%) and microplastic fragments.⁷⁹

Other studies on the ingestion of microplastics by fish were conducted in the North Pacific. Mesopelagic fish stomachs were examined (including Myctophidae) and were found to be contaminated with microplastic fragments (sizes, ~2.2 mm) and fibres.⁸⁰ Lantern fish were also found with microplastics in their stomach contents at the Mariana Islands (Philippines Sea). Unlike the NPCG, the Mariana Islands are not a hotspot of microplastic debris, which illustrates the magnitude of the problem.⁸¹ Surveys with estuarine fishes established that microplastic pollution is widespread. In a small estuary in the western South Atlantic Ocean, catfishes (Ariidae), estuarine drums (Sciaenidae) and mojarras (Gerreidae) have been reported to have synthetic polymers in their digestive tracts.^{82,83}



Figure 14. Microplastics extracted from fish stomach. *Cathorops agassizii* captured still alive in the main channel of the Goiana Estuary entangled to a fragment of nylon monofilament fishing net (Possatto FE, Barletta M, Costa MF, et al. Plastic debris ingestion by marine catfish: An unexpected fisheries impact. *Mar Pollut Bull* 62(5):1092-1102, 2011.).⁸⁴ University of Hawaii scientists analysed the plastics found in stomach contents of 10 species of pelagic fish captured in North Pacific Subtropical Gyre [Choy CA, Drazen JC. Plastic for dinner? Observations of frequent debris ingestion by pelagic predatory fishes from the central North Pacific. *Mar Ecol Prog Series* 485:155-163, 2013,⁸⁵ [http://www.int-res.com/articles/meps_oa/m485p155.pdf]

Ingestion of microplastics by marine biota, including mussels, worms, fish, and seabirds, has been widely reported, but despite their vital ecological role in marine food-webs, the impact of microplastics on zooplankton remains under-researched. Some experiments investigated the effects of microplastics ingestion in the survival, growth and fecundity of copepods (group of small crustaceans found in the sea and nearly in every freshwater habitat). In one experimental setting of acute and chronic toxicity tests three sizes of polystyrene (PS) microbeads (0.05, 0.5, and 6- μm diameter) were used in the feeding of copepod *Tigriopus japonicus* using. *T. Japonicas* ingested and egested all three sizes of PS beads used and exhibited no selective feeding when phytoplankton were added. The copepods (nauplius and adult females) survived all sizes of PS beads and the various concentrations tested in the acute toxicity test for 96 hours. In the two-generation chronic toxicity test, 0.05- μm PS beads at a concentration greater than 12.5 $\mu\text{g}/\text{mL}$ caused the mortality of nauplii and copepodites in the first generation and even triggered mortality at a concentration of 1.25 $\mu\text{g}/\text{mL}$ in the next generation. The 6- μm PS beads did not affect the survival of the *copepod* over two generations. The 0.5- and 6- μm PS beads caused a significant decrease in fecundity at all concentrations (Fig. 15, left). These results suggest that microplastics such as micro- or nanosized PS beads have negative impacts on marine copepods.⁸⁶



Figure 15. Controlled studies showed microplastics ingestion by crustaceans Copepods and Nauplius

In another experiment scientists used microplastics that were ingested by zooplankton (Fig. 15, right). They used bioimaging techniques to document ingestion, egestion, and adherence of microplastics in a range of zooplankton common to the northeast Atlantic. This study determined the impact of microplastics on algal ingestion rates in copepods. Using fluorescence and coherent anti-Stokes Raman scattering (CARS) microscopy identified 13 zooplankton taxa that had the capacity to ingest 1.7–30.6 μm polystyrene (PS) beads, with uptake varying by taxa, life-stage and bead-size. The

findings of the study implied that marine microplastic debris can have negative effect on the zooplankton function and health.⁸⁷

9. Microplastics Ingestion by Seabirds

As top predators, seabirds are considered sentinels of the state of marine environmental pollution by plastics. Marine microplastics have long been known to be found in large quantities in the stomach of seabirds.⁸⁸ Seabirds (flesh-footed shearwater, *Puffinus carneipes*, in Eastern Australia) with high levels of ingested plastic exhibited reduced body condition, and more than 60% exceed international targets for plastic ingestion by seabirds. The amount of plastic ingested is the highest reported for any marine vertebrate, suggesting the condition of the Australian marine environment is poor and probably explains the ongoing decline of this species.⁸⁹

Microplastic particles ingested by marine seabird predators in the Mediterranean Sea. Scientists quantified and measured micro and mesoplastics accumulated in the stomach of 171 birds from 9 species accidentally caught by longliners in the western Mediterranean (2003 to 2010). Cory's shearwaters (*Calonectris diomedea*) showed the highest occurrence (94%) and large numbers of small plastic particles, followed by 70% of Yelkouan shearwaters (*Puffinus yelkouan*). The results of this study point out endemic and threatened shearwater species of the Mediterranean as being particularly exposed to microplastic pollution at sea.⁹⁰



<http://www.oceanvoyagesinstitute.org/seabirds-study-shows-plastic-pollution-reaching-surprising-levels/>



<http://ecowatchorg.tumblr.com/post/-51646365530/california-marine-plastic-pollution-policy-tangled>

Figure 16. Seabirds ingestion of microplastics

Plastic and microplastic ingestion by seabirds is considered by environmentalists as a growing conservation issue. Another seabird studied for effects (in the period 2011-2012) of microplastic ingestion in common and thick-billed Murres (*Uria aalge* and *U. lomvia*) which are pursuit-diving auks in Newfoundland and Labrador, Canada. The study found that approximately 7%

of murrens had ingested plastic. The number of pieces of plastic/bird, and mass of plastic/bird were highest than in similar study in the 1980s.⁹¹ The majority of the ingested macroplastic (>5 mm) and microplastics (>1 mm) fragments in seabirds are commonly reported together. Plastic pellets were identified in migratory petrels, shearwaters and prions in the 1980s and 2000s in the Atlantic and south-western Indian oceans.^{92,93}

10. Experimental Studies of Ingestion of Microplastics by Invertebrates

Controlled laboratory experiments established the rate of ingestion of microplastics in invertebrates, mainly molluscs, crustaceans, annelids and echinoderms. Amphipods (*Orchestia gammarellus*), lugworms (*Arenicola marina*) and barnacles (*Semibalanus balanoides*) showed that microplastics (added in the water) were ingested within a few days of exposure.⁴⁹

