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Microplastic Litter in the Dutch Marine Environment

Providing facts and analysis for Dutch policymakers concerned with marine microplastic litter

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Contents

Appendices

Foreword

Marine environments all over the world are contaminated with marine litter, mainly plastics. The Netherlands has raised the subject of the 'plastic soup' problem at UNEP and the EU Environment Council. As well as large plastic debris, there is growing concern about tiny plastic fragments known as microplastics. Microplastics are part of the overall marine litter issue, which is attracting attention not only from national and international authorities, but also NGOs, the media, scientists, consumers, artists, the plastics industry and others.

Microplastics are an important factor in the EU Marine Strategy Framework Directive (MSFD 2008/56/EC), which is closely linked with monitoring work currently being performed by the OSPAR Commission. The MSFD aims to establish a framework within which member states take measures to achieve or maintain good environmental status (GES) in the marine environment by 2020. One of the eleven qualitative descriptors for determining GES under the MSFD is: "Properties and quantities of marine litter do not cause harm to the coastal and marine environment" (known as 'Descriptor 10'). This definition includes microparticles (particularly microplastics). However, indicators for MSFD Descriptor 10 need to be developed further and used in assessments in Europe. Current MSFD-supporting developments regarding the use of microplastics as indicators have had a major impact on the focus of this report.

The Netherlands launched a fact-finding project to establish what we actually know about the monitoring and effects of microplastics, focusing on the North Sea region. The results are presented in this report prepared jointly by Deltares and the Institute for Environmental Studies (IVM) at VU University Amsterdam. The project aims to provide information that the Dutch authorities can use in order to define and assess the microplastics issue in the wider North Sea region and to devise action plans to address it and contribute to global solutions.

Summary, conclusions and recommendations

Backdrop

The world's oceans are contaminated by marine litter, especially plastics. Plastic is part of the overall marine litter issue and is rapidly attracting the attention of politicians, the media, scientists, industry and the general public. The Netherlands has raised the widely-acknowledged 'plastic soup' problem at UNEP and the EU Environment Council. The European Commission regards plastic waste in the sea as an important problem requiring urgent attention. In the UNEP Year Book (2011), plastic debris in the ocean is recognized as one of the three most pressing emerging issues for the global environment.

Microplastics, MSFD indicator of GES

The EU Marine Strategy Framework Directive or MSFD (2008/56/EC) states that good environmental status (GES) must be achieved in the seas and oceanic areas of all EU member states by 2020. One of the MSFD descriptors of GES (Descriptor 10) states that the properties and quantities of marine litter must not cause harm to the coastal and marine environment. One important type of marine litter is micro-sized plastic particles (known as 'microplastics'). National authorities in the Netherlands are currently implementing the MSFD, which is the only policy instrument in place to address pollution by microplastics in the Dutch environment.

The authorities commissioned Deltares and the Institute for Environmental Studies at the VU University Amsterdam to carry out a fact-finding project examining the state of knowledge of microplastics in the Dutch North Sea. The main aim was to highlight what is currently known about the occurrence, fate and ecological risks of and environmental monitoring methods for microplastics in the North Sea region by examining the scientific literature and consulting stakeholders.

The microplastic materials in question have been defined by the international scientific community as synthetic polymer particles '<5 mm' in diameter. By this definition, nanoplastic particles (orders of magnitude smaller than microplastics) are included. Ubiquitous in the global marine environment, they are created either by the weathering and fragmentation of mass-produced macro-sized plastic litter or are released directly as preproduction pellets and powders, polymer particles in personal care products (PCPs) and medicines, etc.

Microplastics contain a cocktail of chemical compounds, such as plastic additives, which may leach out to the ambient environment or when ingested. In addition, contaminants from other sources tend to absorb to microplastics: the more hydrophobic a chemical, the greater its affinity for microplastics.

Occurrence, exposure and ecological and human health risks

The potential ecological and human health risks of microplastics are a new area of scientific research, and there is currently a large degree of uncertainty surrounding this question. Evaluating these risks requires knowledge both of exposure levels (i.e. the quantities of microplastics detected in the environment, including in living organisms) *and* of hazard (i.e. the toxicity of microplastics or their ability to cause adverse effects).

Exposure to microplastics in the wider North Sea and other areas has been demonstrated by studies cited in this report (Chapter 3). Investigations using current detection methods have so far identified microplastics contamination in North Sea sediments (offshore, harbours, beaches), North Sea water (surface and 10 m depth) and North Sea marine life (Northern fulmars, crustaceans, fish etc.). Current knowledge on occurrence of microplastics in Dutch coastal waters and the greater North Sea is limited.

Hazards of microplastics are more difficult to characterize because of: i) a worldwide lack of dedicated studies; ii) the fact that particle toxicity is size- and shape-dependent; iii) the fact that toxicity is also dependent on the specific chemical make-up of the microplastic particle (polymer, monomer, additives, sorbed contaminants); iv) the sheer diversity of possible types of microplastics in any given environmental matrix; v) the diversity of uptake routes and accumulation patterns in vastly different marine life forms and; vi) the challenges of studying the diversity of potential ecological effects (e.g. vectors for viruses and invasive species; food chain transfer; biogeochemical cycle effects, etc).

Nevertheless, several studies of the fate and pathology of ultrafine plastic particles in animal models and human cells, and human placental perfusion studies (to investigate transfer from mother to foetus) have provided particle toxicity data which is useful when assessing the hazards posed by microplastics. Toxicity data for many polymer additives and environmental contaminants associated with microplastics are also available for use in hazard assessment. The emerging field of aquatic nanotoxicological research has many links to the study of microplastics toxicity.

From a regulatory point of view, it is also important to note that microplastics are clearly persistent, bioaccumulate to various degrees in living organisms, are potentially intrinsically toxic (esp. due to additives, monomers and particles << 1 mm) and can be transported over long distances, notably to the five oceanic gyres. By travelling great distances microplastics can also act as a substrate and vector for the dispersal of alien species, exotic diseases and anthropogenic chemical compounds.

Biological interactions with microplastics

Living organisms are exposed to microplastics in the marine environment via various routes. For instance, biofilms[1] form on microplastics, as the particles are quickly colonized by microorganisms including bacteria and diatoms. Field and laboratory research has shown that microplastics are ingested and retained by marine organisms, after which size-dependent absorption into certain tissues may take place; food chain transfer of microplastics from prey to predator has already been demonstrated in a field study. Many possible effects of exposure to microplastics have been postulated but these hypotheses must be tested with scientific rigour.

The potential impacts of microplastics and their contaminant load (sorbed chemicals, monomers additives – which may constitute from ca. 4 up to 80% of the polymer end product) in the food chain, as well as the implications for ecosystems and human consumers, are a major concern. While little is known about their toxicity, studies have found that microplastics can affect phytoplanktonic species and filter-feeding bivalves, which can absorb microplastics into their tissues.

Drug delivery and occupational exposure research have demonstrated that polyethylene microparticles (e.g. 150 µm) can also be absorbed by the gastro-intestinal lymph and circulatory systems of exposed humans. Preliminary research indicates that airborne nanoplastics (up to 240 nm) can enter the human blood stream and can cross the human placenta, possibly exposing the developing foetus to these particles. Plastic particles from the nm to the low µm range are likely to be absorbed by human tissue should exposure to nano- and microplastics arise.

[1] *Biofilms are thin layers of microorganisms (diatoms, bacteria, etc.) that form on surfaces.*

Global concern

The global scale of the distribution of microplastic litter, coupled with recent scientific evidence of microplastics' potential to transfer through marine food chains and potentially cause adverse effects in various marine organisms, has fuelled environmental concerns about this marine contaminant. These early warning signals are being recognized by both state and non-state actors and lend support to the inclusion of microplastics as a GES indicator in the MSFD.

The precautionary principle seems warranted in the case of microplastics. Since it will take time to produce conclusive evidence of ecological effects, it is wise not to wait for consensus in the scientific and stakeholder communities before action is taken. There is ample support from the public, the scientific community, NGOs and the plastics industry, in the Netherlands and abroad, to launch efforts to keep litter out of the (marine) environment.

Conclusion I. Our current knowledge of microplastics distribution in Dutch waters and the North Sea is limited

The information available on the composition and distribution of microplastics in the Dutch marine environment is scarce because surveys to date have mainly focused on macro-sized plastic. In the North Sea region microplastics data for beaches are not typically collected, but surveys specifically focusing on microplastics have investigated sediments, seawater, and a small number of biological organisms, mostly run by research teams in either the UK, Belgium or Sweden. In the Netherlands and other countries participating in the OSPAR[2] monitoring programme, seabird (Northern fulmar) stomachs are monitored for litter, including microplastics (between 1 and 5 mm).

Conclusion II. Marine organisms are exposed to microplastics but biological effects have not been adequately studied

Microplastics have been detected in the tissues of a variety of key species in the marine food chain worldwide (plankton, crustaceans, mussels, fish and seabirds), and they increase the substrate surface area for microorganism growth. A number of the studies demonstrating environmental exposure to microplastics were conducted in the North Sea region. There is

[2] *OSPAR: Oslo and Paris Conventions for the Protection of the Marine Environment of the North-East Atlantic; www.ospar.org*

currently a worldwide shortage of dedicated studies on the biological and ecological effects of microplastics. It is expected that the ecological effects of microplastics will be comprehensively characterized and quantified in the coming decades.

Conclusion III. Microplastics sampling and analytical methods exist, but require further development

Sampling and sample pretreatment methods for microplastics exist for seawater and sediment. However, they need further development, validation and standardization to fit the purpose of monitoring under the MSFD. Current methods for microplastics analysis of environmental samples separate the microplastics by visual identification. More advanced imaging methods are being developed to increase the objectivity of sample identification. FTIR and Raman spectroscopy are commonly used techniques for identification of microplastic polymers detected in environmental samples.

Conclusion IV. Monitoring and research need to be coordinated at national and international level

Member states are obliged to establish and implement monitoring programmes for marine litter (with associated environmental targets and indicators) to support the implementation of the MSFD. Criteria and methodological standards are currently being developed by the EU MSFD Technical Subgroup (TSG) on Marine Litter. In the case of microplastics the current focus is on research, but in the coming years monitoring programmes are likely to be developed based on the guidelines set out in the framework of other established marine monitoring programmes such as OSPAR JAMP, programmes set up under other regional conventions and the EU TSG on Marine Litter. In this context several member states (e.g. UK, Belgium) have already started preliminary surveys and microplastics monitoring activities. The Netherlands has not yet done so, however.

Research into micro- and nanoplastics as environmental pollutants is a rapidly emerging field. Microplastics research initiatives are not well coordinated in the Netherlands at present. Researchers in the Netherlands specializing in microplastics in the marine environment come from four major research universities/institutes: Deltares, TNO, Imares/WUR and IVM-VU. Additional expertise in environmental monitoring and policy on microplastics exists at the Dutch Ministry of Infrastructure and Environment.

Key outcomes of the expert dialogue

On 26 September 2011 close to 30 key experts from the Netherlands, the UK and Belgium met in Utrecht to discuss microplastics. The diverse group of stakeholders participating in the dialogue received a draft version of the present report with great interest. It was reiterated that microplastics represents a new, major, complex global environmental problem that could have great adverse effects on the environment and on humans. The dialogue made clear that there is broad agreement among these expert stakeholders that microplastics do not belong in the marine environment and should be prevented. The experts concluded that continuing research should stay focused on the impact of both the plastic particles themselves and the chemical substances that make up plastic products or which later become sorbed to them. More field research was considered necessary to identify the nature and scale of the problem in the North Sea, including attention to riverine systems and sediments, the latter of which are suspected to be sinks. Additionally, group discussions led to the recommendation that marine microplastic reduction measures should be initiated without delay. Indicators must also be developed for the implementation of the MSFD and to guide and track progress made with mitigation measures. The importance of experimental research into adverse effects and risks was also underlined. The discussions inspired stakeholders at different points during the day to call for solutions to the microplastics problem and ideas about points in the system to target for mitigation actions. The participants supported the proposal to establish a regional expert group on microplastic litter along with neighbouring countries.

Recommendations

Short term:

- A preliminary assessment should be conducted to establish the scale and severity of microplastics pollution in Dutch marine waters. This survey should focus firstly on presumed sediment accumulation areas on the Dutch Continental Shelf (DCS) and in the Wadden Sea as well as known emission sources (e.g. wastewater treatment plants). Key species low in the food chain should be selected to supplement the information provided by the OSPAR monitoring of Northern fulmars.
    - A first step would be to analyze samples (water, sediment, etc.) for the presence and composition of microplastics.

- Methods and QA/QC for microplastics sampling and analysis should be further developed, taking into account the recommendations of the EU TSG on Marine Litter.[3] Special attention should be focused on methods for measuring the occurrence of microplastics in sediments and in the water column.
- The advice and recommendations provided by the EU MSFD TSG on Marine Litter should be considered when designing a tailor-made monitoring programme for the EU MSFD.
- Transport models should be used to support the design of field surveys and monitoring programmes for microplastics.
- The effort and thus funding required to analyze microplastics in an environmental sample are similar to those for other environmental contaminants such as persistent organic pollutants; opportunities should be sought to combine efforts with existing monitoring programmes for chemicals and their biological effects.
- Combine forces: cooperation with other countries (UK, Belgium, etc.) through the exchange of research methods, data (where possible) and monitoring.

Medium to long term:

- Stimulate research into the sources, fragmentation, biodegradation and dispersal of microplastics in the marine environment, and adapt transport models and food web models (energy transfer) to microplastics pollution.
- The microplastics issue clearly affects a great range of disciplines and the solutions will require a range of expertise. Natural and social scientists (biologists, chemists, oceanographers, materials scientists, microscopists, modellers, political scientists, sociologists, psychologists, economists, legal experts, educators and others) should be encouraged to work together in interdisciplinary forums, research programmes, etc. Solutions are likely to be most effective and stand the test of time if they are developed in teams with attention to the systems and feedback loops affected by the actions. It must also be acknowledged that integrated, interdisciplinary work is more time-consuming.
- Cooperation with both EU and overseas partners should be stimulated to provide input into the policies being developed both at EU level and globally.
- The Dutch Ministry of Infrastructure and Environment could facilitate the formation of a regional plastic and microplastics litter expert group (together with UK, Belgium and

[3] *The final report of the EU Technical Subgroup on Marine Litter is expected in November 2011.*

Germany)[4] to guide the development of coordinated monitoring and research efforts in the aquatic environment. The expert group could aim to:

- coordinate and guide the design of new monitoring and research initiatives at national level, taking into account ongoing international activities;
- identify and catalogue the current questions and research needs of society and industry;
- present a forum to discuss questions, problems and predictions related to the risks and other issues associated with microplastics, and subsequently advise the Dutch government, industry and other stakeholders.

To make the expert group sustainable, funding could be made available where necessary so that both government staff and non-governmental experts were able to contribute.

[4] *Similar to the CMA, Chemical Monitoring and Analysis expert group*

1 Introduction

Plastics and their associated chemicals constitute an emerging environmental issue that is impacting on our oceans. At the same time, plastics also bring extensive benefits to modern life (Andrady & Neal 2009). As with most environmental problems, we are seeking a sustainable balance between societal benefit and environmental damage.

In 2010, Europeans consumed 57 million tonnes of plastic containing chemical additives (while other chemicals are emitted during the production process) and, due to unclosed recycling loops and short life applications, Europeans created 24.7 million tonnes of post-consumer plastic waste (Anon. 2011). Worldwide, we are currently expected to consume at least 308 million tonnes of plastic and plastics will remain a major growth market for the years to come (Andrady & Neal 2009). The general public is becoming familiar with unsightly images of the macroplastic 'soup', seabirds dying with plastic debris in their stomachs, and turtles and other marine life entangled in plastic debris. Awareness of the risks of chemicals associated with plastics is also growing.

This material so essential to our modern lifestyle is not currently part of a closed loop, with only small volumes of the total amount of plastic waste currently being recycled (in a limited number of cycles, Mulder 1998). Some plastic finds its way to incineration facilities, but plastic waste also can end up in landfills, become urban street litter, or reach wastewater treatment plants, rivers, beaches, seas and coastal zones and the oceans, where it tends to accumulate in the oceanic gyres and other sometimes very remote locations (see e.g. Barnes et al. 2009; Browne et al. 2011; Derraik 2002; Moore 2008; Moore et al. 2001, 2011; Ramirez-Llodra et al. 2011; Thompson et al. 2004, 2009).

Given enough time, this large plastic debris will eventually fragment into micro-sized plastic particles (which we refer to in this report as 'microplastics'). Microplastics are pervasive in seawater and marine sediments. In gyre areas (e.g. in the Pacific Ocean) plastic has been observed to outweigh plankton biomass by a factor of six (Moore 2008). Other hotspots in the North Sea have been identified (macroplastics: Galgani et al. 2000), also in the proximity of industrialised zones (microplastics: Norén 2008). The degradation rates of these synthetic polymers are extremely low - the material is expected to persist for hundreds to thousands of years, even longer in deep sea and polar environments (Andradry 2011; Barnes et al. 2009). Although macroplastics do not fully degrade, they break down into less conspicuous microplastics, defined by the scientific community currently studying marine litter as '<5 mm,' and subsequently into nanoplastics, with particle diameters <1 µm. An illustration of various types of physical, chemical and biological processes involved in the transport and fate of microplastics in the marine environment, the leaching and absorption of environmental chemical contaminants, and interactions with biota, is given in Figure 1.1.

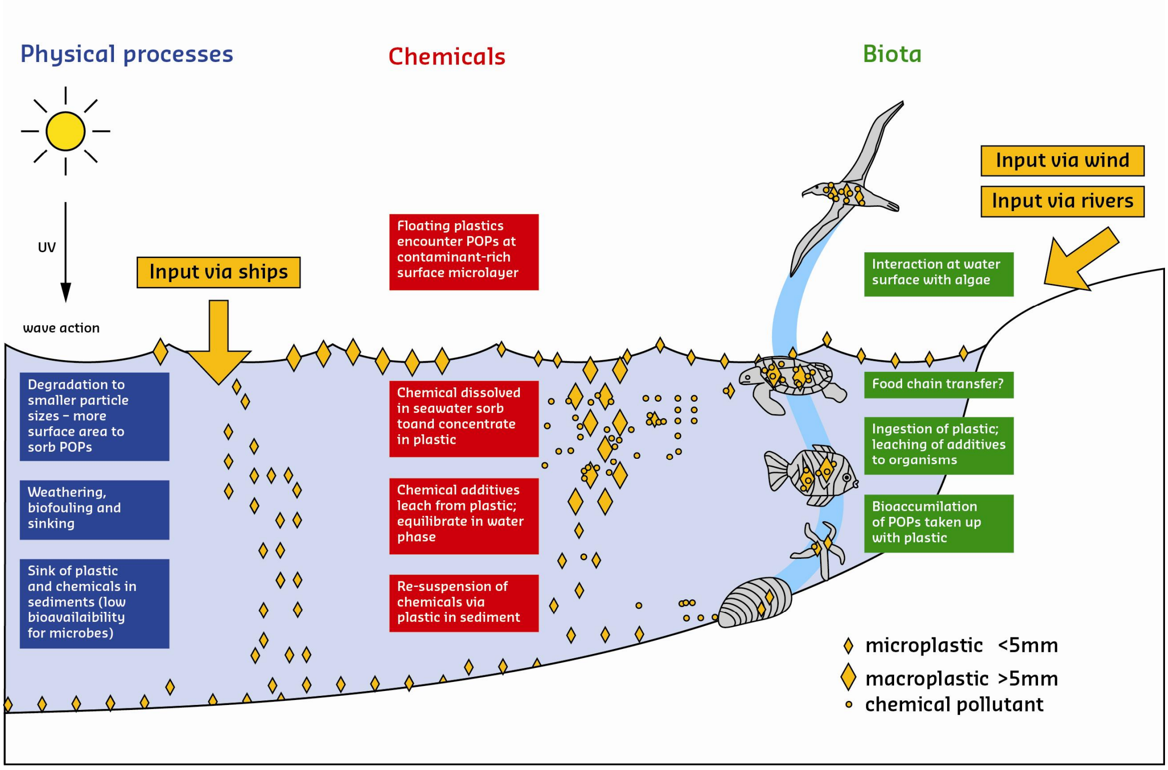

Figure 1.1 Sources of marine microplastics and the various physical, chemical and biological processes affecting microplastics in the marine environment.

Not only is the ecology of the ocean at potential risk (Goldberg 1997; Thompson et al. 2004), a multitude of interlinked marine ecosystem services to humans are also under threat (Beaumont et al. 2007). For instance, as consumers of seafood, humans are likely to ingest microplastics and associated contaminants if the marine organisms have been exposed to them.

The various signals indicating problems arising from the 'plastic soup' have resonated with the governing bodies of the EU. The Marine Strategy Framework Directive (MSFD 2008/56/EC) requires the European Commission to establish criteria and methodological standards to enable a consistent evaluation of the extent to which good environmental status (GES) is being achieved in the marine environment of the EU. To fulfil this obligation the

Commission contracted International Council for the Exploration of the Sea (ICES) and Joint Research Council (JRC) to provide support in the form of ten scientific reports, one for each MSFD descriptor of GES listed in Annex 1 of the Directive. Considering the current body of data available on microplastic litter in the marine environment, the experts in MSFD Task Group 10 on Marine Litter recommended that the overriding objective of the MSFD for Descriptor 10 (marine litter) of GES 'be a measurable and significant decrease in comparison with the initial baseline in the total amount of marine litter by 2020', including a reduction in '*microparticles, especially microplastics*', as one of the GES indicators[5] (Galgani et al. 2010; MSFD 2008/56/EC).

