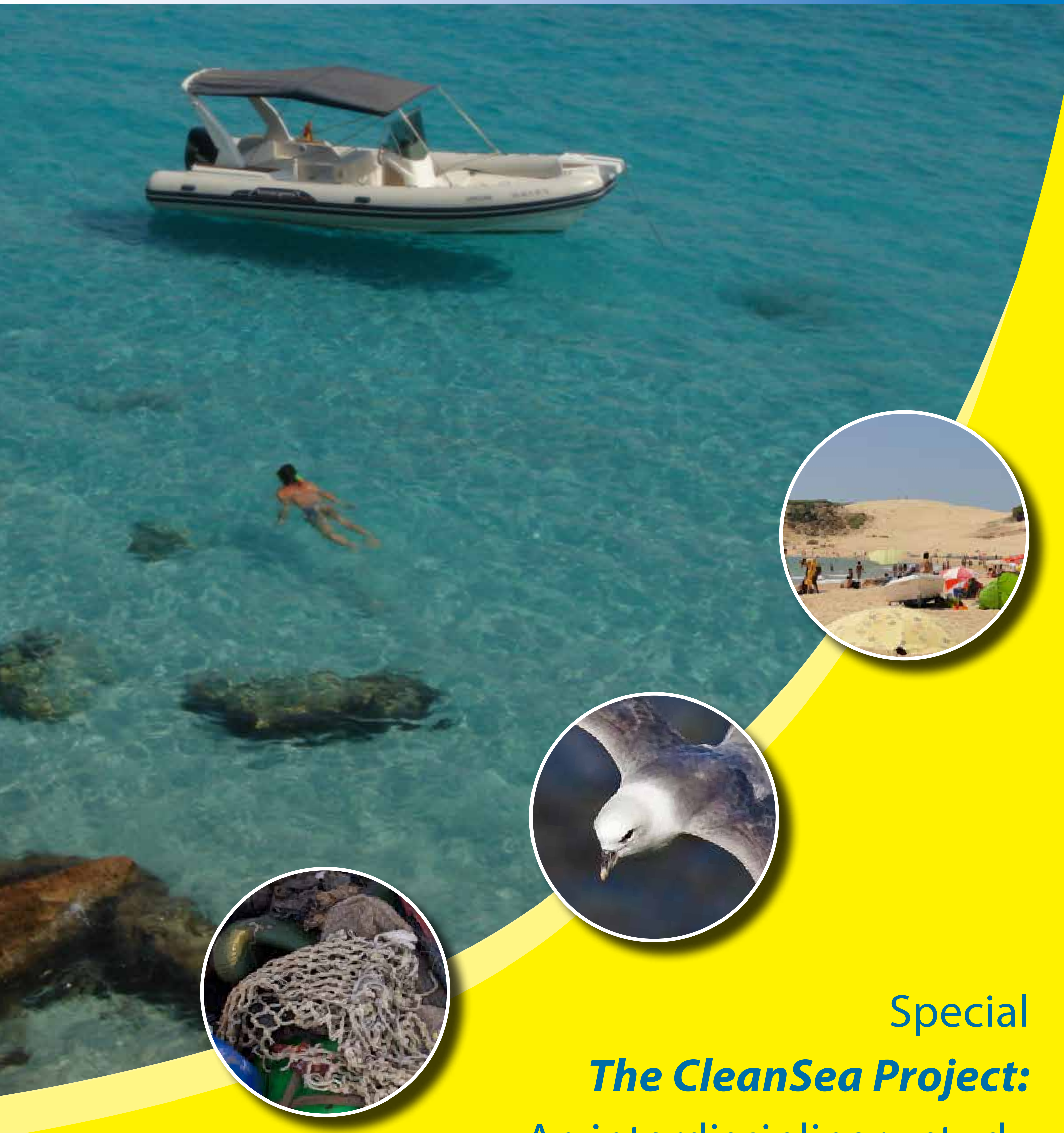
COASTAL & MARINE



Special

The CleanSea Project:

An interdisciplinary study of marine litter in the EU

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CleanSea

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Editorial

This special issue of Coastal & Marine presents some of the results that have been achieved by the CleanSea Project, the first European Framework Programme (FP7) research project aiming to support European efforts to reduce marine litter to keep European seas clean, healthy and productive. This entails improving the knowledge and understanding of marine litter composition, distribution and impacts and identifying a mix of strategies and measures to abate this problem.

One of the striking features of the CleanSea Project is the interdisciplinary and collaborative research, which you'll find reflected in the spirit of the pages you are about to read. With contributions from governance experts, environmental economists, legal experts, chemists, biologists, engineers, civil society actors, consultants, municipal government civil servants and ourselves, representatives of the marine-focussed NGO, EUCC Mediterranean Centre, there is no lack of diversity in the approach to studying marine litter. In this special issue you will find articles on everything from novel microlitter sampling techniques and biota-litter interaction data from the field and laboratory, to specific examples of economic costs of marine litter and governance gaps, to good practices.

This magazine is the result of a joint effort from researchers all over Europe and stakeholder engagement via the CleanSea platform that has been active in the four regional seas.

Through this special issue magazine we would like to share a selection of the output on a variety of aspects of the marine litter research going on in different regional sea areas within the CleanSea Project. There is still a lot more to come so we warmly welcome you to stay tuned (www.cleansea-project.eu, Facebook, LinkedIn). CleanSea is committed to making the most out of the European funds made available for our research and to ensuring that results are broadly disseminated to interested stakeholders and the general public.

We hope you will enjoy reading this issue. Please do not hesitate to contact our CleanSea team to learn more and develop collaborations.

Pedro Fernández and Carolina Pérez
EUCC Mediterranean Centre, Spain
CleanSea Project Partner, Communication work package leader

Coastal & Marine Union (EUCC)

The Coastal & Marine Union is dedicated to conserving and maintaining healthy seas and attractive coasts for both people and nature.
EUCC's mission is to promote coastal and marine management that integrates biodiversity conservation with those forms of development that sustain the integrity of landscapes, the cultural heritage and the social fabric of our coast.

EUCC advocates best practice by developing coastal and marine policies, mobilising experts and stakeholders, and providing advice, promoting capacity building actions and information.

EUCC's activities range from innovative policy advice (e.g. ICZM progress indicators and sustainable development indicators) to involvement in initiatives aiming at the improvement of access to coastal information and knowledge (e.g. distance learning training packages), and field projects combining coastal and marine biodiversity conservation and sustainable development.

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Content

SEVENTH FRAMEWORK PROGRAMME

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Foreword

Lex Oosterbaan

Coordinator Implementation
MSFD Marine Litter Ministry of Infrastructure and the Environment of the Netherlands

Chair of OSPAR EIHA Committee
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The Netherlands, a country with a long and distinct relation with the sea, is now facing a growing issue at local, regional and worldwide scales: marine litter. The standpoint of the Dutch government is that litter does not belong in the sea, and that is reason enough to take measures to mitigate marine litter at every opportunity.

At the European level, the Marine Strategy Framework Directive (MSFD) is a driving force for Member States to achieve what is termed Good Environmental Status (or GES) in 2020. In terms of marine litter this means that "the characteristics and the amounts of marine litter do not cause harm to the coastal and marine environment". The MSFD cycle consists of Member States preparing an initial assessment of marine litter (2012), a monitoring plan (2014), and this year we in the Netherlands are working hard on a program of measures to reduce marine litter that is to be implemented in 2016. The development of the program of measures in the Netherlands is a collaborative process with input from a diverse array of stakeholders, including CleanSea researchers.

It is essential that for monitoring and assessment and the implementation of measures coordination takes place at a regional level. Therefore, we welcome the adoption of the Regional Action Plan Marine Litter by the OSPAR Commission in 2014 as well as the development by OSPAR of common indicators.

As implementers of the MSFD in the Netherlands, we at the Ministry of Infrastructure and Environment recognise that research is needed on distribution, impacts and effects of marine litter as well as on how measures to reduce marine litter could work. Additional information will be needed for the new cycle of the MSFD that is scheduled to start in 2018, especially in relation to microplastics. We know that the marine litter issue is not only an environmental one, but also economic and social. We need a better understanding of the extent of the impacts, what should we measure, and especially what should be done to further decrease marine litter levels. Implementing the MSFD not only helps us clean our seas but also forces us to develop a greener economy, which is good news for future generations.
I welcome this special issue of Coastal & Marine showcasing a variety of CleanSea Project results and hope it will be of interest for the European audience.

Mussel beds in the Dutch Wadden Sea © Joos Versfelt

A plastic bag is suspended in the ocean © Patrick Kelley Worldwide Photographer/Marine Photobank

The CleanSea Project: Towards solutions to the 'wicked problem' of marine litter

A complex problem like marine litter we can easily label a *wicked problem*: it's a symptom of another problem, resistant to analysis and solutions. A proposed 'solution' may unintentionally create another problem due to complex and poorly understood feedback loops and quirky behavioral economics. The common approach is to: signal the problem, identify the practices that could solve it, make these practices known to the actors involved, and try to convince the actors to support the right practices (Harich 2010). This can work for simple problems. It is not guaranteed to succeed for complex ones like marine litter – an issue interlinked to many aspects of the greater sustainability crisis. We can only hope to do the things we see, and there are many aspects of marine litter that we cannot yet understand or even see. *Things are not always as they seem*; the first appearance deceives many is as true today as it was in ancient times. There is more than one answer to reducing marine litter, and many of those answers are carefully hidden.

The CleanSea Project is addressing many branches of the marine litter problem. We are analyzing marine litter distribution, fate and biological and socio-economic impacts. We are identifying good practices through research and stakeholder engagement and disseminating them in the hope that the ideas will be picked up by the actors who can implement and scale them up. These are important steps to be taken. While tackling the various branches we are trying - as daunting as it may be - to pay attention to the root causes of this problem: deep and powerful drivers of marine litter. Under these forces, we produce an enormous amount of synthetic materials and technical nutrients that are incompatible with ecosystems. These materials, and the energy imbedded in them, enter a linear economy and are lost. Most of the material never makes it back to the factory where it came from.

Corporate, government and civil society sponsored litter awareness programs date back to the early twentieth century. But there is powerful resistance to changing the practices that are driving the longstanding littered state of our seas.

1950s anti-littering campaign poster, before plastic packaging trumped paper.

We talk of innovation mostly in the sense of (quick) technological fixes for marine litter, such as biodegradable latex balloons or producing jeans from PET recovered from the oceans. But to what extent is the problem solved by technology alone? What we might need now is more *social*, *cultural* and *political* innovation. And if you look, you will see this happening.

The CleanSea Roadmap now under construction will present ideas for regulatory and economic instruments with which Member States and the Commission can effectively reduce marine litter, but there will be bottom up co-management approaches presented as well. There is plenty of low-hanging best practice fruit waiting to be picked across the waste hierarchy spectrum, such as app-based awareness raising campaigns, to recyclability by design, to the volunteer beach litter recovery projects. There are some interesting branches further up in the canopy to share too, including companies that are working in the circular economy, using business models that are regenerative and litter-free by design. We will attempt to address the questions lingering near the roots of the problem, such as the large systemic forces that are resisting marine litter problem resolution. Perhaps as important as signaling the marine litter in the sea, is signaling where these forces are in the system so we can begin to address them effectively. These are systemic barriers to Good Environmental Status for marine litter in European seas, and they are costing Europe's coastal communities and maritime, fisheries and tourism sectors millions in damages. With a better and braver understanding of what's keeping the seas littered, we help clear the way for transitioning to a restorative, prosperous economy, healthy seas and healthy citizens. This is part of the long term vision of CleanSea. It seems like a long shot, but we need not underestimate the power of human ingenuity and spirit. It's possible to someday have a truly Clean Sea again.