Model organisms for microplastic ingestion were the mussels *Mytilus edulis* which is the most commonly studied. *M.edulis* ingested and accumulated microplastics (size <1 mm) within 12 h of the experiment start time.⁹⁴ High quantities of microplastics (mostly in sizes <3 µm) were found in the hemolymph of the organism for exposures until the 12th day. In another experiment the presence of HDPE microplastic particles (sizes ≤80µm) were found in gills and inside the digestive system of *M. Edulis* was also investigated. Microplastics were trapped in the gills and in the intestine.^{95,96} Microplastics can be ingested also by organisms of the higher trophic level, such as crabs. Experiments showed that microplastics can translocate to the hemolymph and tissues of the crabs. Therefore, the implications are evident for the rest of the food web including humans.^{97,98}

Research in the Clyde Sea (The Clyde Sea is a semi-enclosed basin on the west coast of Scotland) found that 83% of the sampled lobsters contained microplastics, mainly filaments in the form of balls, in their stomachs. Visual analysis revealed that the material of these balls is the same polymer (PP) found on the ropes used by the fishing industry. In the laboratory, lobsters also ingested plastic seeds in the first 24 h after exposure.⁹⁹

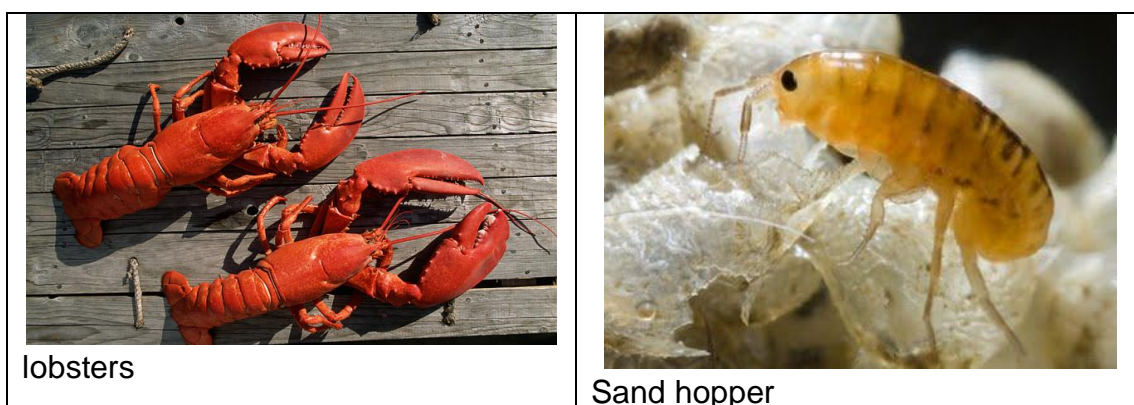


Figure 17. Controlled experiments with lobster and sand hopper showed that they ingest microplastics.

Sand hoppers (*Talitrus saltator*) (common amphipod crustacean of sandy coasts around Europe) were found to ingest PolyEthylene and PolyPropylene microplastics on sandy shores in Pisa (Italy). Laboratory, experiments (feeding with dry fish mixed with PE microspheres, 10-45 µm) confirmed that they are able to ingest microplastics and expel the plastic within one week. FT-IR analyses carried out on faeces of freshly collected individuals revealed the presence of polyethylene and polypropylene¹⁰⁰

Different Baltic Sea zooplankton taxa were investigated for their potential to ingest microplastics. Mysid shrimps, copepods, cladocerans, rotifers, polychaete larvae and ciliates were exposed to 10 µm fluorescent PS (polystyrene) microspheres. These experiments showed ingestion of microspheres in all taxa studied and for the first time the potential of plastic microparticle transfer via planktonic organisms from one trophic level (mesozooplankton) to a higher level (macrozooplankton).¹⁰¹

11. Adsorption of Chemical Pollutants onto Microplastic Particles and Transfer to Marine Organisms

Another hazardous aspect of plastics in the marine environment is the adsorption of organic toxic chemical pollutants onto microplastics and then transfer to marine organisms via ingestion. This transference of organic pollutants adsorbed onto marine microplastic to vertebrates via ingestion was detected with seabirds *Calonectris leucomelas* and *Puffinus tenuirostris* (is the most abundant seabird species in Australian waters).^{39,102}

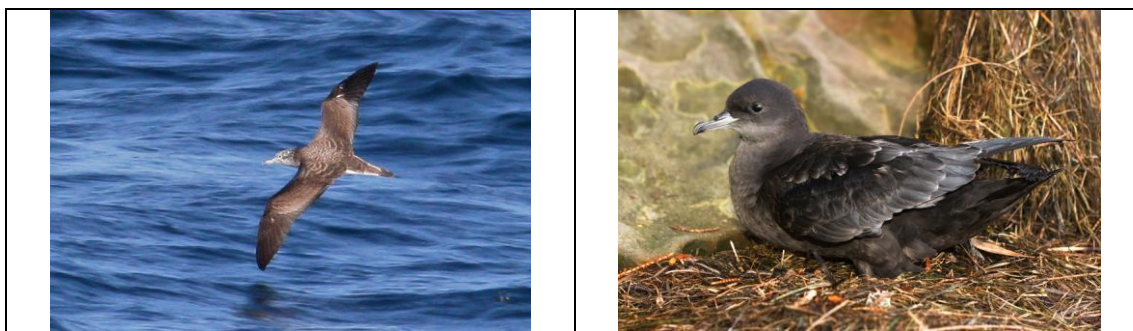


Figure 18. Seabirds fed plastic pellets contaminated with PCBs. Plastic-derived PCBs were detected in the biological tissues of the seabirds.

Shearwater chicks were fed with pellets that were contaminated by significant amounts of PCBs. After 7 days, the identification of lower chlorinated congeners of PCBs was verified the transference of this contaminant from ingested plastics to the biological tissues of the seabirds.¹⁰² Also, in the second experiment measured the concentrations of PBDEs from ingested plastic fragments in the natural prey of birds (fish) and in their adipose tissues. Two PBDEs congeners were not found in their prey, but were

adsorbed onto the plastics, which indicate the transfer of plastic-derived chemicals to the seabird.³⁹

Recently, organic pollutants were identified in the stomachs of harbour seals *Phoca vitulina* (also known as the common seal, is a true seal found along temperate and Arctic marine coastlines). A large number of stomach contents and intestines that were analysed and were found contaminated (11% and 1%, respectively) mostly by plastic sheets and plastic threads.¹⁰³

Other studies investigated the impacts of microplastics on cetaceans (fin whales, *Balaenoptera physalus*). Analysis of their blubber found concentrations of phthalates (polymer plasticizers) which are linked to the pollutants measured on marine microplastics sampled in the same area of the Mediterranean Sea where the whales live and feed.¹⁰⁴



Figure 19. Harbour seals were used to investigate the microplastic debris in their stomach and intestines.