Scope

The focus of this report will be microplastic particles (<5 mm diameter). The microplastics issue is intrinsically linked to the macroplastic litter issue since microplastics reach the environment not only by emissions of manufactured microplastic particles but also by fragmentation of macro-sized plastic litter.

The report provides information on current activities for the monitoring of microplastics in the North Sea. It is also supplemented with microplastics studies elsewhere in the world, since this field of study is still at an early stage of development. We look at methods currently applied in the sampling of microplastics in the North Sea area. Different matrices (water column, sediment, biota) are studied and we summarize what is known from the current (small) body of scientific literature about the ecotoxicological and human health effects of microplastics.

The issue of microplastics in the environment is a complex subject matter and a novel and rapidly evolving area of marine environmental research. Recent reports have tackled many aspects of this issue. They include Galgani et al. (2010), Thompson et al. (2009), UNEP (2005), Van Weenen & Haffmans (2011), as well as reviews in the scientific literature and conferences (e.g. Andrady 2011, Arthur et al. 2009a; Bowmer & Kershaw 2010).[6] We make no attempt to repeat this commendable work, focusing instead on providing a critical review of

[5] *An 'indicator' is a measurable parameter for an MSFD descriptor of Good Environmental Status.*

[6] *Socioeconomic impacts, waste management issues and public awareness are not the focus of this report. We would refer interested readers to other literature such as: Ewalts et al. 2010; Galgani et al. 2010; Gregory 1999; Hall 2000; Ivar do Sul & Costa 2007; Mouat et al. 2010; National Research Council 2008; Steegemans 2008; Ritch et al. 2009; UNEP 2005, 2009.*

monitoring methods and offering perspectives which can be useful for policymakers in the Netherlands.

The proliferation of scientific publications over the last decade has provided major input to the report. This has been supplemented with information from the authors' participation in recent international scientific conferences and meetings, various stakeholder meetings and the expert dialogue described below.

A key aim of this report is to identify knowledge gaps and to identify research priorities for the environmental monitoring and impact assessment of microplastics that are broadly supported by Dutch stakeholders, which the government of the Netherlands may then choose to promote internationally and/or pursue itself at the national level.

Main objectives of this report

1 to provide an overview of current knowledge on the occurrence and fate of microplastics in the North Sea region obtained from pilot field studies of microplastics and monitoring initiatives in the Netherlands and neighbouring countries (Chapters 3,4); where possible, the ecological risks and implications for the food chain and human health will be considered (Chapter 5);
2 to describe the sampling and analytical methods available for microplastics and discuss the implications for monitoring (Chapter 6);
3 to establish a dialogue among experts and important actors at a national level who are part of the solution to the plastic/microplastic soup problem, report on the outcome of the dialogue and improve the report where possible on the basis of expert input (Chapter 7).

2 Background: materials, sources, persistence and regulation of microplastic litter

This section contains relevant background information on the types of materials that make up microplastic litter and on the sources of microplastic litter. Also some remarks on the environmental persistence of these materials and a brief overview of relevant legislation will be given.

Polymers

The main component of most microplastic particles is synthetic polymer(s). Normally these polymers have high production volumes and are made from petroleum-based raw materials: about 8% of global oil production goes towards the production of plastics (Andrady & Neal 2009). Currently a very small percentage of polymers (not more than 1%) are produced from biomass-based feedstocks. These are the subject of important research.[7] Polymers are synthesized either by joining monomer units to form a polymer, e.g. nylon, or by creating a free radical monomer, which by a chain reaction quickly produces a long chain polymer, e.g. polyvinyl chloride (Bolgar et al. 2008). The plastics with the highest production volumes - polyethylene, polypropylene, polyvinylchloride, polystyrene and polyethylene terephthalate (see also list of substances in Table 2.1) - together supply 75% of the demand for plastics in Europe (Anon. 2011).

Table 2.1 List of commonly produced plastic polymers (Anon. 2011).

Polypropylene (PP)	Acrylonitrile butadiene styrene (ABS)	Polyamides (PA) (Nylons)
Polystyrene (PS)	Polyethylene terephthalate (PET)	Polyvinyl chloride (PVC)
High impact polystyrene (HIPS)	Polyester (PES)	Polyurethanes (PU)
Polycarbonate (PC)	Polyethylene (PE)	Polycarbonate/Acrylonitrile Butadiene Styrene (PC/ABS)
Polyvinylidene chloride (PVDC) (Saran)		

[7] *In the Netherlands, DSM and the Dutch Polymer Institute are involved in the development of methods using fresh biomass as a replacement for fossil resources in the production of synthetic polymers, which are then chemically identical to synthetic polymers from petroleum-based feedstocks.*

Additives

The polymers in plastics are almost never pure. Plastics can be regarded as a cocktail of polymers combined with different additives. By way of a 'compounding' process, additives give the plastic product a variety of desirable properties. Additives include plasticizers that make plastics flexible and durable, flame retardants, surfactants, additives that enhance resistance to oxidation, UV radiation and high temperatures, modifiers to improve resistance to breakage, pigments, dispergents, lubricants, antistatics, nanoparticles or nanofibres, inert fillers, biocides, and even fragrances. Besides additives, other chemicals such as auxiliary substances (catalysts of polymerization, initiators and accelerators) are used and may be emitted during the plastics production process (Mulder 1998).[8]

Additives need to be considered part of the potential ecological impact of microplastics due to their sheer production volumes and the known or suspected toxicity of many of these substances. The market is growing, with demand for global plastic additives estimated at 11.1 million tonnes in 2009, up from 8.3 million tonnes in 2000; about half of this volume is plasticizers (Reuters press release Feb 2011). Comparing this 2009 figure to plastics production, additives account for around 4% of the total weight of plastics produced. However, the percentage of additives can vary significantly; in some cases additives make up half of the total material, especially in the case of soft PVC (Mulder 1998). In polymers sampled from electronic waste, brominated flame retardants alone were detected in all products tested in amounts ranging from approx. 5% to over 15% of the total weight (Schlummer et al. 2005).

Sometimes additives are already added to preproduction pellets, but other additives may be added after that stage, when the plastic is being processed into the end product. The additives in polymers can leach out of plastics at various points during the life cycle of the product (e.g. Sajiki & Yonekubo 2003). This can amount to large emissions of chemical additive leachates downstream in the plastic use chain, which may cause toxicity to aquatic life (Lithner et al. 2009). This adds to the plastics-related emissions by the chemical industry and plastics processing industries (Mulder 1998). The role of additives in the ecological impact of microplastics is discussed later in this report (Chapter 5).

[8] *Chemical emissions during plastics production include volatile organic substances, monomers, as well as auxiliary substances, although these emission patterns can differ (in quantities, toxicological profiles of substances, etc.) compared to the emission of substances from microplastic litter once it has reached the marine environment (Mulder 1998).*

Primary microplastics

Primary microplastics are engineered for applications such as personal care products (PCPs), e.g. toothpaste, shower gel, scrubs etc. (Arthur et al. 2009a,b; Derraik 2002; Fendall & Sewall 2009; Gregory 1996; Thompson et al. 2004; Zitko & Hanlon 1991). These are typically down the drain items from households or industry in the case of industrial scrubs. The sandblasting industry now uses primary microplastics (which are vacuumed up for reuse) because they stay sharper and effective for longer than sand particles. When industrial cleaning products containing microplastics are released, they may also be contaminated with materials from the surfaces they were cleaning, e.g. machinery parts (Gregory 1996). The amounts of microplastics in PCPs in Europe are unknown, although emissions of micro-sized polyethylene in PCPs by the US population have been estimated at 263 tonnes/yr (Gouin et al. 2011). Primary microplastics are not expected to be as common as secondary microplastics (Barnes et al. 2009).

Secondary microplastics

Secondary microplastics consist of fragments of macroplastic litter (Figure 2.1) which can be emitted from sea or land (Fendall & Sewell 2009; Gregory 1996). Sea-based sources include litter dumped overboard on ships, derelict fishing gear, aquaculture (Astudillo et al. 2009; Hinojosa & Thiel 2009) and water-based recreation (Bowmer & Kershaw 2010).

Figure 2.1 Macroplastics, such as in this picture of Dutch beach litter at Vlissingen, NL, degrade into smaller fragments, thereby acting as a source of microplastics. Photo A.D. Vethaak.

Land-based sources of macroplastics that reach the sea include street litter, uncovered landfills, dumps or waste containers, agricultural plastics, wastewater effluents and overflows, rivers, various human (recreational) activities in coastal zones, emissions of plastic debris (e.g. Ryan et al. 2009), and emissions during transport of plastic products (e.g. Bowmer & Kershaw 2010; UNEP 2009). Browne et al. (2011) report that in excess of 1900 microplastic fibres from clothing can be released into domestic wastewater by laundering a single garment in a domestic washing machine; these researchers found the same types of fibres in shoreline habitats around the world. The estimates of the proportion of land-based/sea-based macroplastic litter vary and are subject to uncertainty, particularly in the case of waste that can be generated on land as well as on ships. The rates and routes of transport of microplastics via the air (possibly emitted during sandblasting, from fragmenting macroplastic urban or agricultural plastic litter, etc.) and subsequent atmospheric deposition at sea are unknown at this time.

Persistence of microplastics in the marine environment

Plastics are valued for their extreme durability and have been considered to be among the most non-biodegradable synthetic materials in existence (Sivan 2011). The abiotic and biotic degradation rates of synthetic polymers are extremely low - the material is expected to persist for hundreds to thousands of years, even longer in deep sea and polar environments (Andrady 2011; Barnes et al. 2009; Drimal et al. 2006; Gregory & Andrady 2003; Lavender Law et al. 2010; Shah et al. 2008). Extremely slow degradation rates also apply to ‘bioplastics’, which are synthetic polymers made from plant biomass used as feedstock, and which do not differ chemically from synthetic polymers made from fossil feedstocks. ‘Biodegradable’ plastic polymers have been developed but will degrade only under specific conditions (of light, O_2 levels, microbial species, presence or absence of other carbon sources etc.). Generally speaking biodegradable plastic does not degrade under normal environmental conditions, as verified by its persistence in landfills. Some plastics marketed as biodegradable are blends of nondegradable synthetic polymers with starch, in principle enabling enzymatic degradation of the starch component, but yielding micro-sized particles of the persistent synthetic polymer. These micro-sized fragments then further degrade at the usual extremely slow rate (hundreds of years). Such types of biodegradable plastic should therefore also be considered a source of secondary microplastic particles.

Policies and legislation on microplastics pollution

Table 2.2 Policies, legislation and agreements most relevant to plastic litter, with short description of the purpose.

International	
OSPAR Convention 1992	Guidance for international cooperation on the protection of the marine environment of the North-East Atlantic
MARPOL Annex 5 1988 (revised 2011) International Maritime Organization (IMO)	Prevention of marine litter pollution under IMO (International Maritime Organization) conventions
London Convention on the Prevention of Maritime Pollution by Dumping of Wastes and Other Matter (1972)	Prevention of marine pollution by dumping of wastes and other matter
UNEP Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (GPA) and UNEP Regional Seas Programme	These UNEP units joined forces to establish a Global Initiative on Marine Litter in 2003, an ongoing platform for managing the problem through establishing partnerships and cooperative arrangements and coordinating joint activities
FAO (UN)	Plastic Water Bottle Awareness Campaign and promoting alternatives
The Honolulu Strategy	Global framework for a comprehensive and global effort to reduce the ecological, human health and economic impacts of marine debris
European	
EU Marine Strategy Framework Directive (2008/56/EC)	To achieve ‘good environmental status’ (GES) by 2020 across Europe’s marine environment
EU Directive on port reception facilities for ship-generated waste and cargo residues (2000/ 59/EC, December 2002)	To enhance the availability and use of port reception facilities for ship-generated waste and cargo residues
EU Directive on packaging and packaging waste (2004/12/EC)	Harmonizing national measures concerning the management of packaging and packaging waste, enhancing environmental protection
EU Fisheries Policy	Setting quotas for fish caught by member states, as well as encouraging the fishing industry by various market interventions
EU Waste Directive	Encouraging recycling of waste within EU member states
REACH Directive (EC1907/2006)	Registration, evaluation, authorization and restriction of chemicals
EU Water Framework Directive (2000/60/EC)	Ensures that all aquatic ecosystems and wetlands in the EU have achieved 'good chemical and ecological status' by 2015
EU Directive on the landfill of waste (1999/31/EC)	To prevent or minimize possible negative effects on the environment from the landfilling of waste, by introducing stringent technical requirements for waste and landfills
Bathing Water Directive (2006/7/EC)	To preserve, protect and improve the quality of the environment and to protect human health
National	
Wet voorkoming verontreiniging door schepen	Implementation of the MARPOL Convention
Waterwet (integration of eight water laws, 2009)	Implementation of the London Convention

There is currently no international, EU or national legislation in the Netherlands that specifically mentions microplastics, apart from the Marine Strategy Framework (MSFD 2008/56/EC). Annex 1 of the MSFD lists qualitative descriptors for determining good environmental status in the marine environment in Europe. Descriptor 10 reads “Properties and quantities of marine litter do not cause harm to the coastal and marine environment”. It further states that “Member States shall consider each of the qualitative descriptors listed in this Annex in order to identify those descriptors which are to be used to determine good environmental status for that marine region or subregion.”

The EU Waste Directive defines waste very broadly and sets no minimum size limits in the definition of litter. It also promotes recycling, which is regarded as a means of reducing the emissions of plastic by extending the use of the material by several extra cycles before it becomes waste, thereby reducing the rate of creation of secondary microplastics. Other legislative instruments may indirectly address microplastic environmental pollution through the regulation of marine litter emissions from sea-based sources (e.g. MARPOL Annex 5), restrictions on plastic packaging (e.g. EU Directive on packaging and packaging waste), policies banning plastic bags, etc. A list of these and other regulations which may be linked to the marine microplastics issue is presented in Table 2.2. For a more extensive overview, see Appendix B.

3 Overview of existing microplastics monitoring programmes and surveys

The Netherlands

There are a number of monitoring programmes and surveys concerned with macroplastics in the Netherlands. They include *Fishing for Litter* (KIMO[9] Netherlands-Belgium), *Coastwatch* (North Sea Foundation) and the marine litter on beaches survey (OSPAR) (Appendix C). Furthermore, at IMARES, stomach contents of Northern Fulmars are studied to assess the presence of marine litter in the OSPAR region. In 2011 the North Sea Foundation sampled microplastics from seawater near the Dutch coastal zones and purchased PCPs in local stores for microplastics analysis at IVM-VU as part of a pilot project (in progress at time of writing). The majority of the surveys in the Netherlands consider macroplastics only, however, focusing particularly on beach clean-ups. A unique study of plastic litter (including microplastic litter) in Dutch river systems was performed by a Utrecht University bachelor's student (Van Paassen 2010).

Apart from monitoring marine litter, a number of initiatives have also been undertaken to raise awareness of marine litter in the Netherlands. A few of these are highlighted here, although there are many more. *Zwervend langs Zee*, for example, a project set up by RWS Noordzee, KIMO and the North Sea Foundation that aims to clean up Dutch beaches and raise awareness among the general public. In 2009 Dutch writer Jesse Goossens published a Dutch-language book on the subject entitled 'Plastic Soup', which was instrumental in raising awareness in the Netherlands (Goossens, 2009). The *Plastic Soup Foundation* was initiated in the Netherlands in 2010, aiming to raise awareness of environmental issues surrounding plastic litter, including marine microplastics. In 2010 Dutch broadcasting organization VPRO made a documentary entitled 'The Beagle: In the Wake of Darwin' (http://beagle.vpro.nl) in which representatives of waste management companies Royal Boskalis and Van Gansewinkel Group participated, cruising on the clipper 'Stad Amsterdam' (outside the North Sea area) to observe marine litter in the field and come up with solutions to the plastic soup problem. Students of Wageningen University in the Netherlands, which was commissioned by Oost NV to conduct an academic consultancy training project, also joined the voyage of the Beagle to work on plastic soup projects in cooperation with the North Sea Foundation (see De

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[9] *KIMO is the abbreviation for Local Authorities International Environmental Organisation; more information at www.kimointernational.org/NetherlandsandBelgium.aspx.*

Vreede et al. 2010). The aim of this study was to organize the existing knowledge on the plastic soup in a more systematic manner and to map the first steps towards possible solutions. Maria Gorycka (2009) wrote a comprehensive MSc thesis on the environmental risks of microplastics at the Institute for Environmental Studies in Amsterdam in cooperation with the North Sea Foundation. Prof. Hans van Weenen (2011) wrote an exploratory review of microplastics in the oceans. The Royal Dutch Chemistry Society's (KNCV) Macromolecule Section and Environmental Chemistry Section are organizing a joint symposium on the topic of synthetic polymer environmental pollution in 2012. For an overview of the most relevant stakeholders see Appendix D.

North Sea region

So far, no European country has set up a monitoring programme specifically for microplastics. A number of research initiatives are currently underway however, initiated mainly as a result of the introduction of the MSFD (OSPAR 2011):

1 **Belgium** has set up the AS-MADE (Assessment of Marine Debris on the Belgian Continental Shelf) programme with the aim of creating an integrated database containing data on the presence, occurrence and distribution of marine debris including both macro- and micro-litter. This will provide an overview of the environmental hazard posed by marine debris.
2 **Germany** has made microparticles part of a research and development programme designed to come up with initial proposals on how to monitor the digestion of micro-particles and the accumulation of toxic substances in organisms.
3 **France** is automating evaluation methods and creating models to predict accumulation areas of microparticles.
4 **Sweden** is using the national plankton sampling of 2010 to make a preliminary assessment of microplastics abundance. At the University of Gothenburg, Dr. Delilah Lithner completed a PhD thesis entitled Environmental and Health Hazards of Chemicals in Plastic Polymers and Products (Lithner 2011).
5 The **United Kingdom** has launched a project led by Dr. Richard Thompson from the University of Plymouth that intends to look at 'harm' of microplastics. Another project, by U of Plymouth and SAPHOS, focuses on the spatial and temporal trends in microplastics using CPR. Defra sponsors a number of projects on microplastics and work is being carried out by Cefas (monitoring) and the University of Exeter and University of Plymouth (PhD project). Dr. Tamara Galloway of the University of Exeter is

currently conducting a study (UK NERC 2010-2013) of the impact of microplastics at the base of the marine food web, effects on life history traits in planktonic species, especially coastal calanoid species, uptake and feeding studies.

The UK (Cefas, University of Plymouth, University of Sheffield, University of Exeter) and Belgium (University of Ghent, ILVO) and N-Research AB in Sweden cooperation with KIMO can be considered frontrunners in microplastics research in the North Sea area. However, none of these research and surveying activities has yet been undertaken in a regional setting.

In terms of raising awareness, some initiatives do exist at regional level, including *Fishing for Litter*, *Save the North Sea* and *Blue Flag* (see Appendix C). These programmes focus mainly on macro-litter.

International

On an international scale, the USA is one of the main countries setting up campaigns and research programmes for plastic litter in the marine environment. The USA has enacted the Marine Debris Research, Prevention, and Reduction Act (2006), created the Interagency Marine Debris Coordinating Committee and the government-funded NOAA Marine Debris Program (Glackin and Dunnigan, 2009; http://marinedebris.noaa.gov/) that develops protocols, collects data and communicates on the issue. The NOAA also organised the high-profile Fifth International Marine Debris Conference (5IMDC), held March 20-25, 2011 in Honolulu. In addition, strong NGOs such as Algalita, set up by Charles Moore, the ‘discoverer’ of the garbage patch in the North Pacific Gyre, have been instrumental in providing data and momentum to develop the monitoring and assessment of marine debris, including microplastics. UNEP is currently sponsoring a round-the-world expedition to sample microplastics.

Keys to success include sustained funding and institutional support for the prevention and removal of marine debris, and a focus not only on the international level, but also on the national, regional, state and local levels.

EU research initiatives

The European Union is stimulating research on litter by providing funds to research institutes in consortia. Dutch research institutes, consultants and NGOs are well represented in the consortia which submit proposals for these calls. The most relevant activities are listed:

- ENV.G.4./FRA/2008/0112, contract 07.0307/2009/545281/ETU/G2, EU-commissioned report “Plastic Waste in the Environment” Final Report April 2011 (171 pp);
- FP7 EU Science and Society “MARLISCO” project with 19 partners (start date in 2011);
- EU FP7 NV.2012.6.2-4 Management and potential impacts of litter in the marine and coastal environment (‘The Ocean for Tomorrow’) - FP7-ENV-2012-two-stage (expected start date in 2012);
- ENV.D.2/ETU/2011/0045 Feasibility study of introducing instruments to prevent littering (expected start date in 2012);
- ENV.D.2/ETU/2011/0041 Pilot Project - Plastic recycling cycle and marine environmental impact - Case studies on the plastic cycle and its loopholes in the four European regional seas areas (expected start date in 2012);
- ENV.D.2/ETU/2011/0043 Study of the largest loopholes within the flow of packaging material (expected start date in 2012);
- INTERREG offers opportunities for further regional microplastics work (expected start date in 2012).