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Analysing marine litter levels in organisms

Microlitter in invertebrates along the freshwater – marine transect

A wide variety of marine organisms ranging from zooplankton to whales can ingest microlitter, the fraction of marine litter consisting of microscopic particles. That is not the only way microlitter can enter an organism; it may also be taken up by the gills (see page 8). When a predator consumes microlitter-contaminated prey, microlitter in the prey is transferred to the consumer. A full body analysis of microlitter in organisms in the food web allows for the study of microlitter uptake and the amount of microlitter that is available for transfer via the food chain.

In this investigation, new techniques for extracting microlitter from biota were used to analyse environmental samples of invertebrate species such as mussels, sponges, snails, crabs, brittle stars, anemones and isopods. Study sites in both freshwater and marine ecosystems in the Netherlands were selected to enable a comparison of microlitter concentrations in biota these distinctly different habitats. Water and sediment samples were also collected. Samples locations included coastal areas, harbours, lakes and canals around Amsterdam and Rotterdam. All sampling sites investigated were impacted by microlitter, reflecting the ubiquitous nature of microlitter as an environmental contaminant. Microlitter between 10 and 5000 µm were included in the survey. The average length of the particles was found to be around 200 µm with a median of 50 µm. The average lengths were slightly higher in sediment and water samples than in biota. Blue particles and fibers were common in all matrices (Fig. 1).

About a thousandfold higher amount of microlitter was typically found in biota compared to surrounding waters and sediment. The analysis showed that 9 out of 10 species contained microlitter and microlitter was found in 85% of the samples analysed. Several of these species have not previously been investigated for microlitter, for example the filterfeeding brittle stars which contained the highest average amount of microlitter. Other filter feeders also displayed a high accumulation of microlitter.

Many of these litter particles are likely to be excreted by most organisms, although they may affect feeding. Once inside an organism some particles, particularly if small enough, could be translocated to other parts of the body where they may or may not cause a toxic response. Aside from the potential particle toxicity of microlitter, there is concern about effects caused by toxic chemicals absorbed into or gathered on the surface of plastic microlitter (see page 7). We are only starting to understand the effects that microlitter uptake has on different organisms and ecosystems.

This study demonstrated that the wide distribution of microlitter is not limited to species inhabiting the marine environment. Freshwater invertebrate species can also be heavily exposed to microplastic contamination. Implementation of future microlitter research and monitoring programs will be necessary in order to understand the full extent of how different foodwebs are affected by microlitter.

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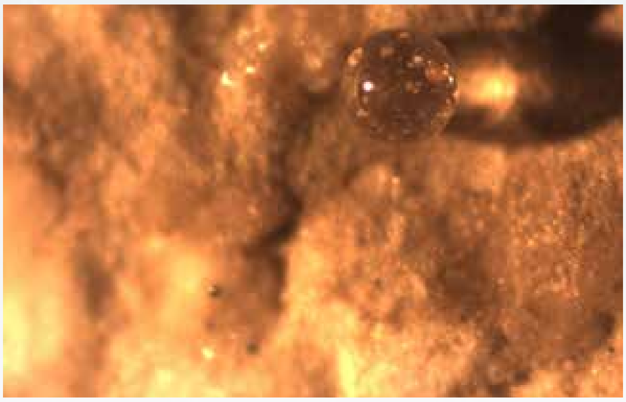

Figure 1. Microlitter detected in environmental samples. Blue particles (top-left) were found in almost 90% of the samples of biota. Pellets (right) were common in sediment samples and fibers (bottom-left) were common in all samples, but especially in surface water (>50 %). (Images: T.M. Karlsson)

Microplastics, a vector for contaminants through the marine ecosystem?

Small pieces of plastic in the marine environment can act as tiny sorbent materials for all kinds of chemicals including toxic pollutants of high concern. Especially those pollutants that do not dissolve easily in water tend to have a much greater affinity for plastic particles, organic matter and living things than for the surrounding seawater. In addition to the purely physical damage caused by ingestion of brittle plastic pieces, the contaminants can piggyback on the plastic particles ingested by the organisms. Once ingested, what happens next will depend on many factors. One important factor is the concentration gradient between the contaminants on the plastic and the contaminants already in the animal at the moment of ingestion. Contaminants may be released from the plastic in the digestive tract, particularly if the plastic particle is more contaminated than the animal's body. If the plastic is relatively uncontaminated, it may absorb contaminants already in the animal's body, as the transfer can work both ways. The adsorption/desorption process is also governed by the physicochemical properties of the contaminant, the polymer, the biology of the organism and the residence time of the plastic in the body.

One of the important questions addressed in the CleanSea project concerns the potential of microplastics to act as a vector for chemicals such as persistent organic pollutants (POPs) or plastic related additives to enter organisms. Two species, representing bottom and surface feeders, the Norway lobster (*Nephrops norvegicus*) and the Northern Fulmar (*Fulmarus glacialis*) were selected to investigate the impact of ingested contaminated plastic on levels of polychlorinated biphenyls (PCBs) in the tissues of the same animals under controlled laboratory conditions. Murray & Cowie (2011) showed that the ecologically and commercially important Norway lobsters are able to consume microplastics. Northern fulmars have been used for quite some time to monitor plastic ingestion by seabirds, due to their longevity and spending almost their whole life foraging off shore (van Franeker et al. 2011). Healthy, uncontaminated Norway lobsters were fed PCB-loaded plastic microspheres together with their food to assess the uptake of PCBs adsorbed to plastic particles by the animals (see Fig. 1). Two types plastic microspheres were used in the experiments, polyethylene and polystyrene. After 3 weeks of exposure, the PCB levels in the tissues of Norway lobster were quantified. The short time plastic spheres resided in the intestinal tract of the Norway lobster was sufficient to release a small amount of the PCBs from the polyethylene particles. No evidence of PCB desorption from the polystyrene particles to the lobster tissues was found. These experiments demonstrated that exposure to contaminants via ingested plastic is a complex phenomenon. Ingestion of plastic particle does not automatically mean extra chemical exposure for the organism, as these tissue analyses have shown.

In 2012 and 2013, 84 fulmars were unintentionally caught as by-catch on long-lines off the coast of Northern Norway. Liver and muscle samples were collected together with plastic particles found in the stomach of each individual by the Norwegian Institute of Nature Research (NINA). Plastic particles (including fibers) were found in 82% of the bird stomachs examined (see Fig. 2). Counts ranged from 1 to 127 pieces (0.002 - 0.725 g) per individual. Liver, muscle and plastic pieces were analysed for POP levels in selected individuals (n=30). Birds with a high, medium and no load of ingested plastic were selected for comparison. The correlations between ingested plastic and of POP concentrations between liver and plastic samples origin from the same individual, (as indicated by the r^2 value, where correlations get stronger as they approach 1.0) ranged between 0.46 (PCB153) and 0.88 (*p,p'*-DDE). No correlation between plastics and was found for PBDEs. This suggests that these animals were to a large extent exposed to these chemicals via routes other than plastic ingestion, such as through chemicals in their food and through inhalation of POPs-contaminated air.

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Figure 1. Controlled exposure area designed for microplastic research at ILVO – Belgium

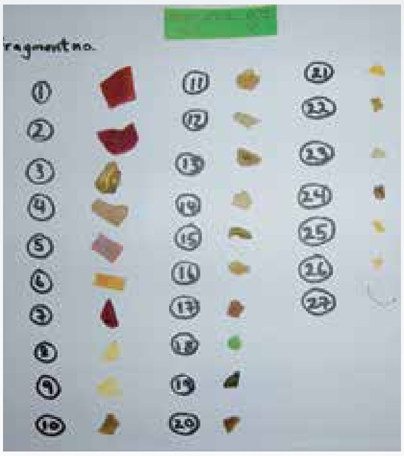

Figure 2.
Example of ingested plastic found in one stomach of Northern Fulmar.
©Håvar Syslak

Diver working around skipjack tuna fishing net © Alex Hofford/ Greenpeace/ Marine Photobank

More ways than one: uptake routes of microplastics in marine animals

From zooplankton to whales, over one hundred different marine animal species are known to ingest plastic particles. Plastic is an environmental contaminant that affects multiple levels of the marine food web. Most research to date has focused on studying the gut contents of marine organisms in order to look for the presence of microplastic particles. Recent CleanSea research has demonstrated that ingestion may not be the only route of microplastic uptake in marine organisms. The shore crab *Carcinus maenas* not only has the ability to consume tiny plastic particles, it can also 'breathe' in these particles, which become trapped on its gills (Watts et al. 2014).

Crabs breathe by drawing seawater into the gill chamber via openings between their walking legs. Oxygenated seawater then passes over their nine gills to facilitate oxygen uptake (anterior gills) and to regulate ion levels in their blood (posterior gills) (Fig. 1). We wanted to know if the gills were a potential route for microplastics to enter the crab, and if this was the case, whether the microplastics would pass straight through the crab or stick to the gill lamellae? To investigate this, we set up simple experiments, placing crabs in tanks of seawater containing particles made of polystyrene microspheres 10 micrometres in diameter. We covered the mouth parts of the crab with a small latex mask to prevent them from being able to eat any of the plastics in the seawater. This meant that the only way plastic particles could enter the crab was via the water they were ventilating through their legs. We then dissected the crabs to look for the presence of these microplastics on their gills. Polystyrene particles were detected on the gill surface of all the exposed crabs (Fig. 2) proving that crabs do indeed 'breathe' in microplastics from the seawater.

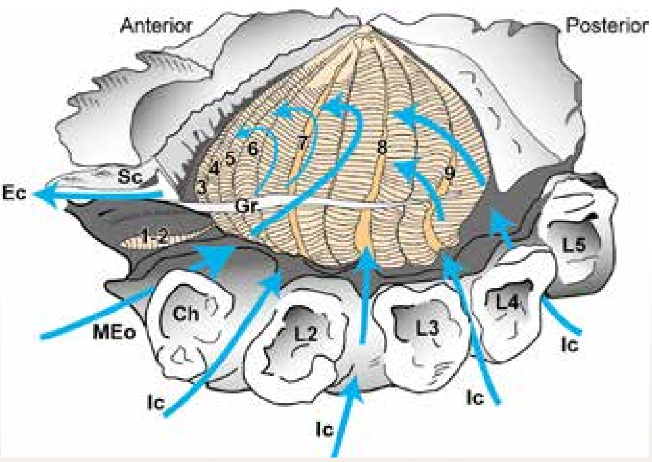

Figure 1.
A view of the crab from the left side after removal of the carapace showing the ventilation mechanism. (Image: Watts et al, 2014) Reprinted with permission from American Chemical Society.

Up to 7.7% of the polystyrene particles that had been added to the seawater was trapped by crab gills, with posterior ion regulatory

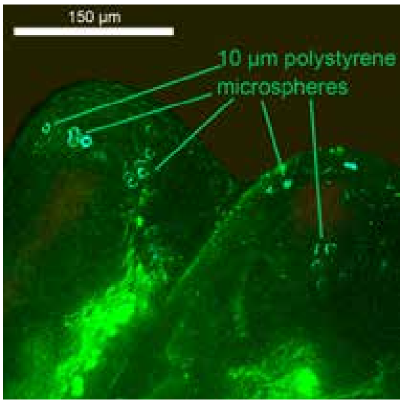

Figure 2.
Coherent anti-Stokes Raman Scattering image showing two crab gill lamellae with polystyrene microspheres adhering to the surface. (Image: A. Watts)

gills retaining more particles than anterior oxygen exchange gills. We also found that these microspheres were still present on the crab gills 22 days after exposing them to the particles in the seawater. What effects tiny pieces of plastic on crab gills might have is still not understood, however any interruption of gill tissue ion channels could impair the crab's tolerance of the wide range of salinities it experiences in its habitat.