Scientists analysed white, coloured and aged pellets along the Portuguese coast for PolyChlorinatedBiphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and DDTs. The concentrations of PCBs adsorbed onto the pellets were one order of magnitude higher around the major cities and were directly related to industrial and urban discharges. In less-developed cities, PCBs are most likely airborne from industrialised areas.¹⁰⁵⁻¹⁰⁷ Similar studies in sea beaches of the Saronikos Gulf (Athens, Greece). Samples of pellets were analyzed for PCBs, DDTs, HCHs, and PAHs. Plastic pellets collected in Saronikos Gulf beaches demonstrate much higher pollutant loading than the ones collected in a remote island or close to an agricultural area. Based on data collected in this study and the International Pellet Watch program, pollution in Saronikos Gulf, Greece, is comparable to other heavily industrialized places of the world.¹⁰⁸ Persistent Organic Pollutants (POPs) desorbed from the microplastics and entering in the digestive tracts of marine species can eventually enter the bloodstream, reach other organs and possibly result in physiological damage. Seabirds and other marine top predators may eat pelagic microplastics when feeding, but they likely also

ingest planktivorous fish and squids that had previously ingested microplastics from seawater. Plastic additives also can leach out of microplastics.¹⁰⁹⁻¹¹²

12. The Shores of Six Continents are Polluted with Microplastics

In the last decade there was a large number of investigations and surveys for the presence of microplastics in the coastal areas and in deep water of oceans. Scientific data found that the shores on six continents are contaminated with microplastics. Fibres (with sizes in μm) are prevalent in the eastern North Atlantic and the North Sea due to continental effluent discharges (urban and industrial). Microplastic fragments and plastic pellets (1-5 mm) are more common in the Eastern and Western coasts of South America. However, fibres are most likely also spread throughout these sediments, mostly around urban areas. Oceanic islands were also reportedly contaminated by microplastic fragments. The presence of microplastics in terrestrial ecosystems and the soil are very limited in the scientific literature. The presence of microplastics in coastal sediments resulted in unexpected consequences, such as changes in the physical properties of beaches and associated problems.¹¹³⁻¹¹⁵

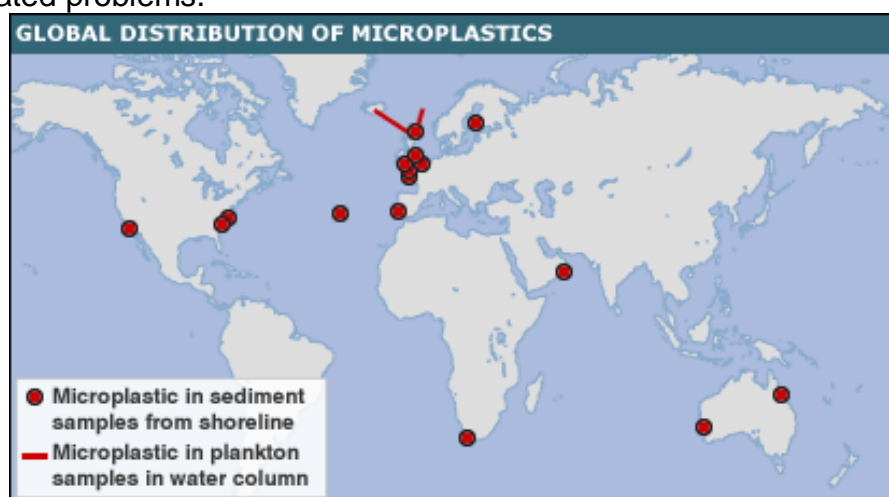


Figure 20. The map of the Earth and the shores of the continents with the highest concentrations of microplastics. Microplastics in sediment, microplastic in plankton [<http://news.bbc.co.uk/2/hi/science/nature/6218698.stm>]

13. National and International Environmental Actions for Marine Litter and Microplastics Pollution

Several international agreements designed to address marine pollution and especially to reduce marine litter. These include: the United Nations Convention on the Law of the Sea (UNCLOS), the International Convention for the Prevention of Pollution from Ships (MARPOL), and the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter, also

known as the London Dumping Convention. Some of the most promising regionally-focused agreements and directives include: the European Marine Strategy Framework Directive, Barcelona Convention, Cartagena Convention, Convention for the Protection of the Marine Environment of the North East Atlantic (OSPAR, 1972, mechanism by which 15 Governments of the western coasts of Europe, with the European Union, cooperate to protect the marine environment of the North-East Atlantic), and Helsinki Convention and other national regulations.¹¹⁶⁻¹¹⁸

In the last decade the leading national environmental administrations in the USA, European Union, Japan and other developed industrial countries have recognised the emerging threat of plastic pollution and especially microplastics in the marine environment. The environmental movement at national and international level started long time ago to campaign for a reduction of marine litter and a ban of certain persistent plastic products and personal care products that pollute the marine environment. For example, a group of conservation societies, such as the North Sea Foundation, the Marine Conservation Society, Seas At Risk and Plastic Soup Foundation initiated a campaign to ban a large number of personal care products containing microplastics (micro beads) reaching the effluent of water treatment installations and from there the marine environment¹¹⁹

In the USA, from 2001 to 2006, the National Marine Debris Monitoring Program (NMDMP) analyzed marine debris deposited on beaches monitored along the west coast of the United States (i.e., Washington, Oregon, and California and on the main Hawaiian Islands), to characterize sources of debris and estimate the relative contribution of plastic debris observed on beaches. Systematic studies found that sources of marine debris are either land-based and/or from fishing activities. Also, plastic debris are generated on land at marinas, ports, rivers, harbours, docks, and storm drains. Debris (mainly plastic) is generated also at sea from fishing vessels. The threat of microplastics formed by degradation of polymer waste, is considered very important environmentally for the regional seas, oceans and the marine species by Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA).^{120,121}

In the European Union, the Marine Strategy Framework Directive (MSFD) Technical Subgroup on Marine Litter was tasked by the European Commission to deliver guidance so that European Member States could initiate programmes for monitoring. The present document provides the recommendations and information needed to commence the monitoring required for marine litter, including methodological protocols and categories of items to be used for the assessment of litter on the beach, water column, seafloor and biota, including a special section on microparticles.¹²²⁻¹²⁴