Balance between macroplastics and microplastics initiatives

It is apparent from this summary that there is a lack of microplastics research and monitoring in the Netherlands, as well as in most other European countries. The focus of surveys on marine plastics tends to be macro-sized plastic particles. This is probably due to the fact that macro-plastics are more visible, making the issue evident to the general public. Furthermore, larger pieces of plastics are easier to clean up and sample than microplastics, especially when it comes to litter on beaches.

Some neighbouring countries in the North Sea region (e.g. the UK, Belgium) are setting up research and monitoring programmes specifically for microplastics. However, insight into the scope of the problem in the region is still lacking. Cooperation between countries, for example through EU consortia or INTERREG projects within this region, would be beneficial to the advancement of knowledge and best practice. With macroplastics as the source of secondary microplastics, trends in macroplastic litter will always remain relevant to the study of marine microplastics. As we will discuss in later chapters of this report, microplastics are expected to have different toxicokinetics (i.e. rates of absorption, distribution, elimination and perhaps even biodegradation), different toxicodynamics (mechanisms of toxic action) and different ecological effects than macro-sized plastic litter. It is therefore also important to characterize microplastic litter if we are to assess the ecological and human health risks of marine litter.

4 Microplastics occurrence – seawater, sediments, biota

In this chapter we briefly review data on the occurrence of microplastics in i) seawater (and rivers), ii) sediments and iii) biota, for which sampling and analytical protocols or guidelines are either in use or under development (e.g. Arthur et al. 2009b; Baker et al. 2010). The body of literature is limited compared to many surveys of macroplastics, particularly those using methods for sampling on beaches (e.g. OSPAR 2007).

Microplastics in seawater (and rivers)

Microplastics were first identified 40 years ago by Carpenter et al. (1972) in plankton net trawls of seawater in the Sargasso Sea. They identified the presence of microbial biofilms on the plastic particles and examined the gut contents of 14 species of fish caught on the same voyages to confirm the ingestion of microplastics in eight of those species. The plastic particles sampled from the seawater surface with a plankton net (333 µm mesh size) were present at average concentrations between 0.04 and 2.58 microplastic particles/m^3 (maximum concentration observed: 14 microplastic particles/m^3), and were identified by infrared spectrometry as polystyrene. Colton et al. (1974) also counted microplastic particles in a large number of surface plankton samples in the Atlantic Ocean and determined that 62% of them also contained plastic. See Table 4.1 for an overview of these data and references and all other data discussed in this section.

A temporal trend analysis was performed on specimen-banked plankton samples collected off the shores of Great Britain between the 1960s and the 1990s. Thompson et al. (2004) showed an increase in the incidence of microplastics in these samples over time. Swedish researchers have performed other important seawater sampling studies in the North Sea region (Norén 2008; Norén & Naustvoll 2011). One important observation was that when an 80-µm mesh size was used to extract microplastics from seawater (150 to 2400 particles/m^3), up to 100,000 times higher concentrations were collected than when a 450-µm mesh size (0.01 to 0.14 particles/m^3) was used at the same location. Norén & Naustvoll (2011) then studied an even smaller range of microparticle sizes: 10 µm to 500 µm, resulting in concentrations 1000 times higher than most other previously reported concentrations. Most of the microparticles detected in the 2011 study were not microplastics but had other anthropogenic origins (such as ash, paint, rubber, particles from road wear, oil fractions). Microplastic fibres in samples were below the limits of detection due to the level of the blanks (i.e. a control of the background concentrations), which appeared to be 0.2 to 1 particle/L in two different blanks in which ultra pure water (MilliQ) was filtered in the same manner as the samples.

Only a handful of studies of the occurrence of microplastics in seawater and marine sediments in the North Sea area have been performed to date. They show that microplastics are present in these matrices (Table 4.1). Reported concentrations range from 1 to 400 microplastic particles/kg dry sediment and from 0.01 to 102,000 particles/m^3 in seawater (the last figure representing a ‘hotspot’, Norén 2008). Elsewhere in the world, many more studies have demonstrated the ubiquitous nature of microplastic pollution at low background levels to high levels at hotspots (Table 4.1).

Table 4.1 Microplastics concentrations observed in seawater surface samples from the North Sea Area, greater Atlantic Ocean and Pacific Ocean (CPR, continuous plankton recorder).

Sampling mesh size	Occurrence	Location	Reference
North Sea area			
127 mm^2 aperture in the CPR on to a scrolling 280 µm-mesh silkscreen	Microplastics in CPR records increased since 1960, peak: 0.04 - 0.05 fibres/m^3 (1980s).	Samples collected at 10 m over 40-year period on standard shipping routes	Thompson et al. 2004
80 µm	150-2400 particles/m^3	Harbour and ferry locations in Sweden, depth 0-0.3 m	Norén 2008
450 µm	0.01 to 0.04 particles/m^3	Harbour and ferry locations in Sweden, depth of 0-0.3 m	Norén 2008
0.5-2 mm	102,000 polyethylene particles/m^3	Harbour near polyethylene plant	Norén 2008
10-500 µm although method optimal for 10-300 µm	Microplastic fibres in samples same concentration as control (0.2 to 1 particle/L)	Skagerrak, Norwegian South coast	Norén & Naustoll 2011
Continuous Plankton Recorder studies	Microplastics widely detected over the North Atlantic Ocean.	UK coastal areas and North Atlantic Ocean	Edwards et al. 2011
Atlantic Ocean			
333 µm, between 30 and 600 m^3 seawater sampled per trawl	Polystyrene spherules (<2 mm) 0.04 and 2.58 particles/m^3 (max 14/m^3)	North-Eastern coastal waters USA	Carpenter et al. 1972
Surface plankton net	n=247 samples, 62% contained plastic particles	Cape Cod USA to the Caribbean	Colton et al. 1974
A neuston net 0.4x0.4 m opening; 308 µm mesh size	3.5 particles/km^2	20 transects (length 1.85 km, sampling approx. 740 m^2 each transect) (200 km E of N.S., Canada)	Dufault & Whitehead 1994

Table 4.1. continued. **Sampling mesh size**	**Occurrence**	**Location**	**Reference**
Atlantic Ocean			
330-µm mesh manta net	142 mg microplastic/g dry weight seawater. Microplastics between 0.33 and 5 mm.	Baltimore Harbour, USA	Arthur et al. 2009c
335-µm mesh plankton net	Time series 1986 – 2008: 60% of 6136 surface tows collected buoyant microplastic pieces; highest microplastics incidence observed between 22° and 38°N.	N. Atlantic Subtropical Gyre	Lavender Law et al. 2010
Pacific Ocean			
Neuston net mesh size 3.0 mm and 0.333 µm	Concentration microplastic particles/ km^2 in Bering Sea 80±190; in Subarctic North Pacific 3370±2380; in Subtropical North Pacific 96100±780000.	Bering Sea, Subarctic and Subtropical North Pacific	Day & Shaw 1987
Net of mesh size 0.053 µm (Sameoto neuston sampler)	Most plastic fragments fell into the 0.5 mm size class (22 locations, 81.5%).	27 locations in the North Pacific Ocean	Shaw & Day 1994
330 µm plankton net	5114 particles/km^2. 98% were thin films, PP/ monofilament line or unidentified plastic.	11 neuston samples North Pacific Gyre	Moore et al. 2001
Manta trawl lined with 333 µm mesh	Average plastic density: 8 pieces/ $m^{-3;}$ density after the storm was 7x higher than prior.	5 locations offshore of San Gabriel River (California, USA)	Moore et al. 2002
10 L of seawater collected per sample, filtered over 1.6 µm glass microfiber filter	PE, PP and PS microplastic (1-2 particles/10 L when detected; 35% of samples <LOD) in surface microlayer samples (top 50-60 µm) and subsurface layer (1 m).	2 locations on north and south sides of in Singapore Island coastal waters. 20 samples total	Ng & Obbard 2006
Neuston net (mouth opening 50 x 50 cm; side length 3 m; mesh size 330 µm)	Plastics detected at 72% of locations; mean mass of 3600 g/km^2 and mean abundance of 174,000 particles/km^2. Dominant size class: 3 mm.	76 stations in the Kuroshiro Current area (North Pacific Ocean)	Yamashita & Tanimura 2007
Manta net neuston sampler	Detectable microplastics at 56-68% of stations; average size 2.3-2.6 mm. Median concentrations range 0.011–0.033 particles/m^3 in different years, with a maximum of 3.141 particles/m^3.	California current system - California Cooperative Oceanic Fisheries Investigations. Winter sampling in 1984, 1994, 2007	Gilfillan et al. 2009

Zones to which wind-driven currents lead are typically locations where large amounts of floating microplastic debris accumulate (e.g. North Atlantic gyre, Lavender Law et al. 2010). Lavender Law et al. estimated, based on concentrations of particles and the average mass of each particle (1.36×10^{-5} kg), that the total amount of plastic in the North Atlantic Subtropical Gyre is 8×10^{10} pieces or 1100 metric tons. No time trend could be identified in the observations made by Lavender Law et al. (2010), covering 22 years during which plastics production and concomitant plastic waste production increased exponentially. These data suggest that the residence time of microplastics (>333 µm) in the sea surface layers is fairly short – weeks or months rather than years.

Further support for this hypothesis comes from the study by Lattin et al. (2004), who found microplastic litter (>333 µm) to be most prevalent in the epibenthic part of the water column (sampled with an epibenthic sled, which also samples part of the sediment), followed by the surface layers sampled with a manta trawl, and then the mid-depth zone. The mid-depth zone sampled by Lattin et al. with a Bongo plankton net was the least enriched with microplastics.

Microplastics sampled at the water surface can also be influenced by storms. Moore et al. (2002) found an average of eight microplastic pieces/m^3 in a Californian coastal zone, though in the same area, the concentration increased by a factor of seven after a storm event. It was suggested that the higher river discharge brought more microplastics to the upper sea layers. Having collected microplastics in the upper 20 cm seawater surface in a zone between Hawaii and the US West Coast since 2003, Proskurowski et al. (2010) measured higher microplastics concentrations at wind speeds <15 knots (equivalent of 28 km/h). They also noticed that towing nets simultaneously in the top 20 cm and at a depth of 3-5 m affected the microplastics concentrations detected, with neuston layers showing up to 25% of the surface layer concentrations.

Vertical transport of plastic debris has been discussed by Holmström (1975) and by Ye & Andrady (1991). When buoyant plastics are biofouled, they tend to sink. Holmström (1975) reported LDPE sheets found by fishermen at 180-400 m depths in Sweden, and suggested that at different depths, the species distribution of the biological growth on the plastic will change. However, after some time in the deep sea, the biofouling may slough off and cease, creating buoyancy again (Ye & Andrady 1991). A list of microplastics in seawater surveys can be found in a report by the National Research Council entitled ‘Tackling marine debris in the 21st century’ (National Research Council 2008).

Input of plastic waste from rivers (Table 4.2) is recognized as a major source of plastic waste in the marine environment. In the Netherlands it has been estimated that 5000 tonnes of waste is transported to the marine environment on an annual basis (cited in Van Paassen 2010). Moore et al. (2011) measured large emissions in the LA River in California. Smaller particles (<5 mm) were 16 times more abundant than those >5 mm and the total mass of <5 mm was also three times higher than large mesoplastic particles. In the case of rivers, sewage treatment plant (STP) effluents may be important emission sources of microplastics (including primary microplastics). One study to date has reported on levels of 1 microplastic particle/L STP effluent sampled from two different STPs in Australia (Browne et al. 2011).

Table 4.2 Microplastics concentrations observed in riverine environments.

Sampling	Occurrence	Location	Reference
Visual collection according to OSPAR beach survey methods	Micro pellets were found on the river banks of the Meuse.	River banks, the Netherlands	Van Paassen 2010
Manta trawl, 0.9 x 0.15 m, mesh size 333 µm	Total number of plastic objects and fragments: 2,333,871,120.0 (2.3 billion); total weight of plastic objects and fragments: 30,438.52 kg (30 metric tons) in 72 hours. The majority of these were foams.	Los Angeles River, San Gabriel River and Coyote Creek, California USA	Moore et al. 2011

Microplastics in sediment

As discussed in the previous section, it has been suggested that the residence time of microplastics at the water surface is short. As a result of biofouling and degradation, the particles eventually sink to the bottom as marine snow. If this hypothesis is true, higher concentrations of plastics would be expected in sediments than in the water layers above. Research on microplastics occurrence in submerged sediments (i.e. not on beaches) is hampered by extra difficulties and the expense of collecting sea sediments compared to surface seawater sampling. As a result of irregular sampling, different protocols and different observers (samples are typically analyzed visually), there are few datasets spanning more than a decade (Barnes & Milner 2005).

Richard Thompson was one of the first researchers to look at the occurrence of microplastics in sediments. In addition to studying CPR microplastics samples, Thompson et al. (2004) studied submerged marine sediments in the UK, demonstrating that microscopic particles and filaments had accumulated in 23 of 30 sediment samples.

Norén (2008) sampled marine sediments from Swedish coastal areas, at Tjuvkils harbour and Stenungsund. In 100 ml sediment samples taken with an Eckman grab (top layer) between one and ten microplastic particles were detected in Tjuvkils harbour, while over 300 plastic particles of 0.5 to 1.0 mm diameter were detected in 100 ml of sediment from Stenungsund.

Another important study in the North Sea region analyzed sediment samples from the Belgian continental shelf (BCS), as well as harbour and beach samples, identifying maximum concentrations (390 particles/kg sediment, dry weight) - more than an order of magnitude higher than previously reported sediment microplastics levels (Claessens et al. 2011). Taking all types of microplastics together, mean concentrations (with standard deviations, s.d.) in units of microplastic particles/kg dry sediment in the Belgian harbours studied were 167 (s.d. 92), on the Belgian continental shelf (BCS) they were 96 (s.d. 19) and on Belgian beaches, 93 (s.d. 37). The levels reported are for particles in the 38 μm to 1 mm fraction range. An example of the amount of (visible) microplastics that can be found on beaches is shown in Figure 4.1.

Figure 4.1 Illustration of the amount of visible microplastics found in beach sand. Photo A.D. Vethaak.

To date, several studies worldwide have looked at microplastics both on beaches and in sediments (Table 4.3). It is difficult to directly compare sediment microplastics levels across all of these studies due to differences in reporting units (e.g. number of particles per kg dry sediment, number of particles/ml of wet (or unspecified) sediment, g of microplastic/g of sediment, etc.). See Chapter 6 for a discussion.

Table 4.3 Occurrence of microplastics in beach and marine sediments.

Sampling method	Occurrence data	Location	Reference
North Sea area			
Sediment samples were collected using a small trowel (strandline), and an Eckman grab (subtidal).	Polymers detected in 23 of the 30 samples. Approx. 0.5 particles/50 ml sediment (sandy), approx. 2.5 (estuarine) and approx. 5.5 (subtidal). Most plastic fragments were fibrous, 20 µm in diameter and brightly coloured.	17 beaches/ subtidal areas of the UK	Thompson et al. 2004
Sediments sampled with Eckman; supernatant of saturated NaCl solution mixed with sediments sieved over 80 µm mesh	Between 2 and 332 ('hotspot') plastic particles were found per 100 ml.	3 Swedish coastal sites: Stenungsund industrial harbour, Stenungsund Bay and small harbour at Tjuvkils Huvud	Norén 2008
Sediment samples collected at strandlines, top 3 cm.	Between 1 and 8 particles per 50 ml sediment; higher density polymers more represented in samples than lower density.	Tamar Estuary UK	Browne et al. 2010
Van Veen grab (70 kg, 0.1 m^2 sampling surface); Beach locations: sediment cores were taken.	Concentrations up to 390 particles/kg dry sediment (15-50 times higher than max. concentrations reported for other similar areas).	Belgian harbours, sea stations and beach locations	Claessens et al. 2011
Van Veen grab of top 10 cm; sediment stored in 500 ml aluminium containers, subsamples sieved (unspecified mesh size)	Microplastic fibers <1 mm were detected on average ca. 1 particle/50 ml sediment.	Two UK marine sewage sludge disposal (and reference site) in North Sea and English Channel	Browne et al. 2011
Atlantic Ocean			
Sand samples were scooped with a small shovel from a 61 x 61 cm^2 quadrant to a depth of approximately 5.5 cm, to fill a 20-L bucket.	72% of the sampled debris by weight was plastics. A total of 19,100 pieces of plastic were collected from the nine beaches, 11% of which was pre-production plastic pellets.	Nine coastal locations throughout the Hawaiian Archipelago	McDermid & McMullen 2004
Bottom samples were taken with an epibenthic sled with a 31 cm^2 opening, a 1 m long, 333 µm net and a 30 x 10 cm^2 collection bag.	Microplastics density greatest in deeper layers. Nearshore surface/middle depths: before storm: 0-1 particles/m^3; after: 10-19 particles/m^3. Offshore deep layers before storm: 6-7 particles/m^3, after: 1-2 particles/m^3.	Two Santa Monica Bay sites offshore from Ballona Creek, which drains Los Angeles. The trawl distance was between 0.5 and 1.0 km.	Lattin et al. 2004

Table 4.3 continued

Sampling method	Occurrence data	Location	Reference
Atlantic Ocean			
Collection of sediments 0.5 m away from the ocean tideline.	Microplastics were found in four out of seven beaches samples. Polyethylene, polypropylene and polystyrene microplastics were also found in the surface microlayer (50-60 um) and subsurface layer (1 m) of coastal waters.	Seven beach locations around Singapore.	Ng & Obbard 2006
Oceanic samples taken by unknown method (likely a manta trawl) others with tweeze, scoops or taken into glass storage jars.	Total concentration of PCBs, DDTs, PAHs and aliphatic hydrocarbons in pre-production thermoplastic resin pellets and post-consumer plastic fragments were 27-980 ng/g, 22-7100 ng/g, 39-1200 ng/g and 1.1-8600 µg/g.	North Pacific Gyre, and selected beach sites in California, Hawaii, and from Guadalupe Island (stomach content of Laysan albatross colony), Mexico.	Rios et al. 2007
Sediments were collected by divers by scooping sediment from the top several centimetres of the benthos with their hands and a bucket.	105 to 214 fragments/L sediment were found.	Three locations along the east coast of the U.S.A.: Panacea and Fort Pierce, Florida; Walpole, Maine.	Graham & Thompson 2009
Beach samples were collected weekly along a 70-m^2 transect at low tide.	Plastic densities on the beach ranged from 0.752-1.39 g/ml. Microplastics identified as: HDPE, low density polyethylene (LDPE) and polypropylene (PP).	An enclosed beach on Washburn Island, Massachusetts, USA.	Morét-Ferguson et al. 2010

Microplastics and marine biota exposure

Field exposure studies

The presence of macroplastics in wild seabirds, sea turtles, mammals and hundreds of other marine animals has been documented and reviewed (Derraik 2002; Thompson et al. 2009). Reports of microplastics in biota sampled in the field are rarer (Table 4.4), although the phenomenon has been known for four decades (Carpenter 1972).

As part of the OSPAR monitoring programme, researchers at IMARES have been examining North Sea-foraging Northern Fulmar stomachs for marine litter >1 mm in diameter (Van Franeker et al. 2011), which includes a microplastics component according to the definition of all polymer particles <5 mm diameter.

In a Scottish study of field-sampled Norway lobsters, *Nephrops norvegicus,* stomach content analysis revealed that microplastics were present in 83% of the 120 specimens' gut contents examined with light and scanning electron microscopy (Murray and Cowie 2011). Microplastics did not appear to be eliminated in the normal digestive process. Microplastics concentrations were measured, but not reported in the publication.

Defra in the UK lists plastics as a 'prey item' in the DAPSTOM long-term fish stomach content monitoring database, and has noted that these analyses could provide an inexpensive supplement to plastics monitoring efforts (Pinnegar & Platts 2011). In the DAPSTOM database generalist predator fish such as cod, whiting and grey gurnard in particular were identified as fish which have eaten plastics, although the size of the particles is not known (Table 4.4).

In the North Pacific Central Gyre, Boerger et al. (2010) detected plastics in the stomach contents of 35% of the planktivorous fish sampled (n=670, 5 mesopelagic, 1 epipelagic species, fish specimens 1-10 cm length) (see Figure 4.2). The most common size class of the plastic in detected these fish was between 1 and 2.79 mm, which indicates the plastic particles the fish were ingesting were mainly in the microplastics category. In fish where plastics were detected, the mean abundance and mass of plastic was calculated (see Table 4.4).

Figure 4.2 Lanternfish with large piece of plastic (unpassable) which broke into three pieces (left); Stomach contents – plankton on left, plastic on right (right). Reprinted with permission of Christina Boerger.