Scientists are now finding microplastics in a range of other tissues of marine animals, as well as on the scales of different fish species collected from the wild (Tang et al. 2015). The authors suggest that mucus on the exterior of fish scales could be acting as adhesives for plastic particles. Crab gills also contain a thin mucus layer. This raises the question are biological surfaces coated in mucus more susceptible to microplastic contamination? Mucus in animal systems is a barrier to protect the animal from foreign bodies and substances, trapping viruses and bacteria before shedding the uppermost mucus layer and thus removing the foreign materials. This may be the animal's first line of defence against microplastic.

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Northsea Crab **Carcinus maenas** *© Powerhauer. Creative Commons License*

Studying biological impacts of marine litter levels

Bacterial diversity analysis of plastic litter in the North Sea

Microscopic organisms in the marine environment colonize various available substrates in the sea, forming a biological layer known as a biofilm. Bacteria and diatoms, a type of unicellular algae, are microorganisms that readily colonize plastic debris in the marine environment. This colonization has both benefits and drawbacks. On the one hand many of these microorganisms play important roles in marine ecological systems, and some may even be able to adapt and develop plastic or plastic additive degrading capabilities, thereby mitigating part of the plastic pollution problem (Zaikab 2011; Ghosh et al. 2013). On the other hand, these hitch-hiking organisms, if pathogenic, can result in risks especially in coastal zones. Invasive species may also use the plastic as a transport vector (Harrison et al. 2011).

Research into bacterial colonisation of plastic took off slowly four decades ago but is now growing exponentially. Zettler et al. (2013) showed for the first time which bacterial species were able to colonise plastic. The bacterial community on floating plastic debris was different to that in seawater and thus considered plastic as a new bacterial habitat in the marine environment: "The Plastisphere". Additionally, different communities appeared on different polymer types, suggesting that bacteria could have specific preferences for a particular substrate type.

In CleanSea, benthic plastic litter, seawater and sediment were sampled from five different areas in the Belgian part of the North Sea. Bacterial communities living on these different substrates were analysed using the innovative V3-V4 16S rDNA amplicon sequencing. Bacterial communities in seawater and in sediment were significantly different from those on plastic, which supports the concept of plastic as a microbial habitat in the ocean. Bacterial species, such as *Vibrionaceae*, were only detected on plastic, but not in seawater. This species may be using plastic as a transport vector.

A high diversity in bacterial community composition was observed among the collected plastics. Location-dependent environmental factors (e.g. fluctuations in salinity), plastic-related factors (e.g. type of polymer, presence of additives) and differences in biofilm formation stages were hypothesized to be important factors impacting the diversity in bacterial communities of plastic. To explore the influences of these potential driving factors further, a CleanSea experiment is being conducted where polyethylene fragments from sheets and 'dolly rope' are exposed on the open sea for one year (Fig. 1). Two sampling locations on the North Sea (background picture) and two plastic sample shapes are being used to test this hypothesis.

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Power offshore wind farm in the concession area on the Thornton bank in the North Sea © ILVO technicians

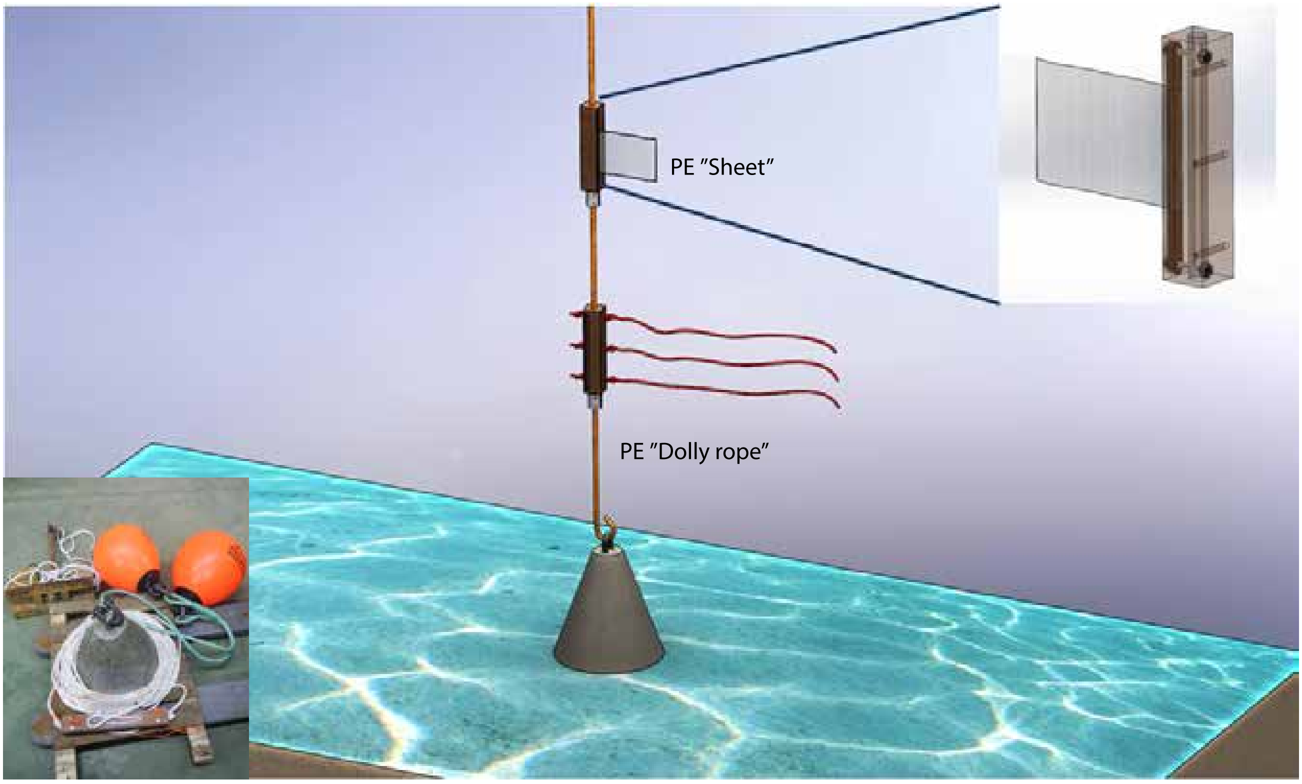

Figure 1. Exposure set-up of polyethylene (PE) 'dolly rope' and sheet for the evaluation of microbial colonization (© ILVO technicians)

Do microplastics affect marine ecosystem productivity?

Marine and coastal ecosystems are among the largest contributors to the Earth's biomass generating capability, also known as 'productivity'. We owe this productivity to algae (mainly phytoplankton), which are the *primary producers* at the base of the marine food web. Marine algal productivity may be negatively affected by plastic particles called 'microplastics,' generally defined as maximum 5 mm in size down to the nanometer scale (see page 11). Microplastics in the sea potentially threaten an important source of the world's biomass. Negative effects on algae that e.g. reduce their abundance, may in turn reduce growth and fitness of the *secondary producers*, animals which feed on algae (e.g. zooplankton). Microplastics may also *directly* affect the secondary producers, as has been reported by CleanSea partners (see page 6 and 8) and others (Wright et al. 2013, Cole et al. 2013). Any changes in secondary productivity may affect consumers at higher levels in the food web, including fish, birds and marine mammals.

Even when experimental results indicate negative impacts of microplastics on individuals of algae and zooplankton species, it is difficult to understand how these impacts could have an effect on the ecosystem level. An ecosystem can be described as a complex set of interactions among organisms, nutrients and the abiotic environment, through which energy flows and nutrients are cycled. Due to the sheer complexity of feedback loops and flows in ecosystems and the reductionist scientific approaches with which we study them, it is a major challenge to trace the impact of a single contaminant class at ecosystem level based on toxicity data for individuals of a tiny fraction of the total species present. Another major challenge is that laboratory toxicity experiments do not take into account the large spatial and temporal variations in microplastic concentrations and environmental conditions under which the ecosystem operates. Such variations may be relevant for the degree of impact at the ecosystem level. Laboratory toxicity experiments also do not yet test the effects of microplastics at the level of the population of a species, and do not factor in transport processes by which a population may be diluted or recolonized. Marine ecosystem models may help to address these issues by bringing together a wide range of variables, biogeochemical and transport processes and marine system knowledge from multiple disciplines. Therefore they capture important parts of the complexity necessary to predict impacts at the ecosystem level.

In CleanSea we used a modelling approach to estimate the impact of microplastics on ecosystem level productivity. For this we extended the Delft3D-GEM ecosystem model for the North Sea to include zooplankton on the basis of Dynamic Energy Budget theory (Kooijman 2011). Benthic organisms were not explicitly included, since most of the productivity in the North Sea takes place in the pelagic phase. Spatially and temporally varying microplastic concentrations were included by means of a forcing function on the basis of designated model results (Stuparu et al. 2015, and page 16 in this issue). Impacts of microplastics on relevant process parameters of algae (respiration rate[1]) and zooplankton (calorie ingestion rate) were calibrated based on data from literature, and were implemented in the model. With this modified model set-up, various runs were performed and resulting productivities were compared to those of the base model without microplastic.

The model output predicted that effects of microplastics on algal biomass are negligible. Model tests confirmed that this result is not very sensitive to the degree to which the model links microplastics exposure to increased algal respiration rate. On the one hand, this stems from the fact that the microplastic concentrations used in the model calculations are smaller than those reported to elicit effects on algae in laboratory experiments. On the other hand, an increase in respiration rate caused by microplastics is only relevant during specific but rare periods when nutrients are not growth-limiting in the North Sea.

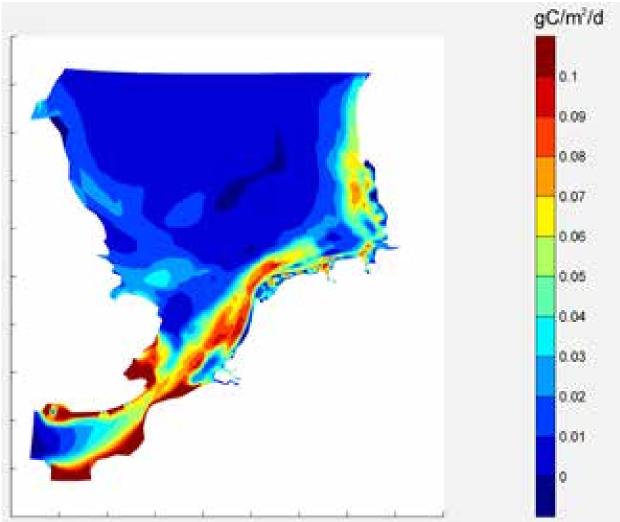

Figure 1.
Annual mean secondary productivity [gram carbon/m²/day] as modelled by the Delft3D-GEM model for the North Sea.

In contrast, the model predicted that direct effects of microplastics on zooplankton would considerably reduce zooplankton biomass and productivity (Fig. 1). In the productive (mostly coastal) areas the reduction in secondary productivity was predicted to be up to 5%. In less productive (off-shore) areas the reduction in secondary productivity may even be as high as 10%. It should be noted that model outputs were based on various assumptions and uncertainties. To reduce these uncertainties, future modelling studies should focus on improving the accuracy of modelled microplastic concentrations, the modelled zooplankton biomass, and calibrated relations between microplastic concentrations and impacts. The current model could be further extended to include impacts on benthic productivity. Although this comprises a relatively small fraction of the total marine ecosystem productivity, the benthic communities occupy a habitat with relatively high microplastic exposure concentrations and thus biological impacts on the seabed might be still be felt at ecosystem level. Finally, the model could also be extended to include direct impacts of microplastics on growth, survival and reproduction of higher trophic levels taking into account bioaccumulation and trophic transfer mechanisms.

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[1]The algal respiration rate refers to rate of oxygen consumption by algae, a process that oxidizes organic carbon molecules in the algae, enabling algal growth and producing carbon dioxide and water.