A European activity for marine litter has been established by a consortium of member states of the EU and located in 15 coastal countries of the European Regional Seas: North-East Atlantic Sea, Baltic Sea, Mediterranean Sea and Black Sea. MARLISCO's (MaRine Litter in Europe Seas: Social Awareness and CO-Responsibility) goal is to raise public awareness, facilitate dialogue and promote co-responsibility towards a joint vision for the sustainable management of marine litter across all European seas under threats from increasing plastic pollution and microplastics. MARLISCO aims to achieve its goals by engaging, teaching and informing

European societies on the dangers of marine litter, especially plastic pollution of the seas. Its activities include a overall study of the sources and trends regarding marine litter in each European regional sea, a collection of best practices on reducing and recycling marine litter from all partner countries, a survey on the prevailing perceptions and attitudes of different stakeholders regarding marine litter, and finally introduces a European video contest for youngsters to collect their visions on the issue of marine litter and empower them as agents of change.^{125, 126} In the Adriatic Sea, a new marine pollution initiative started with the DeFishGear project which is addressing the wider context of the marine litter issue and aims to provide a key strategic input on a regional level. The main objective is to facilitate the efforts of policy makers and stakeholders in effectively dealing with the issue of marine litter in the Adriatic MacroRegion.

Recently, (Athens, May 2014) there was a successful conference on Marine Litter. “The Mediterranean Conference on Combating Marine Litter in the Adriatic MacroRegion”, along with a series of other marine litter events, was launched in Athens on the 12th of May 2014 by Janez Potočnik, EC Commissioner for Environment and well-known advocate for curbing marine litter in Europe, together with Ioannis Maniatis, Greek Minister of Environment, Energy and Climate Change and Lila Iskandar, Egypt's Minister of State for Environmental Affairs. The event was organized by the Mediterranean Information Office for Environment, Culture and Sustainable Development (MIO-ECSDE) within the framework of the IPA Adriatic funded DeFishGear project in collaboration with Horizon 2020 Capacity Building/Mediterranean Environment Programme and MARLISCO, under the auspices of the Greek Presidency of the European Union and the Ministry of Environment, Energy and Climate Change of Greece. More than 130 decision makers, scientists and representatives of civil society and industry from all over the Euro-Mediterranean area met and shared information across borders, identify common goals and initiate joint actions to make a difference in the collective fight against marine litter.¹²⁷

14. Concluding Remarks on Marine Litter and Microplastics

Marine environments all over the world are contaminated with marine litter, mainly plastics. Environmental organisation in all developed countries and international organisations are aware of the importance of the problem and have initiated practical actions on the subject. In the last decade there is growing concern about small plastic fragments known as microplastics, as part of the overall marine litter issue, which is attracting attention not only from national and international authorities, but also NGOs, the media, scientists, consumers, the plastics industry and others. The global scale of the distribution of microplastic litter, coupled with recent scientific evidence of microplastics' potential to transfer through marine food chains and potentially cause adverse effects in various marine organisms, has fuelled environmental concerns about this marine contaminant. These warning signals are being recognized by both state organisations and non-state actors and lend support to the inclusion of microplastics in the international campaign for the drastic reduction of marine litter in regional and international seas.

References

1. Salamore JC. *Concise Polymeric Materials Encyclopedia*. Taylor & Francis, Oxford, 1999.
2. Walton DJ, Lorimer JP. *Polymer*. Oxford University Press, Oxford, 2000.
3. Scott G (Ed). *Degradable Polymers*, 2ND Edition, Kluwer Academic Publishers, London, 2002.
4. S.M. Al-Salem, P. Lettieri, J. Baeyens. Recycling and recovery routes of plastic solid waste (PSW): A review. *Waste Manage* 29(1):2625-2643, 2009
5. Derraik JGB. The pollution of the marine environment by plastic debris: a review. *Mar Pollut Bull* 44(9):842-852, 2002.
6. Fergusson WC, Staudinger JJP (Ed.), *Plastics and the Environment*, Hutchinson and Co, London, 1974, p. 2
7. D.W. Laist. Overview of the biological effects of lost and discarded plastic debris in the marine environment. *Mar Pollut Bull* 18:319-326, 1987.
8. Plastics Europe. Association of Plastics Manufacturers. Plastics-The Facts 2012. An Analysis of European Plastics Production , Demand and Waste. Data for 2011. [available at : http://www.plasticseurope.org/documents/document/20121120170458-final_plasticsthefacts_nov2012_en_web_resolution.pdf, accessed 29.4.2014].
9. Adrandy AL. Microplastics in the marine environment. *Mar Pollut Bull*, 62: 1596–1605, 2011.
10. Plastics Europe. Plastics-the Fact 2013. Analysis of European latest plastics production, demand and waste data, 2013 [available at http://www.vstp.si/Portals/0/FINAL_Plastics_the_Facts_2013_published_October2013.pdf, (accessed in 8.5.2014)].
11. EPA. Plastics. facts, recycling, market for recovered plastics, source reduction.[available at <http://www.epa.gov/osw/conserva/materials/plastics.htm>, accessed 8.5.2014].
12. WRAP. Waste Resources Action Programme. Material Change for Better Environment. UK Plastics Waste. A review of supplies for recycling, global market demand, future trends and associated risks. Nov. 2006, Oxford, Banbury. [available at <http://www.wrap.org.uk/sites/files/wrap/UK%20Plastics%20Waste.pdf>], (accessed 8.5.2014)].
13. Plastic Zero-Action 4.1. Market Conditions for Plastic Recovery. Jan. 2013. Public Private Cooperation for Avoiding Plastics as a Waste (LIFE 10 ENV/Dk/098). Copenhagen. [available http://www.plastic-zero.com/media/30825/action_4_1_market_for_recycled_polymers_final_report.pdf,] (accessed 9.5.2014).
14. Worldwatch Institute. Global Municipal Solid Waste Continues to Grow, 14.5.2014. [<http://www.worldwatch.org/global-municipal-solid-waste-continues-grow-0>], (accessed 14.5.2014).
15. Hoornweg, Daniel and Bhada-Tata, Perinaz. "What a Waste: A Global Review of Solid Waste Management." World Bank, Washington DC, 2012.