The presence of persistent, non-biodegradable (i.e. non-biotransformable) contaminants in organisms ('bioaccumulation') gives rise to concerns about trophic transfer and biomagnification[10] in the food web. Documentation of the transmission of these types of particles through the food web has been provided by Eriksson & Burton (2003), who surveyed Southern fur seal scat on Macquarie Island. They found that scats contained plastic particles from the night-feeding myctophids (lanternfish), which are active near the sea surface, and are consumed by the seals. Myctophids were also shown to bioaccumulate microplastics in their stomachs in the study by Boerger et al. (2010) mentioned above. More studies on food chain transfer of microplastics are expected to be published in the near future, as at least one new project has been initiated on this subject (see Chapter 3). Food chain transfer is of concern particularly in convergence zones (hotspots), where microplastics are potentially consumed in large amounts due to the high concentrations they can reach in the water column, as reported by Moore (2008) who found that microplastics were more prevalent than plankton in some South Pacific Gyre sea surface samples. Any disturbances due to microplastics at such low levels of the food chain could have serious consequences, since plankton and nekton (small swimming organisms, such as fish larvae) facilitate the transfer of energy to higher trophic levels.

A significant proportion of sediment-dwelling organisms' exposure to microplastics may be via ingestion of sediment or filtration of particles near the sea bottom. Many benthic macroinvertebrates ingest sediment and associated organic matter as a food source, or filter out suspended particles from the pore water or overlying water layers. Biota-sediment accumulation factors or bioaccumulation factors for microplastics have not yet been reported in the literature for marine organisms sampled in the field. The concentration in the animal often cannot be compared to the concentration in the sediment or water phase if these matrices are not sampled simultaneously at the same location.

[10] Biomagnification is a process by which the contaminants ingested with prey/food items lead to body residues of contaminants that increase with the trophic level in the food chain. Predators have higher concentrations than their prey, which can be explained in part because the elimination of the contaminant proceeds at a much slower rate than the rate of contaminant intake through food.

Table 4.4 Summary of studies of microplastics exposure in field-sampled marine organisms.

Marine species	Plastics exposure	Reference
North Sea Area		
Fulmarus glacialis (Northern Fulmar)	Plastics were found in the stomachs of 95% of fulmars sampled in the North Sea during 2003-2007. The critical level of 0.1 g of plastics (EcoQO under OSPAR) was exceeded in more than half (58%) of the individuals. 60% of Dutch fulmars exceeded the critical 0.1 g level.	Van Franeker et al. 2011
Cod, whiting, grey gurnard	'Plastics' listed as prey item in UK marine fish stomach content analysis (n=22) cases since 1990.	Pinnegar & Platts 2011
Atlantic Ocean		
Clytia cylindrica, Gonothyraea hyalina (hydroids)	Most microplastics surfaces had these hydroid species, Sargasso Sea.	Carpenter & Smith 1972
Mastogloia angulata *M. pusilla, M. hulburti, Cyclotella meneghiniana, Pleurosigma sp.* (diatoms)	Most microplastics surfaces had these diatom species, Sargasso Sea.	Carpenter & Smith 1972
Myoxocephalus aenus (grubby)	4.2 % with microplastics in gut, Sargasso Sea.	Carpenter et al. 1972
Pseudopleuronectes americanus (winter flounder)	2.1 % with microplastics in gut, Sargasso Sea.	Carpenter et al. 1972
Roccus americanus (white perch)	33 % with microplastics in gut, Sargasso Sea.	Carpenter et al. 1972
Menidia menidia (silverside)	33 % with microplastics in gut, Sargasso Sea.	Carpenter et al. 1972
Sagitta elegans (chaetognath)	1 specimen sampled. Gut contained microplastics, Sargasso Sea.	Carpenter et al. 1972
Larvae of winter flounder and grubby	5 mm fish larvae contained polystyrene beads of 0.5 mm in length, Sargasso Sea.	Carpenter et al. 1972
Calcareous bryozoans and *Lithoderma* (brown alga)	LDPE sheets collected by fishermen (high incidence; nearly every trawl brought up plastics) from seafloor at Skagerak Sweden at 180 to 400 m depth, with a combination of biofilm species: Bryozoans typical at 15 m depth; Lithoderma typical at 15-25 m depth.	Holmström 1975
Nephrops norvegicus (Norway lobster)	83% of animals (n=120) had microplastics in stomach (mainly filaments), Clyde Sea, Scotland.	Murray & Cowie 2011

Table 4.4. continued

Marine species	Plastics exposure	Reference
Pacific Ocean		
Antarctic fur seals *Arctocephalus* spp. (predator) and the fish *Electrona subaspera* (prey)	145 fur seal scats examined, in total 164 microplastic particles found (at least 1 particle per sample). Most particles 3-5 mm length, some as high as 30 mm. Composition: PE 93%, PP 4%, poly(1-Cl-1-butenylene) polychloroprene 2%, melamine-urea (phenol) (formaldehyde) resin 0.5%, cellulose 0.5%. Study site: Macquarie Island.	Erikkson & Burton 2003
Astronesthes indopacifica[1]	1.0 plastics particles and 0.03 mg plastic/fish gut	Boerger et al. 2010
Cololabis saira[2]	3.2 plastics particles and 1.97 mg plastic/fish gut	Boerger et al. 2010
Hygophum reinhardtii[1]	1.3 plastics particles and 1.82 mg plastic/fish gut	Boerger et al. 2010
Loweina interrupta[1]	1.0 plastics particles and 0.64 mg plastic/fish gut	Boerger et al. 2010
Myctophum aurolanternatum[1]	6.0 plastics particles and 4.66 mg plastic/fish gut	Boerger et al. 2010
Symbolophorus californiensis[1]	7.2 plastics particles and 5.21 mg plastic/fish gut	Boerger et al. 2010

[1]pelagic fish; [2]epipelagic fish

Note Boerger et al. (2010) data are means of data for all individuals which had ingested plastic.

Laboratory exposure studies

Laboratory studies (see Table 4.5) are now also showing that microplastics are taken up by invertebrates, e.g. lugworms, amphipods and barnacles (Thompson et al. 2004), mussels (Browne et al. 2008) and sea cucumbers (Graham & Thompson 2009). Marine mussels - a species also used for human consumption - were exposed to seawater containing microplastics accumulated plastic particles in the hemolymph; once the particles were filtered out of the water column and ingested they were able to move from the gut to the circulatory system and be retained in the tissues (Browne et al. 2008). Graham & Thompson (2009) showed that benthic-dwelling sea cucumbers ingest a variety of shapes and sizes of microplastics. Sediments collected from the natural habitat of these animals contained 105-214 plastic fragments/L sediment (US Atlantic coastal zone), and preliminary chemical analysis showed the plastic particles were contaminated with PCBs. Another recent laboratory study by Teuten et al. (2007) has shown that plastics may be important agents in the transport of hydrophobic contaminants to benthic organisms such as lugworms.

It is not yet known to what extent microplastics may be absorbed by plankton, although Bhattacharya et al. (2010) presented results of nano-sized plastic particles (20 nm) sorbing to phytoplankton.

Little data was found in the scientific literature on the occurrence of microplastics in marine mammals, with the exception of a study of fur seals by Eriksson & Burton (2003). Various species of fur seals on Macquarie Island consume the pelagic fish *Electrona subaspera* as a major prey species. Microplastics were observed in association with otoliths of these fish in the scat of various fur seal species, which the authors suggest would indicate a trophic transfer of these materials. Microplastics may potentially also be mistaken for food by large mammalian planktivores such as the blue whale.

Once chemicals enter food chains, the top predators are often at extra risk because of the biomagnification and trophic magnification effects of some chemicals. If plastics and their associated contaminants enter food chains, humans may ultimately be at risk too (Talsness et al. 2009). The next chapter examines the effects of microplastics on exposed biota.

Table 4.5 Summary of studies of microplastics exposure in laboratory-sampled marine organisms.

Marine species	**Plastics exposure**	**Reference**
Suspension- and deposit-feeding bivalves	Particle-feeding bivalves demonstrate a capacity for particle selection.	Ward & Shumway 2004
Mussel *Mytilus edulis* oyster *Crassostrea virginica*	10-um, non-fluorescent polystyrene beads.	Ward & Kach 2009
Four species of sea cucumber (Echinodermata, Holothuroidea)	Deposit- and suspension-feeding sea cucumber ingest small plastic fragments along with sediments (15-25 mm). Furthermore, during feeding trials, the organisms ingested between 2 and 20-fold more plastic per individual (PVC fragments) and between 2- and 138-fold more nylon line than expected.	Graham & Thompson 2009
Arenicola marina (lugworms)	The addition of 1 µg polyethylene (with sorbed phenanthrene) to a gramme of sediment significantly increased phenanthrene accumulation in sediment dweller *A. marina*.	Teuten et al. 2007
Mytilus edulis (mussel)	Initial experiments with mussels showed that microplastic particles accumulate in the gut. Mussels were subsequently treated with seawater containing microplastics (3.0 or 9.6 µg). These particles moved from the gut to the circulatory system within 3 days, persisting there for over 48 days. Smaller particles persisted for longer than larger ones, indicating that smaller particles have a greater potential for accumulation in tissues than larger ones.	Browne et al. 2008
Nephrops norvegicus (Norway lobster)	In an experimental setup, Nephrops were fed fish with strands of polypropylene rope. Plastic particles were found to be ingested, but not excreted.	Murray & Cowie 2011

Table 4.5. continued

Marine species	**Plastics exposure**	**Reference**
Orchestia gammarellus (amphipod) *Arenicola marina* (lugworm) and *Semibalanus balanoides* (barnacles)	*A. marina* were kept at a density of one individual /L in sediment containing 1.5 g microplastics/L, *O. gammarellus* on stones with 1.0 g/L and *S. balanoides* in seawater with 1.0 g/L. All three species ingested plastics within several days.	Thompson et al. 2004
Placopecten magellanicus (sea scallop)	A mixture of three sizes of PS beads (5, 10 and 20 µm) or a mixture of beads of different densities (1.05 g/ml and 2.5 g/ml) were presented to scallops. *P. magellanicus* can distinguish between particle size and density, retaining larger particles (20 µm) longer than smaller ones (5 µm) and lighter particles longer than denser ones.	Brillant & MacDonald 2000
Placopecten magellanicus (sea scallop)	*P. magellanicus* was presented with a mixture of organic (^{14}C-labelled Prorocentrum minimum) and inorganic (^{15}Cr-labelled beads diameter 16-18 um) particles. Ratio decreased in favour of organic particles, indicating that scallops were sorting organic from inorganic particles. Organisms were fed with a mixture of protein-coated and uncoated beads; protein-coated beads were retained in the gut for longer than uncoated beads.	Brillant & MacDonald 2002
Corophium volutator (mud shrimp)	Plastic particles in gut and hepatopancreas.	T. Galloway (pers. comm.)
Scenedesmus and *Chlorella*[1] (green algae)	Nano-sized plastic beads; adsorption of nano plastics.	Bhattacharya et al. 2010
Mytilus edulis (mussel)	Digestive gland vacuoles in mussels absorb 1-80 µm microplastics associated with granulocytoma formation (inflammation). An increase in haemocytes and a significant decrease in lysosome stability were found after 48 h.	Koehler & von Moos (in Bowmer & Kershaw 2010)
Bacteria, picoeukaryotes and Archaea	Biofilm colonization of polyethylene (LDPE).	Harrison et al. 2010
Microbial biofilm	Colonization of microbial biofilms on 2 cm x 2 cm polyethylene films in seawater (3 weeks). This coincided with significant changes in the physicochemical properties of PE and more neutral buoyancy of the films. No indication of the presence of plastic-degrading microorganisms observed.	Lobelle & Cunliffe 2011

[1]freshwater species

5 Effects of microplastics on marine biota

The ecological risks posed by microplastics to marine organisms are a nascent area of scientific research and at present they are largely uncertain. Evaluating such risks requires knowledge of both exposure levels (i.e. the quantity of microplastics detected in the environment, including in biota) and hazard (i.e. intrinsic toxicity or the ability of microplastics to elicit adverse effects). Exposure to microplastics in the North Sea and other areas has been demonstrated by studies cited above (Chapter 3), both in terms of 'external' exposure (the route via abiotic environmental matrices in the marine habitat) and 'internal' exposure (body residues of the contaminant). The hazard is determined by measuring deleterious effects of exposure to microplastics. Such effects can potentially arise from particle toxicity or chemical toxicity (additives, monomers, sorbed chemicals), or both.

In this chapter we review the small body of literature on the effects of microplastics measured in biota, as well as articles relating to ultrafine plastic particles in the nanometre range. At the nanoscale, another type of toxicity issue arises (Browne et al. 2007). Microplastics may fragment into particles in the nano (10^{-9} m) range, but also the production of engineered nanoplastics such as nanoplastic fibrils, plastic-clay nanocomposites, and plastics enriched with carbon nanotubules may contribute to nanoplastic emissions (see e.g. Ajayan & Tour 2007). Nanoplastic organic electronics and nanoplastic templates are also being developed. Nano-sized particles are entering into a huge array of applications and can be expected to contribute to the total mass of plastics debris and also to toxicity to organisms that ingest or are exposed to them. We draw on selected studies from the emerging field of nanotoxicology (mostly focused on ultrafine particles between 1 and 100 nm) and the well-established fields of particle toxicology (e.g. particulates <2.5 or 10 μm or $PM_{2.5}$ and PM_{10} resp.) and drug delivery science (both nanospheres and microspheres) to give an insight into the potential effects of microplastics and nanoplastics, (both primary and secondary). It is moreover important to note that the toxicities of engineered nanoparticles (ENPs) are themselves diverse, and the toxicity of a given ENP is not directly extrapolatable to secondary nanoplastics (Andrady 2011).

Observed effects of microplastics (and nanoplastics) on marine species

Reports of effects caused by microplastics or nanoplastics in marine taxa are as yet extremely rare (Table 5.1). The marine mussel *Mytilus edulis* was exposed to microplastics between 1 and 80 µm, which was absorbed by digestive gland vacuoles and various effects were observed, including granulocytoma formation (inflammation), an increase in haemocytes and a decrease in lysosome stability (Koehler & Von Moos, in Bowmer & Kershaw, 2010). The abundance of individuals of the aquatic insect species *Halobates sericeus* was studied in seawater samples in which microplastics abundance was scored. A positive correlation between abundance of microplastics and abundance of insects was observed, although the study was not designed to prove causality. It could be hypothesized that the insect, which is dependent on substrate surfaces to lay eggs, was able to proliferate more easily in areas enriched with microplastics (see link in Table 5.1). Van Franeker et al. (2011) noted that sublethal effects related to ingestion of plastics are difficult to detect in the field. The amounts of plastics in the stomach content of the seabirds examined do not differ significantly in birds with different causes of death (starvation, drowning, etc.).

Bhattacharya et al. (2010) worked with nano-sized plastic beads and two species of algae (one freshwater and one marine/freshwater species) and found that sorption of nanoplastics to algae hindered algal photosynthesis and appeared to induce oxidative stress. Bioavailability of polystyrene particles is known to be affected by their charge due to electrostatic repulsion (Hussain et al. 2001). What this effect at the basis of the food chain could mean for the productivity and resilience of ecosystems in the long term is unknown.

Polymer mass in stomach contents may irritate the stomach tissue and cause abdominal discomfort, which may stimulate the organism to feel full and cease eating (Derraik 2002; Galgani et al. 2010; Mascarenhas et al. 2004; Robards et al. 1995, others listed in National Research Council Report 2008). The stomach contents of wild Norway lobster contained microplastics that had formed tangled balls of filaments (most probably from the fisheries industry) (Murray & Cowie 2011). Galgani et al. (2010) suggest that polymer mass in the stomach ‘unavoidably has mechanical and chemical consequences that affect their body condition with negative consequences for individual survival and capacity to reproduce’. However, evidence of such effects has yet to be systematically collected.

Xenobiotic particles accumulating in organs and tissues may evoke an immune response: foreign body reaction and granuloma formation (Tang & Eaton 1999). Behavioural responses in terms of feeding (lack of impulse to eat with a ‘full’ stomach) have also been suggested (see Galgani et al. 2010; National Research Council 2008). In addition, abdominal pain may be experienced in some organisms with high amounts of microplastics accumulating in the gut, which may aggregate and affect general fitness (Galgani et al. 2010; National Research

Council 2008). Effects of ingestion of marine litter reported to date include reducing the space available for food in the gastrointestinal tract, ulceration of tissues, and mechanical blockage of digestive processes (e.g. Azzarello & Van Vleet 1987; Fry et al. 1987; Ryan & Jackson 1987; Ryan 1988; Spear et al. 1995).

Table 5.1 Observed biological effects of microplastics exposure in marine organisms and mammalian systems.

Species	Microplastics exposure and effect	Reference
Marine species		
Mytilus edulis (marine mussel)	Digestive gland vacuoles absorbed 1-80 µm microplastics with associated: granulocytoma formation (inflammation), increase in SB haemocytes after 48 h, and decrease in lysosome stability after 48 h.	Koehler & von Moos (in: Bowmer & Kershaw 2010)
freshwater/saltwater *Scenedesmus*	Nano-sized plastic beads; adsorption of nanoplastics hindered algal photosynthesis and promotion of algal ROS (Reactive Oxygen Species) production is indicative of oxidative stress.	Bhattacharya et al. 2010
Fulmarus glacialis (Northern Fulmar)	Sublethal or lethal effects of plastic in stomach were not tested.	Van Franeker et al. 2011
Halobates sericeus (pelagic insect)	90 samples (collected using manta net-1.0 by 0.2 m, 333 µm mesh size) from four cruises analyzed. Strong positive relationship between abundance of *H. sericeus* and plastic debris in the North Pacific Central Gyre found in 2009, but no causal relationship or ecological effects could be tested within the study design.	http://amnh.com/nationalcenter/youngnaturalistawards/2011/marci.html
Mammalian, terrestrial species		
Human oesophageal epithelial cells	Endocytosis of fluorescent latex microspheres.	Hopwood et al. 1995
Rat	Lung inflammation and enzyme activities were impacted, with increasing severity as particle size tested decreased from 535 nm to 202 nm to 64 nm polystyrene.	Brown et al. 2001
Human alveolar epithelial cells	Polystyrene latex beads (240 nm diameter) shown to be phagocytised.	Kato et al. 2003
Human lymph and circulatory system	Polyethylene microspheres taken up in lymph and circulatory system from gastro-intestinal tract.	Hussain et al. 2001
Human placenta (*ex vivo*)	Fluorescently labelled polystyrene particles with diameters of 50, 80, 240 and 500 nm. Particles up to 240 nm were taken up by the placenta and transported through it.	Wick et al. 2010
Human airway smooth muscle cell	Fluorescent polystyrene spheres (40 nm) decreased cell contractility.	Berntsen et al. 2010
Human endothelial cells (interior surface of blood vessels)	Carboxyl polystyrene latex beads in sizes of 20-40-60-140-200-500 nm were tested. 20 nm polystyrene particles induced cellular damage by induction of apoptosis and necrosis. Particles were taken up into endosomes and lysosomes in a size-dependent manner.	Fröhlich et al. 2009

Observed effects of microplastics (and nanoplastics) in mammalian systems

The effects of particles observed in human cells and tissues or in animal models (Table 5.1) gives an insight into the possible risks of particle exposure in other organisms and in humans, who occupy a high tropic level in the marine food chain, and who can potentially be exposed to primary microplastics while using products that contain them.

In a study of exposure to ultrafine polystyrene particles in rats, lung inflammation and enzyme activity were impacted, in a dose-dependent way, the greater the surface area:volume ratio of the particle. Toxicity increased in direct proportion to a decrease in particle size from 535 nm to 202 nm to 64 nm polystyrene (Brown et al. 2001). Many other effects of ultrafine plastic were measured *in vitro* in the same study, including induction of increases in IL-8 gene expression in epithelial cells and an increase in cytosolic calcium ion concentration. The authors suggest that these particle-induced calcium changes may be may be significant in causing proinflammatory gene expression, such as chemokines. A large body of literature has been published on the human toxicity of particles, mainly via the inhalation exposure route (e.g. Dockery & Pope 1994; Hesterberg et al. 2010; Kato et al. 2003; Walczyk et al. 2010), but also via other exposure routes such as the gut (e.g. Hopwood et al. 1995).

More knowledge of the transfer of microparticles, including microplastics and nanoplastics, through biological membranes can also be mined from the drug delivery research literature. There are ongoing investigations of how the bioavailability and uptake of medicines can be improved by way of micro- or nano-particulate carriers (e.g. Hussain et al. 2001 for microplastics and LaVan et al. 2003; De Jong & Borm 2008; Wesselinova 2011 for some reviews of the emerging field of nanomedicinal applications, including attention to toxicity). When humans or rodents ingest microplastics (≤150 µm) they have been shown to translocate from the gut to the lymph and circulatory systems (Hussain et al. 2001). Wick et al. (2010) recently demonstrated how nano-sized polystyrene particles up to 240 µm in diameter cross the human placenta in placenta perfusion experiments. Synthetic polymers may in some cases be less harmful than the classic ENPs. In a recent study, coating toxic carbon nanotubules (a common type of ENP) with a polystyrene-based polymer was tested with the aim of reducing the cytotoxicity, oxidative stress, and inflammation in an *in vivo* mice lung test and an *in vitro* murine macrophage test (Tabet et al. 2011).