Photosynthesis as usual for three species of microalgae exposed to plastic particles

With plastic particles widespread throughout the marine environment, it is important to assess the impact on the primary producers of our oceans, the algae. Marine algae sequester CO_2 and produce an estimated 70-80% of the oxygen that we breathe on earth. Most of the ecotoxicological studies on plastic particles focus on the animal kingdom to date. We investigated the effect of plastic particles on microalgal photosynthesis and growth. A recent study reported that exposure to charged nano-sized plastic particles hindered microalgal photosynthesis, possibly through the physical blockage of light by the nanoparticles (Bhattacharya et al. 2010). With this finding in mind, we hypothesized that shading (reduced access to light) would be a likely mechanism by which both charged and uncharged plastic particles could negatively affect photosynthesis and thereby microalgal growth.

The marine microalgae *Dunaliella tertiolecta* was exposed to different sizes of uncharged polystyrene beads, 0.05, 0.5 and 6 micrometer (µm), for a period of exactly three days whereupon the effects on photosynthesis and growth were determined (Fig. 1).

The algal photosynthesis activity was measured by Pulse Amplitude Modulation (PAM) fluorometry. To measure algal growth, the flow cytometry technique was used to count cells. We also tested the effects of 0.5 µm carboxylated (negatively charged) polystyrene beads on the photosynthesis activity of *Dunaliella tertiolecta* and two other species including the freshwater algae *Chlorella vulgaris*. The photosynthesis of *C. vulgaris* was also reported by Bhattacharya and co-workers to be negatively impacted by both positively and negatively charged 0.02 µm polystyrene beads.

None of the particle types and sizes tested on the microalgal species in our experiments had an effect on photosynthesis. Nevertheless, microalgal growth was negatively affected by polystyrene particles, but only at high particle concentrations (250 mg/L). We currently have no existing evidence for such high concentrations of plastic particles in the marine environment. The study further concluded that the effect on microalgal growth at this high concentration increased with a decreasing particle size, suggesting that smaller-sized particles are more harmful for microalgae compared to larger-sized ones.

Besides direct effects of plastic particles on algal function by e.g. shading, other types of effects might also have occurred, including chemical toxicity. Virgin polystyrene beads used in exposure experiments could possibly be contaminated with chemicals which can leach out into the medium during exposures, e.g. additives and residual and toxic monomers[1] (styrene is known to negatively affect microalgal growth, Cushman et al. 1997). Further concerns for chemical toxicity of virgin microbeads[2] were raised in the preliminary results with fertilization bioassays with sea urchins conducted at the Spanish Institute of Oceanography (IEO, Murcia Oceanographic Centre) in Spain within the CleanSea Project. In this test, polystyrene particles (6 µm, uncharged) elicited a toxic effect on the fertilization rate of the sea urchin eggs in a dose-dependent manner, but in absence of visible interaction of the particles with the egg membranes.

On basis of the results with microalgae and sea urchins, further experiments are planned to test for additional unknown chemicals present in the polymeric[3] materials used. The modes and mechanisms by which micro- and nanosized plastic particles can exert toxicity to marine organisms is a matter of importance that will take time and a concerted effort by the research community to adequately elucidate. Plastic materials are always a mix of polymers and other chemicals, either added during production (the additives and residual monomers) or sorbed to plastic at a later stage of the life cycle. Real-life toxicity scenarios involving plastic particles are expected to be in fact 'mixture toxicity' scenarios, in which multiple pollutants can act through both particle and chemical toxicities at the same time, sometimes in a synergistic or an antagonistic manner.

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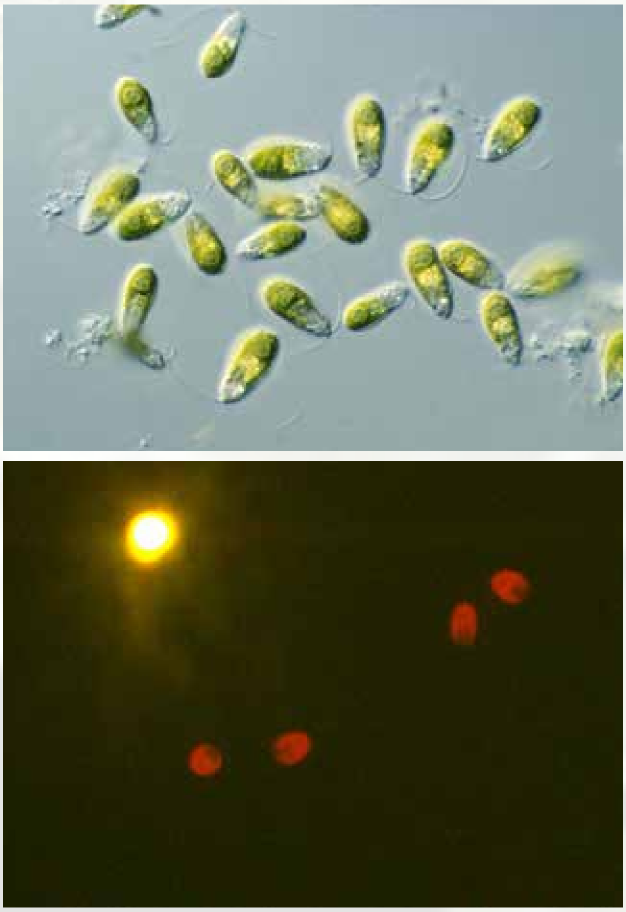

Figure 1. Marine microalgae (*Dunaliella*) under the microscope, top (photo: CSIRO science image library) and algae in the CleanSea experiment exposed to microscopic plastic particles, bottom (Photo: P. Redondo-Hasselerharm).

[1]The word 'monomer' refers to the small molecular repeating subunit in long chains of the macromolecules called polymers.
[2]The qualification 'virgin' refers to materials made of pure polymers, (i.e. raw materials of plastics), before additives and fillers etc. are added or compounded into the material. Residual monomers, catalysts and other impurities may be present in these raw materials.
[3]The polymeric components of plastics are important building blocks of the plastic material. Polymers combined with chemical additives give plastic materials their properties and functions.

Algae in the CleanSea experiment exposed to microscopic plastic particles © P. Redondo-Hasselerharm

Innovative microlitter monitoring techniques

Hyperspectral imaging and multivariate data analysis for polymer identification

Microplastic analyses of environmental samples are often based on visual identification of the particles using a light microscope. To avoid risk of visual misidentification, there is an increased interest in different spectroscopic techniques such as near infrared (NIR), Fourier Transform Infra-red (FTIR) and Raman, which can identify the polymeric component of plastic particles. The polymer is a long chain macromolecule, and a major component of the plastic material. Common polymers, or resins as they are sometimes called, include famous substances like polyethylene, polypropylene and polyvinyl chloride, etc. Plastic materials also contain chemicals added during production to give them their functionality. These are called plastic additives. The analytical techniques involved in measuring microplastics to date consist of weighing and/or counting the individual particles, and identifying the plastic type contained in the particle. Some studies examine the chemicals that leach out of the plastic materials. But much work remains to be done on the polymer identification in environmental samples, particularly of small plastic particles.

In CleanSea, researchers are currently working to create a more objective and faster polymer identification system using hyperspectral imaging techniques (Grahn and Geladi, 2007; Geladi et al. 2010; Geladi and Grahn, 1996) (Fig. 1).

Figure 1.
One of the methods being evaluated for hyperspectral image analysis. Images are collected using a linescan of the sample placed on a conveyor belt. © Schönlau

Polymer identification is important not only for quantification, but also holds clues to possible sources. Microlitter such as microplastics are prevalent in the environment, but little is still known about the sources and their relative impact. Different polymers may have different effects on the environment (Lithner et. al., 2011) and identification of their relative prevalence is therefore important for risk assessments.

With hyperspectral imaging a scan of a sample provides a digital image, where each individual pixel also contains a third dimension of information, in the form of a NIR spectrum (Fig. 2). Due to the large nature of these datasets, multivariate statistics such as principal component analysis and selected classification methods are useful for data handling and to separate the data of the plastic particles from the background interference. Through combining the analysis of marine samples with analysis of reference polymers the unknown, sampled particles will group together with their respective polymers in clusters (Fig. 3). A confirmation of the polymer type can be done through comparing their individual NIR spectra afterwards.

Current tests are being performed for microplastic particles down to 300 µm, which covers the sizes that are often studied in surface water samples. Recent testing on marine samples showed promising results for this technique. The aim is to create a semi-automatic and objective identification system through the use of chemometric models built with multivariate statistics of reference materials.

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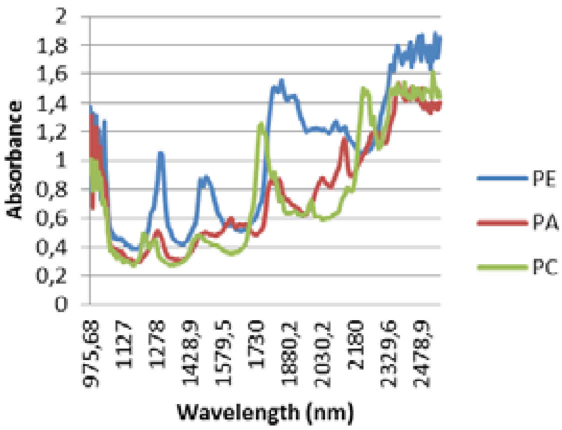

Figure 2.
Spectra from reference polyethylene, polyamide and polycarbonate as measured with the hyperspectral imaging system.

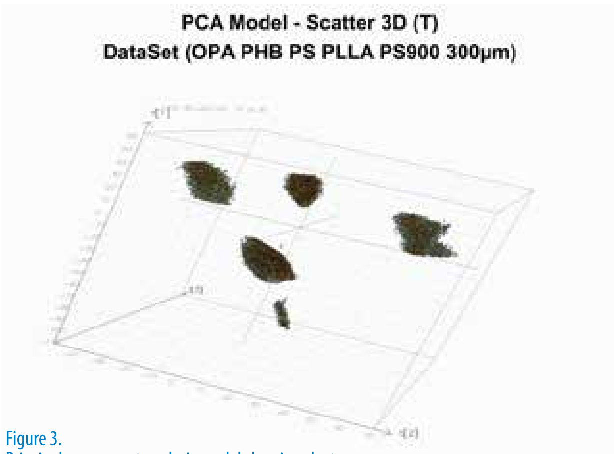

Figure 3.
Principal component analysis model showing clusters of 6 different plastic polymers. © T.M. Karlsson)

A new sampling device for high quality microlitter sampling

Researchers and Member States implementing Europe's Marine Strategy Framework Directive are currently searching for ways to accurately measure and monitor levels of marine microlitter - especially microplastics - in the sea. A team comprised of a Danish marine equipment company and university scientists from Sweden and the Netherlands working in CleanSea Project has been developing a new marine microlitter sampling tool that can be used for this purpose.

Many sampling cruises to date have collected microlitter from the sea surface using surface net trawls, normally with around 300-micron mesh sizes and consequently targeting particles larger than 300 microns. Other studies have looked at microlitter collected at a depth of 10 metres using continuous plankton recorders attached to ships. These devices sieve water through a 280-micron mesh, and are designed to make more accurate seawater volume measurements than are possible for the surface net trawls.

The new CleanSea sampling device has lots of advantages over older sampling devices, including: no plastic parts or plastic nets, deployable at sea surface or at other depths (as desired), accurate seawater sample volume measurement, and the option to sample microlitter down to 50 microns, which is smaller than the conventional 300-micron particle sizes targeted by other methods. Smaller particle size categories are relevant for some research purposes because marine invertebrates and especially filter-feeders target these smaller size ranges for their feeding

Figure 1. Microlitter sampler developed by KC Denmark in cooperation with CleanSea scientists (Image: L. Christensen).

(see page 6). Recent research has shown higher abundance of smaller microlitter particles than larger particles, and the smaller fractions of microlitter can be of interest for risk assessment, monitoring and certain research questions. The CleanSea sampler has been tested with 50-, 300- and 500-micron mesh sizes, which are easy to alternate between.