16. ISWA, 2013. White Paper: Alternative waste conversion technologies. International Solid Waste Association. [<http://www.iswa.org/> , (accessed 10.10.13).]
17. UNEP Global Environmental Alert Service. Municipal Solid Waste: Is it garbage or gold? [http://www.unep.org/pdf/UNEP_GEAS_OCT_2013.pdf , accessed 19.5.2014] .
18. North EJ, Halde RU. Plastics and environmental health: the road ahead. *Rev Environ Health* 28(1): 1-8, 2013.
19. Hopewell J, Dvorak R, Kosior E. Plastics recycling: challenges and opportunities. *Phil Trans R Soc B* 364(1526):2115–2126, 2009.
20. Shah AA, Hasan F, Hameed A, Ahmed S. Biological degradation of plastics: A comprehensive review. *Biotechnol Adv.* 26(3):246–265, 2008.
21. Hammer J, Kraak MH, Parsons JR. Plastics in the marine environment: the dark side of a modern gift. In: Whitacre DM (Ed). *Reviews of Environmental Contamination and Toxicology*. Springer Science–Business Media, Berlin, 2012, pp. 2-41.
22. Ivar do Sul JA, Costa MF. The present and future of microplastic pollution in the marine environment. Review. *Environ Pollut* 185:352-364, 2014.
23. Browne MA, Galloway, Thompson R. Microplastic – an emerging contaminant of potential concern? *Integrated Environ Assess Manage* 3: 559–561, 2007.
24. Browne MA, Crump P, Niven SJ, Teuten E, Tonkin A, Galloway T, Thompson R. Accumulation of microplastic on shorelines worldwide: sources and sinks, *Environ. Sci. Technol.*, 45 (21): 9175–9179, 2011.
25. Cole M, Lindeque P, Halsband C, Galloway TS. Microplastics as contaminants in the marine environment: A review. *Mar Pollut Bull* 62(12):2588-2597, 2011.
26. Zarfl C, Fleet D, Fries D. Microplastics in oceans (editorial). *Mar Pollut Bull* 62:1589-1591, 2011.
27. Zitko V, Hanlon M. Another source of pollution by plastics: skin cleaners with plastic scrubbers. *Mar Pollut Bull* 22:41-42, 1991.
28. Carpenter EJ, Anderson SJ, Harvey GR, Miklas HP, Peck BB. Polystyrene spherules in coastal waters. *Science* 175: 749–750, 1972.
29. Koelmans AA, Gouin T, Thompson R, Wallace N, Courtney A. Plastics in the marine environment. *Environ Toxicol Chem* 33(1):5-10, 2014.
30. Eriksen M, Mason S, Wilson S, Box C, Zellers A, Edwards W. Microplastic pollution in the surface waters of the Laurentian Great Lakes. *Mar Pollut Bull* 778(1-2):177-182, 2013.
31. Deforges J-PW, Galbraith M, Dangerfield N, Ross PS. Widespread distribution of microplastics in subsurface seawater in the NE Pacific Ocean. *Mar Pollut Bull* 79(1-2):94-99, 2014. 2014.
32. Middleton J, Burks B, Wells T, Setters AM, Jasiuk I, Kumosa M. The effect of ozone and high temperature on polymer degradation in polymer core composite conductors. *Polymer Degrad Stabil* 98(11):2282-2290, 2013.
33. Singh RP, Ramarao P. Accumulated polymer degradation products as effector molecules in cytotoxicity of polymeric nanoparticles. *Toxicol. Sci.* 136 (1):131-143, 2013.

34. Shah AA, Hasan F, Hameed A, Ahmed S. Biological degradation of plastics: a comprehensive review. *Biotechnol. Adv.*, 26 : 246–265, 2008.
35. Thompson RC, Moore CJ, vom Saal FS, Swan SH. Plastics, the environment and human health: current consensus and future trends. *Phil Trans R Soc B* 364:2153-2166, 2009.
36. Thompson RC, Swan SH, Moore CJ, von Saal FS. Our plastic age. *Phil Trans R Soc B* 364:1973-1976, 2009.
37. Bakir A, Rowland SJ, Thompson RC. Competitive sorption of persistent organic pollutants onto microplastics in the marine environment. *Mar Pollut Bull* 64(12):2782-2789, 2012.
38. Engler RE. The Complex interaction between marine debris and toxic chemicals in the ocean. *Environ Sci Technol* 46(22): 12302–12315, 2012.
39. Tanaka K, Tanaka H, Yamashita R, Mizukawa K, Fukuwaka M, Watanuki Y. Accumulation of plastic-derived chemicals in tissues of seabirds ingesting marine plastics. *Mar Pollut Bull* 69(1-2):219-222, 2013.
40. Fendall LS, Sewell MA. Contributing to marine pollution by washing your face: microplastics in facial cleansers. *Mar Pollut Bull* 68(8):1225-1228, 2009.
41. Campaign for the abolition of microplastics in cosmetics and personal care products. North Sea Foundation. Marine Conservation Society. Seas at Risk. Micro plastics in personal care products [<http://www.mcsuk.org/downloads/pollutionpositionpaper-microplastics-august2012.pdf>].
42. Oliveira M, Ribeiro A, Guilhermino L. Effects of exposure to microplastics and PAHs on microalgae *Rhodomonas baltica* and *Tetraselmis chuii*. *Comp. Biochem. Physiol. A Mol. Integr. Physiol.*, 163: S19–S20, 2012.
43. Wright, R.C. Thompson, T.S. Galloway. The physical impacts of microplastics on marine organisms: a review. *Environ. Pollut.*, 178: 483–492, 2013.
44. Collingnon A, Hecq J-H, Glagani F, Voisin P, Collard F, Goffart A. Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. *Mar Pollut Bull* 64(4):861-864, 2012.
45. Ryan PG. The characteristics and distribution of plastic particles at the sea-surface off the southwestern Cape Province, South Africa. *Mar. Environ. Res.*, 25: 249–273, 1988.
46. Wilber RJ. Plastics in the North Atlantic. *Oceanus*, 30: 61–68, 1987.
47. Ryan PG. Seabirds indicate changes in the composition of plastic litter in the Atlantic and southwestern Indian Oceans. *Mar. Pollut. Bull.*, 56:1406–1409, 2008.
48. Fossi MC, Coppola D, Bainsi M, Giannetti M, Guerranti C, et al. Large filter feeding marine organisms as indicators of microplastic in the pelagic environment: The case studies of the Mediterranean basking shark (*Cetorhinus maximus*) and fin whale (*Balaenoptera physalus*). *Mar Environ Res* 24.2.2014 (in press).
49. Thompson RC, Olsen Y, Mitchell RP, Davis A, Rowland SJ, John AWG, McGonigle D, Russell AE. Lost at sea: where is all the plastic? *Science* 304: 838, 2004.