These studies issue a warning that when the size of the microparticle approaches the range below approximately a quarter of a mm, adverse effects may start to emerge due to particle interactions with cells and tissues, particle uptake in endosomes, lysosomes, the lymph and circulatory systems and the lungs. These include deleterious effects at cellular level (Berntsen et al. 2010; Fröhlich et al. 2009) or uptake into placental tissue (Wick et al. 2010) or lymph and circulatory systems (Hussain et al. 2001; Kato et al. 2003). Smaller particles are expected to outnumber larger pieces of plastic litter, and reports of microplastics in this size range in the environment are discussed in Chapter 3 of this report. Human exposure is also a concern if seafood containing microplastics is consumed (see Tables 4.4 and 4.5).

Chemical toxicity through exposure to microplastics

The toxicity of microplastics potentially arises from the leaching of additives, associated Persistent Organic Pollutants (POPs) or monomers (Figure 5.1). No studies to measure toxicological endpoints addressing the postulated facilitated uptake of sorbed POPs with ingestion of microplastics have been performed to date. A consortium of researchers coordinated by Blue Oceans Sciences is currently working on the effects of microplastics on biofilms, although this work is as yet unpublished (Andrea Neal, pers. comm. and Neal et al. 2010). The sorption of POPs to plastic pellets have been suggested as a plausible explanation for the elevated levels of well-known toxic chemicals such as polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), and coplanar polychlorinated biphenyls (PCBs) detected in albatross from remote areas of the Pacific Ocean (Tanabe et al. 2004) and in other seabirds (Ryan et al. 1988; Takada et al. 2006).

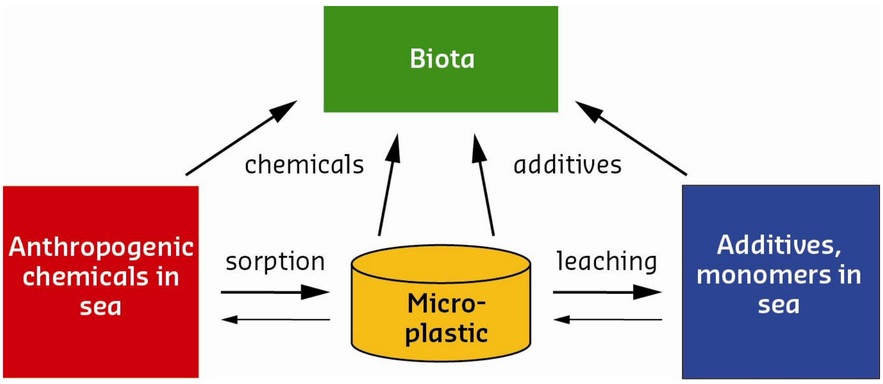

Figure 5.1 Partitioning of chemicals between plastics, biota and seawater.

Further toxicity may be expected from toxic monomers. The first paper to demonstrate plastic (polystyrene) degradation to hazardous monomers at low temperatures such as in seawater was recently presented (Saido et al. 2009). Polystyrene (PS) was found to decompose at 30°C to produce the styrene monomer, 2,4-diphenyl-1-butene (styrene dimer) and 2,4,6-triphenyl-1-hexene (styrene trimer). The styrene monomer is well known in human toxicology, causing both acute and chronic effects in humans, including on the central nervous system (ATSDR 1992). This paper highlighted another new type of contaminant from plastics which should be surveyed in environmental samples. However, such degradation has yet to be tested in seawater or under more field-like conditions.

The widely used endocrine disrupting plasticizers dibutyl phthalate, diethylhexyl phthalate, dimethyl phthalate, butyl benzyl phthalate and bisphenol A (BPA) are toxic to various taxa of wildlife, even at low concentrations relevant to field exposure levels: in the low ng/L to µg/L range (Oehlmann et al. 2009), as well as to humans (e.g. Engel et al. 2010). Plasticizers such as BPA are also well known from the literature and media attention as a human health hazard leaching from plastic drinking bottles (e.g. Lang et al. 2008; Talsness et al. 2009). BPA is a monomer of PVC and an example of a chemical that is toxic even at low doses (Vom Saal & Hughes 2005). Many plastic materials have a tendency to release oestrogenic chemicals, which are also known to cause adverse health effects especially at low (picomolar, nanomolar) doses (Yang et al. 2011). Release of substances can proceed by leaching to aqueous phases (e.g. Sajiki & Yonekubo 2003) or offgassing (e.g. Tuomainen et al. 2006). While examples of toxic monomers of synthetic polymers do exist, the polymeric forms are generally inert and biologically inactive. Polymers are not water-soluble, are typically too large to cross cell membranes and lack functional groups which can interact easily with biological enzymes or receptors.

There is already quite an extensive body of literature on the toxic effects of many types of additives, monomers and other auxiliary substances associated with plastic polymers (especially phthalates, brominated flame retardants, BPA, metals) on biological systems. For a comprehensive assessment of the hazards associated with microplastics in the marine environment, the hazards of the chemicals associated with them (including POPs) should be considered along with their particle toxicities. These toxicity data should be considered in the hazard assessment of microplastics. Known toxicity data for common additives and environmental contaminants should be incorporated into hazard assessments of microplastics.

The hazard posed by microplastics is becoming clearer with research from marine ecotoxicology, human toxicology and the medical sciences. The hazard remains quite complex to characterize because of: i) a worldwide lack of dedicated studies to date; ii) particle toxicity is size- and shape-dependent; ii) particle toxicity is also dependent on the specific chemical make-up of the microplastic particle (polymer, monomer, additives, sorbed contaminants); iv) the sheer diversity of possible types of microplastics in any given environmental matrix; v) the diversity of uptake routes and accumulation patterns in vastly different marine taxa; and vi) the challenges of studying the diversity of potential ecological effects (e.g. vectors for viruses and invasive species; food chain transfer; biogeochemical cycle effects, etc). From a regulatory point of view, it is also important to note that microplastics are clearly persistent, bioaccumulate to various degrees in biota, are potentially intrinsically toxic (especially due to additives, monomers, particles <<1 mm) and are subject to long-range transport, notably to the five oceanic gyres.

As shown above, there is an important knowledge gap as to how microplastics adsorbed to or ingested by marine organisms affect their physiological condition and chemical burdens, and how these may reduce survival, fitness and reproductive performance, and ultimately affect their populations. Concerns have been raised about the potential ecological impact of microplastics as substrates and vectors of the dispersal and introduction of exotic diseases and alien species (e.g. Bowmer & Kershaw 2010; Zarfl & Matthies 2010). These mechanisms of microplastics may cause a considerable ecological and economic impact, but knowledge as to whether and how they pose a significant risk to ecosystems and human health is lacking. The assessment of population effects of microplastics in the marine environment is similar to that for chemical compounds, where ecological risk assessment is supported by results from controlled laboratory studies and semi-field studies (e.g. mesocoms, *in situ* experiments) to provide causal evidence and modelling approaches to predict population effects from sublethal effects (established with biomarkers) in individual organisms (Thain et al. 2008).

Due to the particle-related properties of microplastics, especially at the <<1 mm or nanoscale, it is expected that existing models and concepts to describe and predict environmental risks for the non-macromolecular chemicals do not apply to the intrinsic microplastic particles. A proper risk assessment for microplastics may be decades away and there is a resemblance to the issues related to environmental risk assessments for nano-particles and organic particles. It is believed that many relevant lessons can be learned about microplastics from the field of nanoparticles and their application to issues concerning fate and transport modelling and risk assessment methodologies for the aquatic environment.

In 2001 the Dutch government initiated NanoNextNL (www.nanonext.nl), a collaboration between research institutes and industry that covers most R&D activities on nanotechnology in the Netherlands. The total investment in NanoNext NL for research in nanotechnology for the period 2010-2014 will be approximately €250 million. €15 Million will be used for fundamental and applied research projects under the 'environmental risks of nanoparticles' programme, which aims to understand and predict emission routes, environmental fate processes, exposure of organisms in the ecosystem, and the environmental and human toxicity of nanoparticles. Several institutes (e.g. Deltares, WUR, IVM-VU, etc) are contributing both to NanoNextNL and research on marine microplastics, and synergism can be expected between these activities.

POPs and microplastics – sorption studies

Interest in the toxicity of POPs and other environmental contaminants has led to investigations of the interactions between chemicals in the environment and microplastics. Several studies have identified POPs in plastic fragments and pellets collected from the field (e.g. Carpenter 1972; Carpenter & Smith 1972; Endo et al. 2005; Mato et al. 2001; Rios et al. 2007). The more hydrophobic chemicals, in particular, have an affinity for plastic polymers orders of magnitude higher than their affinity for the aqueous phase (Mato et al. 2001; Takada 2006; Teuten et al. 2007). This was demonstrated in Prof. Takada's Pellet Watch programme in Japan (Ogata et al. 2009; Takada 2006), where the partitioning coefficient for plastic pellets found on beaches (which are in fact equilibrating with the air phase when they are on dry parts of the beach) contain PCB and pesticide concentrations six orders of magnitude higher than are commonly detected in seawater, or air for that matter (www.pelletwatch.org).

Plastic pellets, macroscopic fragments and microplastic particles contain organic contaminants such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, organochlorine pesticides, PBDEs, tetrabromobisphenol-A (TBBP-A), and alkylphenols at concentrations up to the µg/g range (Teuten et al. 2009). For instance, in a study on four Japanese coasts, Mato et al. (2001) collected polypropylene (PP) resin pellets and detected concentrations of PCBs between 4 and 117 ng/g, DDE (a transformation product of the pesticide DDT) between 0.16 and 3.1 ng/g, and nonylphenol between 0.13 and16 ng/g, depending on the sampling site. It is not uncommon to measure concentrations of POPs in pellets that are 10^6 times higher compared to seawater. It would appear that weathered and freshly emitted plastics have similar affinities for some POPs (Beckingham 2009). The hydrophobic contaminant phenanthrene was observed to concentrate in plastic material better than in natural sediments (Teuten et al. 2007). To date, only a few very classic contaminants have been measured in plastics from the field in this way.

The sea surface microlayer is enriched with pollutants from atmospheric deposition[11] and these chemicals will interact with both floating microplastics and plankton in this habitat (Booij and Van Drooge 2001; Wurl & Obbard 2004). Researchers are now suggesting that plastic debris acts as a transport medium, as it concentrates the chemicals to levels many orders of magnitude greater than in other abiotic matrices such as seawater (Figure 5.1). The phenomenon of chemical partitioning of polar and nonpolar organic chemicals to plastic polymers is well known from passive sampling studies (e.g. polyacrylate or polydimethylsiloxane polymers applied in the solid-phase microextraction (SPME) technique (e.g. Leslie et al. 2002). Due to intermolecular spaces in polymers known as the 'free volume', hydrophobic chemical contaminants may not only simply adsorb to the surfaces of polymers, but also be absorbed (Mayer et al. 2000). The more free volume, the more rubbery and less glassy the polymer material tends to be. Combined with the global distribution and mass of this material, microplastic litter has been suggested as a potentially important player in the global fate and transport of chemicals (Arthur et al. 2009a; Thompson et al. 2004).

[11] *In the case of volatile, persistent organic chemicals, long-range transport and atmospheric deposition is one of the significant routes of transport to the world's oceans.*

6 Microplastics monitoring: sampling and analytical methods

Considering the pervasiveness of microplastic litter and the range of potential biological effects as discussed in the previous chapters, it is important to target research to understand the sources, fate and the scale of impacts of microplastic marine litter. In this chapter we describe the sampling and analytical methods currently applied and discuss the implications for monitoring and monitoring programme design, including knowledge from transport and fate modelling. This is also one of the key subjects that the EU MSFD TSG on Marine Litter is working on in 2011 (see also Galgani et al. 2010).

Tracking microplastics in the marine environment and assessing the effectiveness of emissions reduction measures requires reliable, statistically rigorous data on the spatial distribution and temporal trends, and preferably some information on the composition. To achieve this, microplastics must be sampled at appropriate selected sites from relevant matrices, which may include seawater (at given depths), marine sediments, beach sand and biota. Prior to initiating a monitoring programme, exploratory pilot surveys are normally carried out. These may identify hotspots or confirm the location of accumulation zones predicted by model calculations or expert judgement. The Netherlands would benefit from such a survey particularly in anticipation of upcoming activities related to the MSFD.

To determine temporal trends, relevant matrices should be selected that are responsive to changes in inputs of microplastics. This is an inherent challenge for the monitoring of persistent components, as reductions are often not quickly observable. The required statistical power should also be determined. For example, the monitoring programme might need the power (e.g. 90%) to detect a change in the concentration of microplastics (e.g. 50%) in the matrix (e.g. sediments/seawater) over a selected period (e.g. 10 years, although this is a relatively short period for microplastics with such a long half-life in the sinks of the marine environment). A great deal of expertise has been developed on the subject of formulating such quality objectives in existing marine monitoring programmes in Europe for different types of pollution, including marine litter. The ecological quality objective (EcoQO) for plastic litter in the stomachs of Northern fulmars set by OSPAR (2008) reads: 'There should be less than 10% of northern fulmars (*Fulmarus glacialis*) having more than 0.1 g plastic particles in the stomach in samples of 50 to 100 beach-washed fulmars found in winter.'

Any new programme focused on monitoring microplastics should be developed with attention to the guidelines set out within the framework of other established marine monitoring programmes such as those of the International Council for the Exploration of the Sea, ICES (ICES 2001), HELCOM, OSPAR and the TSG on Marine Litter. They should where possible build upon existing monitoring programmes for chemical compounds and their biological effects (OSPAR 2011).

Our current understanding of particle toxicology and nanotoxicology illuminates the importance of defining (and recording) the size categories of microplastics monitored. In toxicological terms, ‘size matters’. In determining the spatial distribution of microplastics in the marine environment, it is important to bear in mind the following:

Representativeness

To what extent do microplastics measurements reflect the actual environmental situation? A number of factors may affect the representativeness of microplastics data. For instance, wave action (Moore et al. 2002; Proskurowski et al. 2010) may affect mixing at the surface layer, in the vicinity of large river systems from urban areas discharging textile fibres from washing machines (Browne et al. 2011). In spring many large river systems may carry large amounts of plastic debris to the sea, as was suggested by Moore et al. (2002), for example. Minimizing the effects of variation is critical in the sampling design for microplastics.

Comparability

Some work towards standardization of sampling and analytical methods for microplastics has already been done. This is critical for the establishment of time trends and to track distribution in the EU’s four seas. Comparability benefits when guidelines and standard operating procedures are developed. It takes time and experience to build up the knowledge, experience, observations and expertise necessary to create a comprehensive set of ‘best practice’. Guided site-selection procedures help ensure comparability.

At the moment, however, it is important to bear in mind that some types of monitoring rely heavily on best professional judgment and that standard methods may not always be optimal for assessing microplastics. It will also be very important to monitor emissions at sources.

Sampling microplastics – methods currently applied

Sampling of microplastics currently targets mainly seawater and sediments, with some exploratory sampling of beaches and organisms (Chapters 3 and 4), and recent work on microplastics in rivers (Moore et al. 2011), on river banks (Van Paassen 2010) and in sewage sludge (Browne et al. 2011). Beach surveys of microplastics are currently not preferred due to various drawbacks, e.g. temporal trends are difficult to measure if the beach is cleaned of microplastics in between sampling surveys, as occurs with macroplastics (Ryan et al. 2009). One hundred percent removal of microplastics from even a small stretch of beach sand using current methods is extremely time-consuming and ineffective. It is also difficult in some countries (e.g. Belgium and the Netherlands) to find beach sand that is not disturbed by recreation between sampling (Claessens et al. 2011). An alternative may be to focus on just the transect of the beach around the high water line where microplastic particles of a given size category are sorted by moving water (and wind).

Sampling microplastics in seawater

In seawater, the surface layers are generally targeted for sampling, since high production volume polymers such as polyethylene are buoyant and other heavier polymers are often suspended in the top layer similar to other forms of SPM (see Transport Modelling section below).

The common approach is similar to plankton sampling using nets of various mesh sizes to filter out particles of a certain size category (Table 6.1). Net methods select a minimum microplastics size category, e.g. >80 µm (Norén 2008), >330 µm (most other surveys) and preconcentrate the microplastics in the sample. The smaller the mesh size the more resistance, which can give problems when towing at sea, or even with the ship's engine off if there are strong water currents. However, one advantage of sampling smaller fragment sizes is that a toxicologically relevant fraction of the macromolecular plastic material is sampled (particle toxicity). Furthermore, observations to date show that more particles/m^3 are found when a smaller size range is included, stretching the limits of detection in a convenient direction.

When sampling with nets (Figure 6.1), it is necessary to use a flow meter to calculate the volume of water that passes through the net if the concentration units in the sample are to be expressed on a per volume basis such as per m^3 (as is the convention with continuous plankton recorders, see Thompson et al. 2004). Wave action and weather conditions at sea affect the suspension of the microplastic particles, and thus the results of surface water microplastics sampling. In a recent study in the USA, the quantities of microplastics detected were different at different wind speeds (Proskurowski et al. 2010). Wind speed is a useful form of metadata to collect when sampling surface layers of seawater.

Figure 6.1 Manta trawl with flow meter (left); Manta trawl in action (right). Samples in the nets are collected in glass containers, and quantitatively transferred from the net to the container with clean drinking water (not seawater). Onboard ship, seawater microplastics samples may be treated with preservatives. To rid the sample of organic matter, a H_2O_2 step is sometimes applied. Ridding samples of organic matter is useful when visual inspection is applied to separate polymer material from other materials (Arthur et al. 2009b). Photos H.A. Leslie.

Examples have been given in this report of sampling 10 L volumes of seawater and later filtering it over a 1.6 μm glass fiber filter to extract microplastics (Ng & Obbard 2006). Norén (2008) also experimented with sampling 5 L seawater followed by separation on board using an 80 μm sieve (which would get clogged less easily than the very low μm mesh size). Norén & Naustoll (2011) also employed a submersible sampling device at 0.1 to 1.5 m.

Standard seawater sampling protocols or guidelines for microplastics have been developed by NOAA (USA) and Cefas (UK), mostly for internal use by researchers. However, little has been published so far and nothing is standardized at the moment. It is nevertheless widely recognized that this is one of the next steps to take in a coordinated effort to characterize spatial and temporal trends in the water column. Cefas in the UK examined historical samples phytoplankton recorders (Thompson, Cefas). Some researchers use data reporting units of particles/water volume (m^3) (e.g. Norén 2008), and sometimes in particles/km^2 (e.g. Moore et al. 2002), which makes comparison more complicated. It is nevertheless common to see both number of particles and mass of particles reported for a given sample.

Sampling expeditions at sea are costly but sampling for microplastics can be combined with sampling expeditions for many other parameters at very little extra cost.

Table 6.1 Methods of sampling microplastics from seawater.

Type of sampler	Lower size limit (µm)	Water sampled	Reference
Mazur Sampler	330 µm	Samples surface water with flow meter	NOAA, U Tacoma Washington (USA)
Regular plankton or neuston nets (continuous plankton recorders)	330 µm	Samples surface water at 10 m depth	U. Plymouth (UK)
Algalita manta trawl	333 µm	Samples surface water, approx. 500 to 3000 m^3 per trawl (normally expressed by Algalita in km^{-2})	Algalita (USA), Cefas (UK)
Bongo plankton net	333 µm	Samples mid-depth water column samples	Lattin et al. 2004 (USA)
Epibenthic sled	333 µm	Samples water column near sea bottom	Lattin et al. 2004 (USA)
Plankton net	80 µm	Samples surface water 0-0.3 m depth, <1 m^3 sample volume	Norén 2008 (Sweden)
Zooplankton net	450 µm	Samples surface water at 0-0.3 m depth; sampling volume 10 to several 100 m^3	Norén et al. 2008 (Sweden) North Sea Foundation (NL)
Bulk water sampling followed by filtration	Depends on filter used, e.g. 1.6 µm glass filter or 80 µm plankton net.	5 - 10 L (0.005 – 0.01 m^3)	Ng & Obbard 2006 (Singapore); Norén 2008 (Sweden)
Submersible water pump and filtering apparatus	10 µm filter used with 30-µm supporting filter	0.5 – 1.5 m depth; sampling volume not specified but control samples were 25 L of pure water	Norén & Naustoll 2011 (Skagerrak/North Sea)

Current detection limits for microplastic particles tend to require very large sample intake volumes (dozens or even hundreds of m^3). The current typical sample sizes require filtration at sea, the samples in Table 6.1 typically representing between 30,000 and 500,000 L of water (1 m^3 water is the equivalent of 1000 L). The number of particles per km^2 is higher than the number of particles in the same trawl when expressed as per m^3 because a trawl of 1 km^2, taking the surface water down to perhaps 10 cm water depth results in a volume of 100,000 m^3, which is the equivalent of 100 million litres – and thus a significantly smaller numerical value in particles/m^3 or particles/L. Increasing the sample volume can increase the frequency of detection. Still, such surface area-based concentration data requires a consistent depth of sampling and cannot be compared with volume-based data unless the depth of sampling is known for data reported per km^2. For large floating marine debris such as macroplastics, the expression of concentrations on a per km^2 basis makes sense. However, when microplastics are being investigated, it may make more sense to express their concentration based on units of the *volume* sampled, since microplastics exist not only at the surface but also (due to wave action, neutral buoyancy due to polymer types or biofilm formations, for example) at all points between the surface and the maximum surface depth of the trawl (whether it be 10 cm or 30 cm, or another depth).