The robust stainless steel device and can pump 24,000 L of seawater per hour. Laboratory tests show that volumes decrease to 17,000 L/h when there are high levels of organic material in the seawater. Laboratory tests indicated high precision and limited microlitter loss from the device, which is considered to be another improvement over traditional trawls. The sampling rate of the device is sufficient to sample thousands of litres of seawater for microlitter within minutes. This is practical for deployment on research ships and on regular national monitoring cruises during which many different types of samples usually need to be taken at each sampling station. In contrast, manta trawls and other net trawls typically require a ship to reduce sailing speed significantly over the course of each trawl, in order not to break the nets.

But developing the microlitter sampler hasn't been easy, even for this experienced team. In depth discussions with a range of CleanSea partners in the design phase were followed by a series of laboratory and field testing activities with an initial prototype, which was subsequently improved and adapted in designing the final microlitter sampler device. It is being tested for field functionality and surveys in CleanSea.

Research and monitoring microlitter in seawater normally requires the sampling device to enable accurate quantification of relatively small differences in microlitter concentrations between different places and between the different points in time that a single location is sampled. This means that the volume of seawater sampled needs to be accurately known. This allows spatial and temporal trends to be detected for microlitter research and monitoring purposes, and it helps when validating microlitter models, such as described on page 15.

The new CleanSea microlitter sampler was designed as a high quality tool for the contemporary microlitter sampling toolbox. The aim was to help increase our understanding of microlitter and increase the value of microlitter monitoring data for the marine environment.

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Testing CleanSea pump in the Baltic Sea © Pangaea Exploration

Our plastic-littered seas and how they transition from 'extra chunky' soup to a plastic 'bouillon'

The plastic materials that make up a large proportion of marine litter are expected to slowly degrade in the sea by photo-oxidation by ultraviolet light (UV), thermo-oxidation, biodegradation and physical shearing (e.g. through waves, friction with sand, or consumption by animals). These processes, which tend to be accelerated by the leaching of additives like plasticizers and UV stabilizers, initiate plastic fragmentation into tiny particles, invisible to the naked eye. The size of the plastic particles is important because it impacts their potential physical, chemical and ecological effects. Think of entanglement of marine fish, birds and mammals, versus ingestion, or micro-particle accumulation in mussels and zooplankton. Fragmentation also affects plastic litter transport through marine systems. Smaller particles have a larger surface area: volume ratio, decreasing their sinking rate. The surface area is also important for biofouling[1], causing changes to the density and hydrodynamics of plastic litter.

Policy makers and stakeholders require information on plastics fragmentation for decision-making. Is all the macroplastic in the ocean today just 'young' microplastic? Is exposure to microplastics going to increase exponentially when all the macroplastics already emitted today have crumbled: a ticking plastic particle time bomb of sorts? If we halt plastic pollution emissions, how long before the seas and seabeds of the planet become plastic-free, via oceanic 'self-purification'? What happens to plastic when it reaches the nano-size scale – a size range, as we are discovering, likely to cause toxicity in living cells and tissues? In CleanSea we are seeking answers to the burning question, *Where does all the plastic go?* Understanding degradation[2] and fragmentation of plastic litter is a big part of that answer.

Fragmentation rates of marine plastic litter have only been roughly estimated, with rare attempts to determine loss of tensile strength or surface area (Andrady 2011, O'Brine & Thompson 2010). In fact, it is currently unknown to what extent plastic litter in the sea is converted into hazardous micro and nano-sized plastic particles, and how long it takes under ambient marine environmental conditions for plastic to be mineralized into harmless carbon dioxide (CO_2) and water. Recently, it was suggested that there appears to be a fast removal of plastic fragments smaller than a millimeter from the ocean surface water (Cozar et al. 2014). Hypothetical explanations for this observation include: sampling and analytical artefacts, selective ingestion of the size category by zooplankton, abrupt fragmentation of micro into nano-plastics, sinking due to biofouling increasing the specific gravity of small particles, or high speed mineralization of plastic particles <1 mm. Fragmentation increases surface: volume ratios of produced plastic particles, creating a larger contact area for further physical, chemical and biological reactions. Our model calculations suggest that smaller plastic particles might indeed degrade and split into smaller fragments at faster rates, but we need experimental evidence for this. Microorganisms (e.g. fungi and bacteria) that can degrade certain plastics under special conditions have been described, but we do not know if they thrive and mineralize plastic in marine environments.

In CleanSea we are also testing new methods to measure plastics degradation and fragmentation. We constructed a laboratory marine mesocosm containing a variety of conventional 'durable' and 'compostable[3]' plastic materials to see if electrical resistance measurements can be used to assess plastic degradation in seawater (Fig. 1 & 2). In the mesocosm the plastics are exposed to fluorescent light, simulating solar radiation, including UV. A water pump is used to produce a constant, mild water current. Heavy biofouling of the plastic materials occurred within several months. Electrical resistances (Ω, measured at 100, 110, 1000, 10,000 and 100,000 Hz AC currents) of the compostable plastics were about 100 times lower than those of the durable plastics. Plastics in the mesocosm showed a decrease of electrical resistance over time, indicating polymer degradation and/or absorption of seawater. Further research within CleanSea is currently underway to determine if such measurements can be a simple, cheap and easy to use alternative method to determine degradation rates of plastics in seawater.

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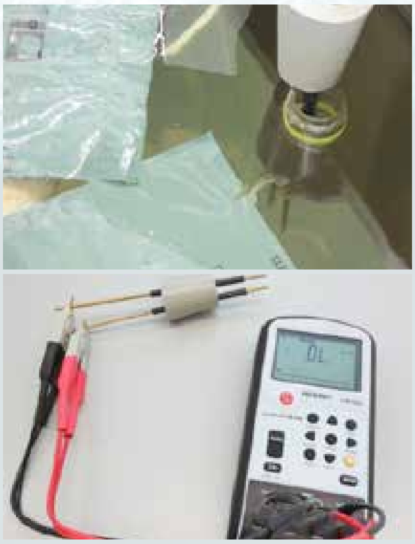
Figures 1.
Marine mesocosm study of plastic degradation in the laboratory, after startup (top) and 10 months (bottom)



Figures 2.
Test of electrical resistance measurements indicating plastic degradation

[1]Biofouling refers to growth of marine organisms on the substrate, either microorganisms or larger organisms, like mussels.
[2]Here degradation refers to the changes in physical properties of plastic such as tensile strength, colour, shape, cracking, but also chemical breakdown that reduces polymer chain length, which are important steps towards the fragmentation (disintegration) and ultimate mineralization of polymer molecules into CO_2 and water. Degradation, fragmentation and mineralization of a given plastic are processes with rates that can differ by many orders of magnitude.
[3]Plastics that can be composted through biological processes yielding CO_2, water, biomass and inorganic compounds at rates similar to other compostable organic materials, and without leaving toxic residues.

Plastic bags found floating in a bay in Greece © Gavin Parsons / www.gavinparsons.co.uk / Marine Photobank

Quantities, fate and distribution of marine litter

Where do the microplastics go?
Modelling plastic microlitter transport from estuaries to the sea

How marine litter is transported within marine systems is a complex and only partially understood process governed by parameters such as the physical-chemical properties of the litter, the point of litter emission, litter degradation rates and hydrodynamics of the marine system. In the CleanSea project, we explore the application of existing hydrodynamic models as a basis for modelling litter transport. The starting point was to model the three dimensional transport of plastic litter of defined densities, sizes and shapes. At a later stage, other types of litter can also be modelled.

The model was run in a computational grid of the North Sea domain that is affected by 17 river discharges as sources of plastic microlitter in the model. The contribution of microliter per river is proportional to the river discharge, which makes the Rhine, the Elbe and the Seine the most significant river litter sources to the North Sea. The water surface currents carry water and any suspended microlitter in a northerly direction along the Dutch coast (Fig. 1).

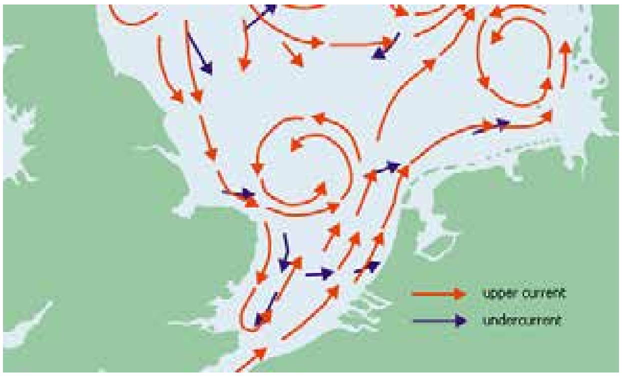


Figure 1. Patterns of currents in the North Sea (Ecomare, 2013).

Wind, flow velocity, water depth, salinity, bottom topography and other seasonal phenomena simultaneously affect the movement of the water flows and subsequently, the litter transport. Due to this complexity, in CleanSea, a phased modelling approach has been embraced, starting from fairly simple representations of litter transport, and developing into more complex descriptions. The simulation of the microliter pathways has been done using a particle tracking method.

Delft3D-Part model simulations were performed for spherical polyethylene particles with mean diameters of 10 µm, 330 µm or 5 mm (5000 µm) being emitted to the North Sea from 17 rivers at an assumed concentration of 1 g/m^3, over the course of one year (2008, Fig. 2). Polyethylene is a material with a mean density of 910 kg/m^3, lower than the average density of North Sea water, 1024 kg/m^3. There are several mechanisms due to which particles can move in the vertical: 1) the buoyancy (using the Stokes assumption, the larger the particles the larger the buoyant force), 2) the vertical advective transport and 3) the vertical dispersion. The buoyant particles are therefore expected to have the highest concentration at the water surface, with much lower concentrations in the deeper layers.

The model simulations show that the 330 µm and 5 mm sized particles are distributed further offshore in the surface layer compared to plastics with a smaller mean diameter (10 µm). This is because the 10 µm sized particles have a smaller buoyant force and therefore higher chances to reach deeper layers of the water column compared to bigger particles. Also, from the hydrodynamics, the horizontal transport in the top layer is larger than in the deeper layers. The result is reduced horizontal particle transport of the 10 µm sized particles compared to particles of a bigger size. The plastic concentration in the water surface for the 330 µm and 5 mm particles is quite similar.

We note that the density of the particles can also be influenced by other processes, such as algal or bacterial growth or agglomeration with suspended sediments, although these processes have not yet been included in the modelling process.

Current objectives within CleanSea focus on extensive analysis of the behaviour of different plastic types and linking observations with model results to advance on questions connecting area characteristics with accumulation patterns (such as distance to shoreline, sedimentation zones, gyres or eddies). Another focus will be to incorporate the litter fragmentation process in the model structure (see page 14), as it can significantly influence the abundance of plastic litter at the sea surface but also on the sea bed and as this preliminary modelling exercise would suggest, litter size is expected to have an impact on where microlitter is transported in the marine environment.