50. Law KL, Morét-Ferguson S, Maximenko NA, Proskurowski G, Peacock EE, Hafner J, Reddy CM. Plastic accumulation in the North Atlantic subtropical gyre. *Science* 329:1185–1188, 2010.
51. Kukulka T, Proskurowski G, Morét-Ferguson S, Meyer DW, Law KL. The effect of wind mixing on the vertical distribution of buoyant plastic debris. *Geophys. Res. Lett.*, 39: L07601, 2012.
52. Ivar do Sul JA, Costa MF, Barletta M, Cysneiros FJA. Pelagic microplastics around an archipelago of the Equatorial Atlantic. *Mar Pollut Bull* 75(1-2):305-309, 2013.
53. Morét-Ferguson S, Law KL, Proskurowski G, Murphy EK, Peacock EE, Reddy CM. The size, mass, and composition of plastic debris in the western North Atlantic Ocean. *Mar. Pollut. Bull.*, 60: 1873–1878, 2010.
54. Eriksen M, Maximenko N, Thiel M, Cummins A, Lattin G, et al. Plastic pollution in the South Pacific subtropical gyre. *Mar Pollut Bull* 68:71-75, 2013.
55. Collignon A, Hecq JH, Galgani F, Voisin P, Collard F. Neustonic microplastic and zooplankton in the North Western Mediterranean Sea. *Mar. Pollut. Bull.*, 64: 861–864, 2012.
56. Faure F, Saini C; Potter, G, Galgani F, de Alencastro, L, ;Hagmann P. An evaluation of surface micro and meso plastic pollution in pelagic ecosystems of western Mediterranean Sea. Presented at: 6th International Conference on Water Resources and Environment Research (ICWRER), Koblenz, Germany, June 3-7, 2013.
57. De Lucia GA, Caliani I, Marra S, Camedda A, Coppa S, Alcaro L, et al. Amount and distribution of neustonic micro-plastic off the western Sardinian coast (Central-Western Mediterranean Sea). *Mar Environ Res* 4.4.2014 (available on line).
58. Shaw DG, Day RH. Colour- and form-dependent loss of plastic microdebris from the North Pacific Ocean. *Mar Pollut Bull* 28:39-43, 1994.
59. Lattin GL, Moore CJ, Zellers AF, Moore SL, Weisberg SB. A comparison of neustonic plastic and zooplankton at different depths near the southern California shore. *Mar Pollut Bull* 49:291-294, 2004.
60. Yamashita R, Tanimura A. Floating plastic in the Kuroshio Current area, western North Pacific Ocean. *Mar Pollut Bull* 54:485-486, 2007.
61. Eriksen M, Maximenko N, Thiel M, Cummins A, Lattin G, Wilson S, Hafner J, et al. Plastic pollution in the South Pacific subtropical gyre. *Mar. Pollut. Bull.*, 68:71-76, 2013.
62. Law KL, Moret-Ferguson SE, Goodwinj DS, Zettler ER, DeForce E, et al. Distribution of Surface Plastic Debris in the Eastern Pacific Ocean from an 11-Year Data Set. *Environ Sci Technol* 48(9):4732-4738, 2014.
63. Turra A, Manzano AB, Dias RSS, Mahiques MM, Barbosa IK et al. Three-dimensional distribution of plastic pellets in sandy beaches: shifting paradigms. *Nature Scientific Reports* (open access) 4:4435, 27.3.2014
64. Gregory MR. Accumulation and distribution of virgin plastic granules on New Zealand beaches. *J. Mar. Freshw. Res.*, 12:399–414, 1978.
65. Gregory MR. Virgin plastics on some beaches of eastern Canada and Bermuda. *Mar. Environ. Res.*, 10: 73–92, 1983.
66. Fotopoulou KN, Karapanagioti HK. Surface properties of beached plastic pellets. *Mar. Environ. Res.*, 81: 70–77, 2012.

67. Hidalgo-Ruz V, Gutow L, Thompson RC, Thiel M. Microplastics in the marine environment: a review of methods used for identification and quantification. *Environ. Sci. Technol.*, 46: 3060–3075, 2012.
68. Browne MA, Crump P, Niven SJ, Teuten EL, Tonkin A, Galloway T, R.C. Thompson RC. Accumulations of microplastic on shorelines worldwide: sources and sinks. *Environ. Sci. Technol.*, 45: 9175–9179, 2011.
69. Claessens M, Meester SD, Landuyt LV, Clerc KD, Janssen CR. Occurrence and distribution of microplastics in marine sediments along the Belgian coast. *Mar. Pollut. Bull.*, 62: 2199–2204, 2011.
70. Harrison JP, Ojeda JJ, Romero-Gonzales ME. The applicability of reflectance micro-Fourier-transform infrared spectroscopy for the detection of synthetic microplastics in marine sediments. *Sci. Total Environ.*, 416: 455–463, 2012.
71. Vianello A, Boldrin P, Guerriero V, Moschino R, Rella A, Sturaro L, Da Ros. Microplastic particles in sediments of Lagoon of Venice, Italy: first observations on occurrence, spatial patterns and identification. *Est. Coast. Shelf Sci.*, 130: 54–61, 2013.
72. McDermid KJ, McMullen TL. Quantitative analysis of small-plastic debris on beaches in the Hawaiian Archipelago. *Mar. Pollut. Bull.*, 48: 790–794, 2004.
73. Baztan J, Carrasco A, Chouinard O, Cleaud M, Gabaldon JE, et al. Protected areas in the Atlantic facing the hazards of micro-plastic pollution: First diagnosis of three islands in the Canary Current. *Mar Pollut Bull* 80(1-2):302-311, 2014
74. Liebezeit G, Dubaish F. Microplastics in beaches of the East Frisian Islands Spiekeroog and Kachelotplate. *Bull. Environ. Contam. Toxicol.*, 89: 213–217, 2012.
75. Van Cauwenberghe L, Vanreusel A, Maes J, Janssen CR. Microplastic pollution in deep-sea sediments. *Environ Pollut* 182:495-499, 2013.
76. Wright SL, Thompson RC, Galloway TS. The physical impacts of microplastics on marine organisms: a review. *Environ Pollut* 178:483-492, 2013.
77. Obbard RW, Sadri S, Wong YQ, Khitun AA, Baker I, Thompson RC. Global warming releases microplastic legacy frozen in Arctic Sea ice. *Earth's Future* (Wiley), open access, on line, available 30.5.2014 (<http://onlinelibrary.wiley.com/doi/10.1002/2014EF000240/abstract>).
78. Boerger CM, Lattin GL, Moore SL, Moore CJ. Plastic ingestion by planktivorous fishes in the North Pacific Central Gyre. *Mar Pollut. Bull.*, 60: 2275–2278, 2010.
79. Lusher AL, McHugh M, Thompson RC. Occurrence of microplastics in the gastrointestinal tract of pelagic and demersal fish from the English Channel. *Mar. Pollut. Bull.*, 67: 94–99, 2013.
80. Davison P, Asch RG. Plastic ingestion by mesopelagic fishes in the North Pacific Subtropical Gyre. *Mar. Ecol. Prog. Ser.*, 432: 173–180, 2011.
81. Van Noord JE. Diet of five species of the family Myctophidae caught off the Mariana Islands. *Ichthyol Res* 60:89-92, 2013.
82. Dantas DV, Barletta M, Costa MF. The seasonal and spatial patterns of ingestion of polyfilament nylon fragments by estuarine drums (Sciaenidae). *Environ Sci Pollut Res* 19:600-606, 2012.