Sampling microplastics in sediments

Methods of sampling microplastics from submerged sediments are shown in Table 6.2. Sediments are sampled as for organic contaminants and metals, with attention to sedimentation rates and sedimentation layers, avoiding disturbed sediment layers, particularly in temporal trend studies. The widely used technique first described in Thompson et al. (2004) takes advantage of the density of a saturated salt solution. When salt solution is added to the sediment sample and a slurry is made, the polymers of low enough density will float to the surface. The polymers that are still heavier than saturated saline water will not be retrieved from the sediment sample. The technique is not therefore suitable for nylon, for example, a heavy polymer that will not float in this solution.

Claessens et al. (2011) slightly modified the method used by Thompson et al. (2004) by increasing the volume of the sediment sample intake for extraction to 1 kg, to which 3 l of saturated saline solution was added. After stirring for two minutes, the sediment settled for one hour and the supernatant was poured through a 38 µm sieve. Filtered material was examined under a binocular microscope. The levels reported are for microplastics in the size range 38 µm to 1 mm. Browne et al. (2011) also defined a 1 mm cut-off in the size of microplastics for their publication, although convention since the First Microplastics Research Symposium in the USA (Arthur et al. 2009a) has been to define microplastics as <5 mm. Norén (2008) also modified the method devised by Thompson et al. (2004).

An alternative method is visual inspection of the sediment sample under a microscope, which is even more time-consuming than examination of the filtrate. Standardization of sediment sampling methods, as well as the units in which the results are expressed, could aid in the comparison of sites on a global scale.

Table 6.2 Methods of sampling microplastics from submerged sediments.

Sediment sampling	Method	Size range (µm) and units	Reference
Sediment sampling at strandline with small trowel and from subtidal zone using an Eckman grab	Mix 250 ml sediment with saturated salt solution (1.2 kg NaCl/litter) and filter supernatant	Depends on the size of sieve used for filtration of supernatant	Thompson et al. 2004
Eckman[1] grab sampling of top 5 to 10 cm of sediment surface layer	Mix 100 ml of sediment with saturated salt solution and filter supernatant over 2 µm sieve	Depends on the size of sieve used for filtration of supernatant; this study used 2 µm. Units: particles/100 ml sediment (wet)	Norén 2008
Van Veen grab sampler or sediment core	Mix 1 kg wet sediment with saturated NaCl solution and filter supernatant over 38 µm sieve	38 µm – 1 mm particles were both counted and weighed and expressed and particles/kg dry sediment.	Claessens et al. 2011

[1] The Van Veen grab sampler can be used as an alternative to the Eckman grab

Sampling microplastics in organisms

Only a handful of studies report on the presence and fate of microplastics in marine biota. These include the sampling and analysis of the gut contents of birds, fish, plankton and also of faecal matter (Table 6.3). Biota samples were derived from surveys of macroplastic and microplastics (manta trawl) or dead animals. Microplastics analysis is usually conducted by microscopic dissection of samples. In a laboratory exposure mussels to microplastics, fluorescent polystyrene microspheres (beads) were used; gut tissue and haemocytes were isolated and fixed and subsequent microscopic and histological analyses were performed for quantification of microplastics. When fibrous microplastics in the stomach contents of organisms form tight intertwined balls, often mixed with other food items, the determination of the number of microplastic particles or weight of microplastics becomes more time-consuming and challenging, as was observed in the case of *Nephrops norvegicus* (Murray & Cowie 2011).

Another approach to sampling microplastics in organisms is to sample biofilms composed of organisms which are tinier than microplastics and which use microplastic particle surface as a substrate – these are also studied using microscopy (e.g. Harrison et al. 2010; Lobelle & Cunliffe 2011).

To obtain a representative picture of the occurrence and fate of microplastics in marine organisms, a number of key species in the marine food chain should be sampled and analyzed. These might include: marine mammals (stranded seals or porpoises), birds (Norther fulmar corpses), pelagic/demersal fish (derived from fish stock assessment cruises), plankton (derived from routine plankton surveys) and other invertebrates such as lugworm, mussels and crustaceans. Sampling biota gives a direct measure of their exposure to microplastics. The ecological relevance of microplastics in biota as well as the biofilm formation on microplastics is potentially high due to the direct contact between biological systems and particles, and between biological systems and chemicals leaching from the particles.

Table 6.3 Methods to sample microplastics from biota.

Species/Target tissue	Size range	Methods	Reference
Fur seal scat	>0.5 mm	Field-collected seal scats frozen and later broken apart with water in a series of two sieves with mesh diameters of 1 mm and 0.5 mm. Sigma Scan Pro image analysis for measurement. SEM photos made. Thin slices scanned with FTIR.	Erikkson & Burton 2003
Laboratory mussels	3.0 or 9.6 µm	Fluorescent beads were used. Mid-gut tissue and isolated haemolytes. Histological analysis and imaging techniques	Browne et al. 2008
Planktivorous fish from the N Pacific Central Gyre	µm-mm	Neuston samples obtained by manta trawl (tows varied from 1.5 to 5.5 h). Samples fixed in 5% formalin, then soaked in freshwater and transferred to 70% isopropyl alcohol. Fish stomach was removed and categorized by size, colour and type using a dissecting microscope and weighed.	Boerger et al. 2010
Fulmars (frozen corpses)	>1mm	Gut content sieved over 1 mm sieve. Smaller sizes were not included and the sieve often became plugged. Microscopic inspection.	Franeker et al. 2011
North Sea fish	µm-mm	Inventory of the presence of plastics in the digestive track.	Foekema et al. 2011
Nephrops norvegicus	µm-mm	Stomach contents analysis: mid-guts were removed from 120 animals and set in 0.04% formaldehyde for 24 h before being transferred to and stored in 70% ethanol. Examination under light microscope 400x.	Murray & Cowie 2011

Analyzing microplastic

Once environmental samples for microplastics are taken to the laboratory they undergo various stages of pretreatment and analysis, as described per matrix above. When the microplastics have been sufficiently separated from the matrix, analysis of the particles begins (mass of particles, or number of particles per size category, see Table 6.4).

Some techniques allow for identification of the polymer type, such as FT-IR spectroscopy or RAMAN spectroscopy. RAMAN microscopy combined with imaging techniques in theory offers the chance to detect microplastics down to approx. 1 µm in size, and to perform polymer analysis and multiple points on the surface of a sample. Thin sample layers are normally used for Raman and FTIR analyses. If thick layers of samples are to be examined, 'Deep Raman' may also provide data for microplastics lying underneath other materials, but this is a more complicated procedure. Other analyses based on visual examination with light or electron microscopy cannot be used to determine polymer type. Various imaging techniques are emerging which may be practical for the visualization of microplastic particles.

Table 6.4 Analytical techniques for microplastics, polymer identification, applications for field monitoring.

FTIR spectroscopy	Yes	Field or lab samples, all matrices
Raman spectroscopy	Yes	Field or lab samples, all matrices
Electron microscopy (TEM, STEM)	No	Field or lab samples, research purposes, (not monitoring)
Fluorescence	No	Microplastics histopathology (Not applicable for field monitoring)
Spectrophotometry	No	Lab (feeding) studies
Field flow fractionation	No	More suited to lab studies
Flow cytometry	No	Lab studies, (experimental work, not monitoring)
Mass spectrometry	Yes	Lab studies and also to measure chemical contaminants
Coulter Counter	No	Used to measure microplastics in personal care products (Arthur et al. 2009c)

The main method of analysis is based on visual inspection after filtration and H_2O_2 digestion of organic material (seawater and gut content analysis) or density separation (sediments) or tissue imaging (biota). The visual inspections are not yet automated and are thus associated with relatively high costs. FTIR and Raman microscopy are most commonly used in studies where determination of the polymeric composition is an objective.

Quality control issues such as blanks have been pointed out by Norén & Naustvoll (2011), who noted background levels of textile fibres in their control samples which were quite near the concentrations measured in the surface water. They and other sampling teams (such as in Browne et al. 2011) take precautions by avoiding wearing synthetic clothing during sampling. It is also important that the microplastics counted by different individuals are correctly identified as such, since many kinds of particles (e.g. paint, oil products, ash) may also be present in the sample (Norén & Naustvoll 2011).

Transport models to support design of microplastics monitoring

Modelling the transport and fate of microplastics in the Dutch coastal zones and North Sea area can assist in interpreting microplastics monitoring information and can help link other monitoring data (for microplastics in rivers, macroplastic litter, manufacturing emissions, etc.) with the microplastics distributions observed in marine areas.

Given the particle size and various properties such as the buoyancy of some polymers (Andrady 2011), the ability of some to absorb water in the ‘free volume’ between the polymer chains (Bashek et al. 1999), and the colonization of microorganisms on their surfaces (e.g. Harrison et al. 2010; Holmström 1975; Lobelle & Cunliffe 2011), microplastics may behave similarly to suspended particulate matter (SPM) in marine systems.

A great deal of work has been done on modelling and monitoring SPM in the North Sea by scientists at Deltares, IVM-VU, etc. (e.g. Blaas et al. 2007; Gerritsen et al. 2000; Van Kessel et al. 2011). This previous modelling could provide a basis for the development of models to estimate how microplastics will be transported once emitted from land-based sources (via rivers, harbours, effluent outlets, wind) or via the gradual fragmentation of macroplastic litter in the water column or sediments. Horizontal transport in Dutch marine areas will be driven by both tidal and wind-induced currents. Fettweis et al. (2007) estimated long-term suspended solids fluxes in the Southern part of the North Sea using a combination of mathematical models and satellite imagery. Vertical transport in the area will likely be characterized by the settling velocities of the particles, which is governed by the particle size and density difference between the particle and surrounding water. Dobrynin et al. (2010) investigated transport mechanisms of suspended solids, indicating areas that may be subject to erosion or sedimentation and seasonal differences between calm and storm periods and the relative importance of waves and currents. In the southwestern part of the North Sea resuspension dominates and is mainly governed by currents while near the Dogger Bank waves drive the resuspension process in stormy conditions. In deeper parts of the North Sea sedimentation of SPM generally dominates.

Gyres leading to the ‘Great Garbage Patch’ phenomenon in the Pacific Ocean, made famous by the work of Charles Moore and Algalita (http://www.algalita.org/index.php), are not expected in the North Sea, where most currents are tidal. Eddies do occur in the North Sea (depending on the coastal contours and other characteristics), but given the tidal currents that dominate in these areas, they are very dynamic and unlikely to capture microplastics and create local accumulation zones. Eddies emanating from river outflows may have a more permanent character, which would lead to possible zones of net sedimentation. Whether these sedimentation zones lead to accumulation of microplastics is at present poorly understood, and will depend on the settling characteristics of the microplastic particles and local hydrodynamic conditions.

Important differences between properties of SPM and microplastics may lead to differences in settling processes between the two. For example, the density of a microplastic particle (typical polymers have specific gravities between 0.6 and 1.5) is significantly lower than the density of SPM (about 2.6, i.e. about the same as rock). Microplastic materials may be buoyant with a specific gravity of less than 1, neutral (approximately 1) or negatively buoyant (greater than 1) and tend to sink. Modelling of microplastics will need to account for this range of buoyancy. Considering the relatively small density difference between marine waters and plastics, density stratification of microplastics is expected to occur, distributing the denser particles deeper in the water column, with the lighter particles in the upper layers. Since transport mechanisms may differ as a function of depth, three-dimensional resolution of these processes is required.

The second main difference between microplastics and SPM is that SPM concentrations are significantly higher and easier to detect. Compared to SPM, microplastics fluxes will be significantly lower and it is highly likely that the outcome of the models will be more sensitive to the model settings (parameters) and plastic input fluxes, such as river sources. It is important that the sources of microplastics entering the North Sea are well monitored, allowing examination of the relative contribution of land-based sources and sources outside the North Sea (such as the Atlantic), fragmentation of macroplastic litter to microplastics, and sinks (settling/uptake by organisms). To some extent, this is similar to the analysis by Zarfl & Matthies (2010), who examined pollutant fluxes (dissolved or absorbed to plastics) from the North Atlantic into the Arctic and estimated the main contributing factors such as currents and atmospheric transport.

Due to the relatively low microplastics concentrations expected (commonly between approx. 0.05 and 20 particles/m^3, apart from hotspots where concentrations can be 100,000 particles/m^3, see Chapter 3) and high levels of uncertainty in stochastic modelling approaches, deterministic modelling may need to be adopted. Several options are available, such as data model integration techniques (e.g. Kalman filtering), Monte Carlo approaches or other data assimilation techniques that are also used in suspended solids transport modelling (e.g. Dobrynin et al. 2008). Probabilistic methods may also be considered, similar to Maximenko et al. (2011), for example, who used drifter modelling to identify accumulation zones.

Characteristics of microplastics may also vary over time, for example due to changes in size (degradation) or growth of biofilms on the particles, changing their bulk density (Harrison et al. 2010; Lobelle & Cunliffe 2011; Ye & Andrady 1991). A significant mass balance discrepancy between sources and observed and/or modelled concentrations points to a lack of understanding of fluxes and processes. Additional monitoring and/or modelling will then be needed to enhance our understanding and reduce this discrepancy.

A number of river systems discharge large quantities of water and SPM into the North Sea, such as the Rhine/Meuse and the Thames. They are likely to carry a significant fraction of macro- and microplastics into the North Sea region and hence any hotspots are likely to be associated with one or more of these sources (see also Van Paassen 2010). An example of SPM distribution from satellite images (Figure 6.2) clearly illustrates the effect of the Thames River in the UK emitting SPM to the North Sea flowing in a northeasterly direction (Blaas et al. 2007). Along the Dutch coast the residual current also flows towards the northeast. Any SPM, including microplastics, from the Rhine may travel in the direction of the Wadden Sea, for example, making this a suitable area for monitoring in the Dutch marine environment.

The objectives of any future North Sea survey or monitoring programme may be to select microplastics sampling sites in zones where high and low microplastics accumulation rates are expected. Transport models such as those modelling SPM (e.g. Van Kessel et al. 2011) can help in determining these zones. No transport models dealing specifically with microplastics transport in the North Sea (including the Wadden Sea) exist and should therefore be developed. If sensitive species are identified in biological effects studies, e.g. fish larvae, microplastics could also be measured in key foraging zones etc.

Existing three-dimensional models show us the relative contribution of each river (as a water fraction) and boundary is potentially known for the entire North Sea region. If estimates of microplastics loads from these rivers and boundaries exist, this will give us an initial estimate of the importance of these contributions. If, for example, boundaries provide the main source, then this already points to a wider scale issue that cannot be resolved by local measures.

It is clear that modelling would need to be carried out in phases, starting from a mass balance perspective and evolving towards more complex process descriptions. Models provide an understanding of where additional empirical data are needed to allow more accurate estimates of microplastics fluxes and concentrations. Existing modelling suites, such as Delft3D, provide a good basis for developing a microplastics transport and fate model for the North Sea. Process descriptions that explain the fate of microplastics are likely to be needed, given the complexity of the issue.

Figure 6.2 MODIS Terra recording of the colour of the southern North Sea, March 26, 2007. The yellow-greenish colours in are due to suspended particulate matter, algae and dissolved organic matter. (Image courtesy MODIS Rapid Response Project NASA/GSFC).

7 Expert dialogue – Summary and key outcomes

An important element of the inventory and factfinding exercise is testing the results presented in the report against the knowledge of experts in the Netherlands and neighbouring countries. The report's authors have participated in dialogues with expert stakeholders concerned with microplastics in different national and international fora over the past few years, and it was agreed that an expert dialogue based on the draft report findings would provide input into the report and might lead to a more harmonized (Dutch) standpoint on the status and needs assessment of the issue of microplastics in the marine environment.

On 26 September 2011, a group of nearly 30 experts from science, the plastics industry, consultancies, government and non-governmental organisations from the Netherlands, the UK and Belgium met in Utrecht to discuss aspects of the microplastic issue brought up in this report (see Appendix E for participants list). A draft version of the present report was received by participants with great interest. The report was briefly presented by the authors and then discussed with participants in the plenary session. Microplastic mind mapping in four smaller groups with reporting back to the main group provided the chance for further input from participants.

It was reiterated by the group that microplastics is a major, complex and global environmental problem that could have significant adverse effects on the environment and on humans. While the problems and solutions are certainly global, it was also recognized that there always remains a local component - in both the problem and the solution - that should be addressed too. There was unanimous agreement among participants from the diverse organisations represented in the dialogue that microplastics do not belong in the marine environment and should be prevented. Many of the participants' organisations have already been contributing in various ways to efforts to solve the microplastic environmental issue. There was general agreement that attention should focus on reducing the impact of both the plastic particles themselves and the chemical substances that make up plastic products or which later sorb to the products after they become litter. This acknowledged the fact that adverse effects on individual organisms may occur through both particle (and fiber) toxicity (well-known from PM10, asbestos and nanotoxicity examples), and chemical toxicity when substances leach out of microplastic (well-known from studies of POPs and many other chemical toxicants). The suspected hazard of microplastics that emerged from the discussion of human and mammalian studies cited in this report were of concern to participants and considered relevant to the marine microplastics problem. The importance of experimental research into adverse effects and risks was also underlined. It was also noted that a complicating factor when addressing microplastics with the definition of '< 5 mm' one must deal with a large range of different toxicities that could arise at the different size categories. A 4 mm particle will likely have very different type of impact on a living organism (or population, or community) than a particle that is 4 µm or 4 nm, which may or may not be easy to describe in classical ecotoxicological terms. The concerns about effects were considered linked to public perception of the problem, but work should be done to back up this perception with scientific facts. More field research, including effects studies, was called for in order to identify the nature and scale of the problem in the North Sea.

It is widely recognized that indicators in particular for microplastic litter must be further developed for the implementation of the MSFD. In terms of abiotic matrices which should be targeted for sampling, sediments were identified as a probable microplastic sink, with next highest concentrations expected in surface water, followed by intermediate depths in the water column. Suitable biotic indicator species should be selected to give meaningful signals about the general ecological health of a food chain, community or ecosystem, if possible. Experts recommended attention be paid to riverine systems (as one key land-based source of marine microplastics). It was suggested that an integration of the WFD[12] and the MSFD could increase the impact of mitigation measures, since rivers transport microplastic to the sea.

From the group discussions the recommendation emerged that marine microplastic reduction measures should be initiated without delay. The question arose as to how much knowledge do we need before we starting an action and implementing a measure? Not waiting until full scientific evidence becomes available and a future consensus is reached regarding the degree of harm to the public or the environment is in line with the precautionary principle as well as with the ambitions of the participants to prevent microplastic in the marine environment. Furthermore, there is a very tight time schedule for generating information and achieving GES under the MSFD. The discussions inspired stakeholders at different points during the day to call for solutions to the microplastics problem and ideas about points in the system to target for mitigation actions. Where to begin? Although solutions were outside the scope of the report and assignment, it illustrates the prevailing ambition to curb the current emission trends for various reasons. Participants summarized the four key subjects they felt

[12] *However, the WFD is mainly focused on 33 priority substances – not including microplastic or any sort of litter - in freshwater and in principle also narrow coastal zones*

more information needs to be collected on as follows: microplastic sources, occurrence, effects and solutions.

The participants regard OSPAR as a good platform for further developments and guidance but also very much supported the proposal to establish a regional expert group on microplastic litter along with neighbouring countries.

Epilogue

Marine microplastics and the 'plastic soup' problem form an extremely complex issue. Devising reliable methods to sample, analyse, monitor time trends and effects of microplastics as discussed in this report is an important but small part of the overall challenge. Cleaning up the marine litter 'soup' after it has been made and served to the oceans of the world appears to be neither cost-effective nor energy-efficient. For microplastics, cost-*in*effective remediation measures do not even exist. Experts tend to agree that the main focus should be on emission prevention measures, as with many other pollutants in water and air. Our 21st century global society already recognizes it needs to transition to more sustainable consumption and production of plastics, doing more with less. This will require technological advances in greener feedstock selection and production processes, product ecodesign, a lengthier service life for polymer products, green chemistry alternatives for toxic additives, recycling, eliminating superfluous plastic packaging etc. The plastics cycle needs to be closed and pollutant emissions (of polymers but also monomers, catalysts, additives and auxiliary chemical substances) need to be reduced or eliminated throughout the plastics production chain and life cycle. We also should try to avoid path dependence on unsustainable technological developments. These technological advances are less complex and unpredictable than the social, economic and political adaptations that will accompany, co-evolve with and direct them.

Working towards both global and local solutions for the microplastics (and other marine litter) problem can be synergistically combined with work towards solving a range of other issues such as reducing CO_2 emissions and ocean acidification, improving recycling infrastructure, replacing hazardous substances with safe ones, moving towards more sustainable consumption of goods etc. (also see Thompson et al. 2011). Past experience and learning through solving complex problems have demonstrated that some of the most effective solutions may turn out to be the counterintuitive ones (Meadows 1999). It will be important in approaching this issue to resist clinging to preferred paradigms, and instead adopt a spirit of openness and a willingness to work very hard.