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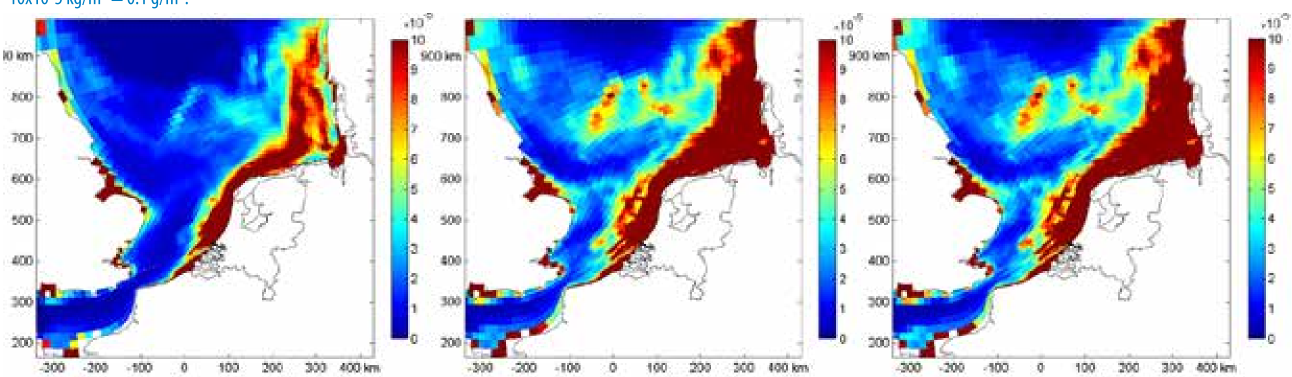
Figure 2. Model simulations comparison for different polyethylene sizes, spherical shape and mean diameter: a) 10 µm, b) 330 µm and c) 5 mm.
Mean concentration of particles at the water surface [kg/m^3] calculated on last day of a simulation run of year 2008. Maximum range colour corresponds to a plastic concentration of 10x10-5 kg/m^3 = 0.1 g/m^3.



Seabed and beach litter monitoring provides Romania with valuable baseline data

Although neither national nor regional programs are in place to monitor seabed litter in Romania, the National Pelagic and Demersal Fish Species Status Evaluation Program that uses bottom sampling trawling allowed the National Institute for Marine Research and Development (NIMRD) to collect and assess types and quantities of marine litter on the seabed. Furthermore, coastal land expeditions have been used to identify and record beach litter. In 2013, CleanSea offered NIMRD the opportunity to address a new research direction to marine litter monitoring and its impacts and drivers. In this context NIMRD is increasing efforts to conduct surveys with sampling bottom trawl for demersal fish stock assessment to monitor waste (solid or emulsion) reaching the sea from different sources (vessel traffic, oil wells, fishing activity, etc.).

Shoreline monitoring was performed along the entire Romanian coast, from Vama Veche to Sulina, on a quarterly basis through direct observations. Seabed monitoring was carried out through bottom trawl hauls at depths ranging between 20 and 80 m.

The trawl duration was 60 minutes travelling at a speed of 2.5 knots. The horizontal opening of the sampling device was 13 metres, resulting in a sampled marine area corresponding to about 6 hectares per trawl. In the period 2011-2014, 90 samples were collected, representing a sample area of over 300 ha. These were analysed in terms of marine litter types and materials as well as numbers of items. As for items, plastic is by far the most abundant material, followed by processed wood and fishing nets (Fig. 1). 2,098 kg of marine litter were collected in this period.

Regarding beach monitoring, as in many other locations, the top items were made also out of plastic. They are followed by paper and metal (Fig. 2). A total of 168,659 items were recorded in the period 2011-2014.

Seabed surveys show that the abundance and distribution of marine litter has a considerable spatial variability. Their geographical distribution on the seabed is strongly influenced by hydrodynamics, geomorphology and human factors. Major concentration is found around the ports of Constanta, Cape Midia and Mangalia. Shipping was identified as an important litter source, although the areas studied are also greatly affected by the Danube River, bringing land-based litter to the Black Sea. Fisheries related waste is also substantial, and there is some evidence that much of the derelict fishing gear litter comes from Turkish, Bulgarian and Romanian vessels that practice illegal fishing.

Along the Romanian coast, recorded litter varies notably between the autumn-spring period and the summer season, when beaches are cleaned on a daily basis. The predominant source of beach litter may be beach recreation, although the Danube contributes significantly especially after heavy rain episodes.

This experience and data has been useful for defining the national monitoring programme for marine litter in the context of the Marine Strategy Framework Directive implementation in Romania.

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[2] EUCC Mediterranean Centre, Spain

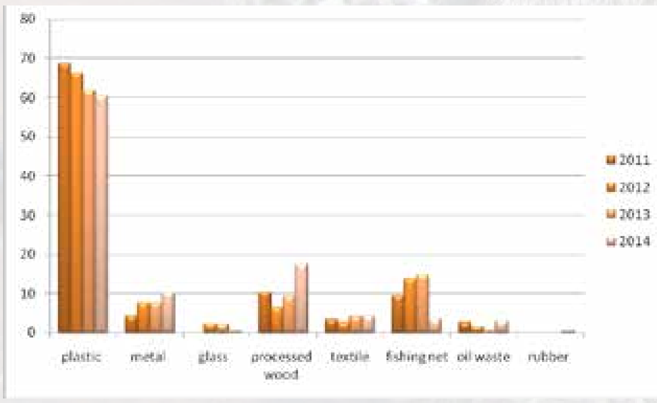

Figure 1. Distribution of marine litter per material (% of total items) in seabed samples 2011-2014 (source: NIMRD)

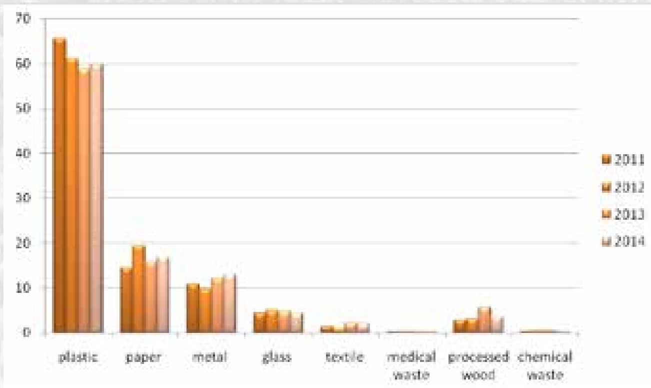

Figure 2. Distribution of marine litter per material (% of total items) in beach samples 2011-2014 (source: NIMRD)

Collected litter in the Black Sea © NIMRD

All photos © KIMO

Fishermen, waste managers and KIMO Netherlands and Belgium collaborating for a CleanSea

Data collection protocols used by CleanSea partner KIMO Netherlands and Belgium within the 'Fishing for Litter' program have been successfully adapted for the CleanSea Project. KIMO works together with ten fishing vessels which have been collecting waste at different places on the North Sea seafloor. The waste is collected in big bags by the participating fishermen who record the times and locations of the trawls corresponding to the big bag. The litter is brought onshore to one of four harbours in the south, in the middle and the north of the Netherlands. Around 300 tonnes of litter were removed in 2013. The litter 'catch' is being analysed in the CleanSea project as a seabed monitoring exercise. In the last three months of 2014 KIMO performed a trial with two fishing vessels to collect domestic waste on board of the vessels. This trial was very successful and in cooperation with ports and the Dutch government, this subject will be introduced into the OSPAR Commission Marine Action Plan.

This task of macro-litter removal and sampling in collaboration with fishermen and a local waste management company is synchronised with the hydrodynamic modelling team at project partner Deltares. A large amount of litter was removed and a large data set has been collected to be used as input for the hydrodynamic models or for the validation of such models.

The removal of litter is also part of the development of 'Green Deal' for the fisheries in the Netherlands, as part of the national programme of measures to achieve Good Environmental Status.

In this project KIMO works together with many social organisations and local governments. It started situated along the Dutch coast but the project will be extended to other European countries and marine areas.

KIMO Netherlands and Belgium is a CleanSea partner deeply committed to addressing the marine litter issue on many fronts. KIMO has positioned itself well in its CleanSea project role, and is able to make powerful contributions to seabed litter studies, policy recommendations and new measures, and is also responsible for broad dissemination activities to important CleanSea stakeholder groups.

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Socio-economic impact of marine litter

What a kilometre of littered beach can cost a community

Beach litter is not just a source of nuisance and of potential harm to marine ecosystems. It is also a significant cost item on the annual accounts of many coastal municipalities. CleanSea researchers made a comparison between the municipal clean-up costs in coastal municipalities in the Netherlands on the North Sea and in the Italian province of Rimini on the Adriatic Sea coast. Survey responses were received from seven Dutch and three Italian municipalities.

Plastics were the largest category of non-organic litter materials found in both countries. On some of the Dutch beaches, fishing gear was a dominant type of beach litter as well. The amounts of beach litter collected on Italian beaches was much higher than in the Netherlands, with two of the three Italian municipalities reporting more than 1,000 tonnes of litter per km of beach, compared to less than 100 tonnes per km of beach in most of the Dutch municipalities (litter data for 2013). This may be partly explained by the relatively high amounts of sand and sea weed included in the Italian figures.

All Italian and most Dutch municipalities have outsourced their beach clean-up activities. The frequency varies by season, with daily clean-ups being general practice during the summer. Most municipalities apply both mechanical and manual cleaning. The latter is obviously more labour intensive, but mechanical cleaning is less targeted, reducing its cost-effectiveness. Annual clean-up costs per km coastline varied between around €5,000 (Veere and Den Helder, NL) and around €115,000 (Katwijk, NL and Cattolica, IT). The costs per tonne of litter ranged from €25 (Rimini, IT) to €3,810 (Katwijk, NL). In some of the study locations, intensive litter removal activities by private parties such as hotels, beach pavilions and volunteers may partly explain the lower municipal clean-up costs.

Despite the substantial cost involved in beach clean-up, the municipalities apparently consider these to be justified by the benefits, mainly in terms of increased attractiveness of their beaches for tourism and recreation. Other motives play a less prominent role. Just two municipalities (Veere and Vlissingen, NL) mentioned the impact of marine litter on animal wildlife.

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Bulgarians value a clean beach

Coastal zones provide important benefits to people. There are families that exclusively rely on the ecosystem services delivered by the coastal environment in terms of food, recreation, and coastal protection. A growing variety and intensity of human activities threaten the provision of these services. Whether accidentally or deliberately discarded, marine litter in coastal zones damages both ecological habitats and local communities. Ecosystem services valuation can be difficult and controversial as the value individuals attach to economic and non-economic environmental assets and the tradeoffs they perceive largely differ, and their preferences are subject to change.

In an assessment of the wide socio-economic costs of marine litter, the CleanSea Project has analyzed the value of having clean beaches through a willingness-to-pay (WTP) approach along Bulgaria's Black Sea coast. A survey was performed that aimed to test the respondents' individual willingness to sacrifice something (to pay or to volunteer to clean up) for the sake of a clean beach. Being the first survey of its kind in the country, this study could serve policy makers in setting future policy priorities.

Two highly visited urban beaches along the Bulgaria coast were selected for the study. 'North City Beach' is located in Burgas, a city situated in the south in the country. 'Bunite Beach' is one of the preferred beaches in densely populated city of Varna, situated in the north. Both beaches are leased and concessionaires clean them daily during the high season.

Beach visitors including both residents and tourists were interviewed in both cities during the high season in 2014 (149 in Burgas and 152 in Varna). The target group for the study was defined as domestic summer site visitors, aged 18 and older. Out of the 563 beach visitors approached to participate in the survey, 53.5% responded positively. The interviewees sampled in each city varied in gender, age and education level. Each beach visitors' profile was associated with the individual perception of beach litter and the individual response to it – either their WTP or to volunteer to clean up.

Survey results revealed that beach litter is an important reason to avoid visiting a given beach. Litter is considered 'highly annoying' for 33% of beach visitors and 'somewhat annoying' for an additional 40-50%. When interviewees were asked about their perception of beach litter types, the most common is cigarette butts, followed by plastic bottles and bags. However, there are differences in litter types perception between Varna and Burgas (Fig. 1).

There is an evident willingness among locals to get involved in clean-up activities and to pay higher taxes for cleaning and maintenance tasks. The estimated average annual WTP per visitor for cleanup activities of marine litter in Varna and Burgas is 5.8 EUR/year and 10.0 EUR/year, respectively. Furthermore, in Varna 78% of the respondents demonstrated willingness to volunteer in clean-up activities compared to 66% in Burgas.