83. Ramos JAA, M. Barletta, M.F. Costa. Ingestion of nylon threads by Gerreidae while using a tropical estuary as foraging grounds. *Aquat. Biol.*, 17: 29–34, 2012.
84. Possatto FE, Barletta M, Costa MF, et al. Plastic debris ingestion by marine catfish: An unexpected fisheries impact. *Mar Pollut Bull* 62(5):1092-1102, 2011.
85. Choy CA, Drazen JC. Plastic for dinner? Observations of frequent debris ingestion by pelagic predatory fishes from the central North Pacific. *Mar Ecol Prog Series* 485:155-163, 2013.
86. Lee K-W, Shim WJ, Kwon OK, Kang J-H. Size-Dependent Effects of Micropolystyrene particles in the marine copepod *Tigriopus japonicus*. *Environ Sci Technol* 47(19):11278-11283, 2013.
87. Cole M, Lindeque P, Fileman E, Claudia Halsband C, Goodhead R, Moger J, Tamara S. Galloway. Microplastic ingestion by zooplankton. *Environ Sci Technol* 47(12):6646-6655, 2013.
88. Colabuono FI., Taniguchi S, Montone RC. Polychlorinated biphenyls and organochlorine pesticides in plastics ingested by seabirds. *Mar. Pollut. Bull.*, 60: 630–634, 2010.
89. Lavers JL, Bond AL, Hutton I. Plastic ingestion by Flesh-footed Shearwaters (*Puffinus carneipes*): Implications for fledgling body condition and the accumulation of plastic-derived chemicals. *Environ Pollut* 187:124-129, 2014.
90. Codina-García M, Militão T, Moreno J, González-Solís J. Plastic debris in Mediterranean seabirds. *Mar Pollut Bull* 77(1-2):220-226, 2013.
91. Bond AL, Provencher JF, Elliot RD, Ryan PC, Rowe S, Jones IL, et al. Ingestion of plastic marine debris by Common and Thick-billed Murres in the northwestern Atlantic from 1985 to 2012. *Mar Pollut Bull* 77(1-2):192-195, 2013.
92. Ryan, PG. Seabirds indicate changes in the composition of plastic litter in the Atlantic and southwestern Indian Oceans. *Mar. Pollut. Bull.*, 56: 1406–1409, 2008.
93. Ryan PG, Moore CJ, van Franeker JA, Moloney CL. Monitoring the abundance of plastic debris in the marine environment. *Phil. Trans. R. Soc. B*, 364:1999–2012, 2009.
94. Browne MA, Dissanayake A, Galloway TS, Lowe DM, Thompson RC. Ingested microscopic plastic translocates to the circulatory system of the mussel, *Mytilus edulis* (L.). *Environ. Sci. Technol.*, 42: 5026–5031, 2008.
95. von Moos N, Burkhardt-Holm P, Köhler A. Uptake and effects of microplastics on cells and tissue of the blue mussel *Mytilus edulis* L. after an experimental exposure. *Environ Sci Technol* 46(20):11327–11335, 2012.
96. von Moos N, Burkhardt-Holm P., Köhle A. Uptake and effects of microplastics on cells and tissue of the blue mussel *Mytilus edulis* L. after an experimental exposure. *Environ Sci Technol* 46:11327–11335, 2012.
97. Farrell P, Nelson K. Trophic level transfer of microplastic: *Mytilus edulis* (L.) to *Carcinus maenas* (L.). *Environ Pollut* 177: 1–3, 2012.

98. Wegner A, Besseling E, Foekema EM, Kamermans P, Koelmans AA. Effects of nanopolystyrene on the feeding behavior of the blue mussel (*Mytilus edulis* L.). *Environ. Toxicol Chem*, 31: 2490–2497, 2012.
99. Murray F, Cowie PR. Plastic contamination in the decapod crustacean *Nephrops norvegicus* (Linnaeus, 1758). *Mar Pollut Bull* 62: 1207–1217, 2011.
100. Ugolini A, Ungherese G, Ciofine M, Lapucci A, Camaiti M. Microplastic bebris in sanhoppers. *Estuar Coastal Shelf Sci* 129(1):19-22, 2013.
101. Setälä O, Fleming-Lehtinen V, Lehtiniemi M. Ingestion and transfer of microplastics in the planktonic food web. *Environ Pollut* 185:77-83, 2014.
102. Teuten EL, Saquing JM, Knappe DRU, Barlaz MA, Jonsson J, Björn A, Rowland SJ, Thompson RC, Galloway TS, et al. Transport and release of chemicals from plastics to the environment and to wildlife. *Phil. Trans. R. Soc. B*, 364: 2027–2045, 2009.
103. Rebolledo ELB, Van Franeker JA, Jansen OE, Brasseur SMJM. Plastic ingestion by harbour seals (*Phoca vitulina*) in The Netherlands. *Mar. Pollut. Bull.*, 67: 200–202, 2013.
104. Fossi MC, Panti, Guerranti C, Coppola D, Giannetti M, Marsili L, Minutoli L. Are baleen whales exposed to the threat of microplastics? A case study of the Mediterranean fin whale (*Balaenoptera physalus*). *Mar Pollut Bull* 64: 2374–2379, 2012.
105. Ogata Y, Takada H, Mizukawa K, Hiraia H, Iwasaa S, Endo S, Mato Y, Saha M, et al. International Pellet Watch: global monitoring of persistent organic pollutants (POPs) in coastal waters. 1. Initial phase data on PCBs, DDTs, and HCHs. *Mar Pollut Bull* 58: 1437–1446, 2009
106. Frias JPGL, Sobral P, Ferreira AM. Organic pollutants in microplastics from two beaches of the Portuguese coast. *Mar Pollut Bull* 60: 1988–1992, 2010.
107. Mizukawa K, Takada H, Ito M, Geok YB, Hosoda J, Yamashita R, Saha M, et al. Monitoring of a wide range of organic micropollutants on the Portuguese coast using plastic resin pellets. *Mar Pollut Bull* 70: 296–302, 2013.
108. Karapanagioti HK, Endo S, Ogata Y, Takada H. Diffuse pollution by persistent organic pollutants as measured in plastic pellets sampled from various beaches in Greece. *Mar Pollut Bull* 62: 312–317, 2011.
109. Koelmans AA, Besseling E, Wegner A, Foekema EM. Plastic as a carrier of POPs to aquatic organisms. A model analysis. *Environ Sci Technol* 47: 7812–7820, 2013, 2013.
110. Endo S, Yuyama M, Takada H. Desorption kinetics of hydrophobic contaminants from marine plastic pellets. *Mar Pollut Bull* 74: 125–131, 2013.
111. Koelmans AA, Besseling E, Foekema EM. Leaching of plastic additives to marine organisms. *Environ Pollut* 187:49-54, 2014.
112. Browne MA, Crump P, Niven SJ, Teuten EL, Tonkin A, Galloway TS, Thompson RC. Accumulations of microplastic on shorelines worldwide: sources and sinks. *Environ Sci. Technol* 45: 9175–9179, 2011.
113. Rillig MC. Microplastic in terrestrial ecosystems and the soil? *Environ Sci. Technol* 46: 6453–6454, 2012