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A Abbreviations used in this report

ABS	Acrylonitrile butadiene styrene
AS-MADE	Assessment of Marine Debris on the Belgian Continental Shelf
BCS	Belgian Continental Shelf
CPR	Continuous plankton recorder
DCS	Dutch Continental Shelf
EcoQO	Ecological quality indicator (OSPAR programme)
ENP	Engineered nanoparticle
FAO	United Nations Food and Agriculture Organization
FTIR	Fourier transform infrared spectroscopy
GES	Good Environmental Status
HIPS	High impact polystyrene
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organization
INTERREG	INTERREG Community Initiative (programme to stimulate interregional cooperation in EU)
IVM-VU	Institute for Environmental Studies, VU University Amsterdam
JRC	European Commission Joint Research Centre
KIMO	Local Authorities International Environmental Organisation
L	Litre
mm	Millimetre (10^{-3} m)
MSFD	Marine Strategy Framework Directive
TSG	Technical Subgroup (on Marine Litter for the MSFD)
NGO	Non-governmental organisation
nm	Nanometre (10^{-9} m)
NOAA	National Oceanic and Atmospheric Administration
OSPAR	Oslo and Paris Conventions for the Protection of the Marine Environment of the North-East Atlantic
PA	Polyamides (nylons)
PC	Polycarbonate
PC/ABS	Polycarbonate/Acrylonitrile butadiene styrene
PCP	Personal care product (cosmetics)
PE	Polyethylene
PES	Polyester
PET	Polyethylene terephthalate
POP	Persistent Organic Pollutant

PP	Polypropylene
PS	Polystyrene
PU	Polyurethanes
PVC	Polyvinyl chloride
PVDC	Polyvinylidene chloride (Saran)
QA/QC	Quality Assurance and Quality Control
REACH	Registration, Evaluation, Authorization and Restriction of Chemicals Directive (EC1907/2006)
SEM	Scanning electron microscopy
STP	Sewage treatment plant
UK NERC	United Kingdom Natural Environment Research Council
µm	Micrometer (10^{-6} m)
UNEP	United Nations Environment Programme
WFD	Water Framework Directive

B International legislation and policies relevant to microplastics

Global conventions and agreements

United Nations Convention on the Law of the Sea (UNCLOS) and General Assembly (GA) Resolutions	Sets out the legal framework within which all activities in the oceans and seas must be carried out. The General Assembly carries out annual reviews of the law of the sea (Resolutions), based on annual comprehensive reports prepared by the Secretary-General.	http://www.un.org/Depts/los/index.htm
Global Programme of Action for the Protection of the Marine Environment from Land-based Activities (UNEP GPA)	An intergovernmental programme which addresses the inter-linkages between freshwater and the coastal environment.	http://www.gpa.unep.org/
International Convention for the Prevention of Pollution from Ships (MARPOL 73/78) and Annex V	Prevention of marine litter pollution under IMO (International Maritime Organization) conventions.	http://www.imo.org/
London Convention 1972, Convention on the Prevention of Maritime Pollution by Dumping of Wastes and Other Matter and 1996 Protocol Thereto	Prevention of marine pollution by dumping of wastes and other matter.	http://www.imo.org/home.asp?topic_id=1488
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal	The Convention has 175 Parties and aims to protect human health and the environment against the adverse effects resulting from the generation, management, transboundary movements and disposal of hazardous and other wastes	http://www.basel.int/
Agenda 21 and the Johannesburg Plan of Implementation	Agenda 21 is a programme ran by the United Nations (UN) related to sustainable development.	http://www.un.org/esa/sustdev/
Convention on Biological Diversity, with the Jakarta Mandate	Ministerial Statement on the Implementation of the Convention on Biological Diversity	http://www.oceanlaw.net/texts/jakarta.htm
FAO Code of Conduct for Responsible Fisheries	Appropriate measures should be taken to minimize waste, clean up discards, etc.	http://www.fao.org/docrep/005/v9878e/v9878e00.htm
Convention on Biological Diversity, with the Jakarta Mandate	The conservation of biological diversity, the sustainable use of its components, and the fair and equitable sharing of benefits arising from the use of genetic resources.	http://www.cbd.int/history/
Convention on Migratory species, with the agreement on the conservation of albatrosses and petrels	The parties shall take appropriate measures to minimize the discharge from land-based sources and vessels, of pollutants, which may have an adverse effect on albatrosses and petrels either on land or at sea.	http://www.cms.int/species/acap/acap_bkrd.htm

Other global actors and initiatives

Intergovernmental Oceanic Commission of UNESCO	The IOC assists governments in sharing their individual and collective ocean problems. In the 1970s and 1980s they were very active on waste, but currently have no programs running.	http://ioc-unesco.org/
Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP)	GESAMP is an advisory body, established in 1969, that advises the United Nations (UN) system on the scientific aspects of marine environmental protection.	http://gesamp.net/page.php?page=1
International Coral Reef Initiative	Environmental partnership that brings stakeholders together with the objective of sustainable use and conservation of coral reefs for future generations.	http://www.icriforum.org/
Seas at Risk (umbrella organization for environmental NGOs at Sea)	The European association of non-governmental environmental organisations working to protect and restore to health the marine environment of the European seas and the wider North East Atlantic.	http://www.seas-at-risk.org/

Global networks of international civil society organizations

International Coastal Cleanup (ICC)	ICC is the largest coastal cleanup campaign. Each year tons of trash is cleared from coastlines, rivers and lakes worldwide and everything is reported.	http://www.oceanconservancy.org/site/PageServer?pagename=press_icc
Clean Up the World	Clean Up the World is a community based environmental program that inspires and empowers individuals and communities to clean up, fix up and conserve their environment.	http://www.cleanuptheworld.org/en/
Cruise Liners International Association (CLIA)	Adopted mandatory environmental standards for cruise ships in 2001.	http://www2.cruising.org/industry/tech-intro.cfm
Project AWARE foundation	International Cleanup Day events involve thousands of dive volunteers removing trash from more than 900 global dive locations in 100 countries and territories. Project AWARE coordinates the underwater portion of International Cleanup Day in cooperation with the Ocean Conservancy.	http://www.projectaware.org/

Global initiatives from Media/Journalists

Plastic Oceans	A team of the world's top scientists and leading filmmakers produce a powerful, high-end documentary in high definition on plastics in oceans.	www.plasticoceans.net

Regional legislation, actors, activities and initiatives on marine litter

North-East Atlantic (OSPAR):		
OSPAR convention	EcoQO on plastics in stomach content of Northern Fulmars (done by IMARES).	http://www.ospar.org/
EU legislation		
	The EU Directive on the landfill of waste (Directive1999/31/EC).	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:31999L0031:EN:NOT
	The EU Directive on port reception facilities for ship-generated waste and cargo residues (Directive 2000/ 59/EC, December 2002).	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32000L0059:EN:HTML
	The EU Directive on packaging and packaging waste (Directive 2004/12/EC).	http://europa.eu/legislation_summaries/environment/waste_management/l21207_en.htm
	The EU Marine Strategy Framework Directive (2008/56/EC).	http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:164:0019:0040:EN:PDF
	The EU Water Framework Directive (2000/60/EC).	http://ec.europa.eu/environment/water/water-framework/index_en.html
	EU Fisheries Policy.	http://ec.europa.eu/fisheries/index_en.htm
	EU Waste Directive.	http://ec.europa.eu/environment/waste/legislation/a.htm
	Bathing Water Directive 1976.	http://ec.europa.eu/environment/water/water-bathing/index_en.html
	REACh Directive (Registration, Evaluation, Authorization & Restriction of Chemicals) EC1907/2006.	http://ec.europa.eu/environment/chemicals/reach/reach_intro.htm
	Integrated Maritime Policy.	http://ec.europa.eu/maritimeaffairs/subpage_en.html

Regional initiatives		
UNEP Regional Seas Program	UNEP regional seas program.	http://www.unep.org/regionalseas/
Coastwatch Europe	NGO; conducted surveys and beach-clean up programs.	http://www.coastwatch.org/Coastwatch.org/Welcome.html
MCS Beachwatch	MCS Adopt-a-Beach and MCS Beachwatch are coastal environmental initiatives organised by the Marine Conservation Society (MCS), involving local individuals, groups and communities in caring for their coastal environment.	www.mscuk.org
European initiatives from Media/Journalists		
BBC	Rebecca Hosking and Tim Green "Hawaii - Message in the Waves" is a film from the BBC Natural History Unit looking at some of the environmental challenges facing the people and wildlife of the Hawaiian Islands.	www.messageinthewaves.com
North Sea:		
KIMO International	International association of Local Authorities, which was founded in Esbjerg, Denmark, in August 1990 to work towards cleaning up pollution in the North Sea.	http://www.kimointernational.org/Home.aspx
Save the North Sea project	To reduce marine litter in the North Sea Region by influencing attitudes and behaviour of the target sectors that are among the key sources of marine litter. These are the oil, fishing and shipping industries and recreational sector.	http://www.savethenorthsea.com/sa/node.asp?node=1368
Fishing for litter	The initiative not only involves the direct removal of litter from the sea, but also raises awareness of the significance of the problem amongst each community. This pioneering project has expanded from an original pilot scheme in the Netherlands to now be a highly recognisable initiative in the United Kingdom and beyond.	http://www.kimointernational.org/FishingforLitter.aspx
Green Port Cruise North Sea	Held in association with Cruise Gateway, an EU Interreg IVB North Sea Region project that has been set up to consider ways of encouraging and promoting Sustainable Cruise activities in the North Sea Region (NSR).	http://www.northsearegion.eu/ivb/user-events/&tid=66
Blue Flag	Blue Flag is an international campaign that was started to protect the marine environment in harbours and on beaches. It takes place in Denmark, Norway, Sweden and the UK.	http://www.blueflag.org/
National legislation on litter in the Netherlands		
Wet voorkoming verontreiniging door schepen	Implementation MARPOL.	http://wetten.overheid.nl/BWBR0003642/geldigheidsdatum_10-08-2011
Waterwet	Implementation London Convention.	http://www.helpdeskwater.nl/onderwerpen/wetgeving-beleid/waterwet
Consumer and private initiatives in the Netherlands		
Duik de Noordzee Schoon	Initiative of Get Wet Maritiem and de Vereniging Kust en Zee, where annually experienced divers free crabs, lobsters and fish from nets and lines on wrecks.	www.duikdenoordzeeschoon.nl
Plastic Whale	Building a boat made out of plastic dbris that will sail accross the Netherlands and to find solutions for the Plastic Soup.	www.plasticwhale.org
TassenBol	A container for plastic bags in every supermarket. Together with Stichting Greenwish and the design agency IDEAL & CO.	www.tassenbol.nl
Dutch initiatives from Media/Journalists		
Plastic Soep	Jesse Goosens has written the book 'Plastic Soep' which put the plastic pollution on our oceans, the environment and our health in the Netherlands on the map.	www.plasticsoep.nl, www.jessegoossens.nl
ACT	Young Dutch scientists look for solutions to important global issues, and make these practically available. The plastic soup is the first problem they're adressing.	http://actglobal.nl/act-portal/plastic-soup
VPRO - The Beagle	In the VPRO-program 'Beagle: in het kielzog van Darwin' the plastic soup problem is demonstrated and awaress for the issue is raised.	http://beagle.vpro.nl/

Other legislation, actors, initiatives and networks

On a global scale

Plastiki	Could a fully recyclable performing vessel be engineered almost entirely out of reclaimed plastic bottles, cross the Pacific whilst demonstrating real world solutions?	www.theplastiki.com
Plastic Pollution Coalition	To create a global community and ignite a social movement to stop plastic pollution and its toxic impacts worldwide.	www.plasticpollutioncoalition.org
TEDx GreatPacificGarbagePatch	A program of local, self-organized events that bring people together to share a TED-like experience.	http://www.tedxgreatpacificgarbagepatch.com/

On a regional scale

Mediterranean:		
Barcelona convention		http://www.unep.ch/regionalseas/regions/med/t_barcel.htm
IOC Committee for the Global investigation of pollution in the marine environment (GIPME)		http://www.unep.ch/regionalseas/main/partners/gipme.html
Hellenic Marine Environment Protection Association (HELMEPA)	NGO; conducted surveys and beach-clean up programs.	http://www.helmepa.gr/en/index.php
CMC-Ocean	NGO; conducted surveys and beach-clean up programs.	http://www.cmc-ocean.org/
Baltic		
HELCOM	The Baltic Strategy on Port Reception Facilities for Ship-generated Wastes.	http://www.helcom.fi/shipping/waste/en_GB/waste/
Keep the Baltic Clean	Network of environment organisations around the Baltic Sea aiming at increasing co-operation, giving environmental education and co-ordinating joint campaigns to improve environmental protection as related to leisure boating and spare time at the seaside.	http://www.keepbalticticly.org/sa/node.asp?node=2269
Wider Carribean:		
Cartagena convention	Mandates of the ICCL are highly relevant here.	http://www.cep.unep.org/cartagena-convention
Northwest Pacific (NOWPAP):		
NOWPAP program	Generation of litter will be reduced at the source and large scale clean-ups will be organized.	http://www.nowpap.org/data/IGM7%20report.pdf
Small Islands:		
Small Island developing states network (SIDSnet)	Initiated as a follow up to the Barbados Programme of Action from 1994. It was recognised that all islands share common issues and SIDSnet was initiated with UNDP Sustainable Development Networking Programme (SDNP) and the Alliance of Small Island States (AOSIS). SIDSnet provides tools for virtual discussion forums chat conferences, focused searching, document submission and storage, mailing lists, events calendar, and links to relevant BPoA web sites.	http://www.sidsnet.org/

National legislation and initiatives

UK:		
Environment Act	Competent authorities are responsible for keeping their land clear of litter.	http://www.legislation.gov.uk/ukpga/1995/25/contents
Merchant Shipping Regulations:		
- Prevention of Pollution	Pollution zone 200 nm off the coast of the UK.	http://www.legislation.gov.uk/ukpga/1995/21/contents
- Port Waste Reception Facilities	Require all ports to provide reception facilities for waste.	
- Prevention of Pollution by Garbage	Prohibit ships and platforms to dispose of plastics anywhere in the sea.	
Maritime and coastguard agency (MCA)	Has conducted a pilot project to establish methodologies and guidelines to identify marine litter from shipping.	http://www.dft.gov.uk/mca/
Marine Conservation Society (MCS)	NGO; two programs: Beachwatch and Adopt-a-beach.	http://www.mcsuk.org/
Local initiatives		
Cumbria Marine Litter Project	Aims to quantify the extent and nature of the marine litter problem on the Cumbrian Coast and find solutions to reduce it.	http://library.coastweb.info/343/1/Microsoft_Word_-_2_Cumbria_Marine_Litter.pdf
Adopt-a-beach	National environmental initiative involving local communities in caring for their local coastal environment. Groups and individuals all over the U.K. are given the opportunity to adopt their favourite stretch of coast and take part in beach cleans and surveys to monitor coastal pollution	http://www.egcp.org.uk/projects/adoptabeach.php
National Aquatic Litter Group	Aims "To achieve a quantifiable reduction in the amount of litter in rivers and the sea around the United Kingdom from domestic and international sources and enhance local aquatic environments through systematic programmes of work."	http://www.nalg.org.uk/
Forth Estuary Forum Coastal Litter Campaign	Aims to "develop and implement a community 'hands on' and public awareness-raising programme intended to tackle and monitor the issue of marine and coastal litter in the Firth of Forth.	http://www.forthestuaryforum.co.uk/
Sweden:		
Environmental Code	Sustainable development. Upon entering a Swedish port, vessels must deliver waste to a reception facility.	http://www.sweden.gov.se/content/1/c6/02/05/49/6736cf92.pdf
Denmark:		
Hands On: Fishing For Litter-Denmark	Part of the Save the North Sea campaign which encourages fishermen to 'fish for litter', so that debris can be returned to a marine litter recycling unit in Skagen Municipality.	http://www.tve.org/ho/series5/07_Green%20Currents_reports/report2.html
Turkey:		
Turkish Marine Environment Protection Association (TURMEPA)	Has works to make the public aware of the importance of a clean marine environment. In addition we have involved the public, our volunteers and our Sea Sweepers in cleaning activities with the aim to ensure that future generations continue to enjoy the health, leisure and economic benefits of the sea.	http://www.turmepa.org.tr/en/default.aspx
Cyprus:		
Cyprus Marine Environment Protection Association (CYMEPA)	Was formed with the initiative of the International Shipping Community of Cyprus with the support of the Commercial Community of the island. CYMEPA is an autonomous, not-for-profit organization funded solely by its members.	http://www.cymepa.org.cy/cgi-bin/banner.cgi?url=http://www.cymepa.org.cy/

USA:		
Shore Protection Act	Reduce waste being deposited in coastal waters.	http://www.epa.gov/regulations/laws/spa.html
Clean Water Act		http://www.epa.gov/lawsregs/laws/cwa.html
Marine Plastic Research and Control Act	Implementation MARPOL.	http://water.epa.gov/type/oceb/marinedebris/lawsregs.cfm
Environmental Protection Agency	Innovations in coastal protection: searching for uncommon solutions to common problems.	http://www.epa.gov/
National Clean Boating Campaign	A nationwide program of the Marine Environment Education Foundation.	http://www.efita.org/Environment-and-Nature/Water-Resources/Organizations/National-Clean-Boating-Campaign-details-24117.html
Adopt-a-Beach	Part of the Public Education Programme of the Californian Coastal Commission. Any group, public or private can volunteer to clean any of one of the adoptable beaches.	http://www.coastal.ca.gov/publiced/aab/aab1.html
Monofilament Recovery and Recycling Program	A statewide effort by the Florida Fish and Wildlife Conservation Commission and its partners to educate the public on the problems caused by monofilament line left in the environment, to encourage recycling through a network of line recycling bins and drop-off locations, and to conduct volunteer monofilament line cleanup events.	http://mrrp.myfwc.com/
CoastSweep Clean-ups	Co-ordinated by Massachusetts Coastal Zone Management and organized by local volunteers, are held at more than 80 locations throughout the state. In 2001, 0ver 5,000 volunteers turned out to remove hundreds of thousands of pieces of debris along almost 200 miles of coastline.	http://www.mass.gov/czm/prcstsw.htm
Beach Sweep	These are organized by the Clean Ocean Action and is one of the longest running cleanups in the world. The first one was conducted in 1985 at Sandy Hook with 75 volunteers.	http://www.cleanoceanaction.org/index.php?id=153
Urban Litter Partnership to Prevent Litter and Illegal Dumping	An initiative in the United States. The American Plastics Council (APC), Keep America Beautiful and the U.S. Conference of Mayors are leading a national Urban Litter Partnership, a program which will focus on gathering available data on the causes and effects of littering in urban settings, and provide quantitative information on the best practices being employed to prevent it.	http://www.kab.org/site/PageServer?pagename=urban_partnerships_to_prevent_litter
United States Environmental Protection Agency Coastal Cookbook	Innovations in Coastal Protection: Searching for Uncommon Solutions to Common Problems', more commonly referred to as the 'coastal cookbook', is an organized collection of successful coastal protection initiatives from across the U.S and includes: Marine Debris Collection and Recycling Program, Reduction of Foam Debris: Foam Encapsulation for Floating Structures in Oregon, Fish Net Collection and Recycling.	
National Oceanic and Atmospheric Association (NOAA)	Marine Debris Program's mission statement is to support a national effort focused on preventing, identifying, removing, and reducing the occurrence of marine debris and to protect and conserve our nation's natural resources and coastal waterways from the impacts of marine debris. The NOAA MDP is committed to addressing debris in the marine environment on a national and an international level.	http://www.noaa.gov/
Puget Sound Microplastics Institute	Youth and adult participants work with scientists to collect samples from the surface water, sea floor, and beaches. This includes students gathering water samples during Discovery Voyages on the SEA vessel Indigo, guided by UWT researcher Julie Masura or research assistants, using a special collection net Julie adapted from a large-scale manta net. The water samples are processed in the laboratory by students or scientists to determine the amount of plastic in the samples. The PSMI coordinates sample collection by other community partners. Data are used to better understand the concentration and distribution of plastic in Puget Sound. Scientists and students work together to characterize the source and routes of microplastics, including discovering "garbage patches" in Puget Sound. Data results will be posted online using Google Maps technology and available to all.	http://www.serviceeducationadventure.org/microplastics.php
Port Townsend Marine Science Centre	Discovering nurdles on our "pristine" stretch of beach brought home to us the reality of plastics in local waters. Soon we were collaborating with the California-based Algalita Marine Research Foundation, which has been studying and teaching about the alarming accumulation of plastic in the North Pacific. We decided to begin an education program and to do research to learn about the extent of plastics contamination in the Puget Sound region.	http://www.ptmsc.org/plastics.html
Canada:		
Environment Canada solutions	Provides a number of examples of what can be done to prevent marine litter, presented by Environment Canada	http://www.ec.gc.ca/Publications/default.asp?lang=En&xml=0EC67A2B-9364-4E65-8983-F903FF1BF777
Pitch-in Canada national marine debris surveillance program	Co-ordinated by the organization Pitch-In-Canada in co-operation with Environment Canada's Marine Environment Division. It is designed to provide detailed data on the problem of marine debris by studying what is washed up on the beach.	http://www.pitch-in.ca/Marine/E-Marine1.html
Beach Sweeps	Improve coastal environments; inform the public about the extent and impact of marine debris; collect data for future studies; encourage people to behave in a more environmentally-friendly manner; and help individuals and groups organize a safe, educational and fun activity.	http://www.glf.dfo-mpo.gc.ca/eng/Beach_Sweep/Home
Great Nova Scotia Pick me up!	Campaign coordinated by Clean Nova Scotia that encourages Nova Scotians to get together to pick up litter.	http://www.clean.ns.ca/
Canadian Ocean Habitat Protection Society	Non-governmental organization dedicated to exploring, understanding, protecting and restoring Eastern Canada's "incredible northern coral forests and those fisheries that can coexist with them.	http://www.unep.org/regionalseas/marinelitter/other/cleanups/default.asp
Bermuda:		
Keep Bermuda Beautiful	Dedicated to action against the proliferation of litter and other environmental conditions damaging to the beauty of Bermuda.	http://www.kbb.bm/
Hawaii:		
Marine debris clean-up	The Northwestern Hawaiian Islands is co-ordinated through a multi-agency partnership made up of the National Marine Fisheries Service Honolulu Lab; the U.S. Coast Guard, National Ocean Service, the Hawai'i Sea Grant; the Ocean Conservancy; the U.S. Fish and Wildlife Service; the City & County of Honolulu; and the NOAA Research Vessel Townsend Cromwell.	http://www.unep.org/regionalseas/marinelitter/other/cleanups/default.asp