Research towards a better understanding of beach visitors' perceptions and willingness to contribute to a better state of the coast is needed and may be valuable for local governments planning on efficient beach management especially if research outcomes can successfully be translated into practical and coherent policy advice. Adequate policy measures to reduce marine litter in coastal zones in Bulgaria are still to be developed. These could range from public awareness raising to provision of sufficient disposal facilities.

Dariya Hadzhiyska[1]

[1] denkstatt, Bulgaria

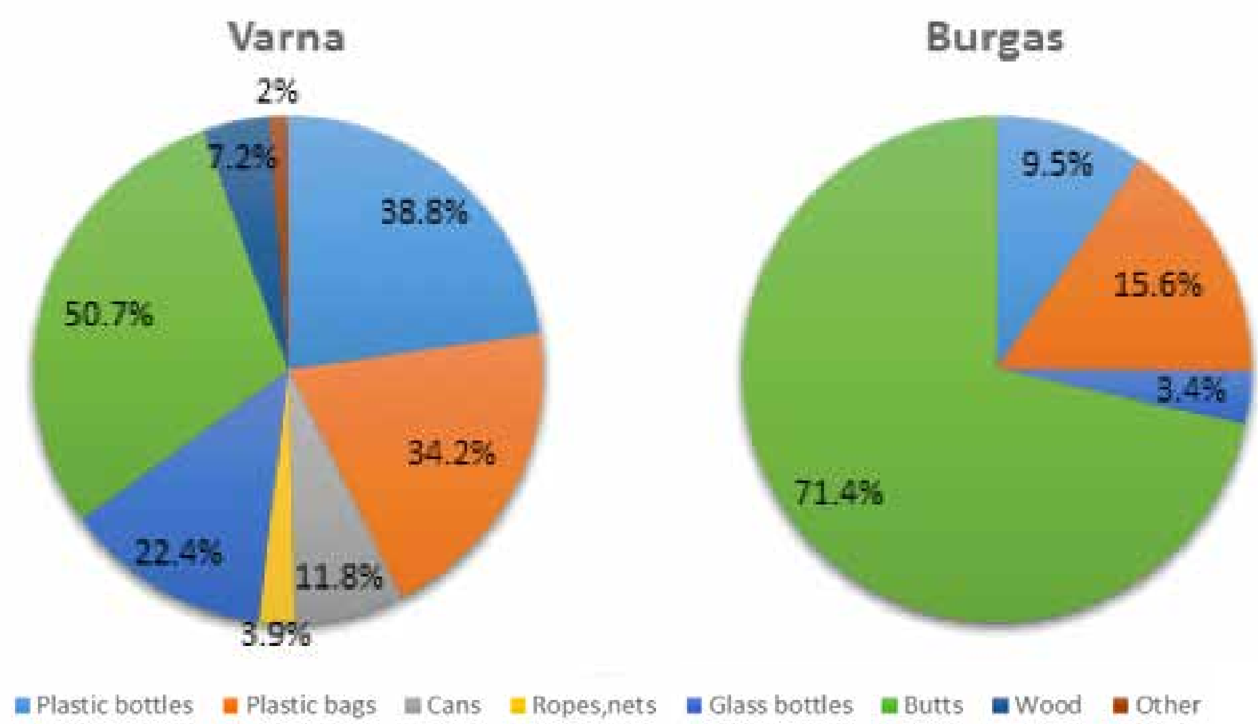

Figure 1. Perception of litter types by beach visitors in Varna and Burgas (Source: denkstatt)

Figure 1. Marine litter collected in the port of Barcelona, 9th May 2014. A. Container lifted from the pelican boat; B. Collected marine litter (total); C. Plastic bottles; D. Fish boxes; E. Aluminum cans; F. Tetra Pak packages; G. Plastic cups

Investigating floating litter within the port of Barcelona: composition, sources and economic aspects

What are the costs and problems associated with floating litter in harbours? In a single sampling of the Port of Barcelona, 2096 items of floating debris were collected weighing a total of 124 kg, at a density of 535 items/km^2. This concentration is approximately 20 times higher than the average for the Mediterranean Sea as a whole. Two important characteristics of this port may explain this observation. Firstly, a large port like Barcelona receives huge amounts of waste, both related to sea-based activities and land-based sources from the surrounding urban environment, some of which may leak out of the waste collection systems. Secondly, the Port of Barcelona is under a great littering pressure due to the largely open access of the port to tourists and citizens for recreation. Floating debris is removed daily within the port reducing the total amount of floating litter reaching the open water.

Plastic was the most abundant material collected in terms of mass, while cigarette butts were the most recurring item. Two methods were used to track possible sources: the OSPAR Indicator Item method and the Matrix Score Technique. In both cases, touristic and recreational activities were identified as major sources of floating litter within the port. Litter generated by fisheries, maritime industry and sewage systems is mainly attributable to loopholes in the waste collection process, single-use products and generally, to deliberate (illegal) or accidental waste disposal.

The Barcelona Port Authority spends around €300,000 annually to remove floating litter, which is approximately five times greater than the average clean-up spending at Spanish ports and four times more than the highest reported clean-up cost for UK harbours. The carbon footprint associated with the collection of floating debris is 38 tons of CO_2eq per year.

Policy options for improving the litter situation at the Port of Barcelona were identified and prioritized based on a cost-effectiveness analysis, linking costs to the expected reduction in marine litter. Preventative interventions were found preferable to remediation and curative measures such as water clean-up, which is relatively expensive in both economic and ecological terms. Based on the comparison of three hypothetical waste management scenarios, waste prevention policies were prioritized according to their expected benefits. The mix of policies identified addressed reducing two flows of waste: wooden and polystyrene fish boxes and plastic beverage containers. By implementing measures like bans, deposit schemes and design for reusability to abate these two flows, the port could save up to €36,000 per year in remediation costs and reduce the associated carbon footprint by 14% compared to current practises. Other measures that should be in the policy mix included public awareness campaigns and increasing the number of bins for litter in and around the port, with the possibility of improvement by upgrading them to recycling bins so that the recyclable waste materials can be collected separately. The mere presence of recycling bins in the port also acts to increase public awareness, killing two birds with one stone.

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Responses to marine litter management and governance

Let's get governing marine litter across Europe

Leadership from government is an important element in addressing marine litter problems in Europe. Each region has its accomplishments and strengths, and each region struggles with marine litter in its own ways. For instance, the two southern regional seas border with a large number of non-EU states, many of which have different cultural traditions, politics, governance systems and weak pollution control. All regions benefit from contemporary EU legislation based on the waste hierarchy that prioritizes waste prevention (Fig. 1). But because the marine litter problem still seems to be getting worse, what else can be done through good governance?

CleanSea social scientists identified gaps in the governance of marine litter in the four marine regions in Europe after reviewing legislation, reports and conducting surveys and workshops with stakeholders in selected Member States. This enabled the researchers to pull together a preliminary list of options for policy improvements. The analysis revealed a number of notable differences between regions.

North East Atlantic. The Member States studied in this region were the Netherlands, Belgium and the United Kingdom all have strong institutional capacity and waste management infrastructure. Implementation of EU legislation is a key contributor to this. However, waste production per capita is high compared to other regions, and current legislation provides insufficient incentives for waste prevention and informed consumer choice.
Major opportunities in this region include stimulating corporate social responsibility such as liability and due diligence, green technological innovations in recycling, and sustainable product development in the form of smart packaging. Improved waste reduction and recycling practices on ships and in ports can be stimulated by incentives to bring as much waste as possible to port. Voluntary implementation of better practises can also be stimulated by pacts known as 'Green Deals' between government, companies and civil society organisations.

Figure1. Waste hierarchy prioritizes waste prevention and discourages disposal in landfills. Source: Drstuey, Stannered. Licensed under CC BY-SA 3.0 via Wikimedia Commons

Baltic Sea. Germany, Sweden and Lithuania each have a certain commitment to marine litter reduction, albeit mainly indirectly through European and national waste management policies. In Western parts of the region. Performance in governing waste in general and marine litter issues in particular is significantly better than in Eastern areas due to disparities in infrastructure, capacities and technologies. Nevertheless, recent assessments of marine litter in German and Swedish waters found it to be a significant problem. There is a lack of (adequate) fines for polluters and litterers. With regards to division of administrative responsibilities in all three countries legislation is unbalanced and often unclear across the many coastal municipalities with sectoral tasks.
Major opportunities in the Central and Eastern parts of the Baltic Sea region include the support of waste management infrastructure, as well as a macro-regional approach to support awareness raising and cooperation on marine litter.

Mediterranean Sea. In this region, improvements in national waste management strategies in Greece, Spain and France were driven by the implementation of EU directives. Both Spain and France are making progress with recycling which is offset by an overall increase in the generation of total municipal waste.
All three countries rely heavily on landfills and although a significant number of illegal dumping sites are still in operation in Greece, they are due to be closed by 2018.
Opportunities in the Mediterranean include placing more emphasis on national resource efficiency. Since the economic crisis, Spain and Greece have emphasised resource effectiveness to replace import needs. France implemented a pilot system of informed consumer choice labelling in 2011 with promising results.

Black Sea. Bulgaria and Romania have adopted but not fully implemented all major European legislation to prevent and manage waste. Adequate enforcement and control by competent authorities and awareness of environmental issues are the main barriers to reducing the marine litter problems in the region. The quantities and distribution of marine litter are not as extensively monitored as in other regions, making understanding marine litter trends in the Black Sea difficult.
This region can benefit from new opportunities to raise awareness and engage the general public and the private sector in activities to abate marine litter. Complementing increased issue awareness and knowhow among professionals, this region can take advantage of opportunities to strengthen technological capacities and incentives for improved waste collection and recycling so that landfills can become obsolete.

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Learning from best European practices to reduce marine litter

Not everything related to marine litter is bad news. There is a wealth of experience to explore and share with potential users in Europe about what can be done. CleanSea researchers from denkstatt Bulgaria, Ecologic, EUCC Mediterranean Centre and the Institute for Environmental Studies (IVM) are analyzing best practices that can reduce marine litter in the four marine regions of the European Union. Best practices are those strategies and measures that demonstrate substantial technological, social, and institutional innovation in their contribution to marine litter reduction. The researchers aim to contribute to the individual programmes of measures for litter reduction now being developed in each EU Member State under the European Marine Strategy Framework Directive. Understanding the best practises and how to strengthen them can help in identifying the policy options that will help Europeans achieve litter-free seas.

What's new about the CleanSea study is that it targets practices from waste prevention to disposal stages and systematically evaluates their potential impacts and what makes them work in the four European regional seas. The study catalogued 180 good practices by reviewing existing inventories, performing web research and engaging with stakeholders. All over Europe, awareness raising appears to be the most common approach to addressing the marine litter issue, followed by cleaning up litter and waste collection (Fig. 1). Next, three indicators were used to narrow down the long list to ten powerful practices with the high potential for long term impact:

I. Social innovation: changes to how the social environment functions, e.g. repair cafés;
II. Technological innovation: modernization and disruptive shifts in the engineering sphere, e.g. advanced plastic recycling techniques;
III. Institutional innovation: new institutional structures to reflect new ideas and practices, e.g. specialized institutions addressing waste management concerns and sector-led initiatives fostering the circular economy.

Major points in the evaluation included the ambition of targets, the number and type of actors adopting the particular initiative or practice, the institutional capacity and feedback loops, the monitoring and compliance methods, and synergy or competition with public regulation. The selected practises (see Table) represent social, technological and institutional innovations across Europe. CleanSea researchers continue to explore under what conditions these approaches can be used as benchmarks and examples for other EU Member States.