114. Carson HS., Colbert SL, Kaylor MJ, McDermid KJ. Small plastic debris changes water movement and heat transfer through beach sediments. *Mar. Pollut. Bull.*, 62: 1708–1713, 2011.
115. Gold M, Mika K, Horowitz C, Herzog M, Leithner L. Stemming the tide of plastic marine litter. A Global action agenda. Pritzker Briefs. Pritzker Environmental Law and Policy Brief, No. 5. UCLA, School of Law, University of California Los Angeles, CA, October 2013.
116. UNEP RONA Workshop. Extended Producer Responsibility sessions of the UNEP RONA Marine Litter Workshop for North America: Legal, Policy and Market-Based Approaches to Preventing Marine Litter at the Source, held on December 3, 2012. See generally UNEP RONA Marine Litter Workshop for North America. (available at http://www.rona.unep.org/about_unep_rona/marine_litter/index.html , last accessed march 2014).
117. Raveender V., Are we “Digging Our Own Grave” Under the Oceans? Biosphere level effects and global policy challenge from plastic(s) in oceans, *Environ Sci Technol* 46(15):7932, 2012 [available at <https://sustainability.water.ca.gov/documents/18/3334111/Ocean+Pollution.pdf>] (accessed 15.6.2014).
118. Micro plastics in personal care products. North Sea Foundation, Marine Conservation Society, Seas at Risk, Plastic Soup Foundation, August 2012 [<http://www.mcsuk.org/downloads/pollution/positionpaper-microplastics-august2012.pdf>] (accessed 12.6.2014).
119. Seas at Risk. A success in the fight against micro plastics [<http://www.seas-at-risk.org/n2.php?page=613>].
120. National Oceanic Atmospheric Administration (NOAA), Marine Debris Division, Proceeding of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris. Baker AJ, Bamford H (Eds). NOAA, Jan 2009.
121. EPA. Marine Debris in the North Pacific. A Summary of Existing Information and Identification of Data Gaps. San Francisco, CA, Nov. 2011. [<http://www.epa.gov/region9/marine-debris/pdf/MarineDebris-NPacFinalAprvd.pdf>].
122. Directive 2008/56/EC, of the European Parliament and of the Council Establishing a Framework for Community Action in the Field of Marine Environmental Policy (Marine Strategy Framework Directive), 2008 O.J. (L 164). See: Borja A, The new European Marine Strategy Directive: Difficulties, opportunities, and challenges. *Mar Pollut Bull* 52: 239-245, 2006.
123. Galgani F, Hanke G, Werner S, Osterboan L, Nilsson P, Fleet D, Kinsey S, Thompson RC, van Franeker J, Vlachogianni Th (MIO-ECSDE), et al. Guidance on Monitoring of Marine Litter in European Seas. A guidance document within the Common Implementation of Marine Strategy Framework Directive. European Commission, Joint Research Centre, Institute for Environment and Sustainability, 2013. [file:///C:/Users/User/Documents/LBNA26113ENN_002.pdf].
124. Galgani, F., Hanke, G., Werner, S., and De Vrees, L. Marine litter within the European Marine Strategy Framework Directive. – *ICES J Mar Sci* 70: 1055–1064, 2013.

125. Hanke, G; Galgani, F; Werner, S, Oosterbaan, L, Nilsson, P, Fleet, D. Kinsey, S. Thompson, R, Van Franeker, J.A; Vlachogianni, T; Palatinus, A, Scoullou, M, Veiga, J.M, Matiddi, M, Alcaro, L, Maes, T, Korpinen, S., Budziak, A, Leslie, H. Gago, J, Liebezeit, G. *Guidance on Monitoring of Marine Litter in European Seas*. Publication Office of the European Union, Brussels, 2013. Also, MARLISCO web site : <http://www.marlisco.eu/about-project.en.html>
126. Kershaw P, Hartley B, Garnacho E, Thompson R. Contributors: Maes T, Nicolaus M, Goodsir F, Leech C, Pabl S, Vlachogiannis T, et al. *MaRine Litter in Europe Seas: Social Awareness and CO-Responsibility. Review of the current state of understanding of the distribution, quantities and types of marine litter*. MARLISCO Consortium, July 2013, pp. 79. Available at file:///C:/Users/User/Documents/REPORT_Current%20state%20of%20understanding%20of%20the%20distribution%20quantities%20and%20types%20of%20marine%20litter.pdf (accessed 15.6.2014).
127. The “Mediterranean Conference on Combating Marine Litter in the Adriatic Mactoregion” and a series of marine litter events took place in Athens, 12th May 2014. The EC Commissioner for Environment Janez Potocnik was present. For an analysis of the conference and the presentations see [<http://www.defishgear.net/> and [http://www.mio-ecsde.org/_uploaded_files/article_file_365_NI48N31SFPM9J.pdf]