Brazil:		
Local Beach, Global Garbage	Project created and run by Brazilian photographer Fabiano Prado Barretto, from the city of Salvador da Bahia, Brazil. The Local Beach - Global Garbage project includes a photo exhibitions and the distribution of a poster (poster image) and stickers of the project logo to ports worldwide. Fabiano Prado Barretto has made catalogues of the marine litter he has found on different Brazilian beaches.	http://www.globalgarbage.org/blog/
Australia:		
Australia's Ocean Policy	Government will undertake action to prevent extinction of species and adverse effects of pollution.	http://www.environment.gov.au/coasts/oceans-policy/index.html
Australian Environmental Protection and Biodiversity Conservation Act	Injury and fatality as a consequence of marine debris is listed here as a key threat.	http://www.environment.gov.au/epbc/index.html
Department of Environment and Heritage:		
- Plastic Bag Reduction Campaign	Reduce impact of plastic bag on Australian environment.	http://plasticbags.planetark.org/
- Marine Waste Reception Facilities Campaign	Assist ports and marine facilties in providing waste reception facilities.	
- Plan for Marine Turtles	i.e. Identifying sources of marine debris and quantify associated mortality rates.	
Australian Maritime Safety Authority (AMSA)	Published brochures of good waste management practices.	http://www.amsa.gov.au/
Australian and New Zealand Environment and Conservation Council	Practical advice on the implementation of MARPOL.	http://www.environment.gov.au/about/councils/anzecc/index.html
Code of Conduct for Responsible Seafood Industry	Based on FOA code for Responsible Fisheries, includes 12 principles for conserving fish stocks.	http://www.pir.sa.gov.au/fisheries/pdf_equivalents/seafood_industry_code_of_conduct
Clean Up Australia Day	Cleaning beaches along the Australian Coast since 1990.	http://www.cleanup.org.au/au/
Coastcare	Major component of Coasts and Clean Seas, the Commonwealth Government's marine and coastal conservation initiative under the Natural Heritage Trust in Australia. It is a national program that encourages community involvement in the protection, management and rehabilitation of Australia's coastal and marine environments.	http://www.coastcare.com.au/
Gould League Bay Litter Watch	Australia's leading environmental education organisation seeks to create on-the-ground measurable improvements to the environment through its education programmes, consultancy, publications and other activities.	http://www.gould.edu.au/media/news.asp
Minimal impact boating initiative (Tasmania)	Project co-ordinated by the Tasmanian Environment Centre to encourage boaters to adopt practices which reduce the adverse impact of small boat use on the marine and coastal environments.The project educates boaters on ways to ensure that the sea and coasts are kept clean from litter, pollution and introduced marine pests.	http://www.environment.tas.gov.au/index.aspx?base=137
New Zealand:		
Seaweek Marine Debris Program	Organized by the Marine Education Society of Aotearoa (NZ), and includes Beach Clean Up activities and marine debris surveys.	http://www.unep.org/regionalseas/marinelitter/other/cleanups/default.asp
Republic of Korea:		
Korea Institute of Ships and Ocean Engineering several projects	Surveys of marine litter in coastal and port areas	http://www.apec-vc.or.kr/?p_name=website&gotopage=50&query=view&unique_num=WD2006000199
	Clean-up of marine litter	
	Prevention of input of marine litter in coastal environments, especially from land-based sources	
	Technical improvement of equipement and facilities for surveys	
	Prevention of input, promotion of re-use and disposal of collected materials	
	Relevant legal and institutional agreements	
Japan:		
Japan Environmental Action Network (JEAN)	Joined the International Coastal Cleanup (ICC), in 1990. JEAN holds two campaigns each year; the spring campaign dates includes Earth Day & Environment Week focused on environmental awareness, the autumn ICC campaign encourages participants to collect and send data on trash for results for analysis.	http://www.jean.jp/e_index.html
Other areas:		
Marine Debris in the Falkland Islands	Provides information by Falklands Conservation on the problem of marine litter and shipping measures that should be adopted to mitigate the problem.	http://www.ncbi.nlm.nih.gov/pubmed/14643779

C Inventory of existing microplastics programmes and surveys

Organization involved	Program name	Country / region	Type of organi-zation	Type of program	Running time	Aims	Website
Netherlands							
Plastic Soup Foundation	Plastic Soup Foundation	Netherlands	NGO	Lobbying	2010	The Plastic Soup Foundations aims to notify the world of this problem, starting in the Netherlands.	http://www.plasticsoupfoundation.org/charles.php
Instituut voor Milieuvraagstukken (IVM)	Microplastics research	Netherlands	research	interdisciplinary research program	since 2011	IVM has formed an interdisciplinary research team lead by Prof. dr. Jacob de Boer in which chemists, economists, policy experts, environmental law experts and ecotoxicologists are all involved. The aim is to come to understand the extent of microplastic pollution in the environment and its ecological impact, but also to investigate options and costs of mitigation and devise governance strategies to solve this problem.	http://www.ivm.vu.nl/en/news-and-agenda/IVM-Newsletter/Archive/September-2010/Chemistry-and-Biology/index.asp
RWS Noordzee, KIMO and Stichting de Noordzee	Zwervend langs Zee	Netherlands	NGO	research & education	since 2010	Cleaning up Dutch beaches and raising awareness among the general public.	http://www.zwervendlangszee.nl/
Kommunes Internasjonale Miljoorganisasjon (KIMO)	Microplastics research	North Sea	research	monitoring	2009	A research programme to address MPs using a range of differing polymer types (including plastics of differing size and age) and contaminants. Uptake of contaminants together with any associated biological consequences will be evaluated using deposit and filter feeding marine organisms.	http://www.kimointernational.org/MicroPlasticResearch.aspx
OSPAR	OSPAR Pilot Project on Monitoring Marine Beach Litter	North-East Atlantic	research	monitoring	2000-2006	The six-year OSPAR Pilot Project on Monitoring Marine Beach Litter (2000–2006) has been the first region-wide attempt in Europe to develop a standard method for monitoring marine litter on beaches in Europe and, using this standardised method, to assess presence of marine litter on the beaches in the OSPAR region.	http://www.noordzee.nl/upload/dossiers/OSPAR.Litter-Pilot-Project-Final-Report.pdf
IMARES	Fulmar studies	North-East Atlantic	research	monitoring	since 2002	Scientist Jan Andries van Franeker of IMARES investigates stomach contents of Northern Fulmars beached in the Netherlands. These seabirds accidentally ingest plastic debris. The abundance of plastic in the stomachs is a useful monitoring tool for the amount of marine litter in the North Sea.	http://www.imares.wur.nl/UK/research/dossiers/plastic/
Programs in the region North Sea							
INBO, VLIZ en Universiteit Gent: onderzoeksgroep Ecotox	Assessment of Marine Debris (AS-MADE)	Belgium	government	Monitoring		To study the presence of marine debris (including the break-down/degradation products, e.g. micro plastics) in the Belgian marine environment, based on the available literature data and on dedicated quantitative monitoring surveys of the seabed, the sea-surface and the beach, to assess the effects of this debris (including possible associated micro-contaminants) on selected marine species (invertebrates and birds), to evaluate the financial impact of this form of pollution (removal vs. prevention), to develop and evaluate science-based policy evaluation tools.	http://www.vliz.be/projects/as-made/
French Institute for Exploration of the Sea (IFREMER)	Plastics research	France	government	research		One of the leading persons on plastic debris, Francois Galgani, works at Ifremer. He has published a range of articles on plastics, including microplastics.	http://wwz.ifremer.fr/institut_eng
Stichting de Noordzee	Coastwatch	International	NGO	research & education program	since 2008	Studying the composition of waste, involving high school kids in the process.	http://www.coastwatch.org/Coastwatch.org/Welcome.html
University of Sheffield together with Centre for Environment, Fisheries & Aquaculture Science (Cefas)	PhD Microplastics research	UK	research	monitoring	2010	A PhD studentship co-funded by Cefas is enabling investigations into the potential for microbes to biodegrade marine plastic waste. Jesse Harrison's research at the University of Sheffield utilises DNA-based methods to detect and evaluate the interactions between microbes and fragments of synthetic plastics on the seabed.	http://www.cefas.co.uk/media/362133/cefas-ara-2009-10.pdf

Programs in the region North Sea							
University of Plymouth (Richard Thompson) & Sir Alistair Hardy Foundation for Ocean Science (SAHFOS), funded by Defra	PhD Research Studentship Accumulation of microplastic debris in the oceans	UK	research	research	2010-2013	This research aims to establish the extent to which microplastic debris might cause harm to organisms in the marine environment. The plan of work and the objectives below have been specifically tailored to inform UK policy in relation to the European Union Marine Strategy Framework Directive. The project has five specific objectives: 1. To establish whether plastic microparticles sorb contaminants present in the marine environment, which contaminants are of concern, and are they made bioavailable at levels which may cause significant 'harm' above background concentrations. 2. To establish whether common chemical additives in plastics persist after ageing in the marine environment and whether they are made bioavailable on ingestion and as such have the potential to cause significant 'harm'. 3. To establish whether and how microplastics are passed on through food web interactions and what the implications are for populations and ecosystems. 4. Research to determine the extent to which the physical presence of microplastics can cause significant 'harm' and in what quantities. 5. To establish whether new	http://phdscholarship.co.uk/phd-research-studentship-accumulation-of-microplastic-debris-in-the-oceans-university-of-plymouth-faculty-of-science-and-technology.html
University of Exeter (Tamara Galloway)	PhD on Impact of nanoparticles and microplastics at the base of the marine food web: response of reproduction and development in calanoid copepods	UK	research	research	2010-2013	This project will examine the effects of nanoparticles and microplastics in different concentrations on the egg production, hatching success, development rates and differential gene expression of coastal calanoid copepod species. The project will provide the scope for laboratory culture studies as well as weekly fieldwork sampling at station L4.	http://www.pml.ac.ukwww.amt-uk.org/PDF/Studentship%20Projects_2010.pdf
Programs in other regions							
Instituto do Mar (IMAR)	Studying plastics on beaches	Portugal	research	monitoring	since 2008	Studying plastic debris stranded on the beaches in mainland Portugal, analyzing the types of plastic and their distribution, and more recently verifying the presence of microplastics in plankton samples and the degradation of such materials in the coastal environment.	http://www.aprh.pt/rgci/pdf/rgci-267_Frias.pdf
University of Patras (prof. Hrissi Karapanagioti)	Monitoring of plastic pellets on beaches	Greece	research	monitoring		Plastic pellets on beaches, transport of persistent organic pollutants, pollution monitoring in Greece.	http://www.upatras.gr/index/index/lang/en
EU member states around the Mediterranean	Meditteranian Endangered (M.E.D.)	Mediterranean	research	research program	2010 - 2013	Will better quantify the distribution and understand the dynamics of debris pollution in the Mediterranean, especially in marine protected areas.	http://www.expeditionmed.eu/images/Expedition-MED-en.pdf
National Oceanic and Atmospheric Administration (NOAA)	Marine Debris Program (MDP)	USA	government	Monitoring	2006	Assess the quantity of debris at a location and expand to regional, characterization according to associated land use, determine the types and density of debris present by material category (i.e. plastic, metal, etc.), examine spatial distribution and variability of debris and investigate temporal trends in debris amounts.	http://marinedebris.noaa.gov/projects/monitoring.html
Algalita Marine Research Foundation	Microplastics research	USA	NGO	research program	1994	Algalita cooperates with a range of partners on many different topics on plastics. Charles Moore, the fuonder of the foundation, was the first to discover the plastic soup in the Saragasso Sea. He has published a range of articles on both macro- and microplastics.	http://www.algalita.org/index.php
Scripps Institution of Oceanography at UC San Diego	SEAPLEX Scripps Environmental Accumulation of Plastic Expedition Seeking the Science of the Pacific Ocean Garbage Patch	USA	research	research	2009-now	From August 2-21, 2009, a group of doctoral students and research volunteers from Scripps Institution of Oceanography at UC San Diego embarked on an expedition aboard the Scripps research vessel New Horizon exploring the problem of plastic in the North Pacific Gyre. The Scripps Environmental Accumulation of Plastic Expedition (SEAPLEX) focused on a suite of critical scientific questions. How much plastic is accumulating, how is it distributed, and how is it affecting ocean life? With their new results the researchers hope to provide critical, timely data to policy makers and combine Scripps' long tradition of Pacific exploration with focus on a new and pressing environmental problem.	http://sio.ucsd.edu/Expeditions/Seaplex/
International Pallet Watch	Global Monitoring of Persistent Organic Pollutants (POPs) using Beached Plastic Resin Pellets.	Japan	research	monitoring	since 2010	Organic micro-pollutants in the pellets will be analyzed in the laboratory*.Based on the analytical results, global distribution of organic micro-pollutants will be mapped. The results will be sent to the participants through e-mail and released on the web. This monitoring is based on our finding that marine plastic resin pellets adsorb hydrophobic organic pollutants with concentration factor up to 1,000,000. The purpose of International Pellet watch is to understand the current status of global POPs pollution.	http://www.pelletwatch.org/index.html

D Inventory of stakeholders in plastics in the marine environment

Stakeholders involved in micro and macroplastics

Type	Organization	type of organization	website
Dutch	Ministry of Infrastructure & Environment (I&M)	government	http://english.verkeerenwaterstaat.nl/english/
	Nederlandse Rubber- en Kunststofindustrie (NRK)	industry	www.nrk.nl
	IMSA	industry	www.imsa.nl
	Plastics Europe Nederland	industry	http://www.plasticseurope.org/
	Dutch Polymer Institute	industry	http://www.polymers.nl/
	Plastic Soup Foundation	NGO	http://www.plasticsoupfoundation.org/foundation.php
	Stichting de Noordzee	NGO	http://www.noordzee.nl/
	KIMO Nederland	NGO	http://www.kimointernational.org/NetherlandsandBelgium.aspx
	IVM	research	http://www.ivm.vu.nl/en/index.asp
	Deltares	research	www.deltares.nl
	IMARES	research	http://www.imares.wur.nl/UK/research/dossiers/plastic/
	IVAM (UvA)	research	http://www.ivam.uva.nl/?21
Europe	KIMO	research	http://www.kimointernational.org/Home.aspx
	University of Ghent - Steven de Meester	research	http://www.ugent.be/en
	N-Research - Fredrik Norén	research	www.n-research.se
	Plymouth University - Richard Thompson	research	http://www.plymouth.ac.uk/staff/rcthompson#
	University of Sheffield	research	http://www.shef.ac.uk/
	University of Exeter	research	http://www.exeter.ac.uk/
	Cefas	research	http://www.cefas.defra.gov.uk/home.aspx
	Defra	research	http://www.defra.gov.uk/
	Members of Task group 10 MSFD	research	
	Sir Alistair Hardy Foundation for Ocean Science (SAHFOS)	research	http://www.sahfos.ac.uk/
	Mediterranean En-Dangered (MED)	research	
	Johann Heinrich von Thunen-Institut (vTI)	research	http://www.vti.bund.de/en
	Ifremer	research	http://wwz.ifremer.fr/institut_eng
	Université de Brest	research	http://www.univ-brest.fr/
World	Algalita	research	http://www.algalita.org/index.php
	GESAMP	research	http://gesamp.org/
	NOAA	research	http://www.noaa.gov/
	Members of workshop on Microplastics in Washington (NOAA, 2008)	research	
	Tokyo University - Hideshige Takada	research	www.pelletwatch.org
	University of Washington, Tacoma	research	http://www.tacoma.uw.edu/

Reference Van Weenen et al. (2010)

Stakeholders only involved in macroplastics

Type	Organization	type of organization	website
Dutch	Vereniging Nederlandse Gemeenten (VNG)	government	http://www.vng.nl/
	Plastic heroes campaign	government	www.plasticheros.nl
	Stichting Nederland Schoon	government	www.nederlandschoon.nl
	Stichting Afvalstoffen en Vaardocumenten Binnenvaart	government	http://www.sabni.nl/
	Nedvang	industry	www.nedvang.nl
	Vereniging van Ondernemingen in de Milieudienstverlening	industry	www.voms.nl
	Nederlandse Vissersbond	industry	www.vissersbond.nl)
	Greenpeace Nederland	NGO	http://www.greenpeace.nl/
	WWF Nederland	NGO	http://www.wnf.nl/nl/home/?splash=1
	Waddenvereniging	NGO	http://www.waddenvereniging.nl/
	Duik de Noordzee Schoon	private	www.duikdenoordzeeschoon.nl
	Plastic Whale	private	www.plasticwhale.org
	TassenBol	private	www.tassenbol.nl
	TU Delft	research	http://home.tudelft.nl/
	NIOZ	research	http://www.nioz.nl/
	RIVM	research	http://www.rivm.nl/en/
	ActGlobal		
	T-Xchange	industry	http://www.designforusability.org/participants/companies/txchange
	IUCN NL	NGO	http://www.iucn.nl/
	Wetsus	research	http://www.wetsus.nl/
	DHV	research	http://www.dhv.com/
	Qeam BV	research	http://www.qeam.com/
	de Amsterdamse Innovatie Motor	industry	http://www.aimsterdam.nl/
	Van Ganzewinkel	industry	www.vangansewinkel.com
	Afval Energie Bedrijf (Gem.Amsterdam)	industry	http://www.afvalenergiebedrijf.nl/home.aspx
	BSAF	industry	http://www.basf.nl/ecp1/Netherlands/nl/
	Teijin Aramid	industry	http://www.teijinaramid.com/
	Unilever	industry	http://www.unilever.nl/
	TNO	research	http://www.tno.nl/
	IDEA Consultancy	research	
Europe	EU (DG Mare)	government	http://europa.eu/index_en.htm
	Plastics Europe	industry	http://www.plasticseurope.org/
	Electrolux	industry	http://group.electrolux.com/en/electrolux-unveils-five-vacs-from-the-sea-8687
	European Plastics Converters	industry	http://www.plasticsconverters.eu/
	SABIC	industry	http://www.sabic-europe.com/_en/
	DSM	industry	http://www.dsm.com/en_US/cworld/public/home/pages/home.jsp
	Centrale Commissie voor de Rijnvaart (CCR)	intergovernmental	http://www.ccr-zkr.org
	Seas at Risk	NGO	www.seas-at-risk.org
	Surfrider Foundation Europe	NGO	www.surfrider.eu
	OSPAR	research	http://www.ospar.org/
	European Environment Agency	research	http://www.eea.europa.eu/
	EFSA	research	http://www.efsa.europa.eu/
	HELCOM	research	http://www.helcom.fi/
	WasteKIT	research	http://www.wastekit.eu/
	University of East-Anglia	research	http://www.uea.ac.uk/
	Alfred Wegener Institute fur Polar und Meeresforschung	research	http://www.awi.de/en/home/
World	CIPAD (Council of International Plastics Associations Directors)	industry	www.cipad.org
	American Chemistry Council (ACC)	industry	http://www.americanchemistry.com/default.aspx
	International Maritime Organization (IMO)	intergovernmental	www.imo.org
	Marine Environment Protection Committee (MEPC)	intergovernmental	www.imo.org
	Blue Ocean Sciences	NGO	http://www.blueoceansciences.org/
	Clean Shipping Coalition (CSC)	NGO	www.cleanshipping.org
	Clean Seas Coalition	NGO	www.cleanseascoalition.org
	Greenpeace	NGO	www.greenpeace.org
	Plastic Oceans Foundation	NGO	http://www.plasticoceans.net
	STOP Ocean Plastics	NGO	http://live.stopoceanplastics.org
	Surfrider Foundation	NGO	www.surfrider.org
	Seas at Risk	NGO	http://www.seas-at-risk.org/
	UNEP	research	http://www.unep.org/
	UNESCO	research	http://www.unesco.org/new/en/unesco/
	World Wildlife Foundation (WWF)	NGO	www.wwf.org
	Coordinating Body on the Seas of East Asia (COBSEA)	intergovernmental	http://www.cobsea.org/
	Partnerships in Environmental Management for the Seas of East Asia (PEMSEA)	intergovernmental	http://beta.pemsea.org/
	US-FDA	research	http://www.fda.gov/

Reference Van Weenen et al. (2010)

E Participant list of expert dialogue held 26 September 2011 in Utrecht

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