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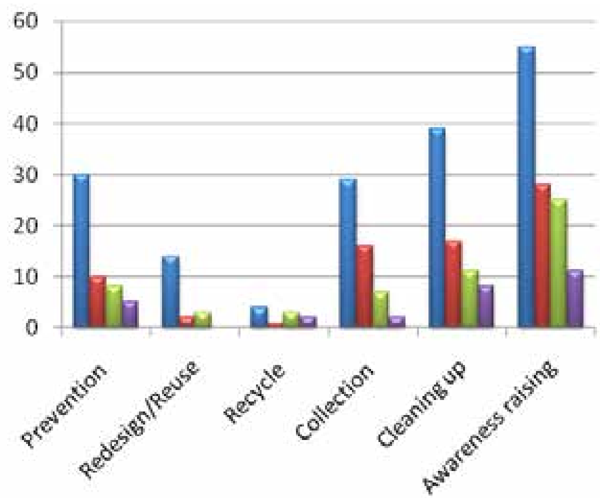

Figure 1. Good practices for marine litter reduction in Europe's Regional Seas are dominated by awareness raising initiatives and cleaning up/waste collection.

HEALTHY SEAS	Converting derelict fishing nets into high quality raw materials for manufacturing socks, swimwear, carpets and other textiles
GREEN DEALS	Agreements made by national governmental agencies with companies and civil society organisations in The Netherlands to carry out marine litter reduction measures for ship waste chain, on beaches and in the fishery sector, with progress monitored by a Green Deal Board
COURTAULD COMMITMENTS	A voluntary agreement aimed at improving resource efficiency and reducing waste within the grocery sector
PLASTIC FREE ISLAND OF JUIST	New means of marine litter collection with cleaning up and awareness raising initiatives
FREE PORT RECEPTION FACILITIES	An incentive for ships to discharge their waste at port in order to reduce illegal dumping of sewage and waste at sea
MARINE CLEAN	Design of new products aimed at reducing marine litter, including: equipment for collection of marine litter, edible & biodegradable packaging. This is accompanied by networking and lobbying at national and EU level for legislative changes.
CADAQUÉS DEPOSIT-REFUND SCHEME	Demonstrating feasibility of a deposit-refund scheme applied to the collection of single use beverage containers
MOTRIL FISHING WASTE MANAGEMENT SYSTEM	Comprehensive waste management system at port with fishermen involvement, particularly removing seabed litter
PAY AS YOU THROW OR "PAYT" PRICING SCHEME	Incentives for reducing waste and landfilling, and increased recycling of packaging and e-waste, through a system of weighing household waste at garbage truck collection
NESSEBAR MUNICIPALITY	Prevention, collection and awareness rising action by a Bulgarian municipality

CleanSea fosters marine litter stakeholder dialogue across Europe

Stakeholder involvement forms an essential part of the implementation of the European Commission's Integrated Maritime Policy (EC 2007). The CleanSea Project is contributing to this by promoting and supporting the formation of marine litter stakeholder platforms in the four regional seas, North-East Atlantic, Baltic, Mediterranean and Black Seas.

Just like the sources and impacts of marine litter, stakeholders who are affected by or can influence the problem of marine litter are very diverse and can include civil society, non-governmental organizations, scientists, policy makers, public administration, such as enforcement agencies, (coastal) municipalities, national environmental agencies, as well as various types of public and private, marine and terrestrial industry such as shipping, fishing, cruise ship operators, waste- and wastewater management companies, port authorities and plastic producing- packaging and cosmetics industries.

In order to promote the formation of stakeholder platforms in the four regional seas, various activities for stakeholder interaction were unrolled. These activities combined workshops of different scopes as a core element, with other stakeholder engagement means, such as personal meetings, interviews or group meetings. CleanSea activities to promote the formation of stakeholder platforms were unrolled in Bulgaria by denkstatt Bulgaria, in the Netherlands by KIMO, a network of coastal communities and the Institute for Environmental Studies (IVM), in Spain by the EUCC Mediterranean Centre and in Germany by Ecologic Institute.

Apart from forming an occasion for networking and constituting a step towards achieving the establishment of regional/national stakeholder platforms, all CleanSea stakeholder workshops aimed to raise awareness on the topic of marine litter and to provide stakeholders with an insight into the results produced by CleanSea so far. These included the results of monitoring exercises on marine litter, the reports on the institutional context and legislative barriers, as well as best practice examples for the management of marine litter, and the identification of policy measures and economic instruments, which can be applied to achieve a better management of marine litter. Furthermore, a link to ongoing national policy processes concerning marine litter was made by presenting and discussing topics of national relevance, such as the national programs of measures for the implementation of the MSFD, such as the three 'Green Deals' for the *Shipping Waste Chain*, *Clean Beaches* and *Fishery for a Clean Sea* in the Netherlands, or other best practice initiatives in Spain, Bulgaria and Germany.

Through its stakeholder platform activities CleanSea is contributing to strengthening the network of stakeholders working in the field of or influencing the existence and management of marine litter. For example, CleanSea has contributed to setting up the Spanish Association of Marine Litter via the partner EUCC Mediterranean Centre. Despite some difficulties to engage the industrial sector in certain regions, two workshops in the Netherlands were successful in engaging industry. Held at the Port of Rotterdam, one of the events was co-organized with the Dutch waste management company Bek & Verburg. This company is also actively participating in the CleanSea's seabed litter monitoring activities via project partner, KIMO.

On the basis of these discussions, joint conclusions and future building blocks of the CleanSea roadmap are being co-developed with stakeholders (see page 5). This aims to support the EU Member States and other stakeholders with an improved knowledge base to promote and maintain clean, healthy and productive seas.

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In Bulgaria, a variety of stakeholders discussed and prioritised marine litter drivers and brainstormed about possible concrehte measures to abate the problem.

In Spain, discussions on responsibilities took place when monitoring results pointed out examples such as beverage containers on the sea-bottom. Despite the Extended Producer Responsibility approach in Spanish law, waste managers declined to take responsibility for the issue, arguing that it's a matter of improper individual behaviour. However, willingness was triggered to cooperate on finding solutions.

Agreeing on Marine Litter Action Plans in the European Regional Seas

For over forty years UNEP's Regional Seas Programme and partner programmes have been promoting sustainable management of the oceans and coastal areas of Europe and the world. This framework engages neighbouring countries in comprehensive and specific actions to protect their shared marine environments. Europe's four Regional Sea programmes and their contracting parties (see table) each address the marine litter issue in different ways but are committed to take joint and coordinated actions within the regions. The current state of play regarding the marine litter action plans in each Regional Sea are highlighted below.

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Regional Seas Conventions	Contracting Parties
OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic, 1992 www.ospar.org	BE, DK, FI, FR, DE, IS, IE, LU, NL, NO, PT, ES, SE, CH, UK and EU
Helsinki Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1974 www.helcom.fi	DK, EE, FI, DE, LV, LT, PO, RU, SE and EU
Bucharest Convention on the Protection of the Black Sea against Pollution, 1992 and its four thematic Protocols www.blacksea-commission.org	BG, GE, RO, RU, TR and UA
Barcelona Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean, 1976, and its seven Protocols www.unepmap.org	AL, DZ, BA, HR, CY, EG, FR, EL, IL, IT, LY, MT, MC, ME, MA, SI, ES, SY, TN, TR and EU

North East Atlantic

The OSPAR Commission was the first to launch a region-wide project in Europe to develop a standard methodology for monitoring beach litter, with which it surveyed over 600 beaches using specific litter items as indicators of the main sources of marine litter. This was a major step forward in the analysis and understanding of sources and trends of marine litter and is currently being used both inside and outside the OSPAR region.
In 2014 the OSPAR Ministers adopted the Regional Action Plan for Prevention and Management of Marine Litter in the North-East Atlantic as an OSPAR "Other Agreement". The Regional Action Plan is designed as a non-legally binding, flexible tool providing a set of actions to address marine litter. It contains actions requiring collective activity within the framework of the OSPAR Commission through, where applicable, OSPAR measures (i.e. Decisions or Recommendations) and/or other agreements such as guidelines. Other actions listed are those that Contracting Parties should consider in their national programmes of measures, included under the Marine Strategy Framework Directive. A third category of actions addresses issues such as international shipping, falling under other international organizations and competent authorities.

Mediterranean Sea

The Mediterranean was the first region to adopt an Action Plan (UNEP MAP) in 1975. Marine litter was since then dealt with within the Barcelona Convention system through the 1980 Land Based Sources (LBS) Protocol implemented through the MEDPOL Programme (the marine pollution assessment and control component of the Mediterranean Action Plan - MAP). An important step towards dealing with the marine litter problem was the 'Adoption of the Strategic Framework for Marine Litter management' at the 17th Ordinary Contracting Parties meeting (COP 17) (February 2012). This Strategic Framework analyses the problem and proposes a number of activities to systematically approach the marine litter problem. COP 17 also adopted the ecological objective on marine litter in the framework of the ecosystem approach

Baltic Sea

The Regional Action Plan for Marine Litter for the Baltic Sea first drafted in 2014 aims to significantly reduce marine litter by 2025, compared to 2015, and to prevent harm to the coastal and marine environment. Following decisions taken during the Annual Meeting (HELCOM 35-2014), two regional expert workshops and one meeting at a governmental level have since then been conducted, enabling the development of successively improved drafts of the Action Plan. The plan should: enable concrete measures for prevention and reduction of marine litter from its main sources; develop common indicators and associated targets related to quantities, composition, sources and pathways of marine litter; and identify the socio-economic and biological impacts of marine litter. Finally, the HELCOM Annual Meeting in March (HELCOM 36-2015) adopted the Regional Action Plan on Marine Litter as HELCOM Recommendation 36/1, to be agreed. The concrete measures as part of the Action Plan are to be finalized during in the spring 2015, for agreement at the next HELCOM Heads of Delegation meeting (HOD 48-2015) in June 2015.

(EcAp) and mandated the Secretariat to prepare the Regional Plan on Marine Litter Management in the Mediterranean. The Marine Litter Regional Plan was adopted in January 2014 (COP 18) as the first regional effort to follow up on the Rio+20 summit global commitment to reduce marine debris by 2025. It aims to ensure environmentally sound solid waste management, reduce waste volumes, recycle and promote sustainable patterns of consumption and production. For the purpose of implementing this legally binding instrument, the Contracting Parties shall adopt the necessary legislation and/or establish adequate institutional arrangements to ensure efficient marine litter reduction and the prevention of its generation. Pparties are to update by 2015 the existing LBS National Action Plans to integrate measures for marine litter monitoring, prevention and management.

Black Sea

The Strategic Action Plan on Rehabilitation and Protection of the Black Sea (BS SAP, 1996, amended in 2009) is the framework under which the Black Sea Commission (BSC) Secretariat developed in 2005, with the support of UNEP Regional Seas Programme, a Regional Activity on Marine Litter. In 2007 the report 'Marine Litter in the Black Sea' assessed the problem and provided a first draft for a Marine Litter Action Plan. The report recommended updating the BS SAP on methodologies, monitoring and assessment, and increased public awareness on marine litter in the Black Sea. In this context the Black Sea Integrated Monitoring and Assessment Program (BSIMAP) for the years 2013-2018 was drafted, in coherence with the EU MSFD. The programme is under revision and is to be adopted as framework guidelines in 2015.

The revised BS SAP of 2009 addresses the main areas of concern and their causes, through the aims of four Ecosystem Quality Objectives. Marine litter, however, is only mentioned as one of the descriptors as well as parameter of discharges under the EcoQO #4 (Ensure Good Water Quality for Human Health, Recreational Use and Aquatic Biota). Nevertheless, the methodology of its assessment is to be further developed as soon as the updated BSIMAP for 2013-2018 is adopted by the Black Sea Commission.

At the BSC Regular meeting in November 2014, the Commission supported the proposal of Bulgaria to work on the issue of marine litter towards development of an Action Plan on Marine Litter. and decided to apply for Thematic Study on Marine Litter under the UNEP Global Initiative on Marine Litter.

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Colophon

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